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. 73

WATER BALANCE OF LAKE KERR - - A DEDUCTIVE STUDY OF A LANDLOCKED LAKE IN NORTH - CENTRAL FLORIDA

By
G. H. Hughes

Prepared by the
UNITED STATES GEOLOGICAL SURVEY
in cooperation with the
BUREAU OF GEOLOGY
FLORIDA DEPARTMENT OF NATURAL RESOURCES

Tallahassee, Florida

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OF
NATURAL RESOURCES

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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 Report of Investigations No. 73 entitled "Water Balance of Lake Kerr -- a Deductive Study of a Land-locked Lake in North-central Florida" by G. H. Hughes.

This study demonstrates the hydrologic parameters that can be developed with a minimum amount of data. This technique should prove of value in the analysis of future lake problems where data has not been accumulated in detail and time may be such that these data cannot be realistically acquired.

Respectfully yours,

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

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July 29, 1974
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Department of Natural Resources
Bureau of Geology

Tallahassee
1974

CONTENTS

	Page
Abstract	1
Introduction	2
Environmental setting of lake	5
Water - level fluctuations	11
Water - balance computations	12
Basic equation	12
Rainfall	13
Evaporation	15
Leakage	16
Surface - water and ground - water inflow	16
Results	18
Analysis of monthly results	18
Nature of expected error of estimate of rainfall	18
Analysis of scatter of water - balance results	20
Search for probable cause of large deviations	21
Error of estimate of evaporation	21
Error of estimate of leakage	23
Error of estimate of ground - water inflow	26
Combined error of estimate of rainfall and surface-water inflow	32
Analysis of yearly results	36
Summary	45
References	59

ILLUSTRATIONS

Figure		Page
1.	Map showing location of Lake Kerr in north-central Florida	4
2.	Map showing shape and general configuration of bottom of Lake Kerr (after Kenner, 1964, fig. 34)	5
3.	Daily hydrograph of Lake Kerr, 1962 - 63	7
4.	Daily hydrograph of Lake Kerr, 1964 - 65	8
5.	Daily hydrograph of Lake Kerr, 1966 - 67	9
6.	Daily hydrograph of Lake Kerr, 1968 - 69	10
7.	Graphs showing month-end level of Lake Kerr and estimate of monthly rainfall in the general area of Lake Kerr, 1962 - 69	11
8.	Graph showing year-end level of Lake Kerr, 1936 - 51 and 1955 - 69	12
9.	Graphs showing yearly rainfall at Crescent City and Ocala, Fla., 1892 - 1969. Cross (x) indicates years for which rainfall was estimated for part of year, usually only 1 or 2 months, on basis of records for other rainfall stations in same general area.	14
10.	Graph showing monthly evaporation from standard, 4-foot diameter, Weather Bureau type pan at Lisbon, Fla., 1960 - 69	15
11.	Graph showing relation between observed and computed monthly change in lake level of Lake Kerr, 1962 - 69	17
12.	Graph showing relation between average of monthly rainfall at two stations some distance apart (DeLand and Palatka) and monthly rainfall at a station midway between the two (Crescent City), 1962 - 69	19
13.	Graph showing time distribution of difference between observed and computed monthly change in lake level of Lake Kerr	22
14.	Graphs showing variation in level of water in wells near Lake Kerr. Wells A, B, and C tap the Floridan aquifer; Well F bottoms in the shallow aquifer. Well locations are shown in figure 15	23

ILLUSTRATIONS – Continued

Figure		Page
15.	Maps showing relation between level of water in Lake Kerr and hydrostatic level of water in Floridan aquifer for contrasting water-level conditions (adapted from Faulkner, 1970, fig. 25)	24
16.	Graphs showing monthly average level of water in Lake Kerr and Sharps Ferry well, 1962 - 69	39
17.	Graph showing relation between monthly water-balance residual of Lake Kerr and difference in water levels at Lake Kerr and Sharps Ferry well for months when estimated rainfall was less than 0.30 foot	40
18.	Graph showing time distribution of difference between observed and computed change in level of Lake Kerr wherein the net of leakage and ground-water inflow is determined by regression equation	42

TABLES

Table		Page
1.	Seasonal distribution of difference between observed and computed monthly change in lake level of Lake Kerr, 1962 - 69, in feet	20
2.	Seasonal distribution of average of monthly rainfall at Crescent City and Ocala, 1962 - 69, in feet	20
3.	Decline in level of Lake Kerr during selected periods of little or no rainfall, in feet	27-31
4.	Estimated monthly rainfall compared to sum of daily rise in level of Lake Kerr for selected months, 1962 - 69, in feet	34-35
5.	Approximate yearly water balance of Lake Kerr, 1962 - 69, in feet; constant leakage assumed	37
6.	Approximate yearly water balance of Lake Kerr, 1962 - 69; in feet; net of leakage and ground-water inflow determined by regression equation	43

WATER BALANCE OF LAKE KERR - - A DEDUCTIVE STUDY OF A LANDLOCKED LAKE IN NORTH - CENTRAL FLORIDA

By
G. H. Hughes

ABSTRACT

Accurate measurements of the many factors that make up the water balance of a lake almost always are lacking. However, enough information may be available to permit speculation about a lake's water balance. Landlocked lakes require less information than other lakes because surface-water outflow is zero.

Of the other parameters required, records of rainfall at National Weather Service offices provide some basis for estimating yearly and monthly rainfall on a lake. Estimates of average yearly lake evaporation for a given area and records of pan evaporation provide a basis for making realistic estimates of yearly and monthly evaporation from a specific lake. Estimates of other factors in a lake's water balance sometimes can be made for selected conditions when the hydrologic characteristics of an area are known.

When such estimates are used in a water-balance equation, the difference between the computed and observed changes in lake level may be large or small and may vary erratically or systematically. If the equation is applied for a wide enough range in lake level, an analysis of these differences may tell which of the estimated factors are causing the bulk of the errors. At least, such an analysis will lead to a better understanding of why the lake level fluctuates than previously existed.

The analytical process just described was used to approximate the water balance of Lake Kerr, which is landlocked. The monthly change in lake level was computed for 1962 - 69 from estimates of rainfall evaporation, leakage, surface-water and ground-water inflow. Although leakage is known to vary, it was assumed to be constant at 0.1 foot per month. Surface-water and ground-water inflows were estimated as zero, even though they may occur at times.

The computed monthly change in level was within 0.10 foot of the observed change in level about 70 percent of the time. Errors substantially greater than 0.10 foot were somewhat erratically distributed in time. Almost all of the large errors indicated inflow not accounted for by the estimates. Because rainfall estimates were based on records from rainfall stations some 20 - 30 miles from the lake, at least some large errors - - substantially larger than 0.10 foot - - were expected; however, errors of this type were expected to balance

over a period as long as 8 years. Because the large errors were related to periods when the lake level rose, the errors were presumed to stem from faulty estimates of rainfall or surface-water inflow.

The reasons why it was concluded that the large errors were caused almost entirely by faulty estimates of rainfall rather than of surface-water inflow are the manner in which the large errors varied when the rainfall estimate was based on different combinations of rainfall stations in the same general area, and from the fact that the lake in 1 year rose greatly when the quantity and seasonal distribution of rainfall were about normal for all stations. The absence of pronounced seasonal variation in errors less than 0.10 foot suggested that ground-water inflow played a relatively minor role in the water balance of Lake Kerr.

Analysis of the yearly water-balance data showed that overall for 1962 - 69 the computed change in lake level was in error by 5.29 feet. Part of the error was readily attributed to the fact that surface-water and ground-water inflows were estimated as zero, for the cumulative effect of small quantities of either could be appreciable over an 8-year period. The error was reduced from 5.29 feet to 3.65 feet when variations in leakage and ground-water inflow were accounted for by regression methods wherein the net of leakage and ground-water inflow was related to the difference between the lake stage and the level of water in a well tapping the same aquifer that underlies Lake Kerr. The remainder of the error was attributed to faulty estimates of surface-water inflow, which conceivably could average from 0.2 to 0.3 foot per year - - rather than zero - - and of rainfall on Lake Kerr which during 1962 - 69 apparently was appreciably greater than estimated on basis of rainfall at Crescent City and Ocala. Over the long term, however, the average of rainfall at Crescent City and Ocala may be more closely representative of rainfall at Lake Kerr.

Based on the long-term averages for Crescent City and Ocala, rainfall at Lake Kerr averages about 54 inches per year. Lake evaporation is estimated to average about 46 inches per year. During 1962 - 69, leakage from Lake Kerr was about 12 inches greater than ground-water inflow to Lake Kerr. If this 12-inch difference is representative of the long-term average, surface-water inflow averaging about 4 inches per year is required to maintain the water balance of Lake Kerr. Ground-water inflow is indicated to be relatively small, probably in the same order of magnitude as surface-water inflow.

INTRODUCTION

Accurate definition of the water balance of a lake requires measurement of quantities of water that move into the lake from various sources and that move

out of the lake to various sinks. For most lakes in Florida, data from which a water balance can be accurately computed are lacking. For many of the lakes, however, measurements of lake-level fluctuations are available. For some of these lakes enough additional information is available to permit some speculation about the lake's water balance. Less information is needed for landlocked lakes than for other types of lakes because surface-water outflow is eliminated as a factor by definition. Records of rainfall at National Weather Service offices provide some basis for estimating rainfall on a lake. Data are available for making realistic estimates of evaporation from shallow lakes in Florida. From general knowledge of the hydrology of an area, reasonable estimates sometimes can be made of other water-balance factors for selected conditions, such as a drought.

When such estimates are used in a water-balance equation, the difference between the computed and observed changes in lake level may be large or small and may vary erratically or systematically. If the equation is applied for a wide enough range in lake level, analysis of these differences may tell which of the estimated factors are causing the bulk of the errors.

The purpose of this report is to apply the analytical process just described to Lake Kerr, a landlocked lake located in north-central Florida as shown in figure 1. In scope, the water balance is computed from sparse data for months spanning 1962 - 69. Computed changes in lake level are compared with observed changes in level. Differences are then examined for significance.

The objective of the study is to provide a basis for understanding why the lake level fluctuates precisely as it does rather than to formulate a method for predicting precisely what the altitude of the lake level will be at any given time. Where adequate lake-level records are available, use of the analytical techniques described in this report or variations of them may lead to increased understanding of other lakes in Florida.

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
feet	0.3048	meters
miles	1.609	kilometers
square miles	2.590	square kilometers

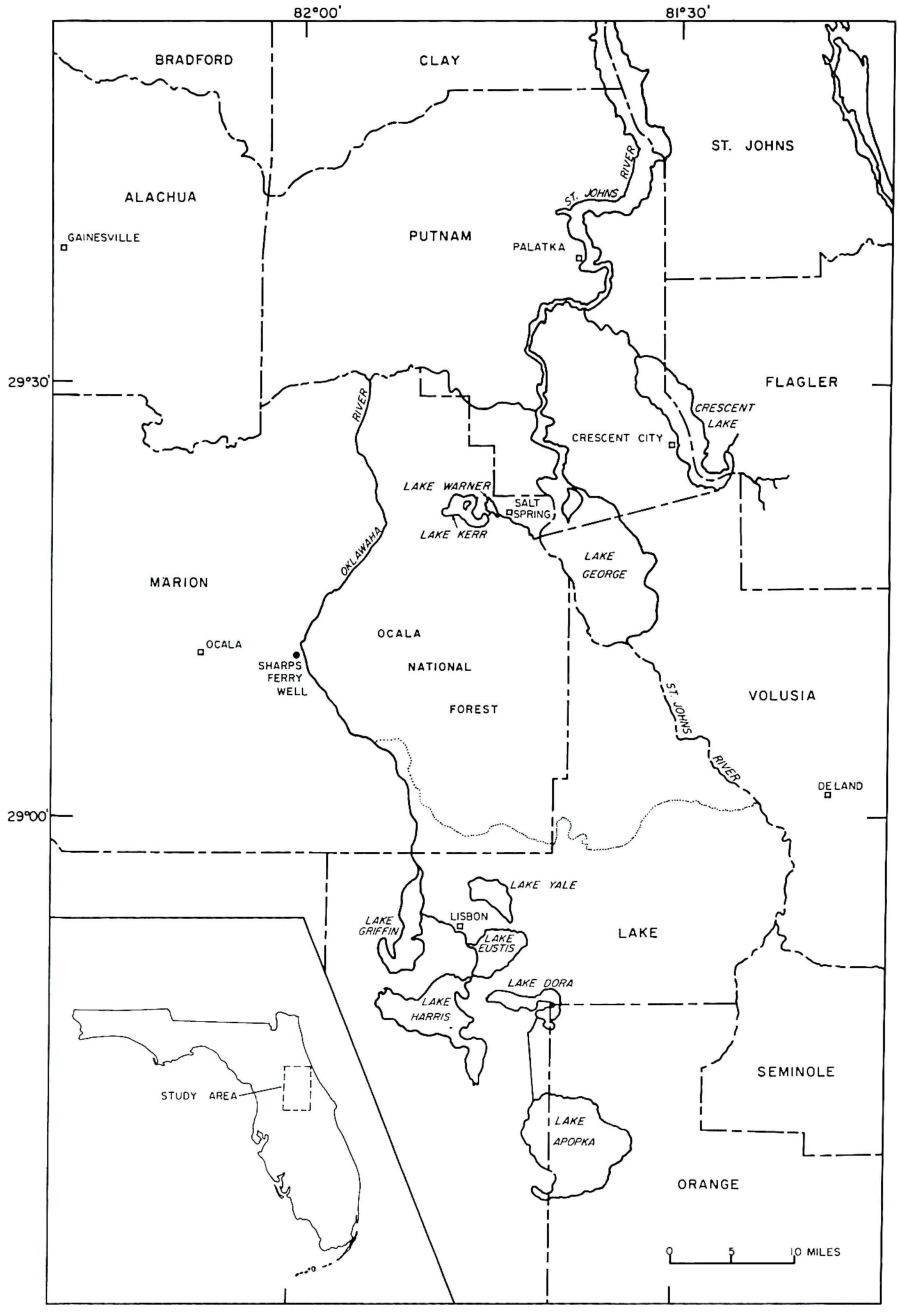


Figure 1. **Map showing location of Lake Kerr in north-central Florida.**

ENVIRONMENTAL SETTING OF LAKE

Lake Kerr is in Marion County. Although almost entirely surrounded by Ocala National Forest, most of the land adjacent to the lake is privately owned. The lake occupies an irregularly shaped depression that probably was formed by subsidence of the land surface owing to the dissolution of limestone at some depth below the surface. A remnant of the former land surface remains as an island, as shown in figure 2. The lake covers about 4 square miles or about 7 percent of the 60 square-mile surface-drainage area.

