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

DIVISION OF INTERIOR RESOURCES
Charles M. Sanders, *Director*

BUREAU OF GEOLOGY
Charles W. Hendry, Jr., *Chief*

Report of Investigations No. 74

HYDROLOGIC CONSEQUENCES OF USING GROUND WATER TO MAINTAIN LAKE LEVELS AFFECTED BY WATER WELLS NEAR TAMPA, FLORIDA

by
J. W. Stewart and G. H. Hughes
U. S. Geological Survey

Prepared by the
UNITED STATES GEOLOGICAL SURVEY
in cooperation with
SOUTHWEST FLORIDA WATER MANAGEMENT DISTRICT
and the
BUREAU OF GEOLOGY
FLORIDA DEPARTMENT OF NATURAL RESOURCES

Tallahassee, Florida

1974

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

DIVISION OF INTERIOR RESOURCES
Charles M. Sanders, *Director*

BUREAU OF GEOLOGY
Charles W. Hendry, Jr., *Chief*

Report of Investigations No. 74

HYDROLOGIC CONSEQUENCES OF USING GROUND WATER TO MAINTAIN LAKE LEVELS AFFECTED BY WATER WELLS NEAR TAMPA, FLORIDA

by
J. W. Stewart and G. H. Hughes
U. S. Geological Survey

Prepared by the
UNITED STATES GEOLOGICAL SURVEY
in cooperation with
SOUTHWEST FLORIDA WATER MANAGEMENT DISTRICT
and the
BUREAU OF GEOLOGY
FLORIDA DEPARTMENT OF NATURAL RESOURCES

Tallahassee, Florida

1974

DEPARTMENT
OF
NATURAL RESOURCES

REUBIN O'D. ASKEW
Governor

DOROTHY W. GLISSON
Secretary of State

ROBERT L. SHEVIN
Attorney General

THOMAS D. O'MALLEY
Treasurer

FRED O. DICKINSON, JR.
Comptroller

RALPH D. TURLINGTON
Commissioner of Education

DOYLE CONNER
Commissioner of Agriculture

HARMON W. SHIELDS
Executive Director

LETTER OF TRANSMITTAL



Bureau of Geology
Tallahassee
October 10, 1974

Honorable Reubin O'D. Askew, *Chairman*
Department of Natural Resources
Tallahassee, Florida

Dear Governor Askew:

We are pleased to make available the report, "Hydrologic Consequences of Using Ground-water to Maintain Lake Levels Affected by Water Wells Near Tampa, Florida" by J. W. Stewart and G. H. Hughes. This report should be of substantial importance as it relates to the problem of urbanization around lakes in Florida and the affects of urbanization on lowering of lake levels. It is possible, under certain circumstances, that the lake levels may be artificially maintained to offset the effects of pumping or below normal rainfall without substantially increasing the loss of water by evaporation. This may well represent an appropriate compromise in order to develope the ground-water resources and also to maintain the surface environment associated with the lakes of Florida.

Respectfully yours,

Charles W. Hendry, Jr., *Chief*
Bureau of Geology

Completed manuscript received
July 29, 1974
Printed for the
Florida Department of Natural Resources
Division of Interior Resources
Bureau of Geology

Tallahassee
1974

CONTENTS

Abstract 1
Introduction 2
Hydrologic setting 5
    Northwest Hillsborough County lakes 5
    Section 21 well field 13
History of pumping from wells into lakes 17
    Round Lake 17
    Saddleback Lake 19
    Lake Charles 23
Maintaining lake stages 23
Movement and distribution of water pumped into lakes 26
Hydrologic consequences 31
Summary 38
References cited 41

ILLUSTRATIONS

Figure		Page
1.	Graph showing yearly rainfall at Tampa, Florida, 1947 - 71 (National Weather Service Office)	3
2.	Map of northwest Hillsborough County showing location of selected lakes	5
3.	Map of Round Lake showing depths	6
4.	Graph showing relation of lake level to lake storage	7
5.	Map of Saddleback Lake showing depths	8
6.	Map of Lake Charles showing depths	10
7.	Oblique photograph of Section 21 well-field area taken July 1971 from elevation of 2,000 feet	11
8.	Graphs showing pumpage at Section 21 well field, water levels in shallow and deep wells, and level of Starvation Lake	12
9.	Section showing water table and potentiometric surface of Floridan Aquifer on May 21, 1971, depth of lakes, and thickness of surficial sediments in the Section 21 well-field area	14
10.	Diagrammatic section showing general relation between lake level, water table of shallow aquifer, and potentiometric surface of Floridan Aquifer in the Section 21 well field before and after the development of the well-field	15
11.	Graphs showing pumpage at Section 21 well field, pumpage into Round Lake, rainfall, and level of Round Lake	18
12.	Photographs showing level of Round Lake at 50.0 feet and 53.5 feet, before and after adding ground water	20
13.	Graphs showing pumpage at Section 21 well field, pumpage into Saddleback Lake, rainfall, and level of Saddleback Lake	21
14.	Photographs showing level of Saddleback Lake before and after adding ground water	22
15.	Graphs showing pumpage at Section 21 well field, pumpage into Lake Charles, rainfall, and level of Lake Charles	24
16.	Graphs showing annual rainfall and pumpage into selected lakes in the Section 21 well-field area	25
17.	Map of Section 21 well-field area and water table of the shallow aquifer, May 21, 1971	28

ILLUSTRATIONS – Continued

18. Map of Section 21 well-field area and potentiometric surface of Floridan Aquifer, May 21, 1971 30

19. Diagrammatic sketch showing how lake area varies with lake level 32

20. Graph showing relation between lake area and increase in lake evaporation attributable to the arrest of the decline in lake level 34

TABLES

Table Page

1. Water-budget data for Round, Saddleback, and Charles Lakes, May 1971 . . 29

2. Selected chemical constituents of water from lakes, Floridan Aquifer, and mixtures of waters from lakes and Floridan Aquifer 36

HYDROLOGIC CONSEQUENCES OF USING GROUND WATER TO MAINTAIN LAKE LEVELS AFFECTED BY WATER WELLS NEAR TAMPA, FLORIDA

By
J. W. Stewart and G. H. Hughes
U. S. Geological Survey

ABSTRACT

Levels of several homesite lakes about 12 miles north of Tampa were lower than usual during the last several years. Rainfall was substantially less than normal, changes in the drainage system diverted storm runoff away from some lakes, and ground-water levels - - and therefore lake levels, because these lakes are hydraulically connected with the aquifer system - - were lowered locally by pumping at a municipal well field.

Extreme declines in lake levels were forestalled since 1966 at Round Lake and since 1968 at Charles and Saddleback Lakes by pumping water from the Floridan Aquifer into the lakes. Levels were maintained at a nearly constant stage slightly below the altitude at which the lakes begin to overflow and generally above the altitude that the lake levels would have attained naturally; that is, an attempt was made to compensate for the effects of (1) pumping for public water supply and (2) below normal rainfall. Combined pumpage into the three lakes averaged 765 gpm (gallons per minute) or 1.1 mgd (million gallons per day) during 1971. During 1971, rainfall was about equal to lake evaporation so the water pumped into the lakes was used entirely to replace water that leaked from the lakes into the local aquifer system. Almost all leakage eventually returned to the Floridan Aquifer. Less pumpage would have been required if the lake levels had been permitted to fluctuate through a range about equal to the natural range in stage for lakes in the same general area.

Evaporation from the three lakes was somewhat greater than would have occurred if the lake levels had continued to decline without the addition of ground water. Assuming that without the addition of ground water lake levels would have declined until the lake areas were reduced by 50 percent, and that annual evapotranspiration from the exposed lake bottoms would have been 18 inches less than lake evaporation, the estimated increase in lake evaporation - - attributable to maintaining the lake levels against the effects of pumping for public water supply and below normal rainfall - - would have been 25 gpm for the three lakes or 3 percent of the ground-water input for 1971. If lake levels had been maintained at a variable stage compensating only for well-field pumping but not for below normal rainfall, only part of the increase in

lake evaporation - - that part associated with maintaining lake levels against the stress of less than normal rainfall - - would be considered a reduction of the local water resource. Thus, in the hypothetical example above, perhaps less than half the 25 gpm can be considered a reduction of the local water resource.

Although maintaining levels of lakes at constant and relatively high stages increases the potential for lakes to overflow, because of sudden storms of high magnitude, Round, Charles, and Saddleback Lakes through 1971 had not lost any appreciable quantity of water by overflow since their levels have been so maintained. During this time, of course, rainfall was generally less than normal. A larger quantity of water may be expected to overflow when rainfall is greater than normal, but during such times the need for water will not be critical.

Adding ground water to the lakes caused a distinct change in the chemical quality of the lake water, generally characterized by increases in calcium, bicarbonate, hardness, and alkalinity. However, many lakes in Florida are naturally supplied with the same kind of ground water; hence, any long-term ecological changes are not expected to be drastic or harmful. Further study will be needed to document whether any long-term ecological changes are likely to occur.

Maintaining levels of lakes in the well-field area at higher than natural levels causes an increase in leakage from the lakes which in turn may lead to an increase in the permeability of materials under the lakes if dissolution of limestone is accelerated. Hence, for the same climatic and hydrologic conditions, the pumpage required to maintain lake levels at a given elevation may increase with time. The increase in required pumpage to date (1971) doubtless has been small. Continued monitoring of pumping rates will assist in determining whether required pumpage will increase markedly for times when climatic and hydrologic conditions are nearly the same.

INTRODUCTION

Lake levels in the vicinity of Tampa were lower than usual during the last decade, largely because of deficient rainfall. From 1961 through 1971, the yearly rainfall at the National Weather Service Office in Tampa averaged more than 8 inches below normal and was above normal only in 1964 and 1969, as shown in figure 1. The problem of low lake levels was worsened in some instances by changes in the natural drainage system caused by highway construction, land reclamation, and urban development. Such changes diverted part or all of the storm runoff away from some lakes. The problem was also aggravated locally by the lowering of ground-water levels caused by pumping at the Section 21 well field of the city of St. Petersburg. The lakes in this area are hydraulically connected with the aquifer system.

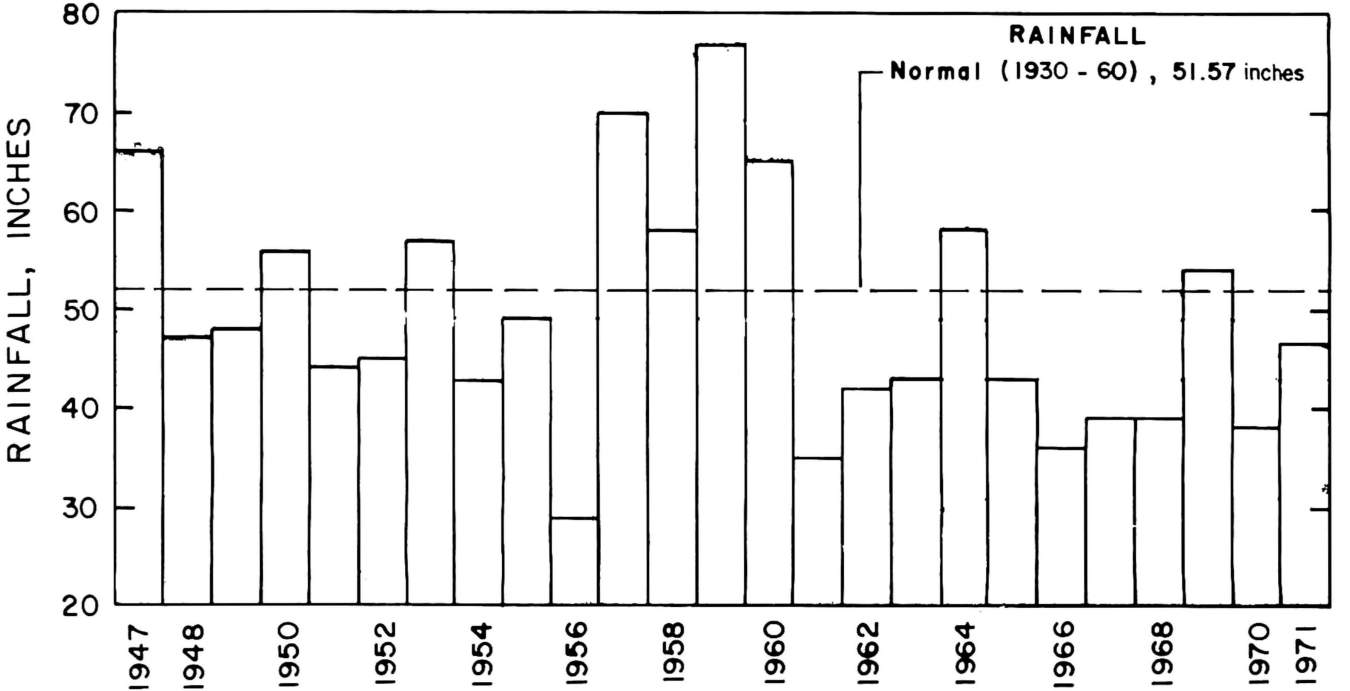


Figure 1 Graph showing yearly rainfall at Tampa, Florida, 1947 - 71 (National Weather Service Office).