Lake Kerr connects with Lake Warner (fig. 1) at times of low water by means of a canal dug an unknown number of years ago and at times of high water by the canal and a natural water course. Except for the interconnection between the two lakes, neither Lake Kerr nor Lake Warner have an established outlet for surface-water outflow. Neither lake is known to have spilled or to have been dry. If both lakes were full enough to spill, water would move from Lake

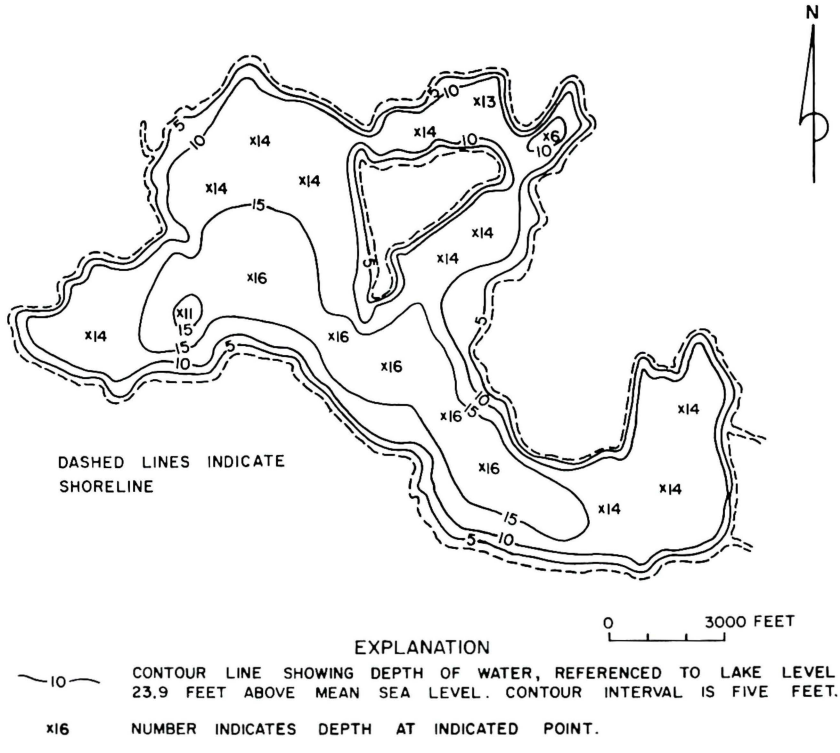


Figure 2. Map showing shape and general configuration of bottom of Lake Kerr.

Kerr to Lake Warner and then to the St. Johns River. Because Lake Kerr and Lake Warner are so close together in the same hydrologic environment, their levels tend to fluctuate together irrespective of the interconnecting channels. Should their levels differ temporarily, the altitude of the common level after equalization would be determined largely by the altitude of Lake Kerr's level before equalization, because Lake Kerr is so much the larger of the two. Consequently, whether Lake Kerr and Lake Warner are considered as poorly connected parts of the same lake, or Lake Kerr is considered as a lake standing alone, as if the interconnecting channels did not exist, is inconsequential to the purpose of this report.

Much of the area immediate to Lake Kerr remains a wilderness. Several homes have been built along the shore and, on the south side, a handful of small groves or orchards are farmed. The area may not long remain a wilderness; some evidence can be seen of plans for additional settlements around the lake.

The drainage area of Lake Kerr is largely covered by pine forest. The surficial materials are dominantly thick to moderately thick, well drained, acidic sands (Florida Agricultural Experiment Stations, 1962) that readily absorb rain of moderate intensity. Much of the absorbed water is retained as soil moisture and in time is returned to the atmosphere by evapotranspiration. When more water is absorbed than can be retained as soil moisture, water moves downward to the water table. Intense rain may cause sheet runoff that is temporarily impounded in local depressions, but the terrain is somewhat uniquely marked by the absence of a throughgoing system of streams.

In the area of Lake Kerr two principal and clearly different aquifers commonly exist. The upper aquifer, the shallow aquifer of this report, is basically the water-table aquifer, which consists of permeable sand at shallow depths and clayey sand interbedded with some clay lenses at greater depths. The shallow aquifer is generally underlain by a layer of material of low permeability that confines or partly confines water in the lower aquifer, a limestone aquifer, hereafter in this report called the Floridan aquifer, following the usage of Parker and others (1955, p. 189) and Faulkner (1970, pp. 89-117). The confining bed in many places is missing or has been fractured or breached by its collapse into solution cavities in the limestone. Such gaps or breaks in the confining bed locally permit downward movement of water from the shallow aquifer to the Floridan aquifer. Water moves down gradient through the Floridan aquifer to emerge as seepage or spring flow in stream valleys or other low areas.

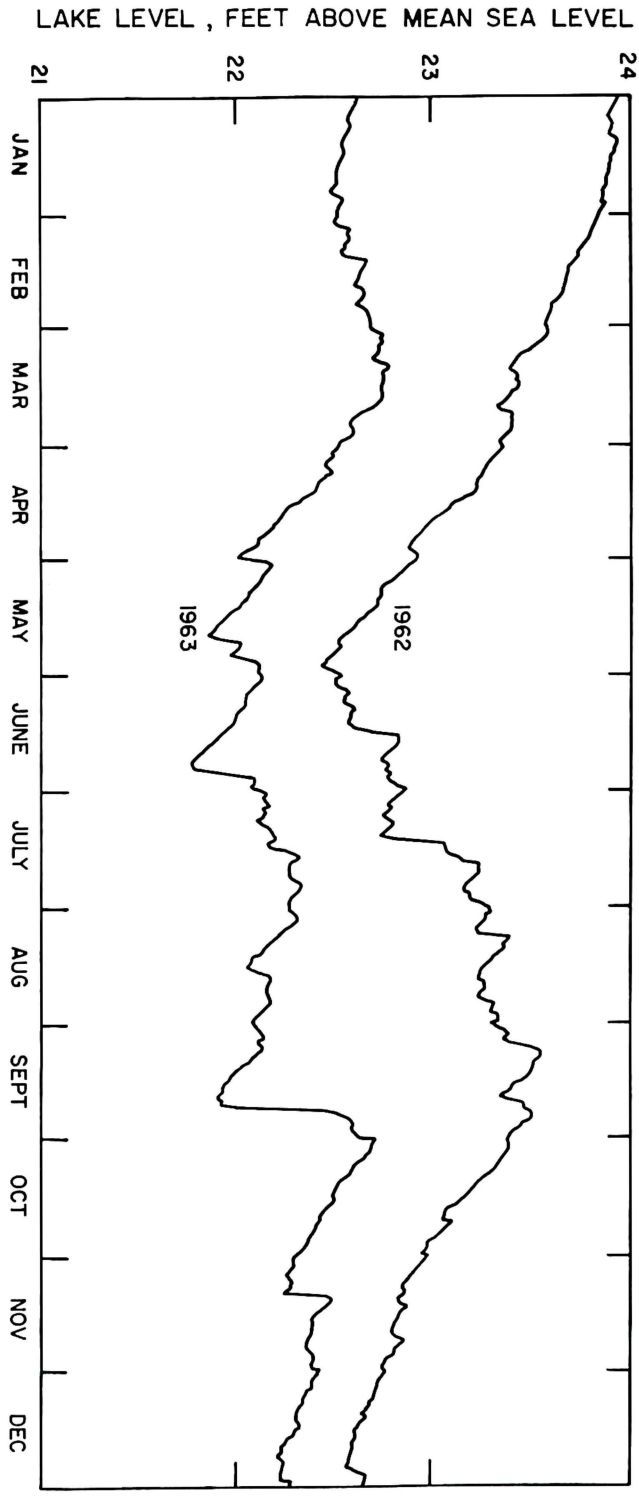


Figure 3. Daily hydrograph of Lake Kerr, 1962 - 63.

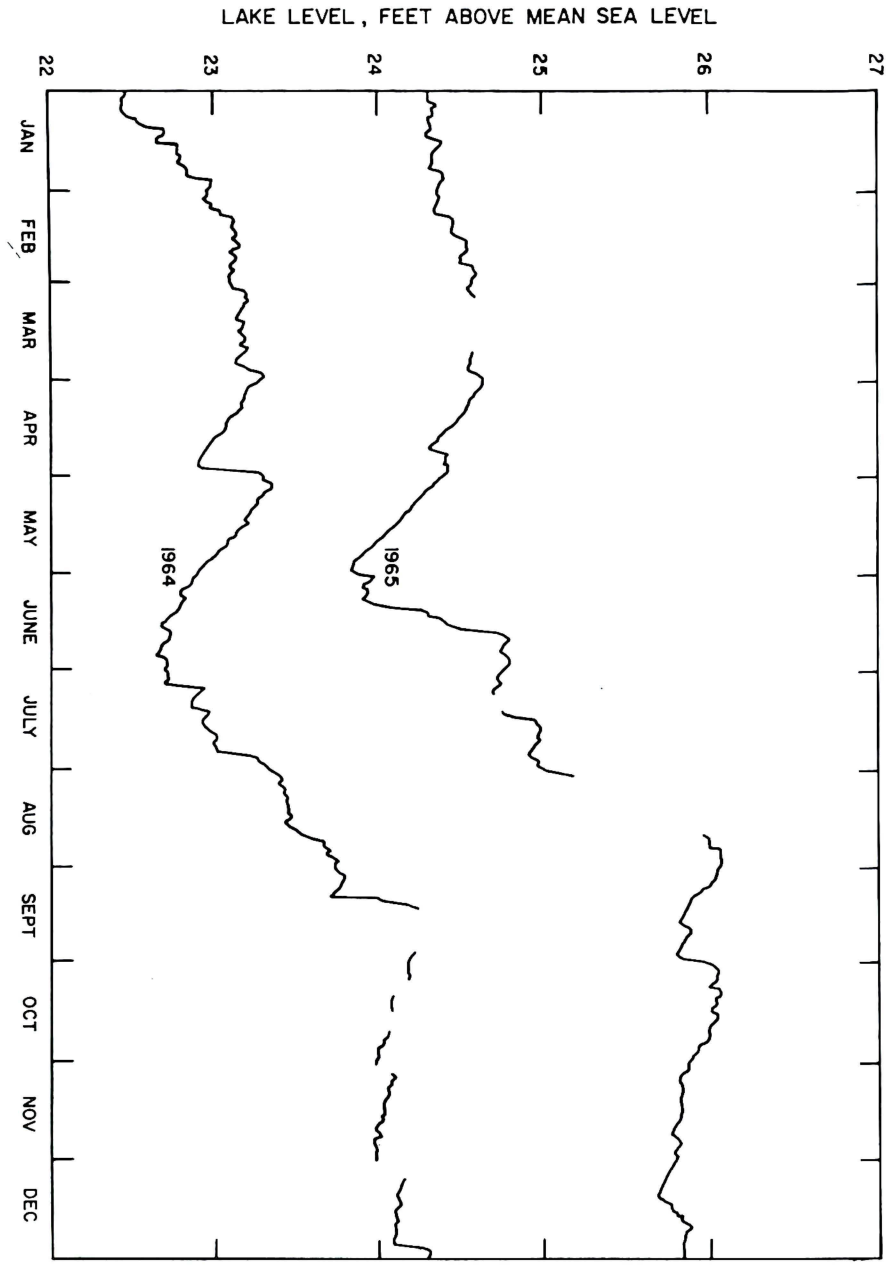


Figure 4. Daily hydrograph of Lake Kerr, 1964 - 65.

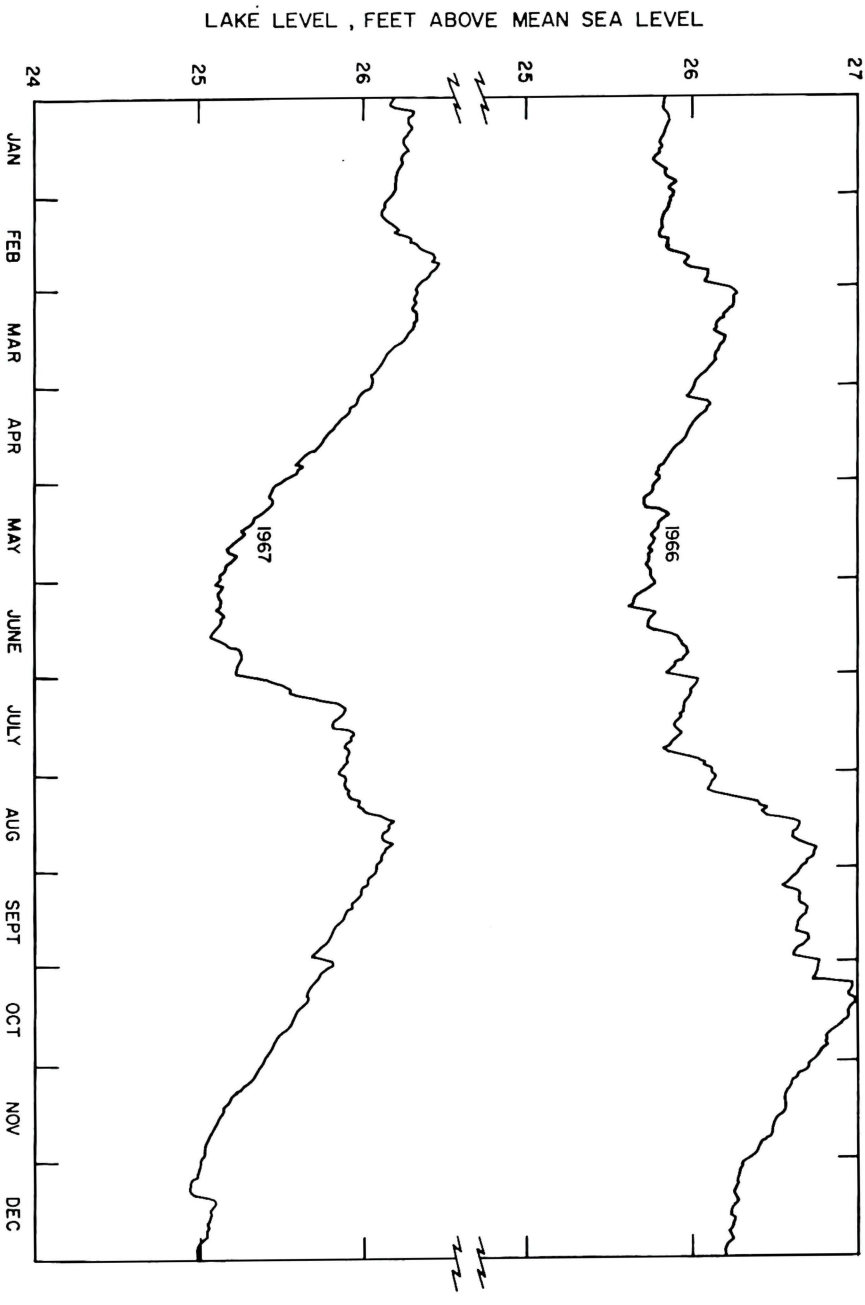


Figure 5. Daily hydrograph of Lake Kerr, 1966 - 67.

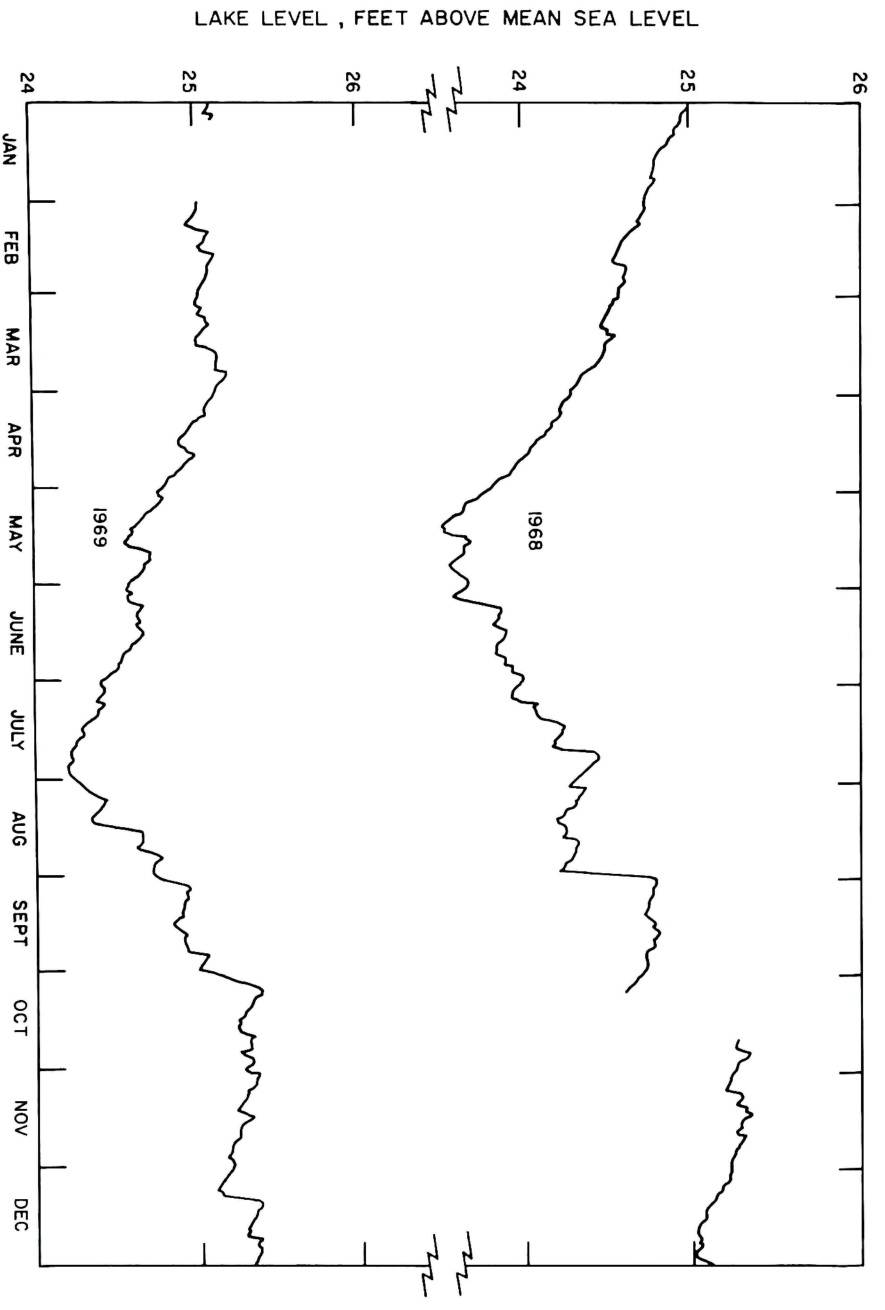


Figure 6. Daily hydrograph of Lake Kerr, 1968 - 69.

WATER - LEVEL FLUCTUATIONS

The level of Lake Kerr has been measured at monthly or weekly intervals since 1936, except from mid-1952 to mid-1955 when no measurements were made. A water-level recorder has been in operation since October 1961. Because a continuous water-level record is more useful than an intermittent one for water-balance studies, only the data for years subsequent to 1961 are used in the more detailed analyses of this report. Data for the preceding years are used in some broad comparisons of conditions during different yearly periods. Unless otherwise stated, the years referred to in this report are calendar years.

Daily lake-level fluctuations of Lake Kerr from 1962 to 1969 are shown in figures 3 - 6. Casual study of the daily hydrograph of Lake Kerr and the record

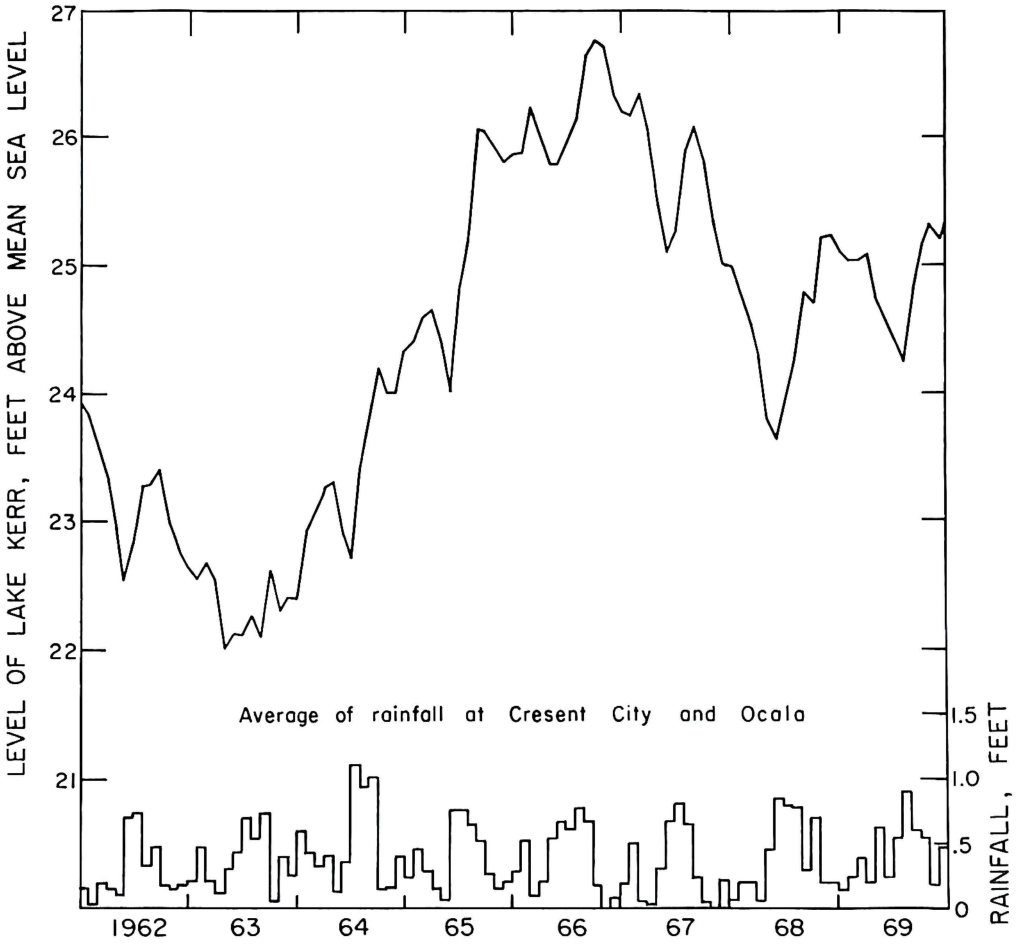


Figure 7. Graphs showing month-end level of Lake Kerr and estimate of monthly rainfall in the general area of Lake Kerr, 1962 - 69.

of daily rainfall in the general area of Lake Kerr (U. S. Weather Bureau, 1961 - 70) suggest that the level of the lake rises abruptly during storm periods but tends otherwise to decline. This implies that the rise of the lake level is caused by rainfall on the lake and possibly by surface-water inflow to the lake. Because surface-water outflow does not occur, any decline in level must be caused by evaporation and probably also by leakage. The decline of the lake level may be modified by ground-water inflow. Month-end and year-end levels of Lake Kerr are shown in figures 7 and 8.