As early as 1963, in the Section 21 well field area in northwest Hillsborough County, lake-side residents complained about excessive declines in lake levels. Between 1965 and 1968 the levels of some lakes declined as much as 10 feet. The decline in level of lakes near the Section 21 well field was considerably greater than in those at a distance from the field. Therefore, well-field pumping must be considered an important cause of the excessive decline in lake levels in that area. The extent to which changes in the natural drainage system may have affected lake levels in the Section 21 well field area has not been ascertained.

In order to stop the progressive decline in lake levels, residents at each of several lakes constructed wells near the lakes to pump water into them. The levels of these lakes were maintained at a nearly constant stage slightly below the elevation at which the lakes begin to overflow and generally above the elevation that the lakes would have attained naturally.

The words "natural" and "naturally", as they pertain in this report to lake levels and hydrologic conditions in general, mean the levels and conditions that would prevail as a result of actual rainfall but without any effect of well-field pumping and (or) of pumping water into the lakes.

The purpose of this report is to describe the hydrologic and geologic conditions in the general area of the Section 21 well field where the lake-level maintenance program is being carried on and to evaluate the hydrologic effects of using water from the Floridan Aquifer to maintain the levels of lakes.

The investigation was done by the U. S. Geological Survey in cooperation with the Southwest Florida Water Management District, as part of the District's overall program of evaluating the water resources of west-central Florida, and with the Bureau of Geology, Florida Department of Natural Resources, as part of the statewide program to develop hydrologic relations.

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

Multiply English unit	By	To obtain metric unit
inches	25.4	millimeters
feet	.3048	meters
miles	1.609	kilometers
acres	4,047	square meters
gallons	3.785	liters
acre-feet	1,233	cubic meters
gallons per minute	6.309×10^{-5}	cubic meters per second
millon gallons per day	.04381	cubic meters per second
square miles	2.590	square kilometers

HYDROLOGIC SETTING

NORTHWEST HILLSBOROUGH COUNTY LAKES

Round, Saddleback, Charles, and Crenshaw Lakes are privately-owned homesite lakes in northwest Hillsborough County about 12 miles north of downtown Tampa (fig. 2). The lakes are 500 to 6,500 feet east of the city of St. Petersburg's Section 21 well field. Four lakes are owned by St. Petersburg within the Section 21 well field: Jackson and Starvation Lakes in the northern part, and Crum and Simmons Lakes in the southern part (fig. 2). The largest declines in

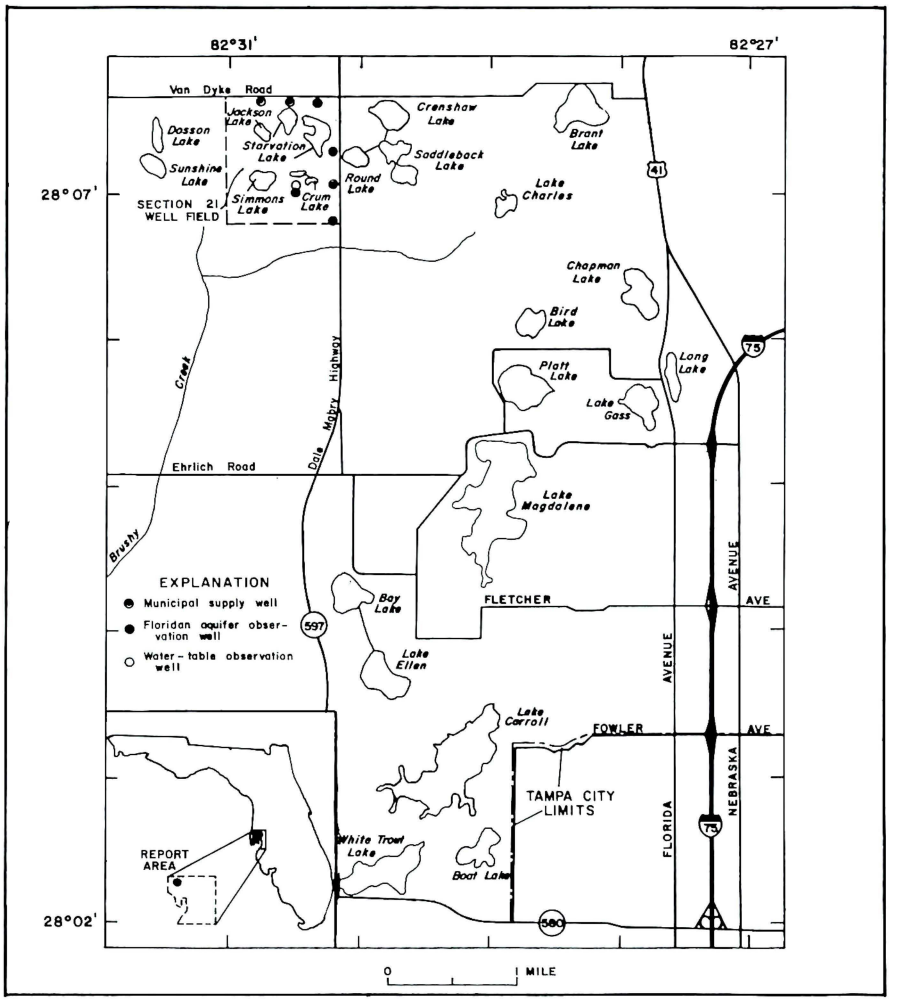


Figure 2 Map of northwest Hillsborough County showing location of selected lakes.

Figure 3 Map of Round Lake showing depths.

lake levels in the area occurred in Crum, Simmons, and Starvation Lakes. The levels of Crum and Starvation Lakes declined so low that the lakes divided into separate pools. Records were not available to determine the amount of decline in Jackson Lake.

Of the privately owned lakes whose levels are being artificially maintained, pumpage records and other data are available for only three, Round, Saddleback, and Charles; the discussion in this report will be concerned chiefly with these.

Round Lake, about 500 feet east of the east edge of Section 21 well field, has a surface area of 11.3 acres when its level is 53.3 feet above msl (mean sea level). At this level the lake is 6 to 8 feet deep except for a dredged channel around all but the south side of the lake (fig. 3). The channel, generally 10 to 20 feet deep, has three depressions 22 to 24 feet deep (29 to 31 feet above msl).

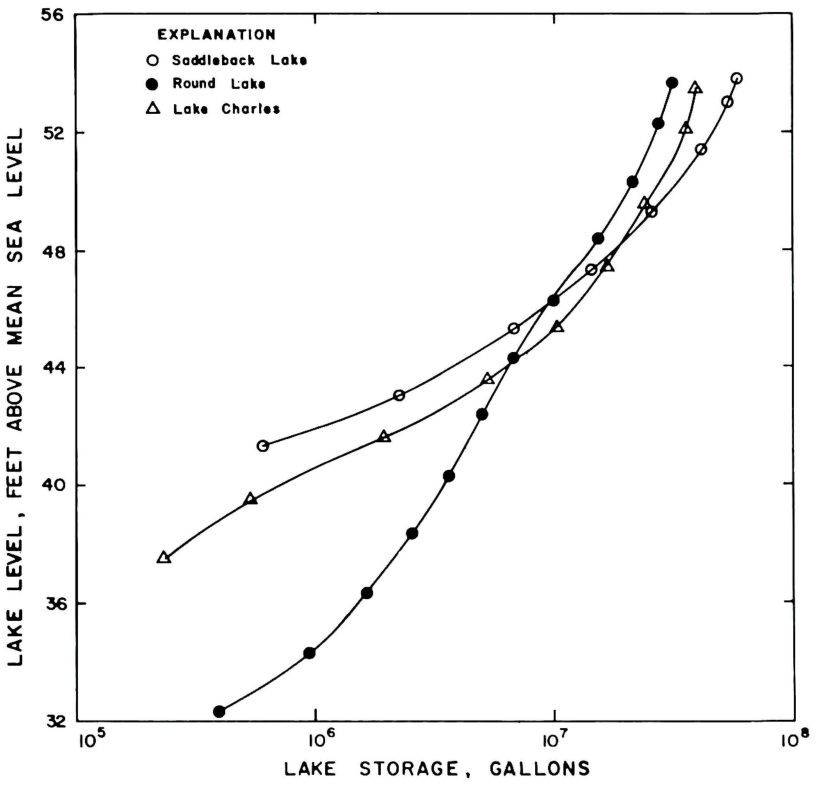


Figure 4 Graph showing relation of lake level to lake storage.

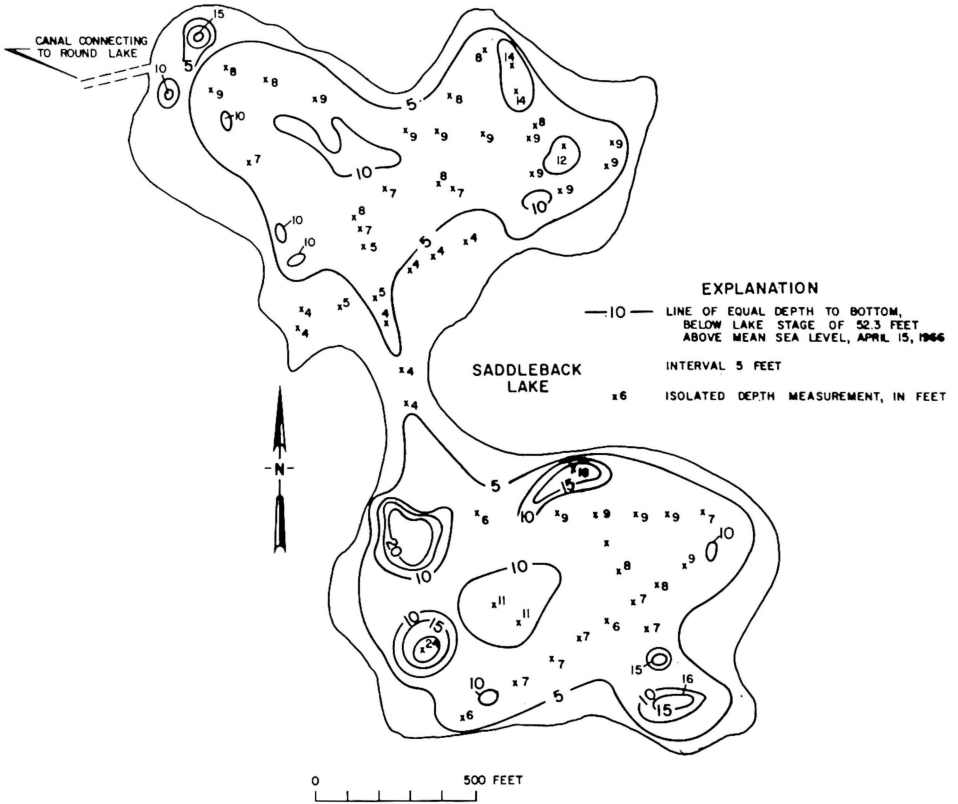


Figure 5 Map of Saddleback Lake showing depths.

These depressions probably are sinkhole depressions caused by subsidence of surficial sediments into solution openings that have developed in the limestone.

Round Lake has no surface outlet and virtually no surface inflow because its drainage area is less than 0.01 sq mi (square mile). A drainage canal constructed in June 1965 from Saddleback Lake to Round Lake carries overflow from Saddleback Lake when the level of Saddleback Lake rises to 54.2 feet above msl; however, this level is seldom reached.

At elevation 53.3 feet above msl Round Lake contains 31.5 million gallons or about 96.7 acre-feet (fig. 4). A change in lake level of 0.1 foot at this elevation represents a volume of about 370,000 gallons.

Saddleback Lake, about 1,000 feet east of Section 21 well field, has a surface area of 31.2 acres when its level is 53.6 feet above msl. The drainage area is about 1.5 sq mi. The lake is hour-glass shaped; at a level of 52.3 feet above msl (fig. 5), the lake averages 8 to 10 feet deep near the centers of the two large sections. In the narrow neck, the lake is 4 to 5 feet deep. Several sinkhole depressions in the south part of the lake are 20 to 24 feet deep (28 to 32 feet above msl). The south part of the lake was dredged in 1961 and again in 1970. Saddleback Lake receives some water from Crenshaw Lake through a canal that connects the two. Crenshaw Lake overflows into the canal at a stage of 55.1 feet above msl.

The volume of water stored in Saddleback Lake at elevation 53.6 feet above msl is about 60 million gallons or 184.1 acre-feet (fig. 4). At this level a change in lake level of 0.1 foot represents a volume of about 1 million gallons of water.

Lake Charles, about 1.2 miles east of Section 21 well field (fig. 2), has a surface area of 12.6 acres at a level of 53.2 feet above msl. Lake Charles receives an undetermined amount of surface inflow from a drainage area of about 0.08 sq mi during wet periods. The lake averages 9 to 10 feet deep at a level of 52.5 feet (fig. 6). Several sinkhole depressions in the lake are 16 to 19 feet deep. The lake has not been dredged.

The capacity of the lake at a level of 53.2 feet is 30.0 million gallons or about 120 acre-feet (fig. 4). A change in lake level of 0.1 foot at this level represents a volume of about 410,000 gallons.

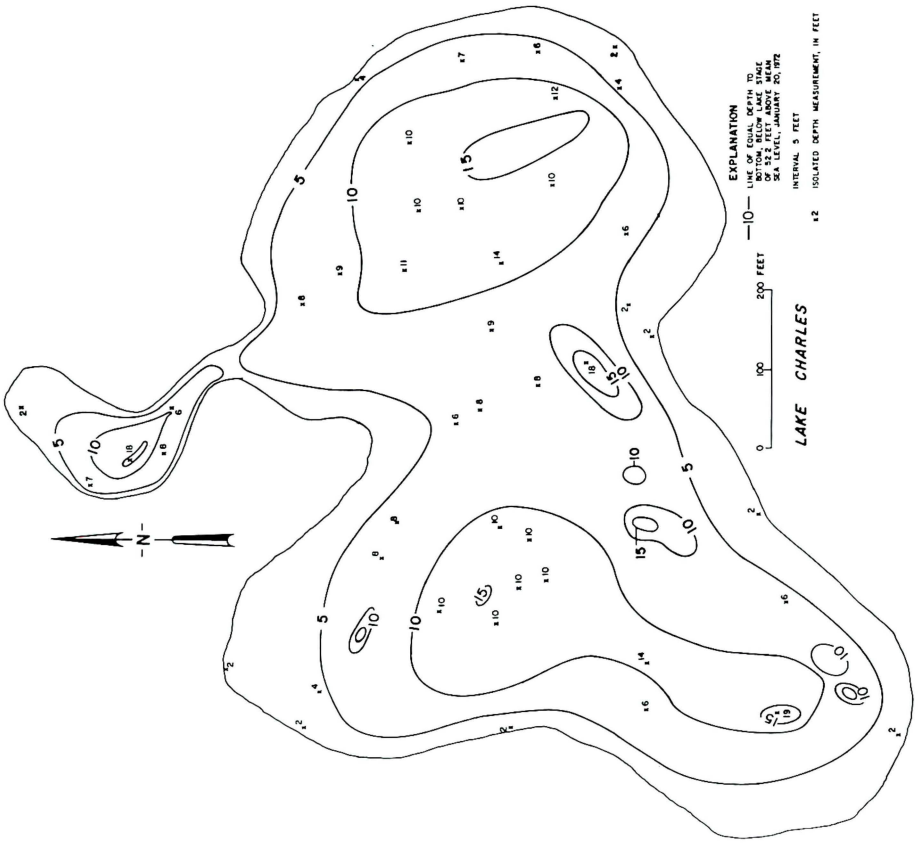


Figure 6 Map of Lake Charles showing depths.

Starvation Lake has a surface drainage area of about 0.3 sq mi and a water-surface area of less than 25 acres at a lake level of about 41 feet above msl. The lake has not been dredged. Throughout most of 1971 the lake level was so low that the lake formed two separate pools. In contrast, the lake had a surface area of about 50 acres at a stage of 53 feet above msl in 1956. A photograph of the Section 21 well field in July 1971 (fig. 7) shows that both Starvation and Crum Lakes consist of two separate pools. The stage of Round Lake is maintained at near the tree line shown in the photograph by pumping ground water into the lake.

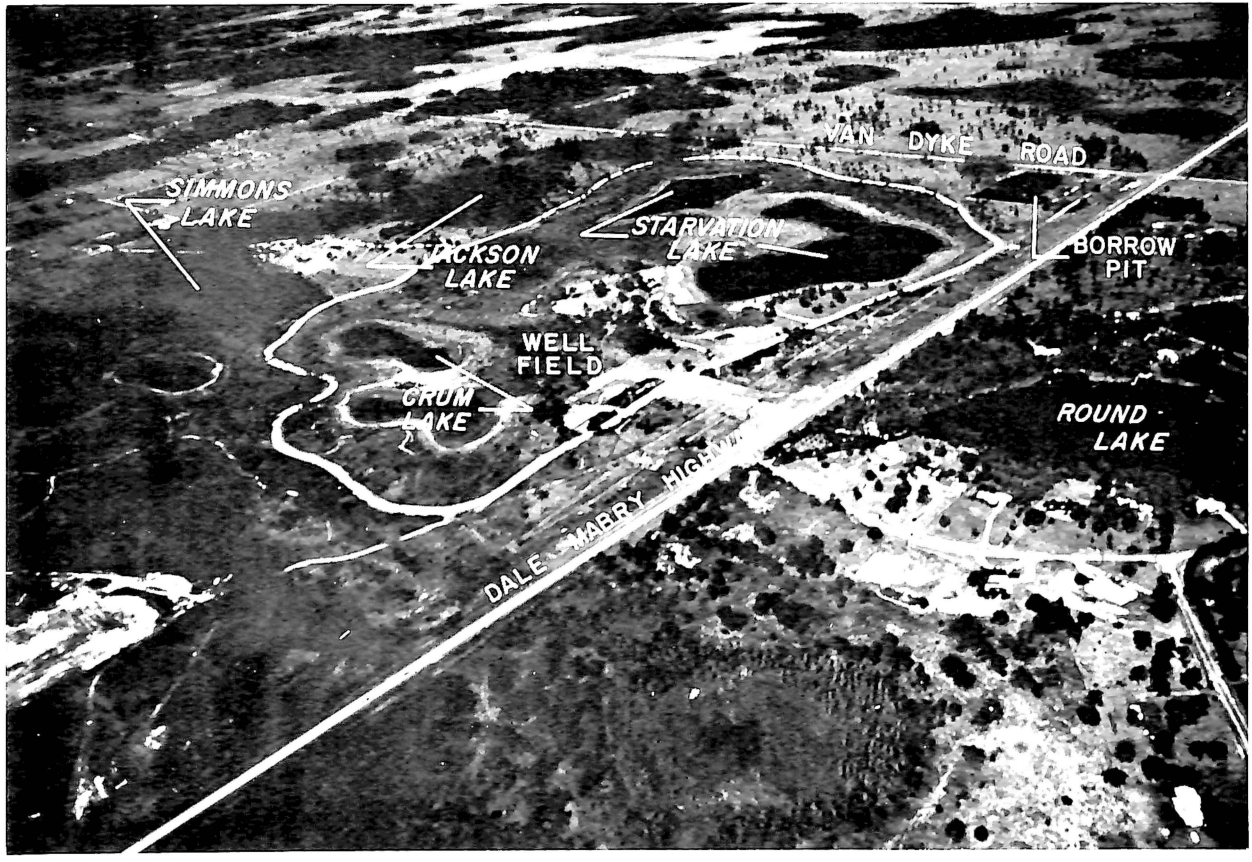


Figure 7 Oblique photograph of Section 21 well-field area taken July 1971 from elevation of 2,000 feet.

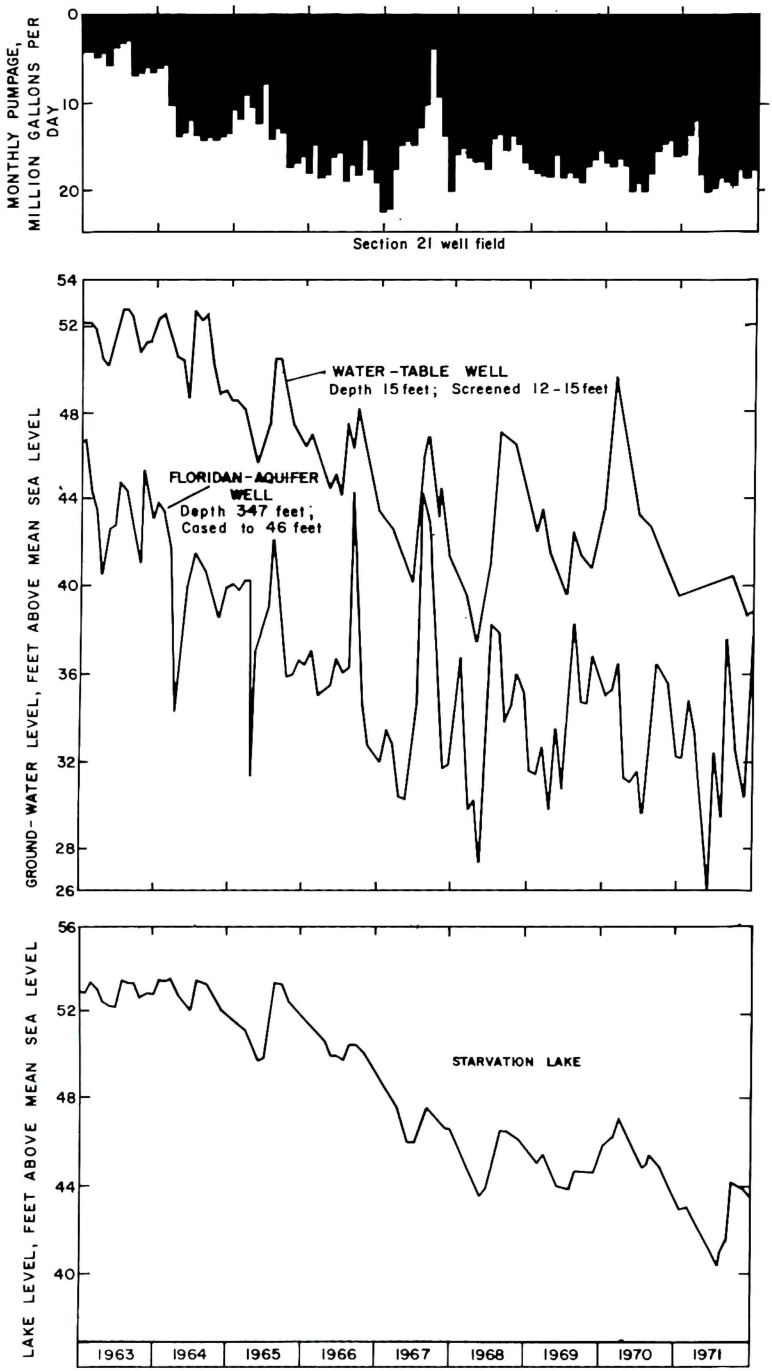


Figure 8 Graphs showing pumpage at Section 21 well field, water levels in shallow and deep wells, and level of Starvation Lake.

SECTION 21 WELL FIELD

Six production wells are in the Section 21 well field. The wells are in two lines that form a right angle. The wells are from 411 to 601 feet deep, cased to depths ranging from 70 to 116 feet, and they produce water from the Tampa Limestone and the Suwannee Limestone of the Floridan Aquifer. Pumping from the well field began in February 1963. Pumpage averaged 12.6 mgd (million gallons per day) in 1964, the first complete year of pumping. Since 1966 pumpage has averaged about 17 mgd, but has ranged from 4 to 24 mgd (fig. 8). Stewart (1968) showed that pumping of the Section 21 wells affected the levels of Round, Starvation, and Saddleback Lakes.

A section through the well field and the lakes illustrates the relation between the water table and the potentiometric surface of the Floridan Aquifer on May 21, 1971, and the depth of the lakes, and the thickness of the surficial sediments in the area (fig. 9). The water table is above the potentiometric surface of the Floridan Aquifer throughout the Section 21 well-field area.

Head difference between the water table and the potentiometric surface of the Floridan Aquifer was greatest west of the Section 21 well field, and least north of Lake Charles. Lake depths ranged from less than a foot to about 10 feet, however the sinkhole depressions of several lakes were more than 20 feet deep. The thickness of the surficial sediments ranged from about 25 feet near Lake Charles to more than 50 feet near Van Dyke Road in the northwestern part of the well field. However, the thickness of the surficial sediments from the deepest parts of the lakes to the top of the limestone ranged from about 12 feet at Lake Charles to about 40 feet at Starvation Lake.

The hydrology of the area and the overall effects of pumping at the Section 21 well field were described in detail by Stewart (1968). Basically, two aquifers are involved in the hydrologic system, a water-table aquifer (surficial sediments) and the Floridan Aquifer (fig. 10).

The water-table aquifer consists predominantly of fine to medium silty sand having an average saturated thickness of 35 feet. The depth to water ranges from less than 5 to as much as 15 feet below land surface. Undisturbed core samples collected at depths of 8 to 32 feet below land surface west of Round Lake had an average hydraulic conductivity of 13 feet per day. An aquifer test of the shallow water-table aquifer in the Section 21 well field also gave a hydraulic conductivity of 13 feet per day, (Oral commun., Sinclair, W. C., 1972).