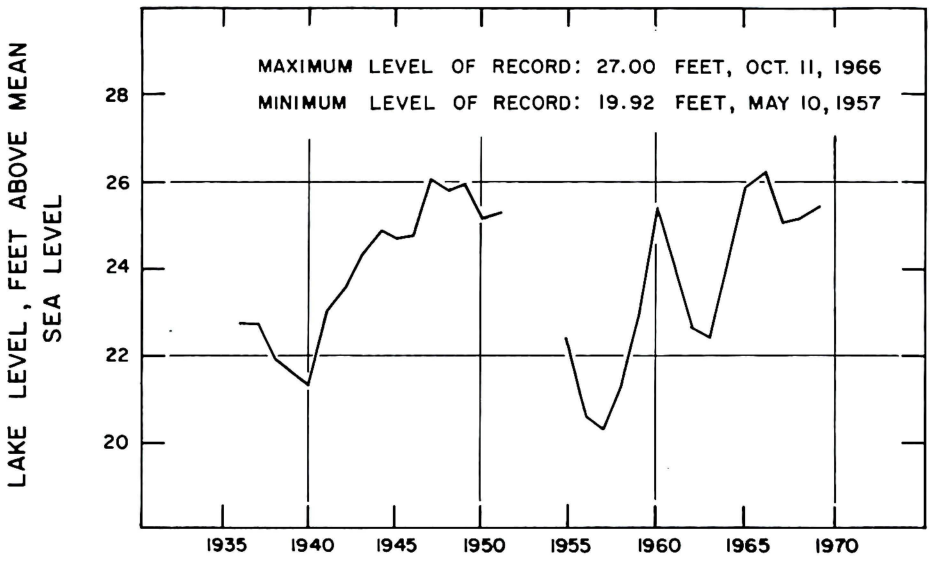


Figure 8. Graph showing year-end level of Lake Kerr, 1936 - 51 and 1955 - 69.

WATER - BALANCE COMPUTATIONS

BASIC EQUATION

Of all the components required for accurate definition of the water balance of Lake Kerr, only the change in lake level has been measured. The water balance of the lake can be approximated, however, if rational estimates of the other components involved can be made and substituted in the water-balance equation:

$$\triangle H = P - E - S + I_{sw} + I_{gw} \quad (1)$$

wherein, $\triangle H$ = change in lake level,

P = rainfall on lake,

E = evaporation from lake,

S = leakage from lake,

I_{sw} = surface-water inflow to lake, and

I_{gw} = ground-water inflow to lake.

Equation 1 can be used for any period for which the different components can be evaluated. The changes in level computed in this report are for each month during 1962 - 69 and the change is expressed in feet without regard for the fact that the lake area varies with the lake level. Error that results from variations in lake area is inconsequential to the purpose of this report, because, as figures 2 and 7 indicate, the change in lake area during the study period was small relative to the total area of the lake.

RAINFALL

For the computations that follow, rainfall on Lake Kerr was estimated as the average of rainfall recorded at the National Weather Service stations in Crescent City and Ocala (fig. 1). For the time spans indicated in figure 9, yearly rainfall averaged 53.48 inches at Crescent City and 53.98 at Ocala. Figure 7 shows the average of the monthly rainfall at these two stations for 1962 - 69.

Records of rainfall are available for several stations in the general ares of Lake Kerr, but not all of the stations are currently active and some of the stations have been operative for only a few years. Records for the stations at Crescent City and Ocala were selected for use in the basic computations of the report because, as a pair, these stations appear to represent Lake Kerr as well as, or better than, any two of the other stations. In addition, the stations at Crescent City and Ocala are currently (1973) active, and the records for these stations are almost complete for the time span of the lake-level record of Lake Kerr. Records for the other rainfall stations in the area were used in supplemental computations.

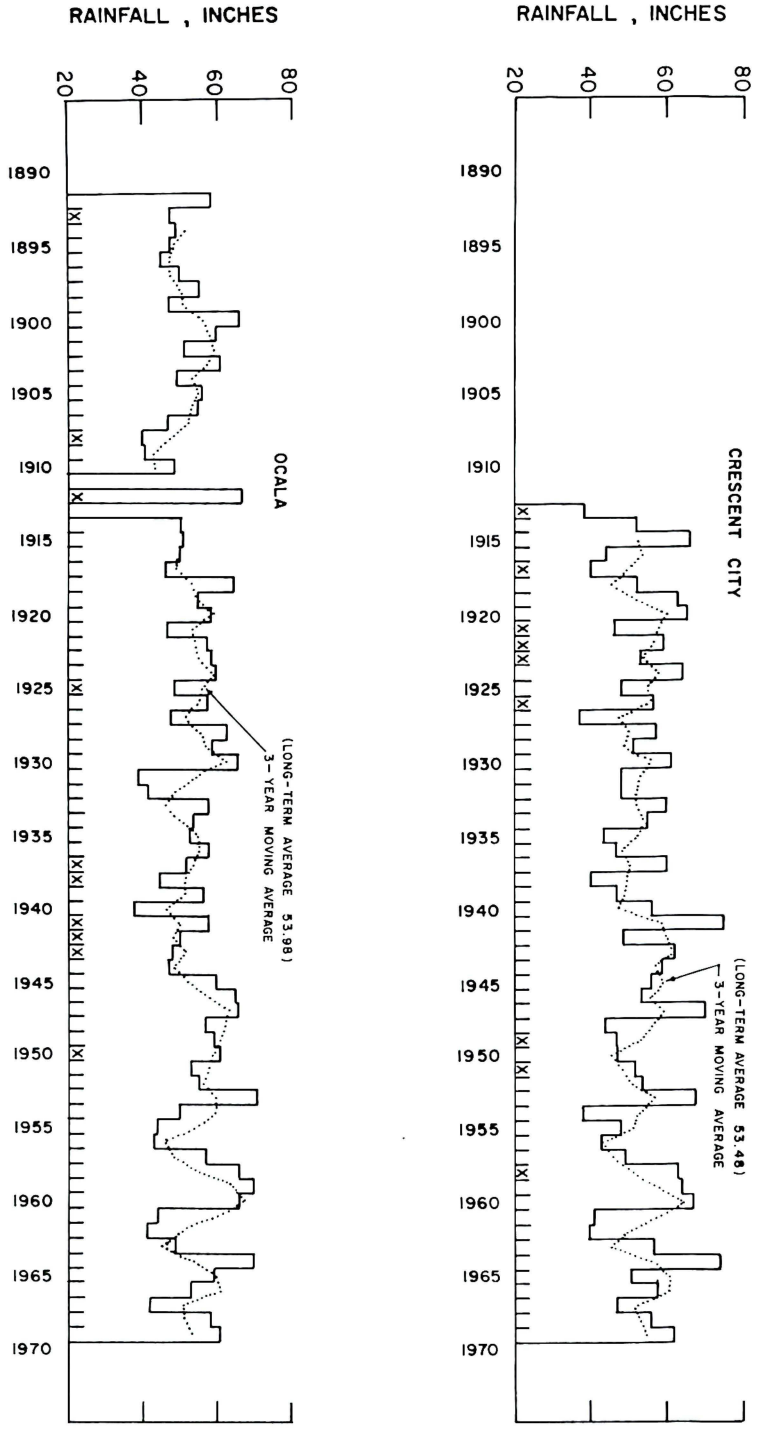


Figure 9. Graphs showing yearly rainfall at Crescent City and Ocala, Fla, 1892 - 1969. Cross (x) indicates years for which rainfall was estimated for part of year, usually only 1 or 2 months, on basis of records for other rainfall stations in the same general area.

EVAPORATION

Estimates of monthly evaporation from Lake Kerr in this report are keyed to the estimate of average yearly lake evaporation of 46 inches given for the Lake Kerr area by Kohler, Nordenson, and Baker (1959). Measurements of evaporation from a standard, 4-foot diameter, Weather Bureau type pan at Lisbon, Fla., (U. S. Weather Bureau, 1961 - 70), about 35 miles south of Lake Kerr (fig. 1), were used to determine the distribution of evaporation during the months and years of the investigation. Means and extremes of monthly pan evaporation are shown in figure 10 for 1960 - 69, when yearly pan evaporation averaged 58.80 inches. From the estimate of average yearly lake evaporation (46 in.) and the average yearly pan evaporation (58.80 in.), a yearly pan coefficient of 0.78 was obtained. For estimates of monthly evaporation, this pan coefficient was varied between 0.66 (for February) and 0.87 (for July and August) to adjust for seasonal variation of the relation between pan and lake evaporation, in accordance with findings for Lake Okeechobee, Fla. (Kohler, 1954, p. 128). This distribution of evaporation gave the same yearly evaporation as would have been obtained by uniform application of a yearly pan coefficient of 0.78. No attempt was made to adjust for the fact that such seasonal variations are not precisely the same each year.

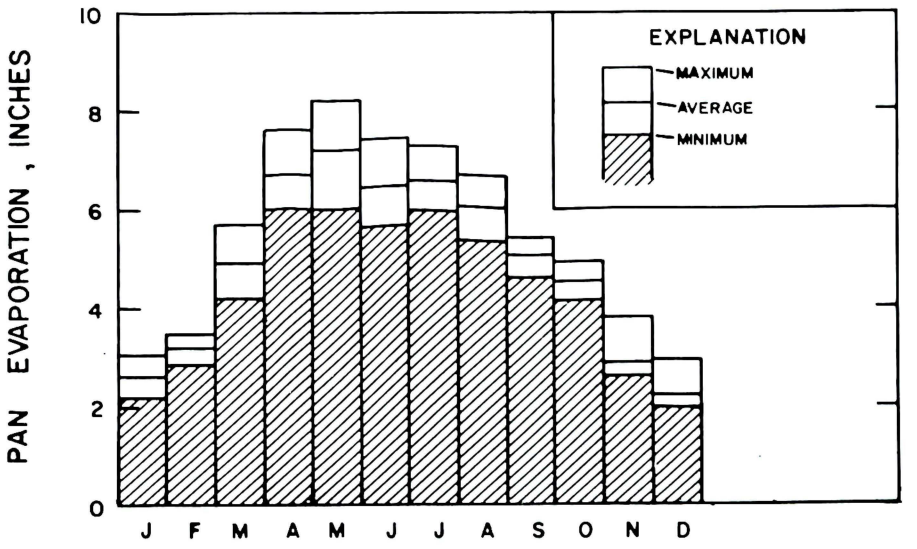


Figure 10. Graph showing monthly evaporation from standard, 4-foot diameter, Weather Bureau type pan at Lisbon, Fla., 1960 - 69.

Data from the Lisbon evaporation pan were selected because the pan is in a relatively low area surrounded by lakes and because it is slightly closer to Lake Kerr than is the only other pan in the area, which is at Gainesville (fig. 1). Because the estimates of monthly evaporation are keyed to Kohler's estimate of average yearly lake evaporation, however, any pan in the area would have served about equally well to define the seasonal distribution of evaporation.

LEAKAGE

Leakage from Lake Kerr was determined as a residual of equation 1 by use of the observed change in lake level and related estimates of evaporation and rainfall determined as previously described. Surface-water and ground-water inflow were assumed to be zero, for reasons to be explained in the following paragraph. Leakage was determined for a few selected winter months in which rainfall was minimal and which followed periods of relative drought. The reasons for selecting these winter months are as follows: (1) Evaporation is small during winter months; hence, a possible error of 10 - 20 percent in the pan coefficient used does not cause a large absolute error in estimated lake evaporation. (2) Surface-water inflow does not occur at Lake Kerr when rainfall is light. (3) Ground-water inflow would be least during droughts, if it occurs at all. The monthly leakage indicated by these computations averaged about 0.1 foot per month. Although leakage from the lake is known to vary in magnitude between wet and dry periods, the value of 0.1 foot per month was used in the water-balance computations for all months.

SURFACE - WATER AND GROUND - WATER INFLOW

In the water-balance computations that follow, surface-water and ground-water inflow to the lake are tentatively estimated as zero for the following reasons: (1) In terrain such as that surrounding Lake Kerr, runoff usually does not result from light or moderate rainfalls. If and when sheet runoff does result from a storm, its duration is not much longer than the storm period. (2) In areas where sinkholes result from solution of limestone some depth below the land surface, and the subsequent collapse of surficial materials into the solution cavity, the level of water in the shallow aquifer has been found at times to be below the level of water in lakes and ponds in the same areas, especially during dry spells (Clark and others, 1964, pp. 15 - 31; Hendricks and Goodwin, 1952, pp. 180, 204, 205). Conceivably, therefore, both surface-water and ground-water inflow to Lake Kerr might be zero or nearly zero much of the time. (3) For times when surface-water and ground-water inflow are not zero, monthly estimates of these quantities cannot be made from the available data.

Allowing that surface-water and ground-water inflow occur at times, and proceeding on the assumption that they do not occur, might lead to errors in the results of water-balance computations. If such errors are found, study of them,

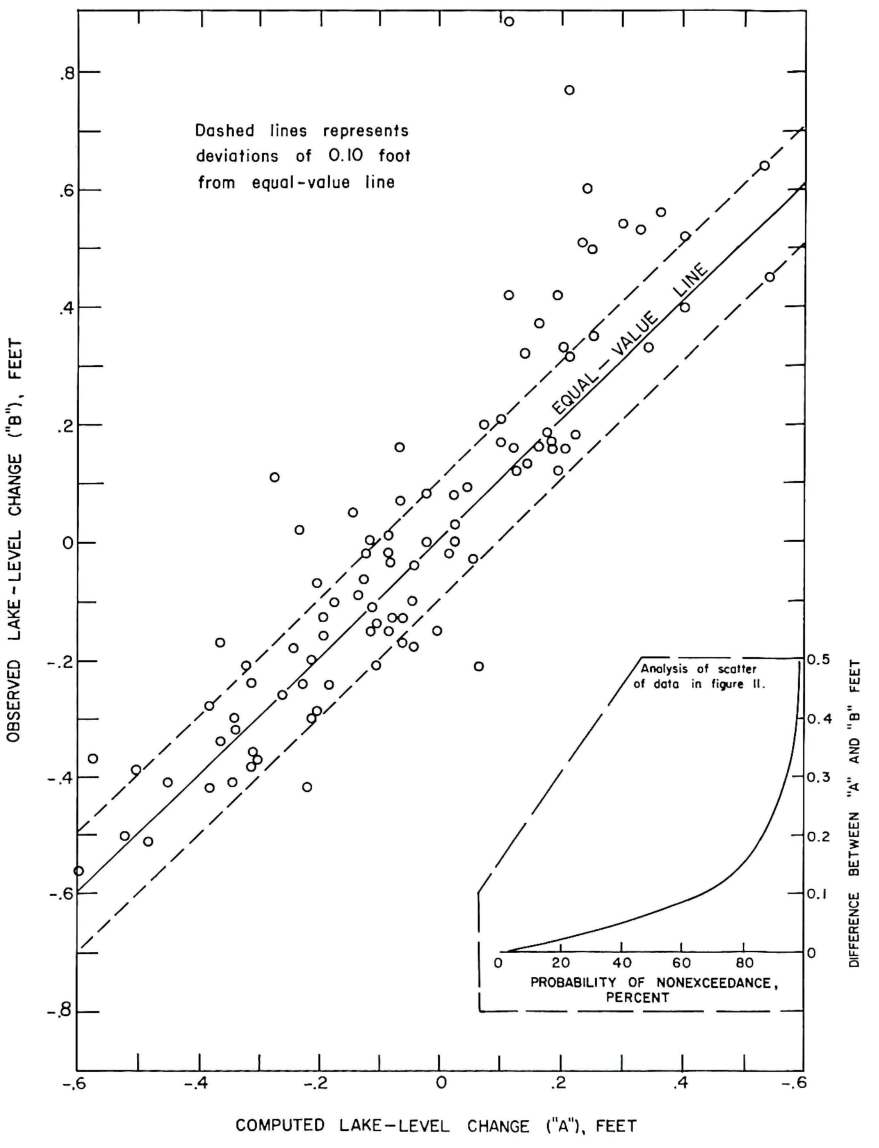


Figure 11. **Graph showing relation between observed and computed monthly change in lake level of Lake Kerr, 1962 - 69.**

or of the trends that they follow, may reveal that surface-water and ground-water inflow are, indeed, appreciably different from zero.

RESULTS

By use of equation 1, and previously described estimates of rainfall, evaporation, leakage, surface-water and ground-water inflow, the monthly change in lake level was computed for Lake Kerr for 1962 - 69. Figure 11 compares the computed change in lake level to the observed change in lake level.

ANALYSIS OF MONTHLY RESULTS

The scatter of the data in figure 11 relates to incorrect estimates or assumptions used in the water-balance computations. For example, if the estimated rainfall on the lake was greater than actual, if surface-water outflow actually occurred, or if estimated evaporation and leakage from the lake were less than actual, data would tend to plot to the right of (below) the equal-value line. On the other hand, if estimated rainfall on the lake was less than actual, if surface-water and ground-water inflow occurred, or if estimated evaporation and leakage were greater than actual, data would tend to plot to the left of (above) the equal-value line.

NATURE OF EXPECTED ERROR OF ESTIMATE RAINFALL

In this report, errors that result from estimates of rainfall at Lake Kerr are likely to be random. This randomness is demonstrable. For example, consider the relation between rainfall recorded at Crescent City and the average of rainfall recorded at DeLand and Palatka, as shown in figure 12. Except for differences in direction, Crescent City lies between DeLand and Palatka in about the same way that Lake Kerr lies between Crescent City and Ocala (fig. 1). Thus, rainfall at DeLand and Palatka provides about the same basis for estimating rainfall at Crescent City that rainfall at Crescent City and Ocala provides for estimating rainfall at Lake Kerr. Consequently, the difference between rainfall recorded at Crescent City and the average of rainfall recorded at DeLand and Palatka represents the error that might be expected in the estimates of rainfall at Lake Kerr.

Figure 12 shows that the estimate of monthly rainfall is greatly in error on the average of 2 to 3 months of the year. Over a long enough time, the errors tend to balance; but the cumulative error still can be large for periods as long as a year. During 1962 - 69, for example, the average of rainfall at DeLand and Palatka differed from that recorded at Crescent City by as much as 0.75 foot per year. Over the 8 years, however, the difference averaged only 0.08 foot per year.

Analysis of the scatter of the rainfall data in figure 12 shows that about 70 percent of the rainfall data plot within 0.10 foot of the equal-value line. A similar analysis showed that for the 47 months having less than 0.30 foot rainfall (based on the average of rainfall at DeLand and Palatka) scatter of the data decreases and that about 85 percent of the data points fall within 0.10 foot of the equal-value line.

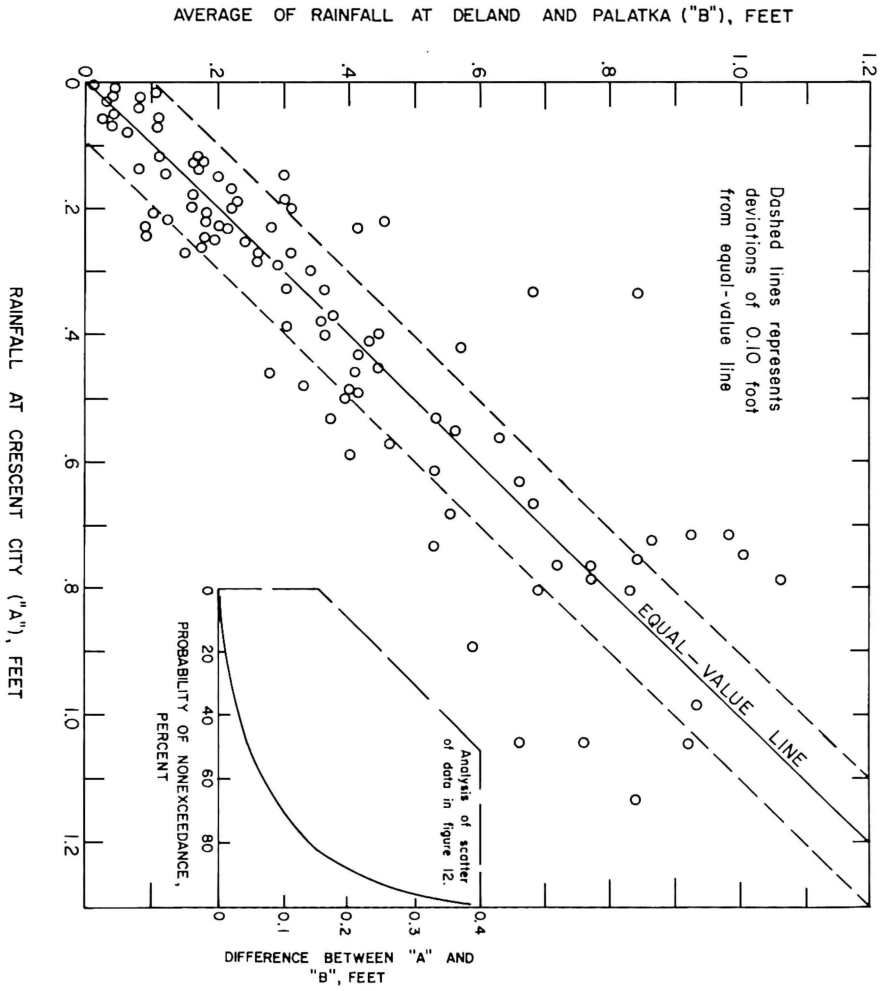


Figure 12. **Graph showing relation between average of monthly rainfall at two stations some distance apart (DeLand and Palatka) and monthly rainfall at a station midway between the two (Crescent City) for 1962 - 69.**

ANALYSIS OF SCATTER OF WATER - BALANCE RESULTS

The scatter of the lake-level data in figure 11 resembles the scatter of rainfall data in figure 12. About 70 percent of the lake-level data plot within 0.10 foot of the equal-value line; however, most of the lake-level data points that deviate greatly from the equal-value line fall to the left of the line. The summary of lake-level data in table 1 indicates that the errors (differences between observed and computed change in lake level) tend to balance for all months except June, July, and August. Although some inconsistencies are apparent, the seasonal distribution of the errors shown in table 1 roughly parallels the seasonal distribution of monthly rainfall shown in table 2.

TABLE 1

SEASONAL DISTRIBUTION OF DIFFERENCE BETWEEN OBSERVED AND COMPUTED MONTHLY CHANGE IN LEVEL OF LAKE KERR, 1962-69, IN FEET.

Month	Average difference	Median difference
January	+0.04	+0.02
February	- .02	- .01
March	+ .05	+ .03
April	+ .05	+ .03
May	+ .04	+ .00
June	+ .13	+ .08
July	+ .14	+ .11
August	+ .20	+ .17
September	+ .02	- .02
October	.00	.00
November	- .02	- .03
December	+ .02	.00

TABLE 2

SEASONAL DISTRIBUTION OF AVERAGE OF MONTHLY RAINFALL AT CRESCENT CITY AND OCALA, 1962-69, IN FEET

Month	Average	Median
January	0.20	0.22
February	.36	.45
March	.22	.20
April	.16	.15
May	.32	.31
June	.59	.67

TABLE 2 - Continued
SEASONAL DISTRIBUTION OF AVERAGE OF MONTHLY RAINFALL AT CRESCENT CITY AND OCALA, 1962-69, IN FEET.

Month	Average	Median
July	.76	.75
August	.69	.72
September	.56	.56
October	.26	.17
November	.16	.16
December	.25	.21

Rainfall at Lake Kerr was estimated to be less than 0.30 foot per month for 47 of the 96 months investigated. For these 47 months, 81 percent of the lake-level data plotted within 0.10 foot of the equal-value line and 89 percent plotted within 0.11 foot. The average deviation for these 47 months was slightly less than 0.01 foot to the left of the equal-value line. For the 49 months when estimated rainfall was greater than 0.30 foot per month, the lake-level data for only 25 months fell within 0.10 foot of the equal-value line; the average deviation for these 25 months was about zero.

The large errors in the lake-level data of figure 11 occur somewhat erratically in time, as indicated in figure 13, and often are preceded or followed immediately by small errors. The small errors show some indication of cyclic variation that may be related to alternate wet or dry periods.

SEARCH FOR PROBABLE CAUSE OF LARGE ERRORS

ERROR OF ESTIMATE OF EVAPORATION

The number of possible sources of large and erratic errors was reduced by process of elimination. The nature of the evaporation process generally precludes large and erratic variations in the monthly evaporation from a shallow lake. Lake evaporation follows a fairly consistent seasonal pattern determined largely by solar radiation. Deviations from the norm for a month are usually less than 0.10 foot. The estimates of lake evaporation appear to serve adequately well in the water-balance computations about 70 percent of the time, often for months immediately preceding or following months having large errors. If pan-based estimates of evaporation from a shallow lake are about correct for a particular month, they are not likely to be greatly in error for the preceding or following months of the same year or for the same month of the preceding and following

years. Thus, the estimate of evaporation is not a likely source of large and erratic errors.

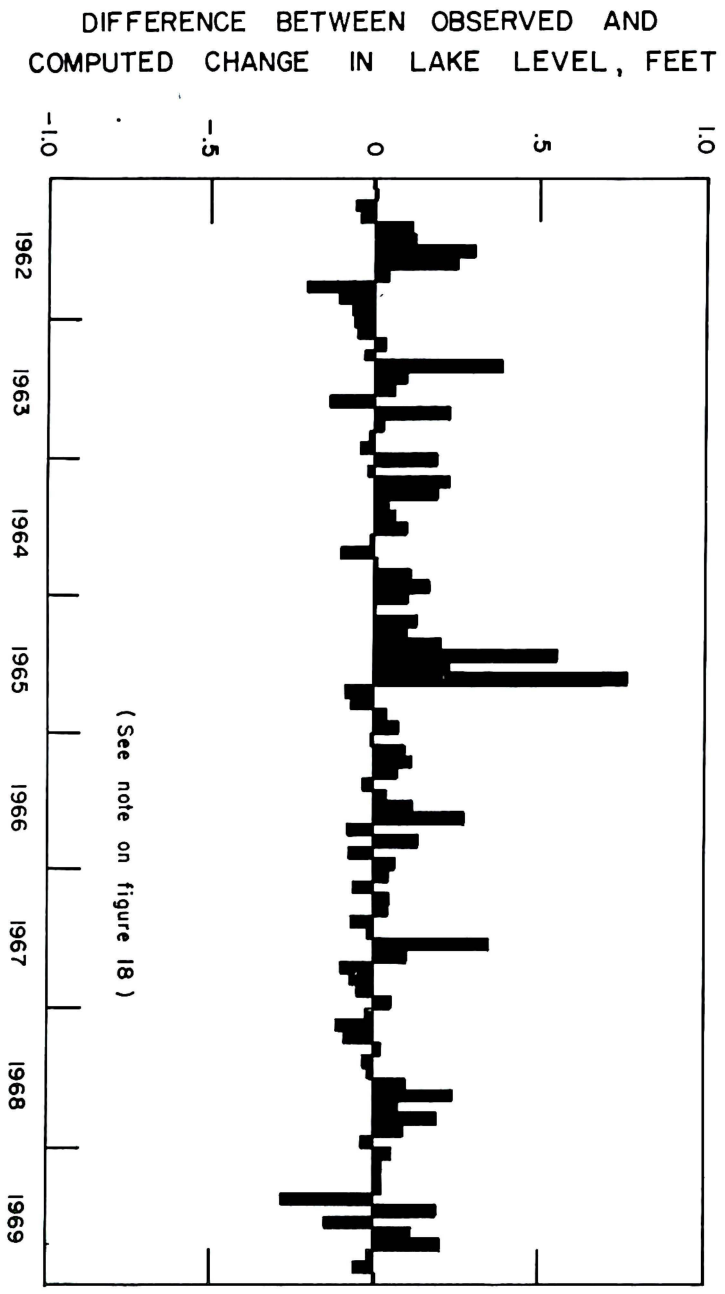


Figure 13. Graph showing time distribution of difference between observed and computed monthly change in lake level of Lake Kerr.