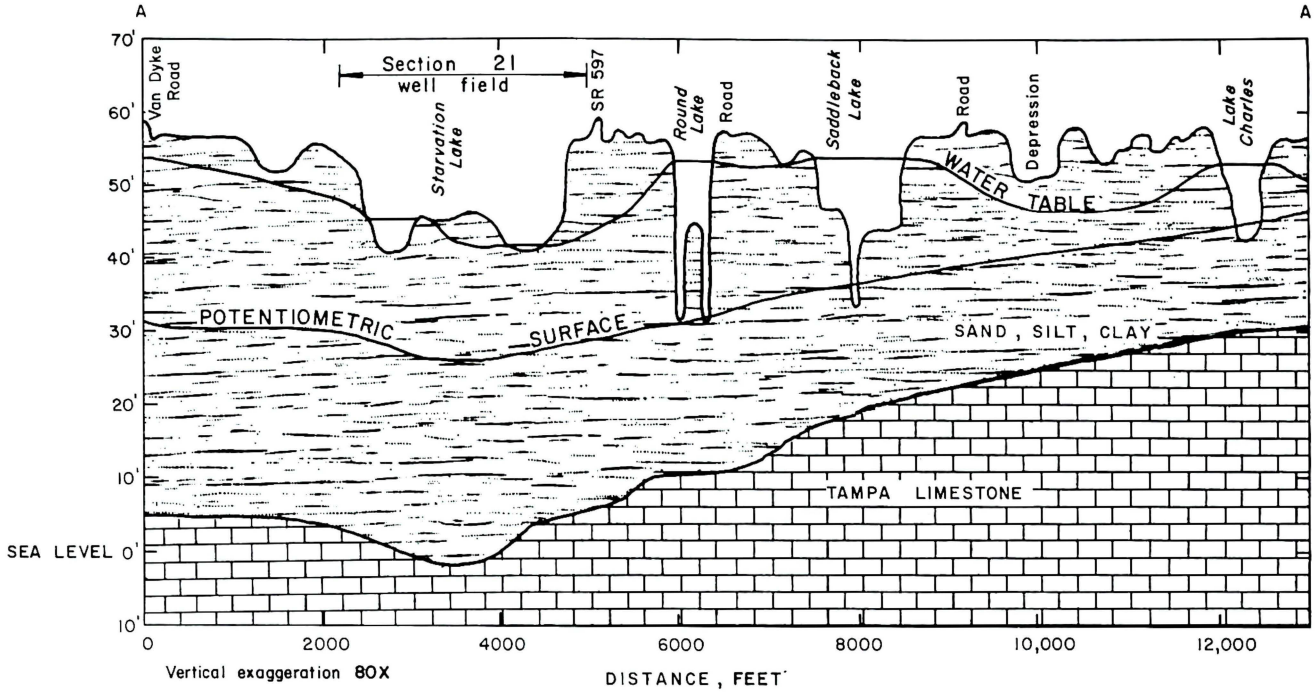
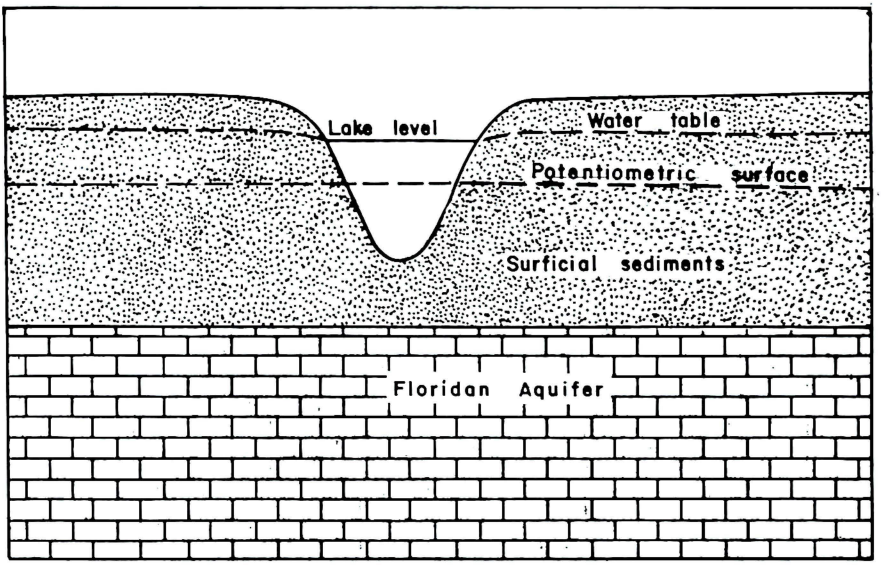
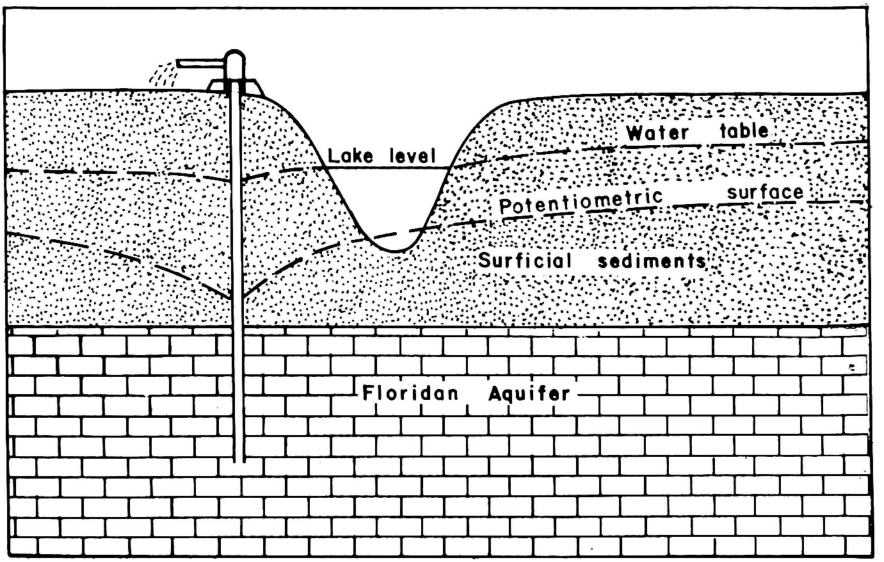


Figure 9 Section showing water table and potentiometric surface of Floridan Aquifer on May 21, 1971, depth of lakes, and thickness of surficial sediments in the Section 21 well-field area.



A. Before



B. After

Figure 10 Diagrammatic section showing general relation between lake level, water table of shallow aquifer, and potentiometric surface of Floridan Aquifer in the Section 21 well field before and after development of the well field.

The principal aquifer in the area is the Floridan, an artesian limestone aquifer interbedded with sand and clay in the upper part and becoming dolomitic at depth. This report is concerned only with the upper part of the Floridan Aquifer consisting of the Tampa Limestone and the Suwannee Limestone because all known large producing wells in northwest Hillsborough County are developed in these formations. The Tampa Limestone is about 100 feet thick in the Section 21 well-field area. The top of the Tampa Limestone ranges from slightly below sea level to about 20 feet above. The Suwannee Limestone, which underlies the Tampa Limestone, is about 400 feet thick in the area.

Water in the Floridan Aquifer is to some degree confined by overlying materials which have a lower hydraulic conductivity than the limestone of the Floridan Aquifer. The potentiometric surface - an imaginary surface that represents the level to which water will rise in tightly cased wells that penetrate the Floridan Aquifer - is above the top of the Floridan. Because the water table of the shallow aquifer is above the potentiometric surface of the Floridan, water moves downward from the shallow aquifer to the Floridan Aquifer primarily in areas where the impermeable confining materials are discontinuous or are absent.

The loss of any substantial quantity of water from the lakes will depend upon the following conditions: (1) large differences between the levels of the lakes and the potentiometric surface of the Floridan Aquifer in the area; (2) occurrence of permeable zones in the surficial sediments that will provide routes for movement of water from the lakes to the Floridan Aquifer; and (3) a high transmissivity of the Floridan Aquifer that will provide for rapid transmission of water out of the area.

The above conditions are fulfilled in the Section 21 well-field area. First, the potentiometric surface of the Floridan Aquifer is well below the water table. The withdrawal of large quantities of water from the Floridan Aquifer from a relatively small area results in large local drawdowns, thereby increasing the differences in head between the lakes and the potentiometric surface of the Floridan Aquifer. In May 1971, the potentiometric surface of the Floridan Aquifer at the well field averaged 13 feet below the water table. Maximum water-level differences occurred at pumped wells and ranged from 15 to more than 60 feet. Second, both Round and Saddleback Lakes have been dredged, and dredging of these lakes may have exposed permeable zones in the lake bottoms. In parts of Round Lake, a dredged channel has several sinkhole depressions that are 29 to 31 feet above msl. The south half of Saddleback Lake has several depressions at 28 to 32 feet above msl or less than 10 feet above the limestone. Lake Charles has several sinkhole depressions 35 to 37 feet above msl. Third, the Floridan Aquifer has a transmissivity of 300,000 to 500,000 gpd (gallons per

day) per foot as determined from aquifer tests of wells in the Section 21 well field. These high values of transmissivity indicate that the Floridan Aquifer is capable of transmitting large quantities of water out of the area.

The rate at which water moves downward from the water-table aquifer varies directly with the distance between the water table and the potentiometric surface of the Floridan Aquifer. Pumping from the Floridan Aquifer at the Section 21 well field lowers its potentiometric surface as indicated in figure 10. This decline in water level temporarily increases the distance between the water table and the potentiometric surface of the Floridan Aquifer and causes an increase in leakage from the shallow aquifer to the Floridan Aquifer; consequently, the water table declines below its natural level for a given climatic condition.

In the vicinity of the well field, a direct hydraulic connection commonly exists between the lakes and the water-table aquifer. Depending on climatic conditions, water moves naturally from the water-table aquifer to the lake or from the lake to the aquifer. When pumping from the Floridan Aquifer takes place, the potentiometric surface is lowered; flow from the water-table aquifer to the Floridan Aquifer increases, and the water table is lowered below its natural level and more water than normal moves from the lakes into the shallow aquifer (fig. 10). In addition, if a direct hydraulic connection exists between the lake and the Floridan Aquifer, the lowering of the potentiometric surface of the Floridan Aquifer induces more water to leak from the lake to the Floridan Aquifer than otherwise would occur. As a consequence of increased flow from the lakes to one or both aquifers, lakes within the area of drawdown must decline below the level that would result naturally from a given climatic condition.

HISTORY OF PUMPING FROM WELLS INTO LAKES

Ground-water pumpage into Round, Charles, and Saddleback Lakes was used to maintain lake levels at a constant stage generally above the level that would occur naturally. Considerably less water would have been required had the lake levels been permitted to fluctuate through a range about equal to the natural range in stage of lakes in the same general area.

ROUND LAKE

Round Lake is the smallest of three privately owned lakes in northwest Hillsborough County into which water from the Floridan Aquifer is pumped to stabilize lake levels. Lake-level records are available for Round Lake beginning January 1965, when the lake level was 51.5 feet above msl. In June 1965 the

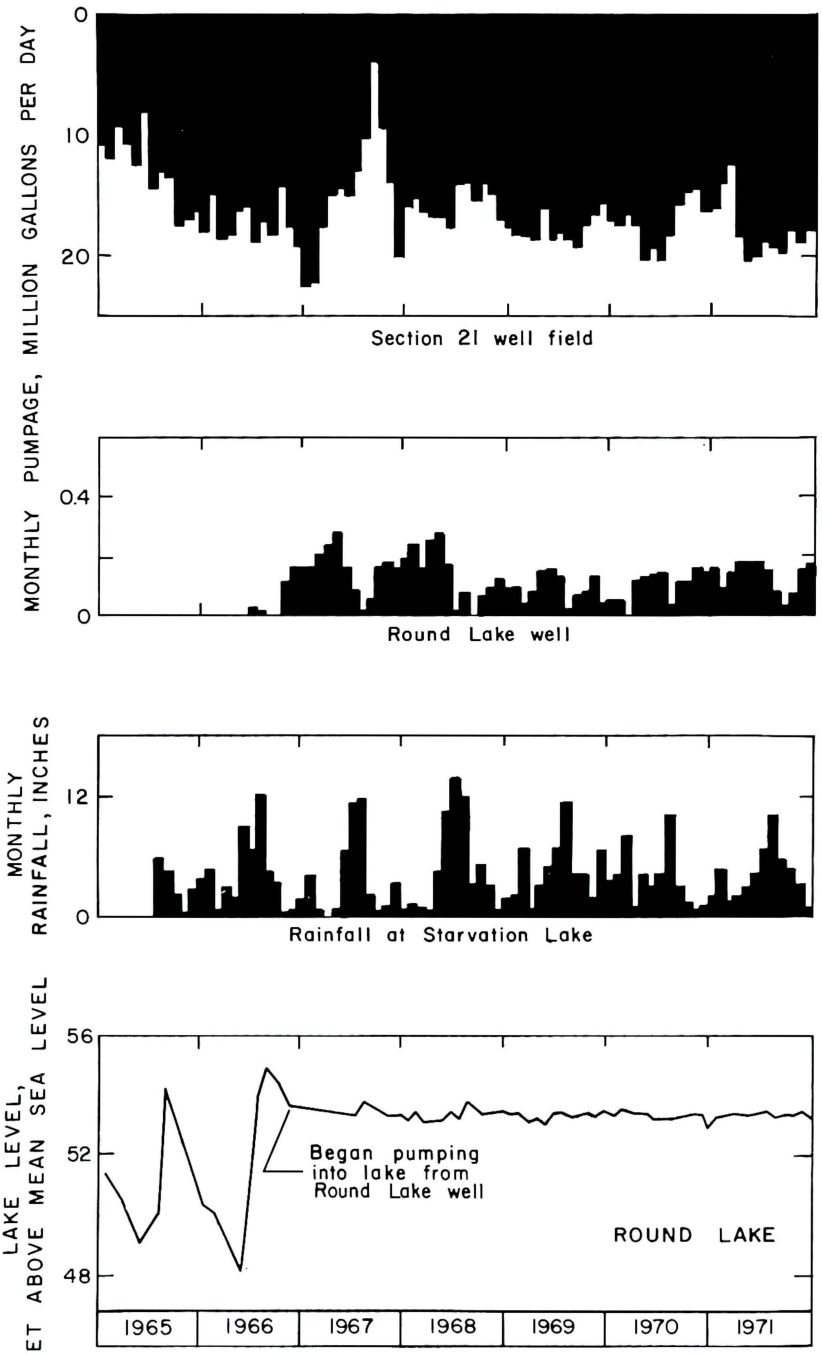


Figure 11 Graphs showing pumpage at Section 21 well field, pumpage into Round Lake, rainfall, and level of Round Lake.

lake level declined to 49.1 feet and in June 1966 it declined to 48.2 feet (fig. 11). Water was first pumped into Round Lake on a trial basis for a few days in June, July, and August 1965 when the city of St. Petersburg filled the lake with water from one of the wells in the Section 21 well field. This trial demonstrated the feasibility of using Floridan Aquifer water to raise the level of the lake.