ERROR OF ESTIMATE OF LEAKAGE

Although leakage of water from natural lakes is known to vary, the assumption that leakage from Lake Kerr occurred uniformly at 0.1 foot per month is not a likely source of large and erratic errors in the monthly water-balance computations. Leakage to the Floridan aquifer is directly proportional to the permeability of the confining bed underlying the lake, the viscosity of the water moving through confining bed, and the difference between the lake level and the hydrostatic level of water in the Floridan aquifer. Although the permeability of the confining bed may change in time, with the formation of new sinkholes or the sealing off of existing sinkholes, for example, it can be considered as being essentially constant for periods lasting several years or even several decades. The viscosity of water does vary with seasonal changes in temperature, but in Florida monthly changes in leakage from this cause can only be small. Both the lake level and the hydrostatic level of water in the Floridan aquifer fluctuate appreciably but they trend alike, as indicated in figure 14. (See fig. 15 for well locations.) Thus, the difference between the lake level

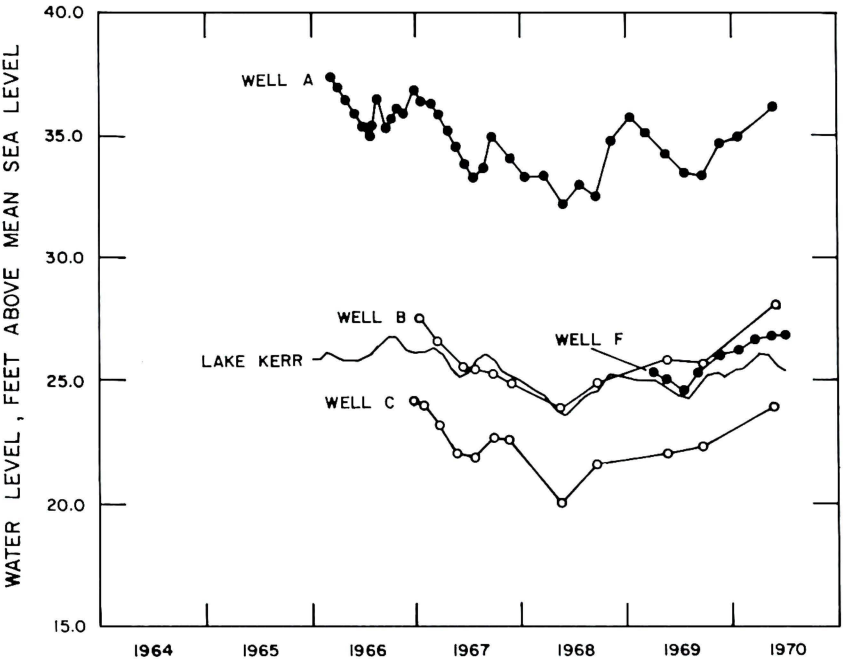


Figure 14. Graphs showing variation in level of water in wells near Lake Kerr. Wells A, B, and C tap the Floridan aquifer; Well F bottoms in the shallow aquifer. Well locations are shown in figure 15.

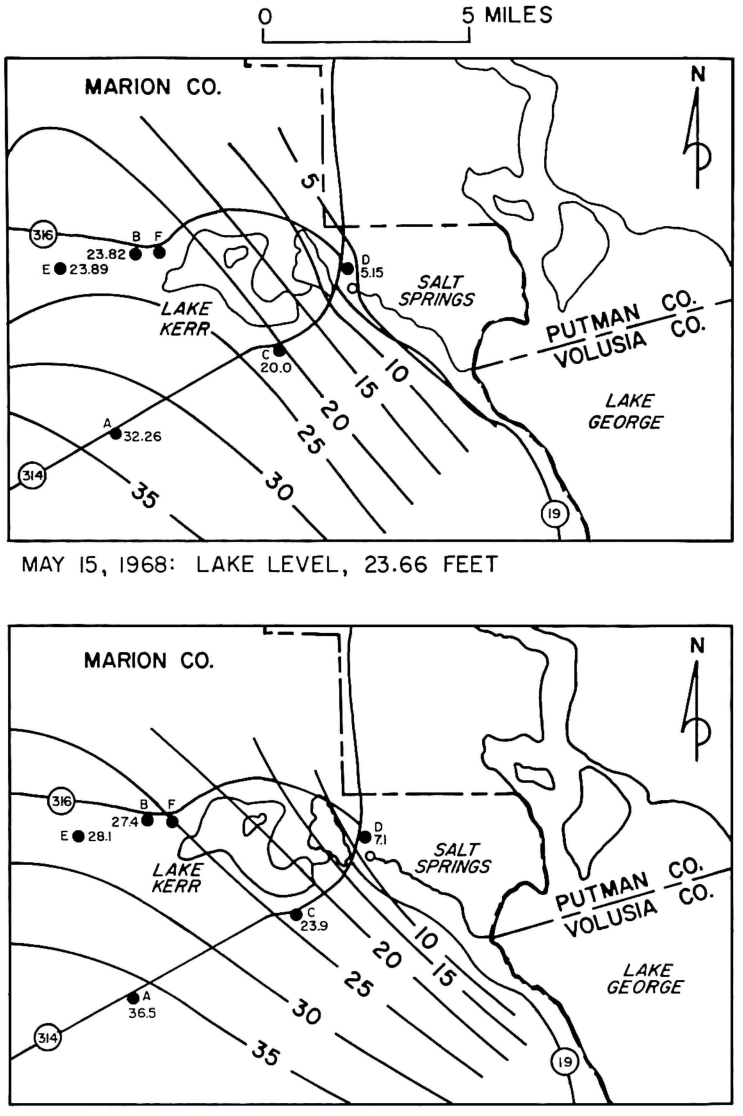


Figure 15. Maps showing relation between level of water in Lake Kerr and hydrostatic level of water in Floridan aquifer for contrasting water-level conditions. Maps adapted from Faulkner (1970, fig. 23).

and the hydrostatic level of water in the Floridan aquifer does not change from month to month as much as might be presumed from the change in either level alone. For example, the hydrostatic level of water in the Floridan aquifer declined about 4 feet between January 20, 1967 and May 15, 1968, as indicated in figure 15, whereas the lake level declined about 2.6 feet. Hence, the difference between the two levels changed only 1.4 feet.

The effective difference between the lake level and the hydrostatic level of water in the Floridan aquifer is not readily determinable because the hydrostatic level evidently decreases from west to east in the area of Lake Kerr, and in May 1968 was about at the level of the lake at the western edge of the lake, and about 8 feet lower than the lake level at the eastern edge. If the permeability of the materials underlying the lake is uniformly distributed across the lake bottom, the difference between the lake level and the hydrostatic level in effect would average about 4 feet. If the difference between the two levels changed 1.4 feet, therefore, the leakage from the lake would change by the ratio of 1.4 to 4, or by 35 percent. In relation to the average leakage from the lake, estimated to be 0.1 foot per month, such a change would amount to less than 0.04 foot per month. The contrast in water-level conditions involved in this example is far greater than any that is likely to occur within a span of 2 months.

The extent of the variation in leakage from Lake Kerr also was appraised as follows: In 1956 - 57 Lake Kerr declined in level a total of 1.88 feet, from an initial altitude of about 22 feet above msl (mean sea level); in 1962 - 63 Lake Kerr declined in level a total of 1.55 feet, from an initial altitude of about 24 feet above msl (fig. 8). In each case the lake level declined steadily the year before and the seasonal trend of the lake level was about the same in both periods. The average of rainfall at Crescent City and Ocala totaled 8.00 feet in 1956 - 57 and 7.78 feet in 1962 - 63. On the assumption that lake evaporation and surface- and ground-water inflow were the same for both periods, it follows from the differences in rainfall and lake-level decline that the lake leaked about 0.55 foot more in 1956 - 57 than in 1962 - 63. Thus, for a difference in lake level that averaged about 2 feet, the difference in leakage averaged about 0.02 foot per month. If an estimate of regional rainfall based on 6 to 9 rainfall stations in the general area of Lake Kerr is used in the preceding example, leakage is indicated to average about 0.03 foot per month greater in 1956 - 57 than in 1962 - 63.

Although the level of Lake Kerr averaged about 2 feet higher in 1962 - 63 than in 1956 - 57, the maximum level in 1962 - 63 was about 4 feet higher than the minimum level in 1956 - 57. The difference in leakage occurring at times of the maximum and minimum levels presumably was about twice as great as the 0.02 to 0.03 foot per month average difference indicated for the 2-year periods.

For 1962 - 69, therefore, when the range in lake level was about 4.7 feet (fig. 7), leakage from the lake might have varied slightly more than 0.04 to 0.06 foot per month between the wettest and driest periods, but it could not have varied enough to cause errors substantially greater than 0.10 foot per month in the water-balance computations.

ERROR OF ESTIMATE OF GROUND - WATER INFLOW

The assumption that ground-water inflow was zero might at times lead to large errors in the results of water-balance computations for Lake Kerr but such errors are not likely to occur in one month and not occur in the following month. For example, ground-water inflow might increase substantially and somewhat abruptly from a rapid buildup of water in the shallow aquifer during an extended period of several intense rainfalls. Once increased, however, the rate of ground-water inflow would be sustained by water stored in the aquifer. Thus, the effect of an appreciable increase in ground-water inflow would be expected to linger long enough to decrease the rate of lake-level decline for one or more months after any such buildup occurred. If this effect is large enough to cause large errors in the results of the water-balance computations, it should be easily detected.

As a test for large variations in ground-water inflow, a study was made of the decline in level of Lake Kerr using selected rainless periods. The periods used involve parts of 54 months and are widely enough dispersed timewise to represent the full range of the lake level during 1962 - 69.

An equivalent monthly rate of lake-level decline was computed on the basis of the observed lake-level decline during periods lasting from a few to several days when the lake-level decline apparently was uninterrupted by rainfall, and when little or no rainfall was recorded at rainfall stations in the general area of the lake. In table 3 the equivalent monthly observed lake-level decline is compared with the lake-level decline attributed to evaporation and leakage from the lake as previously estimated. Without regard to algebraic sign, the difference between the two is as much as 0.16 foot, but is 0.10 foot, or less, for all except 3 of the 54 months, and is 0.05 foot, or less, for 40 months. When the algebraic sign of the difference is taken into account, the differences for all months fall within a range of 0.25 foot; differences for all but 3 of the 54 months fall within a range of 0.16 foot; and, differences for any given month of the year fall within a range of 0.14 foot.

The range of the difference between the equivalent monthly observed lake-level decline and the lake-level decline attributed to evaporation and leakage reflects the combined effects of variations in leakage and ground-water inflow.

TABLE 3
DECLINE IN LEVEL OF LAKE KERR DURING
SELECTED PERIODS OF LITTLE OR NO RAINFALL, IN FEET.