In order to pump water from the Floridan Aquifer into the lake, residents of the area constructed a well on the northeast side of the lake in June 1966. The well is 6 inches in diameter, 395 feet deep, cased to 74 feet, and is equipped with a 7 1/2 horsepower electric motor with a submersible pump that delivers about 400 gpm. The well is about 200 feet from the edge of the lake, and water is pumped into a 15-inch corrugated iron pipe that slopes to the edge of the lake. Pumping begins when the lake level declines to 53.3 feet above msl. The water-level control is set for a fluctuation range of about 0.2 foot. In the absence of natural inflow, the pump operates continuously for about 4 days, then shuts down for a like period while the lake level declines. Routine pumping into Round Lake began in June 1966. Since early 1967 the lake level has been maintained at a stage of about 53.3 feet above msl (fig. 11). The surface area of the lake in June 1965 was about 9 acres, and early in 1967 it was about 11 acres. A decline in lake level of 2 to 3 feet caused a drastic change in the esthetic qualities of the lake (fig. 12).

From June 25, 1966 through December 21, 1971 (5 1/2 years), about 252.4 million gallons of water were pumped into Round Lake from the 6-inch well. In 1971, pumpage averaged 143,000 gpd or about 100 gpm. In that year, 52.3 million gallons of water were pumped into the lake - - enough to fill the lake 1.7 times from a completely empty condition to stage 53.3 feet above msl.

SADDLEBACK LAKE

Saddleback Lake is the largest of three lakes studied in northwest Hillsborough County into which water from the Floridan is pumped to stabilize lake levels. Lake-level records are available for Saddleback Lake beginning in the latter part of April 1965 when its stage was 51.7 feet. Because of the downward trend of the annual minimum lake levels in 1966 - 68 (fig. 13), residents around the lake constructed, in June 1968, an 8-inch diameter well 445 feet deep (cased to 79 feet), tapping the Floridan Aquifer. The well is between Round and Saddleback Lakes and is about 300 feet west of Saddleback Lake and 400 feet east of Round Lake. A turbine pump actuated by a 7½-HP electric motor delivers about 450 gpm.

Since the start of pumping on July 6, 1968, the lake level has fluctuated between 52.4 and 54.4 feet above msl, and has averaged about 53.6 feet. This



A. Before pumping ground water into lake, July 15, 1965. Lake level 50.0 feet above msl.



B. After pumping ground water into lake, September 22, 1965. Lake level 53.5 feet above msl.

Figure 12 Photographs showing level of Round Lake at 50.0 feet and 53.5 feet, before and after adding ground water.

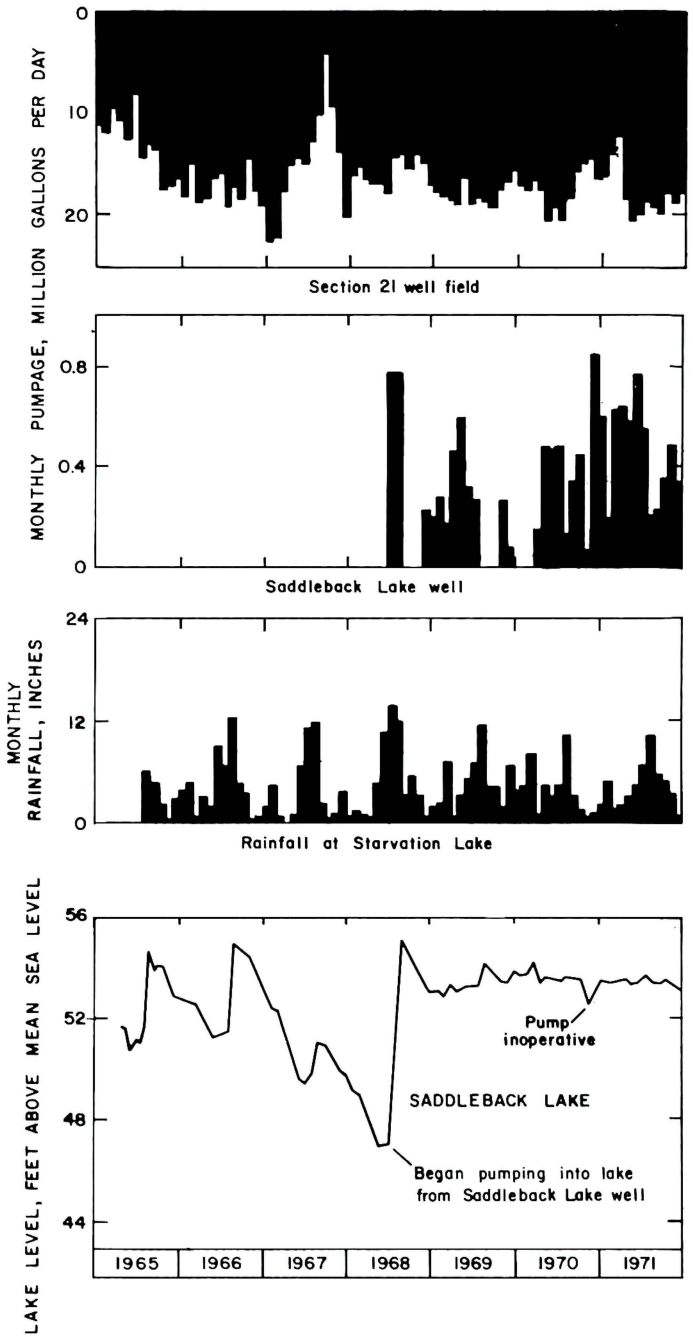
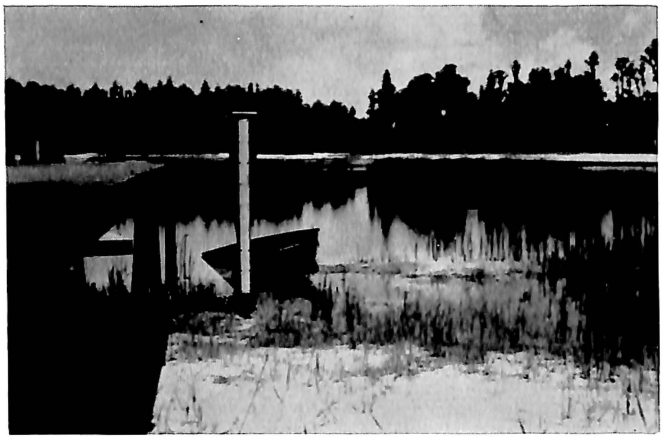


Figure 13 Graphs showing pumpage at Section 21 well field, pumpage into Saddleback Lake, rainfall, and level of Saddleback Lake.



A. Before pumping ground water into lake, June 5, 1968. Lake level 47.0 feet above msl.



B. After pumping ground water into lake, May 11, 1972. Lake level 53.6 feet above msl.

Figure 14 Photographs showing level of Saddleback Lake before and after adding ground water.

wide range in fluctuation was due partly to a rise in level caused by heavy rains in 1968 and partly to a decline in level in 1970 when the pump was inoperative for about 1 month. Otherwise, the lake level would have fluctuated within a range of a few tenths of a foot.

From July 6, 1968 through December 31, 1971 about 410.2 million gallons of water were pumped into the lake from the Floridan Aquifer well. In 1971, pumpage into the lake averaged 468,000 gpd or about 325 gpm. This volume of water was sufficient to fill the lake, assuming it was empty, nearly three times to an elevation of 53.6 feet above msl. Figure 14 shows how the addition of ground water has changed the lake's appearance.

LAKE CHARLES

Lake-level records are available for Lake Charles beginning in September 1965, when the lake level was at 52 feet. The annual minimum lake level trended downward in 1966 - 1968 (fig. 15), reaching a stage of 43.6 feet in June 1968.

Lake-side residents drilled a 485-foot well (cased to 48 feet) in June 1968 to control the lake level by pumping water from the Floridan Aquifer into the lake. The well is about 100 feet northwest of Lake Charles. A turbine pump actuated by a 7½-HP electric motor delivers about 500 gpm.

Pumping into the lake began August 3, 1968. Since that time the level of the lake has fluctuated between 51.2 and 53.7 feet above msl and has averaged 53.2 feet above msl (fig. 15). Through December 31, 1971, about 410 million gallons of water were pumped from the Floridan Aquifer into Lake Charles. In 1971, pumpage into the lake averaged 492,000 gpd or about 340 gpm. The volume of water pumped in 1971 was sufficient to fill the lake 4.5 times to an elevation of 53.2 feet above msl.

MAINTAINING LAKE STAGES

The rate at which water must be pumped from the Floridan Aquifer to maintain the levels of Round, Saddleback, and Charles Lakes at controlled elevations will not be the same each year but rather will vary inversely with rainfall (fig. 16). The quantity of water required to maintain the level of the lakes in 1969 - 1971 ranged from 9,000 to 13,000 gallons per day per acre of lake surface for Round Lake; 7,000 to 14,000 for Saddleback Lake; and 22,000 to 39,000 for Lake Charles. Total pumpage into the three lakes ranged from 217 million gallons in 1969 to 401 million gallons in 1971.

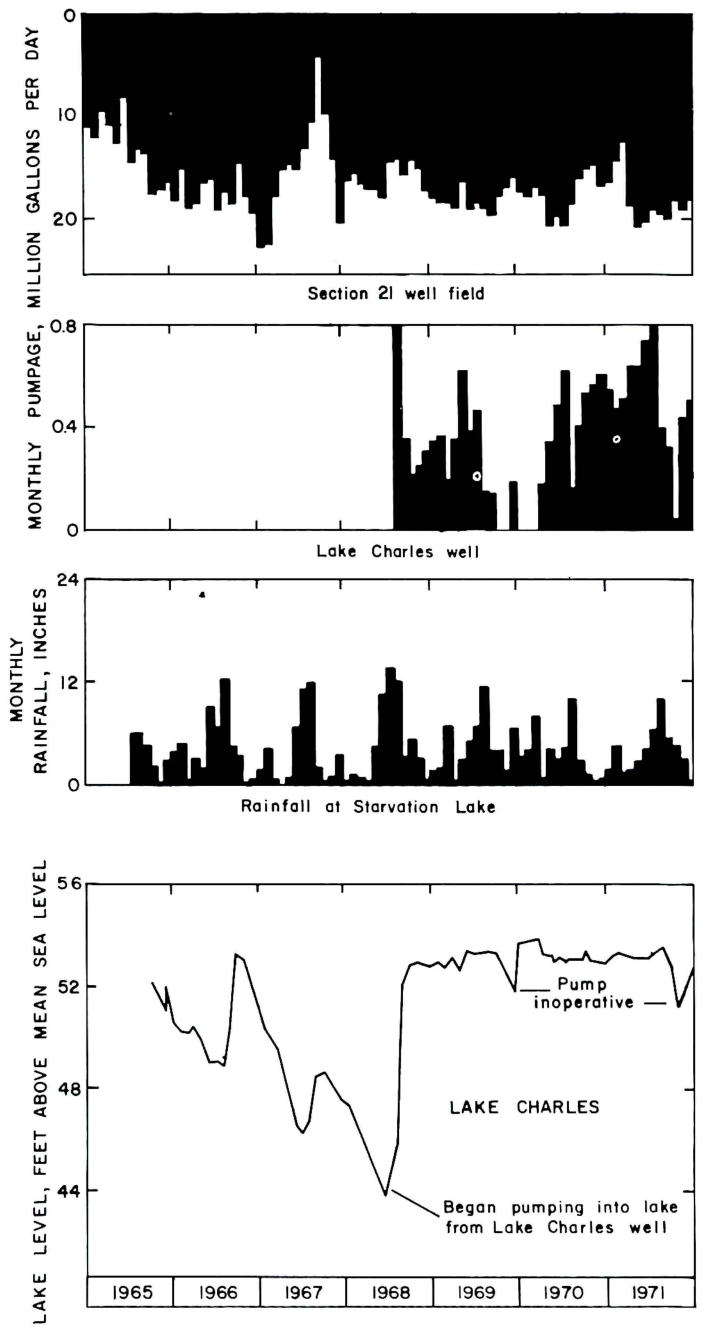


Figure 15 Graphs showing pumpage at Section 21 well field, pumpage into Lake Charles, rainfall, and level of Lake Charles.