Calendar year	Starting date	Ending date	Number of days in period 1/	Observed lake-level decline	Equivalent monthly decline	Estimated evaporation plus leakage
1962	Jan. 12	Jan. 27	15	0.08	0.16	0.25
	Jan. 28	Feb. 9	12	.13		
	Feb. 16	Feb. 28	12	.10		
		Total	24	.23	.30	.29
	Apr. 1	Apr. 6	5	.09		
	Apr. 8	Apr. 25	17	.35		
		Total	22	.44	.60	.53
	Apr. 30	May 10	10	.18		
	May 12	May 21	9	.19		
	May 23	May 28	5	.10		
		Total	24	.47	.61	.59
	Oct. 3	Oct. 21	18	.34		
	Oct. 22	Oct. 30	8	.14		
		Total	26	.48	.55	.39
	Nov. 30	Dec. 11	11	.12		
	Dec. 12	Dec. 22	10	.08		
		Total	21	.20	.30	.25
1963	Mar. 31	Apr. 5	5	.07		
	Apr. 7	Apr. 30	23	.48		
		Total	28	.55	.59	.59
	May 2	May 20	18	.32	.55	.58
	June 1	June 5	4	.07		
	June 9	June 22	13	.24		
		Total	17	.31	.55	.55
	Aug. 3	Aug. 12	9	.19		
	Aug. 25	Aug. 30	5	.08		
		Total	14	.27	.60	.58
	Sept. 6	Sept. 16	10	.18		
	Sept. 17	Sept. 19	2	.03		
		Total	12	.21	.52	.42
	Oct. 1	Oct. 13	12	.19		
	Oct. 19	Nov. 1	13	.17		
		Total	25	.36	.45	.40

1/ Periods start and end at 1200 hours.

TABLE 3 - Continued
DECLINE IN LEVEL OF LAKE KERR DURING
SELECTED PERIODS OF LITTLE OR NO RAINFALL, IN FEET.

Calendar year	Starting date	Ending date	Number of days in period 1/	Observed lake-level decline	Equivalent monthly decline	Estimated evaporation plus leakage
	Nov. 29	Dec. 11	12	.12		
	Dec. 15	Dec. 22	7	.09		
		Total	19	.21	.34	.23
1964	Mar. 5	Mar. 9	4	.04		
	Mar. 13	Mar. 15	2	.02		
	Mar. 20	Mar. 25	5	.07		
		Total	11	.13	.37	.39
	Mar. 29	Apr. 7	9	.13		
	Apr. 9	Apr. 13	4	.08		
	Apr. 16	Apr. 23	7	.12		
		Total	20	.33	.50	.55
	May 3	May 12	9	.15		
	May 14	May 31	17	.32		
		Total	26	.47	.56	.58
	June 1	June 5	4	.08		
	June 7	June 15	8	.15		
	June 19	June 23	4	.08		
		Total	16	.31	.58	.60
1965	Mar. 31	Apr. 20	20	.32		
	Apr. 28	Apr. 30	2	.04		
		Total	22	.36	.49	.53
	Apr. 30	May 17	12	.21		
	May 13	May 26	13	.27		
		Total	25	.48	.60	.64
	Aug. 31	Sept. 13	13	.20		
	Sept. 18	Sept. 25	7	.08		
		Total	20	.28	.42	.46
	Oct. 2	Oct. 5	3	.04		
	Oct. 7	Oct. 12	5	.03		
	Oct. 22	Oct. 30	8	.12		
		Total	16	.19	.37	.32
	Oct. 31	Nov. 5	5	.05		
	Nov. 13	Nov. 21	8	.07		
	Nov. 23	Nov. 27	3	.03		
		Total	16	.15	.28	.27
	Nov. 30	Dec. 10	10	.09		
	Dec. 20	Dec. 24	4	.03		
		Total	14	.12	.27	.25

1/ Periods start and end at 1200 hours.

TABLE 3 - Continued
DECLINE IN LEVEL OF LAKE KERR DURING
SELECTED PERIODS OF LITTLE OR NO RAINFALL, IN FEET.

Calendar year	Starting date	Ending date	Number of days in period 1/	Observed lake-level decline	Equivalent monthly decline	Estimated evaporation plus leakage
1966	Mar. 5	Mar. 11	6	.10		
	Mar. 15	Mar. 31	16	.19		
		Total	22	.29	.41	.40
	Mar. 31	Apr. 3	3	.04		
	Apr. 5	Apr. 12	7	.12		
	Apr. 15	Apr. 26	11	.18		
		Total	21	.34	.49	.53
	June 1	June 5	4	.11		
	June 10	June 12	2	.02		
	June 23	June 29	6	.12		
		Total	12	.25	.62	.54
	Aug. 31	Sept. 5	5	.09		
	Sept. 12	Sept. 17	5	.06		
	Sept. 22	Sept. 25	3	.06		
		Total	13	.21	.49	.47
	Oct. 11	Nov. 1	21	.31	.46	.37
	Nov. 2	Nov. 11	9	.11		
	Nov. 15	Nov. 27	12	.16		
		Total	21	.27	.39	.31
	Nov. 28	Dec. 10	12	.10		
	Dec. 13	Dec. 16	3	.03		
	Dec. 18	Dec. 22	4	.02		
	Dec. 24	Dec. 28	4	.04		
	Dec. 29	Jan. 1	3	.02		
		Total	26	.21	.25	.26
1967	Jan. 31	Feb. 5	5	.04		
	Feb. 22	Feb. 28	6	.11		
		Total	11	.15	.38	.28
	Mar. 1	Mar. 5	4	.03		
	Mar. 8	Mar. 27	19	.28		
		Total	23	.31	.42	.39
	Mar. 31	Apr. 24	24	.44		
	Apr. 25	Apr. 30	5	.15		
		Total	29	.59	.61	.62
	May 7	May 15	8	.17		
	May 16	May 21	5	.12		
	May 24	May 31	7	.11		
		Total	20	.40	.62	.62

1/ Periods start and end at 1200 hours.

TABLE 3 - Continued
DECLINE IN LEVEL OF LAKE KERR DURING
SELECTED PERIODS OF LITTLE OR NO RAINFALL; IN FEET.

Calendar year	Starting date	Ending date	Number of days in period[1]	Observed lake-level decline	Equivalent monthly decline	Estimated evaporation plus leakage
	Aug. 31	Sept. 6	6	.09		
	Sept. 15	Sept. 26	11	.17		
		Total	17	.26	.46	.44
	Sept. 30	Oct. 8	8	.11		
	Oct. 10	Oct. 15	5	.09		
	Oct. 18	Oct. 31	13	.20		
		Total	26	.40	.48	.38
	Nov. 2	Nov. 30	28	.34	.36	.32
1968	Jan. 1	Jan. 8	7	.06		
	Jan. 9	Jan. 22	13	.15		
	Jan. 24	Jan. 31	7	.05		
		Total	27	.26	.30	.27
	Jan. 31	Feb. 5	5	.04		
	Feb. 7	Feb. 17	10	.13		
		Total	15	.17	.33	.27
	Feb. 29	Mar. 5	5	.06		
	Mar. 13	Mar. 31	18	.25		
		Total	23	.31	.42	.39
	Mar. 31	Apr. 4	4	.05		
	Apr. 7	Apr. 9	2	.03		
	Apr. 11	Apr. 30	19	.37		
		Total	25	.45	.54	.55
	June 29	July 1	2	.04		
	July 23	July 31	8	.16		
		Total	10	.20	.60	.57
	Aug. 1	Aug. 3	2	.03		
	Aug. 6	Aug. 11	5	.11		
	Aug. 21	Aug. 27	6	.10		
		Total	13	.24	.57	.54
1968	Sept. 28	Oct. 5	7	.12		
	Oct. 25	Oct. 31	6	.10		
		Total	13	.22	.52	.38
	Oct. 31	Nov. 1	3	.01		
	Nov. 6	Nov. 8	2	.02		

[1] Periods start and end at 1200 hours.

TABLE 3 - Continued
DECLINE IN LEVEL OF LAKE KERR DURING
SELECTED PERIODS OF LITTLE OR NO RAINFALL, IN FEET.

Calendar year	Starting date	Ending date	Number of days in period [1]	Observed lake-level decline	Equivalent monthly decline	Estimated evaporation plus leakage
	Nov. 12	Nov. 17	5	.07		
	Nov. 19	Nov. 30	11	.09		
		Total	21	.19	.27	.28
	Nov. 30	Dec. 3	3	.03		
	Dec. 4	Dec. 13	9	.11		
	Dec. 14	Dec. 19	5	.05		
	Dec. 23	Dec. 27	4	.04		
		Total	21	.23	.34	.29
1969	Jan. 31	Feb. 2	2	.01		
	Feb. 3	Feb. 7	4	.05		
	Feb. 9	Feb. 14	5	.06		
	Feb. 16	Feb. 21	5	.05		
	Feb. 23	Feb. 28	5	.05		
		Total	21	.23	.31	.28
	Feb. 28	Mar. 2	2	.02		
	Mar. 9	Mar. 11	5	.08		
	Mar. 19	Mar. 23	4	.02		
	Mar. 25	Mar. 31	6	.09		
		Total	17	.21	.38	.34
	Mar. 31	Apr. 5	5	.05		
	Apr. 6	Apr. 14	8	.15		
	Apr. 19	Apr. 30	11	.21		
		Total	24	.41	.51	.54
	May 3	May 13	10	.19		
	May 22	May 26	4	.06		
	May 28	May 31	3	.05		
		Total	17	.30	.55	.56
	June 6	June 9	3	.04		
	June 17	June 20	3	.06		
	June 21	June 24	3	.05		
	June 25	June 30	5	.11		
		Total	14	.26	.56	.60
	Oct. 5	Oct. 15	10	.13	.40	.35
	Nov. 1	Nov. 12	11	.12		
	Nov. 15	Nov. 26	11	.11		
		Total	22	.23	.31	.25
	Nov. 30	Dec. 6	6	.08		
	Dec. 11	Dec. 20	9	.08		
	Dec. 26	Dec. 30	4	.03		
		Total	19	.19	.31	.31

[1] Periods start and end at 1200 hours.

The variation in the monthly rate of leakage in 1962 - 69 was previously presumed to be about 0.04 to 0.06 foot. Based on the range of 0.25 foot that encompasses the differences for all of the 54 months investigated, variation in the monthly rate of ground-water inflow would be about 0.20 foot. In analyses of hydrologic data, however, the outliers seldom are given full weight because of the possibility that they reflect the effects of peculiar errors. Hence, the range of 0.16 foot that encompasses the differences for 95 percent of the months investigated is assumed to give the best indication of the combined effect of variations in ground-water inflow and leakage. This puts the variation in the monthly rate of ground-water inflow at about 0.10 foot. Nothing in the analysis indicates that variations in ground-water inflow are a likely source of large errors in the results of the water-balance computations.

The small indicated variation in monthly rate of ground-water inflow to Lake Kerr requires that ground-water inflow be small. The potential for water to move into the lake from the shallow aquifer is proportional to the difference between the lake level and the level of water in the shallow aquifer. The difference between the lake level and the water level in Well F (figs. 14, 15), which taps the shallow aquifer, suggests that the potential for water to move into the lake increased about fourfold between July and November 1969. The change in potential corresponding to the extremely dry and wet periods in 1963 and 1966 (fig. 7) had to be much greater than indicated for July - November 1969. For the rate of monthly ground-water inflow to change in magnitude by several times and still vary within a range of about 0.10 foot, ground-water inflow has to be extremely small (relative to 0.10 foot) during dry periods and cannot be appreciably greater than 0.10 foot during wet periods.

COMBINED ERROR OF ESTIMATE OF RAINFALL AND SURFACE- WATER INFLOW

The preceding discussion indicates that the errors in the water-balance computations for Lake Kerr that are substantially greater than 0.10 foot are attributable to errors in the estimates of rainfall or surface-water inflow. That this is so can be established by comparing the sum of individual lake-level rises during a month (disregarding the intervening lake-level declines) with the estimate of monthly rainfall, as shown in table 4. The comparison is made for months when the error of the water-balance computations was substantially greater than 0.10 foot and was in the direction that indicates inflow not otherwise accounted for. These are the months for which large positive errors (or differences) are shown in figure 13. Data for July and August 1965 could not be included in the analysis because of uncertainties as to how the lake behaved when the lake-level record was incomplete. For 12 of the 16 months included in table 4 the sum of the daily lake-level rises (adjusted for evaporation and

leakage) is substantially greater than the estimated rainfall at the lake. Allowing for the difference between the sum of the daily lake-level rises and the estimated monthly rainfall, the residual error for 13 months is rendered to something less than 0.10 foot. The usual lake-level decline due to evaporation and leakage, which ranged from about 0.01 to 0.02 foot per day, obscures in the record of the lake level the effect of daily rainfalls smaller than about 0.01 - 0.02 foot. Thus, for most of the months listed in table 4, the true lake rise probably was a few hundredths of a foot greater than the indicated sum of the daily lake-level rises.

Whether the substantial differences between the estimated monthly rainfall and the sum of the daily lake-level rises is caused primarily by faulty estimates of rainfall or by faulty estimates of surface-water inflow is not directly determinable. For some months, all or a large part of the difference certainly can be attributed to faulty rainfall estimates, but these months are not readily distinguishable from months in which the difference cannot be so attributed.