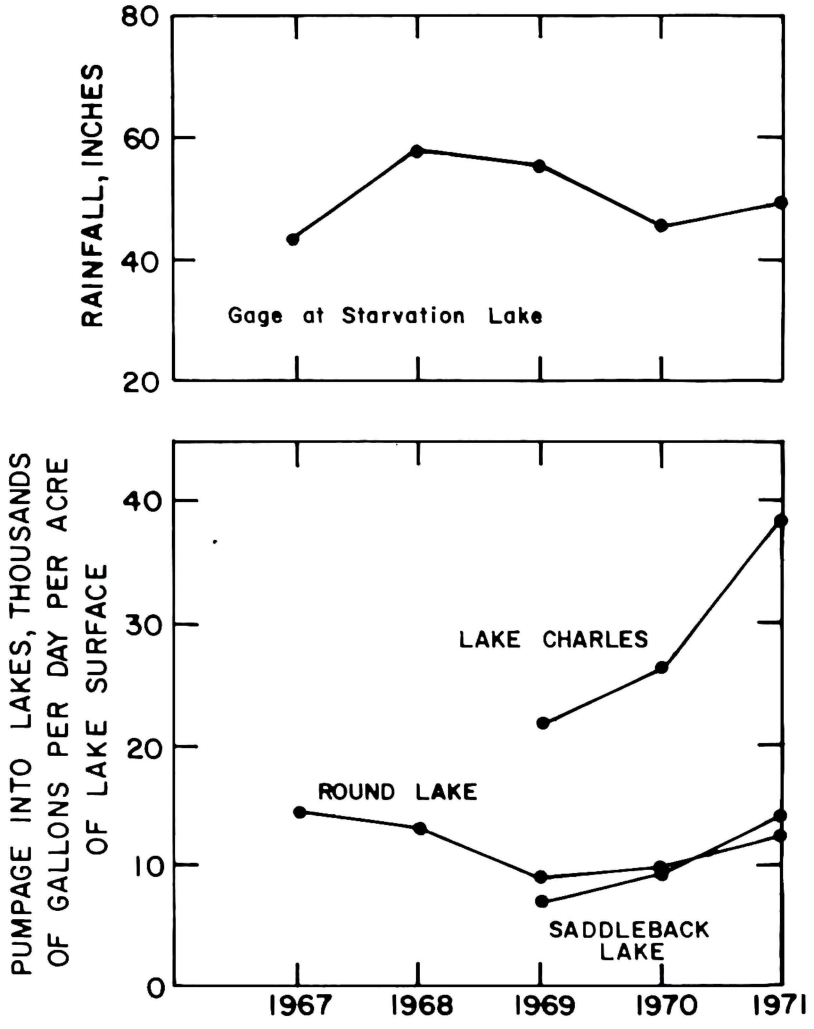


Figure 16 Graphs showing annual rainfall and pumpage into selected lakes in the Section 21 well-field area.

Even though the difference between lake levels and the potentiometric surface of the Floridan Aqufier (fig. 9) was much smaller for Lake Charles than for Round and Saddleback Lakes, ground-water pumpage into Lake Charles (per unit area) was 2 to 3 times greater than for the other two lakes. The hydraulic conductivity of the material between the lakes and the Floridan Aquifer through

one or more sinkholes is much more permeable for Lake Charles than for Round and Saddleback Lakes.

During 1967 - 69, rainfall in the area generally increased and pumpage int Round Lake decreased. Since 1969 pumpage into the three lakes has trend upward, but the trend has been greater for Charles and Saddleback Lakes th for Round Lake. For example, from 1969 through 1971, pumpage increased percent at Round Lake, 80 percent at Lakes Charles, and 110 percent Saddleback.

Pumpage of ground water into the lakes was substantially greater in 197 than in 1969 because in 1971 ground-water levels and lake levels were lowe throughout the area. An analysis of water-level data for Lake Crenshaw and several shallow and deep wells indicates that in 1971 water levels in the general area not only were well below those of 1969, but also were below the levels of 1967. It would be expected, therefore, that pumpage into Round Lake would be significantly greater in 1971 than in 1967. However, this was not the case because about 52 million gallons of water was pumped into Round Lake in 1971 as compared to 58 million gallons in 1967. The decrease in pumpage into Round Lake is explained by the fact that in 1971 the level of Saddleback Lake was controlled by pumping whereas in 1967 it was not. In 1967 the level of Saddleback Lake averaged about 2 feet lower than the controlled level of Round Lake but in 1971 the level of Saddleback Lake averaged about 0.3 foot higher than the level of Round Lake. Thus, in 1971 eastward ground-water flow from Round Lake was blocked by ground-water movement from Saddleback Lake as a result of the higher lake level at Saddleback Lake. If Round Lake and Saddleback Lake are considered as one lake, the increase in pumpage from 1969 to 1971 was 90 percent versus 80 percent for Lake Charles.

Thus, the trend of pumpage from 1969 to 1971 in itself does not necessarily indicate that a progressive increase in pumpage will be required to maintain the lake levels. If water had been pumped into Saddleback and Charles Lakes in 1967, pumpage would have been substantially greater in 1967 than in 1969; hence, between 1967 and 1969 the trend in pumpage would have been downward just as was indicated for Round Lake. On the assumption that the pumpage from Section 21 well field has leveled off at an average of 18 to 20 mgd, pumpage into the lakes will decrease once rainfall in the general area returns to normal.

MOVEMENT AND DISTRIBUTION OF WATER PUMPED INTO LAKES

In 1971 aggregate pumpage from all three wells was 401 million gallons (1.1 mgd or 765 gpm). This quantity of water is equivalent to 22.5 days of

pumping from Section 21 well field, based on the 1971 average withdrawal rate of 17.8 mgd. Rainfall at Starvation Lake gage was about 50 inches for the year and presumably rainfall added about as much water to the lakes as was lost by evaporation (estimated as 50· inches per year). Since none of the lakes overflowed during the year, the ground water that was pumped into the lakes only replaced water that leaked through the lake bottoms.

The general direction of movement of the ground water in the Section 21 well-field area is indicated by the flow lines (arrows) drawn perpendicular to the contours in figure 17. Regional ground-water flow in the water-table aquifer into Section 21 well-field area is from areas north and northeast of the well field. The water table was highest (56 feet above msl) about a mile northeast of the well field, and lowest (38 feet above msl) south of Crum Lake near the south-central part of the well field. On the assumption that depth and permeability of the surficial materials are uniform, flow is greatest where the contours are closest together and least where the contours are farthest apart.

On May 21, 1971, water-table gradients in and near the Section 21 well field were steepest on the south and west sides of Round Lake, and ranged from about 0.01 to 0.005 foot per foot. Most of the lateral ground-water movement from Round Lake was west toward Starvation and Crum Lakes, where the ground water recharged the Floridian Aquifer.

From Saddleback Lake water moved laterally in all directions from the lake into the water-table aquifer, but gradients were steepest to the south, and most of the flow was south toward a water-table depression centered about 3,000 feet south-southeast of the lake. Water that moved eastward and northeastward from Saddleback Lake eventually reached this same water-table depression. Some of the northerly flow from Saddleback Lake moved northwestward into Section 21 well field.

Lateral ground-water movement from Lake Charles was generally to the southwest into the water-table depression south-southeast of Saddleback Lake.

Localized cones of depression are produced by wells pumping into the lakes. Therefore, part of the water that moves into the Floridan Aquifer probably is intercepted by the wells during these pumping periods.

The quantities of water moving into and through the water-table aquifer from Round, Saddleback, and Charles Lakes were computed by use of Darcy's law expressed as $Q = KIA$,

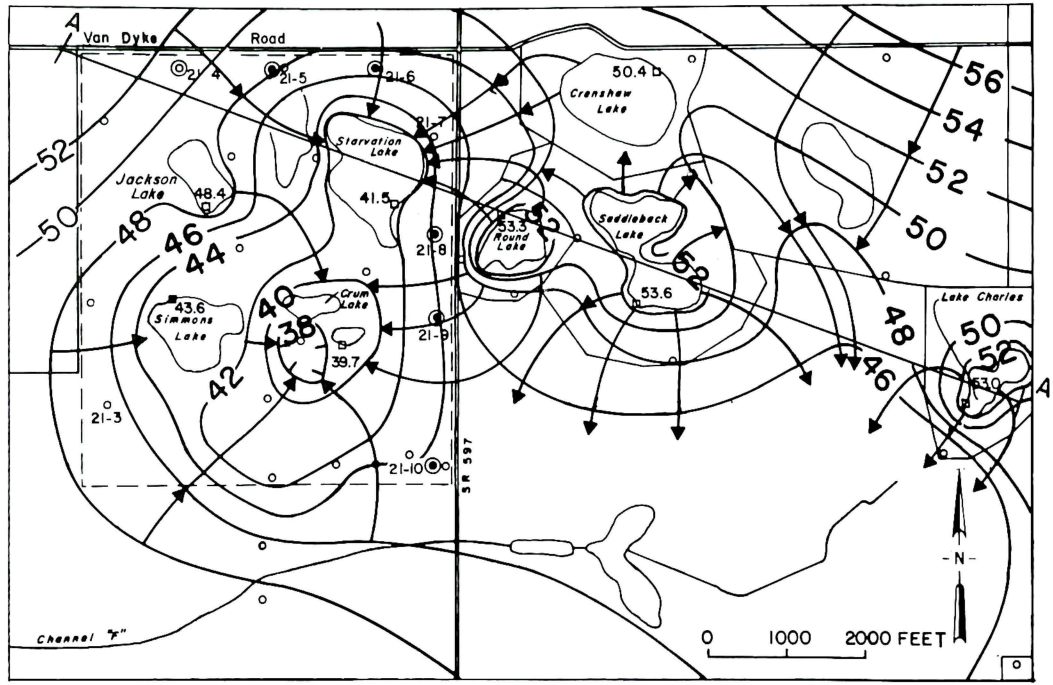


Figure 17 Map of Section 21 well-field area and water table of the shallow aquifer, May 21, 1971.

where

Q = quantity of water, in cubic feet per day
K = hydraulic conductivity of the aquifer, in feet per day,
I = hydraulic gradient, in feet per foot, and
A = cross-sectional area through which water moves, in square feet.

The hydraulic conductivity of the aquifer is 13 feet per day and the aquifer's thickness is 35 feet. Corresponding values of the hydraulic gradient and width of cross-section were estimated for each lake from the contours on figure 17. The computations show that on May 21, 1971, 86,000 gallons moved laterally from Round Lake into and through the water-table aquifer, 89,000 gallons from Saddleback Lake, and 77,000 gallons from Lake Charles.

Based on the assumption that the computed rates at which water moves laterally from the lakes to the water-table aquifer represent the average flow rates from May 1971, the rate at which water moves vertically from the lakes through the shallow aquifer to the Floridan Aquifer can be determined by the water-budget method. For example, during May 1971 total pumpage into Round, Saddleback, and Charles Lakes was 1,410,000 gpd. The change in lake levels was virtually negligible for the month; hence, the change in volume of water stored in the lakes was negligible. The lakes did not overflow nor did they receive any surface-water inflow. Estimated lake evaporation for May was 0.33 foot greater than the monthly rainfall as measured at Starvation Lake; multiplying this value by the total area of the three lakes sets the net loss of water to the atmosphere at 190,000 gpd. The total amount of water that moved from the lakes to the water-table aquifer was computed to be 252,000 gpd. The only unknown item in the water budget for the lakes was the quantity of water that moved vertically from the lakes to the Floridan Aquifer. For May 1971, this quantity was 968,000 gpd. Water-budget data for individual lakes are given in table 1.

TABLE 1
Water-budget data for Round, Saddleback, and Charles Lakes, May 1971
(Quantities in thousands of gallons per day)

Lake	Pumpage into lakes	Net loss Evaporation minus rainfall	Lateral flow from lakes to water-table aquifer	Vertical flow from lakes to Floridan Aquifer
Round	194	39	86	69
Saddleback	574	106	89	379
Charles	642	45	77	520
TOTAL	1,410	190	252	968

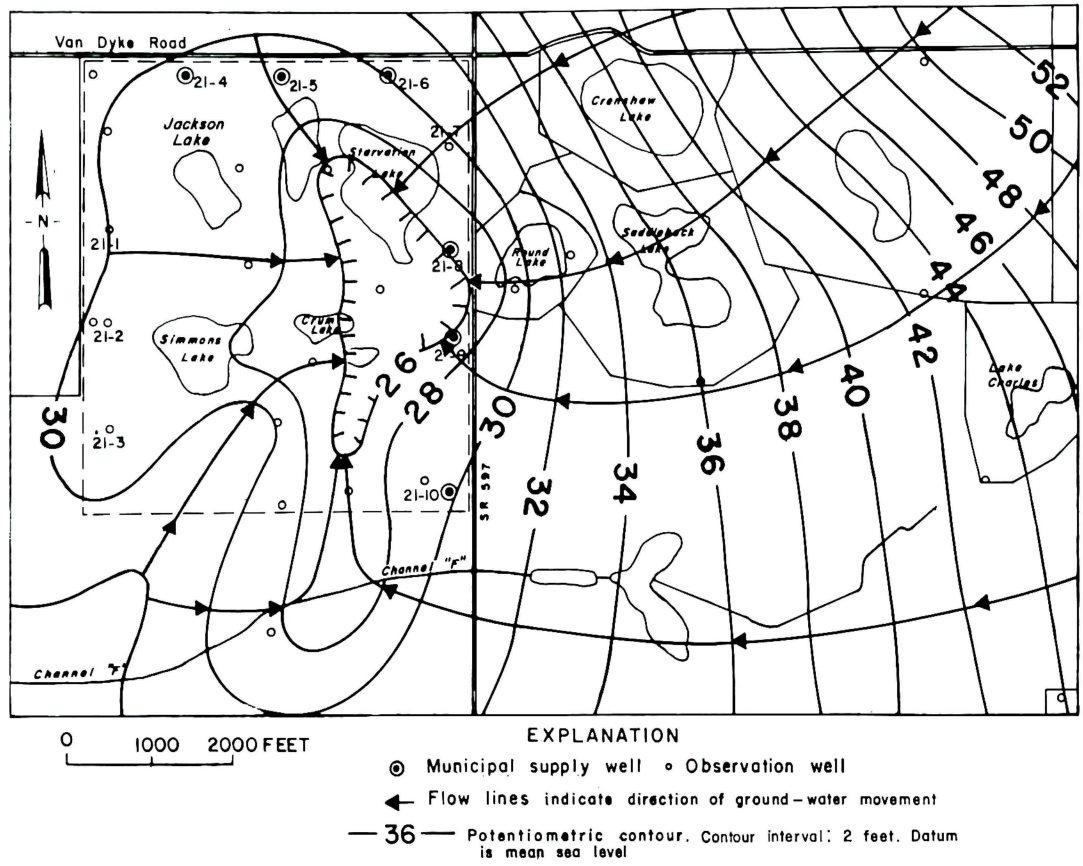


Figure 18 Map of Section 21 well-field area and potentiometric surface of Floridan Aquifer, May 21, 1971.

During May 1971, about 69 percent of the water pumped into Round, Saddleback, and Charles Lakes returned directly to the Floridan Aquifer. An additional 6 percent of the water flowed through the water-table aquifer from Round Lake to reach the Floridan Aquifer in Section 21 well field. About 13 percent of the water was lost by evaporation from the lakes. The remaining 12 percent of the water moved from Saddleback and Charles Lakes into the water-table depression south-southeast of Saddleback Lake and probably returned to the Floridan Aquifer. The water-table depression south-southeast of Saddleback Lake apparently is caused by leakage from the water-table aquifer to the Floridan Aquifer (Oral comm., Sinclair, W. C., 1972). In 1972 several test holes were drilled to map the extent of this depression. The test-hole data indicated a good hydraulic connection between the water-table aquifer and the Floridan aquifer. Detailed maps of the water table indicated that the flood control ditch (Channel F) is not responsible for the depression.

The distribution of the pumpage from 1971 (765 gpm) probably was about the same as that for May 1971 except that the net loss to the atmosphere (evaporation minus rainfall) was negligible for the year; therefore, all the pumpage must be distributed between leakage to the Floridan Aquifer and leakage to the water-table aquifer. On the assumption that the leakage for 1971 was proportional to the leakage for the different lakes and aquifers in May 1971 (table 1), about 79 percent of the yearly pumpage leaked directly to the Floridan Aquifer and 21 percent moved laterally into the water-table aquifer. Almost all of the water that moved laterally to the water-table aquifer eventually reached the Floridan Aquifer.

Figure 18 shows the potentiometric surface of the Floridan Aquifer in the Section 21 well-field area on May 21, 1971 when the wells there were pumped at about 20.4 mgd. Most of the water moved into the well-field area from the north and northeast - - from the same general areas shown for the water-table aquifer on figure 17. The direction of movement of water into the well field proper was toward a low in the potentiometric surface (26 ft above msl). The location of this low generally coincided with the low water levels of the water-table aquifer, indicating a good hydraulic connection between the water table and the potentiometric surface of the Floridan Aquifer.

HYDROLOGIC CONSEQUENCES

If water is pumped into a lake, the lake level is higher and the lake area is larger than either would have been had water not been added, and the lake level is also higher in relation to ground-water levels in the adjacent and subjacent aquifers than it otherwise would have been. Consequently, (a) leakage from the lake increases; (b) lake evaporation increases; and (c) the potential for the lake

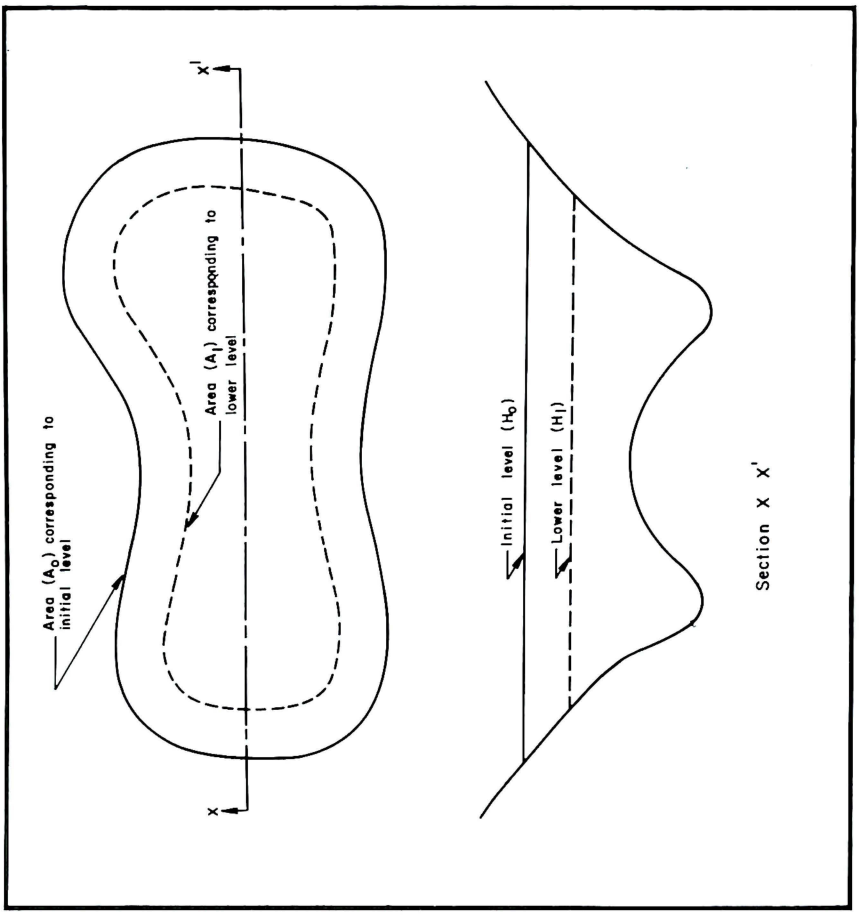


Figure 19 Diagrammatic sketch showing how lake area varies with lake level.

to overflow during wet periods increases. Any of the above may cause a reduction of the local water resource.

Whether the increase in leakage causes a reduction of the local water resource depends on whether the water is locally retrievable for beneficial use. In 1971 almost all of the water pumped into Round, Charles, and Saddleback Lakes eventually returned to the Floridan Aquifer at or generally east of Section 21 well field where the water was retrievable. Because the water is retrievable, leakage from these three lakes constitutes a negligible reduction of the local water resource.

Evaporation from a lake is increased by pumping of ground water into the lake because the resulting lake area is greater than it would have been had water not been pumped into the lake. Data are lacking for an accurate appraisal of the increase in evaporation but the relative magnitude of quantity of evaporated water can be reasonably estimated. The quantity of water that evaporates from a lake is proportional to the lake area, which, because of the basin-like shape of the lake bottom, decreases as the lake level declines (fig. 19). If the input of ground water maintains the lake level at H_o when it otherwise would decline to H_1, the resulting increase in evaporation is expressed as follows:

$$V = (A_o - A_1)(E - E') \quad (1)$$

wherein

V = increase in volume of water evaporated from lake (L^3),
A_o = lake area at level H_o (L^2),
A_1 = lake area at level H_1 (L^2),
E = depth of water evaporated from lake surface (L),
and E' = depth of water evaporated from lake bottom that would be exposed if lake declined to level H_1 (L).

According to estimates of lake evaporation by Kohler, Nordenson, and Baker (1959), yearly lake evaporation in the Tampa area averages about 50 inches. According to Cherry, Stewart, and Mann (1970), evapotranspiration in the Middle Gulf area north of Tampa is about 38 inches per year. For a condition where the water table is lowered by pumping, evapotranspiration from the bare and sandy exposed lake bottoms is presumably less than it would be for the Middle Gulf area as a whole; hence, the value of E' is arbitrarily assumed to be 32 inches per year.

On the basis of equation 1 and an estimate of 18 inches per year for the factor E-E', the yearly increase in lake evaporation that results from arresting the decline in lake level is determined as indicated in figure 20. For example, if the decline of a lake level is arrested at a given level and if at that level it has an area of 10 acres, and if the continued decline in level would have reduced the lake area by 50 percent, on the average, the increase in lake evaporation attributable to the act of arresting the decline in level would average about 4.6 gpm. If the continued decline in level would have dried up the lake, the increase in evaporation would average about 9.3 gpm.

On the assumption that the areas of Charles, Round, and Saddleback Lakes would have been reduced by an average of 50 percent had water not been pumped into these lakes, the increase in evaporation attributable to the arrest of

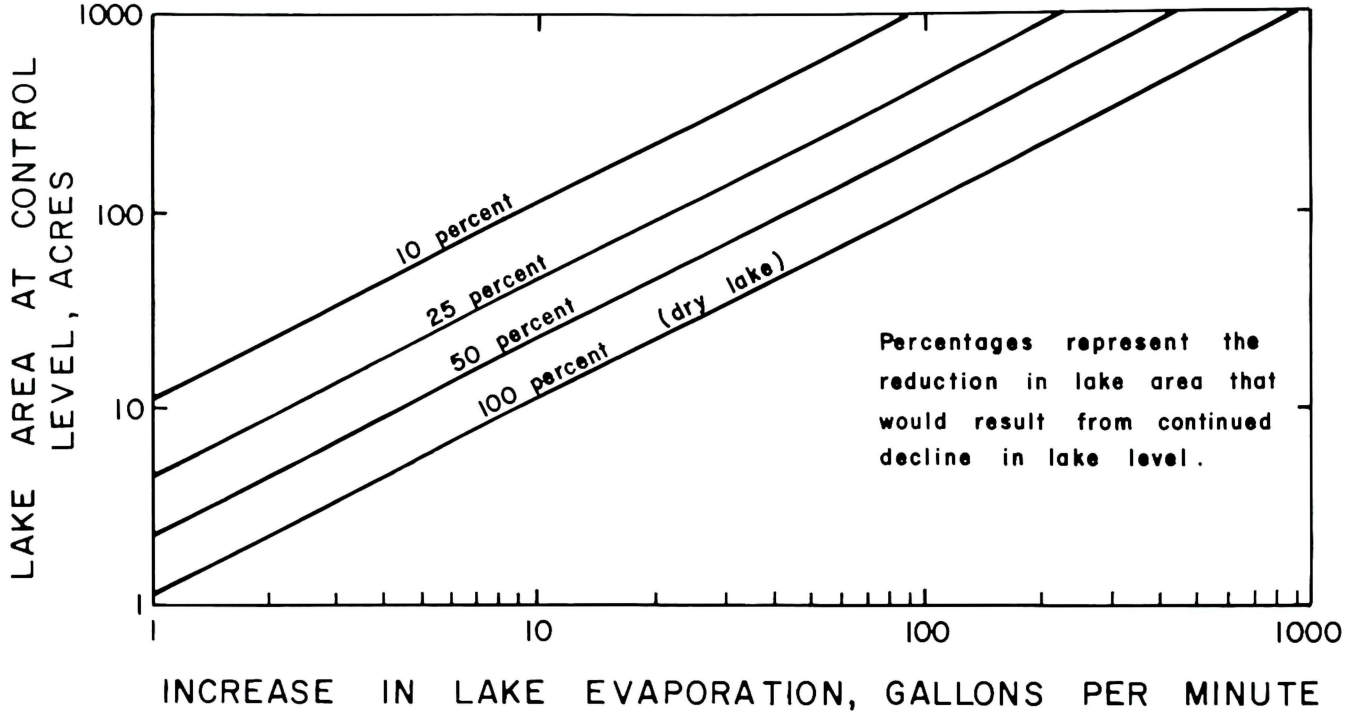


Figure 20 Graph showing relation between lake area and increase in lake evaporation attributable to the arrest of the decline in lake level.

the decline in level would average about 25 gpm for the three lakes compared to the combined pumpage of 765 gpm into the three lakes in 1971.

Whether the entire 25 gpm (which, of course, is intended only to indicate the approximate magnitude of the increase in evaporation) can be considered a reduction of the local water resource is open to question. The decline in level forestalled in the foregoing hypothetical example was presumed to result from the effects of: (1) pumping for public water supply; and (2) less-than-normal rainfall, the first probably being more important than the second for the lakes involved in this investigation. To the extent that the lake levels were maintained at a constant stage against the stress imposed by less-than-normal rainfall, the increase in evaporation represents a reduction of the local water resource. On the other hand, if lake levels had been maintained at a variable stage compensating only for well-field pumping but not for below-normal rainfall, the increase in evaporation that results from maintaining lake levels against the stress imposed by well-field pumping alone would not be considered a reduction of the local water resource. In other words, if the lake levels are maintained so as to compensate only for the effect of well-field pumping, lake evaporation would be exactly the same as would occur in the absence of well-field pumping, and, hence, no tendency to reduce the local water resource could result. Thus, in this view, perhaps less than half of the 25 gpm increase in lake evaporation can be considered as a reduction of the local water resource.

If the decline in level of a lake is arrested by pumping water into the lake, the lake has less capacity remaining to store future natural inflows, and the potential for the lake to overflow is increased. Any water that spills from the lake in excess of the amount that would have spilled naturally represents a reduction of the local water resource.

The loss of water due to overflow can be minimized by maintaining the lake level some distance below the level at which the lake overflows, preferably the level that would have obtained had there been no pumping for public water supply; however, little water would spill from direct rainfall on the lake if the lake were maintained at least 1 foot below the level of the lowest surface outlet. For a lake that normally declines 0.02 foot per day from evaporation and leakage, for example, direct rainfall would be stored without loss in amounts as great as 1.02 feet in 1 day, 1.2 feet in 10 days, and 1.6 feet in 30 days. Rainfall is seldom in excess of these rates.

Some additional freeboard is required to minimize the overflow of lake water derived from storm runoff. The quantity of runoff generated by a given rainfall varies with the size and surficial characteristics of the contributing drainage area; however, these elements differ so widely for individual lakes that few generalizations can be made that are useful.

The natural drainage basins of Charles, Round, and Saddleback Lakes are flat, sandy, and well vegetated. These lakes apparently receive little surface-water inflow. Charles and Round Lakes did not overflow during 1969, for example, when the yearly rainfall was greater than average. Saddleback Lake apparently spilled a small quantity of water during a few days in December 1969. The levels of Charles, Round, and Saddleback Lakes apparently are maintained low enough so that the overflow of water attributable to the input of ground water is small and does not constitute a significant reduction of the water resource.

The addition of Floridan Aquifer water to Charles, Round, and Saddleback Lakes has caused a distinct change in the chemical quality of water in the lakes. As Floridan Aquifer water is continually discharged into the lakes, the chemical quality of the lake water becomes increasingly similar to Floridan Aquifer water. Some variation in the chemical quality results as the discharge rate varies from wet to dry periods. Table 2 lists concentrations of selected chemical constituents of water from natural lakes, from wells tapping the Floridan Aquifer, and from mixtures of natural lake water and Floridan Aquifer water in northwest Hillsborough County.

TABLE 2
Selected chemical constituents of water from lakes, Floridan Aquifer, and mixtures of water from lakes and Floridan Aquifer, northwest Hillsborough County

(All values, exceph pH, in milligrams per liter)

Source of water	pH	Dissolved solids	Hardness	HCO	Alkalinity as $CaCO_3$	Sodium	Calcium
Crenshaw Lake 1/	5.4	22	12	2.0	2.0	4	3
Round Lake 2/	7.9	150	130	168	110	6	50
Lake Charles 2/	8.1	105	140	180	148	5	55
Saddleback Lake 2/							
North end	7.9	30	96	133	103	5	39
South end	7.9	30	76	102	84	5	30
Wells near Section 21 tapping Floridan Aquifer 3/	8.1	220	200	225	180	10	65

1/ Lake water

2/ Mixture of lake water and Floridan Aquifer water

3/ Floridan Aquifer water

Charles, Round, and Saddleback Lakes were not studied for possible ecological changes that might result from the change in chemical quality of the lake water by addition of ground water or from holding the lake level constant. These subjects are being investigated by scientists of the Southwest Florida Water Management District. Several residents reported that the growth of aquatic plants increased after the input of ground water into the lakes. However, many lakes in Florida are naturally supplied with ground water that is similar in chemical quality to the Floridan Aquifer water added to Round, Charles, and Saddleback Lakes, so whatever ecological changes that might occur over the long run are not expected to be either drastic or harmful. Further study is underway, as noted above, to determine whether possible long-term ecological changes are attributable to the addition of Floridan Aquifer water to the lakes.

Under natural conditions - - that is, conditions that were free of the effects of pumping for public water supply and pumping of water to maintain lake levels - - water leaked from Round, Charles, and Saddle back Lakes into the Floridan Aquifer and to some extent contributed to the dissolution of limestone in the Floridan Aquifer. This may have led to a gradual increase in the permeability of limestone beneath the lakes generally and in some instances to the eventual collapse of the materials that overlie the Floridan, as is evident from the sinkhole depressions in the lake bottoms. Leakage from the lakes continues, of course, after pumping for public water supply takes place. When the lake levels are maintained by pumping of ground water into the lakes, however, leakage from the lakes to the Floridan Aquifer is greater than occurred under natural conditions because the hydraulic gradient between the lakes and the Floridan Aquifer is increased. To the extent that leakage from the lakes is so increased, the rate of dissolution of limestone tends to increase; however, the increased leakage consists of pumped ground water that has passed through the limestone of the Floridan Aquifer and, hence, has already used up much of its capacity for dissolving limestone.

Thus, if the rate of dissolution of limestone is increased, as a result of maintaining levels of lakes by pumping ground water into the lakes, the increase probably is small. The effect of such an increase in the rate of dissolution of limestone on the permeability of materials under the lakes - - and, hence, on the pumpage rates required to maintain lake levels at a given stage under the same climatic and hydrologic conditions - - probably is not great enough to be detectable after only a few years of pumping. Over the long term, however, the cumulative effect of a small increase in the rate of dissolution of limestone may be appreciable. Resolution of this important matter will require comparison of present and future pumpage rates for times when climatic and hydrologic conditions are virtually the same.

SUMMARY

Lake levels in the Section 21 well-field area north of Tampa, Florida, have been lower than normal in recent years owing to less-than-normal rainfall and a lowering of ground-water levels by large withdrawals of water from the Floridan Aquifer in Section 21 well field.

By pumping Floridan Aquifer water into the lakes, local residents have stabilized the levels of Round Lake since mid-1966 and of Saddleback and Charles Lakes since mid-1968. Total pumpage into the lakes ranged from 217 million gallons in 1969 to 401 million gallons in 1971; the large increase in pumpage is attributed to weather conditions which were drier in 1971 than in 1969. In 1971 pumpage averaged 143,000 gpd (100 gpm) at Round Lake; 468,000 gpd (325 gpm) at Saddleback Lake; and 492,000 gpd (340 gpm) at Lake Charles. These values represent the water required to maintain lake levels at a nearly constant level which generally was above the level that would have occurred naturally. Considerably less water would have been required had the lake levels been permitted to fluctuate through a range about equal to the natural range in stage of lakes in the same general area.

The distribution of water pumped into the lakes was estimated for May 1971 when the combined pumpage averaged 1,410,000 gpd. Of this amount, 968,000 gpd (69 percent) returned directly to the Floridan Aquifer; 252,000 gpd (18 percent) moved laterally into the water-table aquifer; and 190,000 gpd (13 percent) was lost by evaporation. Almost all of the water that moved laterally into the water-table aquifer eventually reached the Floridan Aquifer at or generally east of Section 21 well field.

The distribution of the yearly pumpage for 1971 probably was about the same as indicated for May 1971 except that the net loss to the atmosphere (evaporation minus rainfall) was negligible for the year. Thus, the entire pumpage for 1971, averaging 765 gpm, was distributed between leakage to the water-table aquifer (21 percent) and leakage to the Floridan Aquifer (79 percent).

The total leakage from Charles, Round, and Saddleback Lakes returned to the Floridan Aquifer at or slightly east of Section 21 well field where the water was locally retrievable for beneficial use. Thus, little reduction of the local water resource resulted from increased leakage because of the maintaining of lake levels in 1971.

Maintaining levels of lakes at a constant and higher than natural stage caused some reduction of the local water resource because of an increase in the

volume of water that evaporated from the lakes. Lake areas were considerably larger than they would have been had water not been added to the lakes. The combined increase in water evaporated from Round, Charles, and Saddleback Lakes was estimated to be 25 gpm on the assumption that lake areas were maintained twice as large as they would have been had ground water not been added to the lakes. The rate of evaporation from a water surface is greater than the rate of evapotranspiration from an exposed lake bottom. The difference between the rates of evaporation and evapotranspiration was assumed to be 18 inches per year. The estimate of 25 gpm - - which is intended only to represent the relative magnitude of the increase in lake evaporation attributable to the maintaining of lake levels - - equals about 3 percent of the water pumped into the lakes in 1971. The lake levels were maintained to compensate for effects of: (1) pumping for public water supply; and (2) less-than-normal rainfall. If lake levels had been maintained at a variable stage compensating only for well-field pumping but not for below-normal rainfall, then only part of the increase in lake evaporation - - that is, the part associated with maintaining lake levels against the stress of less-than-normal rainfall - - would be considered a reduction of the local water resource. Thus, with this view in mind, perhaps less than half the 25 gpm estimated in the hypothetical example above can be considered as a reduction of the local water resource.

The levels of Round, Charles, and Saddleback Lakes seem to have been maintained low enough that no appreciable loss of water resulted from overflow of the lakes during years of normal or below normal rainfall.

The addition of Floridan Aquifer water causes a distinct change in the chemical quality of water in Round, Charles, and Saddleback Lakes generally characterized by increases in calcium, bicarbonate, hardness, and alkalinity. Many lakes in Florida are naturally supplied with ground water that is similar in chemical quality to the Floridan Aquifer for water being added to these three lakes.

Maintaining lake levels in Section 21 well-field area causes an increase in leakage through the lake bottoms because the hydraulic gradient between the lakes and the Floridan Aquifer is increased. This may increase the dissolution of limestone which in turn would increase the permeability of materials beneath the lakes and, hence, increase the pumpage required to maintain levels of lakes at a given elevation under the same climatic and hydrologic conditions. However, the increased leakage from the lakes consists of ground water that has passed through the limestone of the Floridan Aquifer and, consequently, has already used much of its capacity for dissolving limestone. Thus, any resultant increase in pumpage required to maintain lake levels under the same given conditions likely would be small and probably would be undetectable after only a few years

of pumping. Resolution of this important matter - - possible effects of increased dissolution of limestone - - will require careful comparison of present and future pumpage rates for times when climatic and hydrologic conditions are the same.

REFERENCES CITED

Cherry, R. N., Stewart. J. W., and Mann, J. A.
1970 *General hydrology of the middle gulf area, Florida:* Florida Dept. Nat. Resources, Bur. Geology, Rept. of Inv. 56, 96 p.

Kohler, M. A., Nordenson, T. J., and Baker, D. R.
1959 *Evaporation maps for the United States:* U. S. Weather Bur. Tech. Paper 37, 13 p.m. 5 pl.

Stewart, J. W.
1968 *Hydrologic effects of pumping from the Floridan aquifer in northwest Hillsborough, northeast Pinellas, and southwest Pasco Counties, Florida:* U. S. Geol. Survey, open-file rept. 241 p., 60 figs.

DEPARTMENT OF NATURAL RESOURCES
BUREAU OF GEOLOGY

This public document was promulgated at a total cost of $1,050.00 or a per copy cost of $1.05 for the purpose of disseminating hydrologic data.