The average of rainfall at Crescent City and Ocala does not always provide, as shown earlier, an accurate estimate of rainfall at Lake Kerr. For any given month, rainfall at any one station may better represent the rainfall at Lake Kerr than would the average of rainfalls at other stations in the same general area. For example, in September 1963 and September 1969, rainfall at Crescent City was much greater than rainfall at Ocala (table 4), and was great enough to account for the entire rise of the lake level for these months. As long as the potential exists for such rainfalls to occur in the area, the possibility of their occurring at Lake Kerr also exists and must be recognized.

The water-balance computations were repeated using estimates of rainfall based on records for other rainfall stations in the general area of Lake Kerr, taken singly and in different combinations, both including and excluding the records for Crescent City and Ocala. The scatter of the results and the extent of large errors in each set of computations were about the same, but for several of the months in which large errors occurred, the size of the errors tended to vary with the choice of rainfall stations. This indicated that the large errors for these months are probably attributable to faulty estimates of rainfall. For some 7 months - - July 1962, May - August 1965, August 1966, and July 1967 - - the large errors persisted regardless of the rainfall station selected. Because of this persistence, the possibility that surface-water inflow may at times contribute substantially to the lake-level rise cannot be ruled out.

A study of yearly rainfall and lake-level data for 1936 - 69 shows conclusively that rainfall must have been much greater at Lake Kerr during 1965 than was indicated by the catch at each of several rainfall stations in the area.

TABLE 4
ESTIMATED MONTHLY RAINFALL COMPARED TO SUM OF DAILY RISE IN LEVEL OF LAKE KERR FOR SELECTED MONTHS, 1962 - 69, IN FEET

Month and Year	Estimated monthly rainfall			Number of days rainfall occured	
	Crescent City	Ocala	Average	Crescent City	Ocala
(1)	(2)	(3)	(4)	(5)	(6)
July 1962	0.76	0.70	0.73	18	23
Aug. 1962	.33	.31	.32	12	16
May 1963	.23	.39	.31	13	11
Sept. 1963	1.03	.43	.73	15	13
Jan. 1964	.55	.67	.61	15	15
Mar. 1964	.33	.33	.33	12	15
Apr. 1964	.46	.36	.41	6	5
Dec. 1964	.39	.45	.42	9	6
May 1965	.07	.07	.07	4	3
June 1965	.80	.72	.76	18	17
Aug. 1966	.89	.65	.77	20	14
July 1967	.80	.80	.80	21	25
Aug. 1968	.71	.85	.78	14	17
Oct. 1968	.78	.66	.72	16	13
June 1969	.33	.14	.24	12	15
Sept. 1969	.75	.43	.59	17	14

TABLE 4 - Continued
ESTIMATED MONTHLY RAINFALL COMPARED TO SUM OF DAILY RISE IN LEVEL OF LAKE KERR FOR SELECTED MONTHS, 1962 - 69, IN FEET

Number of days of lake rise (7)	Sum of daily lake rises (8)	Estimated evaporation plus leakage, feet per day (9)	Adjusted sum of daily lake rises 1/ (10)	Column 10 minus Column 4 (11)	Magnitude of difference shown in figure 13 (12)
14	0.67	0.020	0.95	0.22	0.30
5	.30	.018	.39	.07	.25
8	.50	.019	.65	.34	.38
13	.79	.014	.97	.24	.23
13	.60	.008	.70	.09	.19
10	.38	.013	.51	.18	.22
3	.39	.018	.44	.03	.19
7	.46	.009	.52	.10	.17
2	.15	.020	.19	.12	.20
16	.98	.018	1.27	.51	.55
14	.72	.018	.97	.20	.27
13	.76	.018	.99	.19	.35
10	.81	.017	.98	.20	.24
8	.83	.012	.92	.20	.19
6	.16	.020	.28	.04	.19
13	.56	.014	.72	.13	.20

1/Column 8 plus the product of values in columns 7 and 9.

For 1936 - 64, yearly lake-level rises ranging from 1 to 2.4 feet occurred in 6 years. During these 6 years the average of rainfall at Crescent City and Ocala ranged from 64.50 to 72.54 inches, compared to the long-term average of about 54 inches. Regional rainfall - - as determined by the average of rainfall at from 6 to 9 stations within a distance of 40 miles from Lake Kerr - - in these same 6 years ranged from 58.28 inches to 67.21 inches, compared to a long-term average of about 53 inches. In 1965, however, Lake Kerr rose 1.52 feet when the average of rainfall at Crescent City and Ocala was only 54.86 inches, and the regional rainfall was only 53.10 inches. The indicated seasonal distribution of rainfall during 1965 was not markedly different from that of 1964, for example, when the lake rose substantially (fig. 4) or from that of many other years when an equal or greater amount of rainfall was recorded in the area. Thus, the only plausible explanation for the 1.52-foot lake rise in 1965 is that substantially more rain fell at Lake Kerr than fell at any of the rainfall stations in the area, including Crescent City and Ocala. On this basis it is concluded that all of the large errors in the water-balance computations resulted primarily from faulty estimates of rainfall. Surface-water inflow may have been a small contributing factor during the most intensive rainfalls.

ANALYSIS OF YEARLY RESULTS

The monthly water-balance computations previously discussed were based on the assumptions that leakage from Lake Kerr was constant at 0.1 foot per month and that ground-water and surface-water inflows were zero. Use of these assumptions did not produce the type of obvious, persistent, and seasonally distributed errors that would be expected to crop up if the assumptions were grossly wrong much of the time. However, assumptions that for some purposes may be adequate for monthly computations are not necessarily adequate for annual computations because in annual computations the cumulative effect of small but persistent errors becomes increasingly important. For example, the general disarray of the monthly water-balance data in figure 11 would be little improved or worsened if ground-water inflow, rather than being assumed zero, were assumed to vary from 0.01 foot per month in some months to 0.05 foot per month in others. Yet, when the monthly results are summed for a year a difference of 0.36 foot would accumulate if ground-water inflow were to average 0.03 foot per month rather than zero, and for 10 years the difference would grow to 3.60 feet.

The cumulative effect of small but persistent errors may be indicated in table 5, which summarizes the monthly water-balance computations by years. The computations indicate that from 1962 to 1969 the level of Lake Kerr declined 3.89 feet whereas the level actually rose 1.40 feet. The difference between the two represents and error of +5.29 feet, which is large in relation to

TABLE 5

APPROXIMATE YEARLY WATER BALANCE OF LAKE KERR, 1962 - 69, IN FEET; CONSTANT LEAKAGE ASSUMED.

Calendar year	Estimated rainfall	Estimated lake evaporation	Estimated leakage	Estimated ground-water inflow	Estimated surface-water inflow	Change in lake level		Error[1/]
						Computed	Observed	
1962	3.37	3.83	1.2	0	0	- 1.66	- 1.32	+0.34
1963	4.40	3.92	1.2	0	0	- .72	- .23	+ .49
1964	6.04	3.88	1.2	0	0	+ .96	+1.92	+ .96
1965	4.57	3.87	1.2	0	0	- .50	+1.52	+2.02
1966	4.60	3.75	1.2	0	0	- .35	+ .35	+ .70
1967	3.70	3.99	1.2	0	0	- 1.49	- 1.20	+ .29
1968	4.75	3.84	1.2	0	0	- .29	+ .10	+ .39
1969	5.12	3.76	1.2	0	0	+ .16	+ .26	+ .10
Total	36.55	30.84	9.6	0	0	- 3.89	+1.40	+5.29
Average	4.57	3.86	1.2	0	0	–	–	+ .66

[1/] Error is the difference between observed and computed change in lake level.

the total range in stage over the time involved. The direction of the error indicates that the estimated inflow was consistently less than actual or that the estimated outflow was consistently greater than actual. The first of the two possibilities would be consistent with the fact that both ground-water and surface-water inflow were estimated as zero.

Regression methods (Riggs, 1968) were used to evaluate the possible effect of ground-water inflow to Lake Kerr. Terms of the water-balance equation (equation 1) were rearranged to obtain a monthly residual from values of the observed change in lake level, estimated rainfall on the lake, estimated lake evaporation, and estimated surface-water inflow (estimated as zero). The water-balance residual represents the net effect of leakage from the lake and ground-water inflow to the lake plus the net effect of errors in the estimates of all the other factors involved.

The water-balance residual was related by a linear-regression equation to the level of Lake Kerr and to an index of ground-water levels in the vicinity of Lake Kerr. The best index of ground-water levels available for the 8 years involved was the level of water in Sharps Ferry well, which taps the Floridan aquifer about 8 miles east of Ocala (fig. 1). The level of water in Sharps Ferry well represents the potentiometric surface of the Floridan aquifer at that point. Because the aquifer integrates the effect of rainfall over a fairly large area, the fluctuations of the potentiometric surface at Sharps Ferry well generally should be proportional to the fluctuations of the potentiometric surface of the Floridan aquifer at or beneath Lake Kerr, or, at least, the potentiometric surface at the two points of concern should follow the same general trend through pronounced wet and dry periods. Figure 16 shows a general comparison of fluctuations in the water levels of Lake Kerr and Sharps Ferry well.

The equation used in the regression analysis was as follows:

$$Y = a + b\ (X_2 - X_1) \qquad (2)$$

wherein Y is the monthly water-balance residual, X_1 is the monthly average level of Lake Kerr, and X_2 is the monthly average level of water in Sharps Ferry well. The constants a and b are determined by regression.

Leakage from Lake Kerr varies inversely with the $X_2 - X_1$ term; that is, when the $X_2 - X_1$ term takes on its largest values, the potentiometric surface of the Floridan aquifer at Lake Kerr is highest in relation to the lake level - - but not necessarily above the lake level - - and the potential for water to leak from Lake Kerr to the Floridan aquifer is at its smallest. Conversely, when the $X_2 - X_1$ term takes on its smallest values, the potentiometric surface of the Floridan

aquifer at Lake Kerr is lowest in relation to the lake level and the potential for water to leak from Lake Kerr is at its greatest.

Variations in ground-water inflow to Lake Kerr from the shallow aquifer run counter to variations in leakage from the lake to the Floridan aquifer; that is, when the potentiometric surface of the Floridan aquifer is high in relation to the level of Lake Kerr, the level of water in the shallow aquifer is also high in relation to the lake level because the two aqufers are recharged by the same

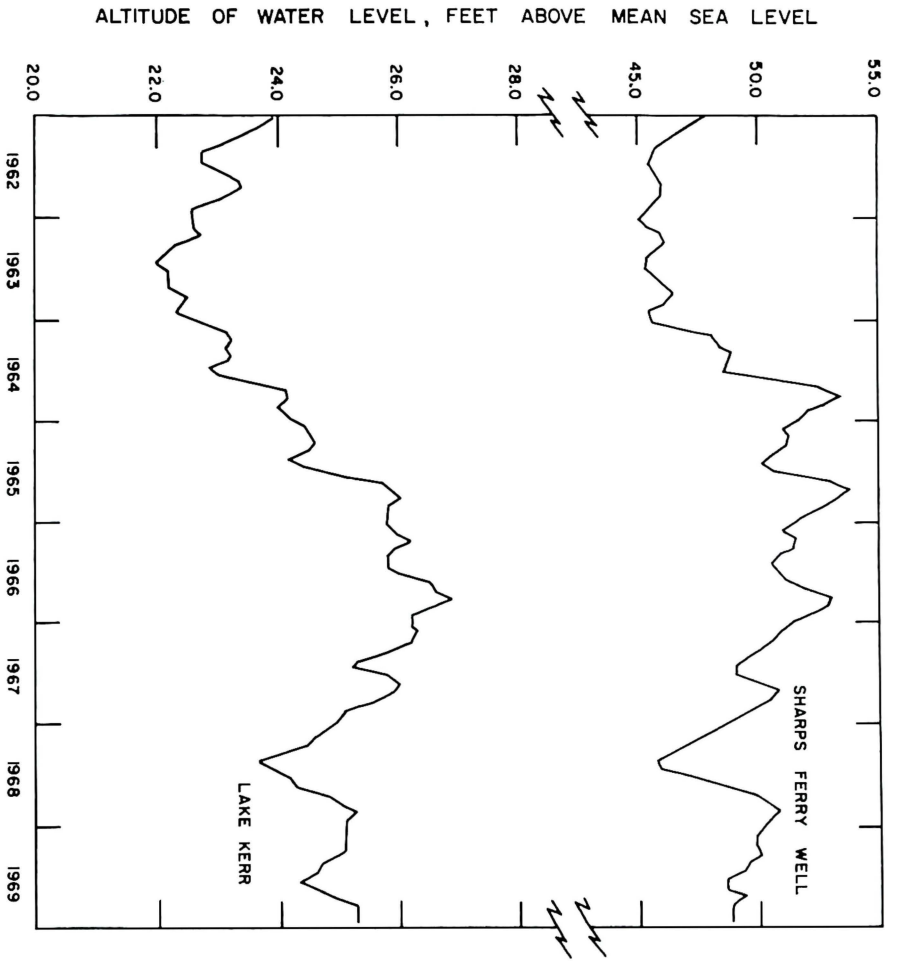


Figure 16. Graphs showing monthly average level of water in Lake Kerr and Sharps Ferry well.

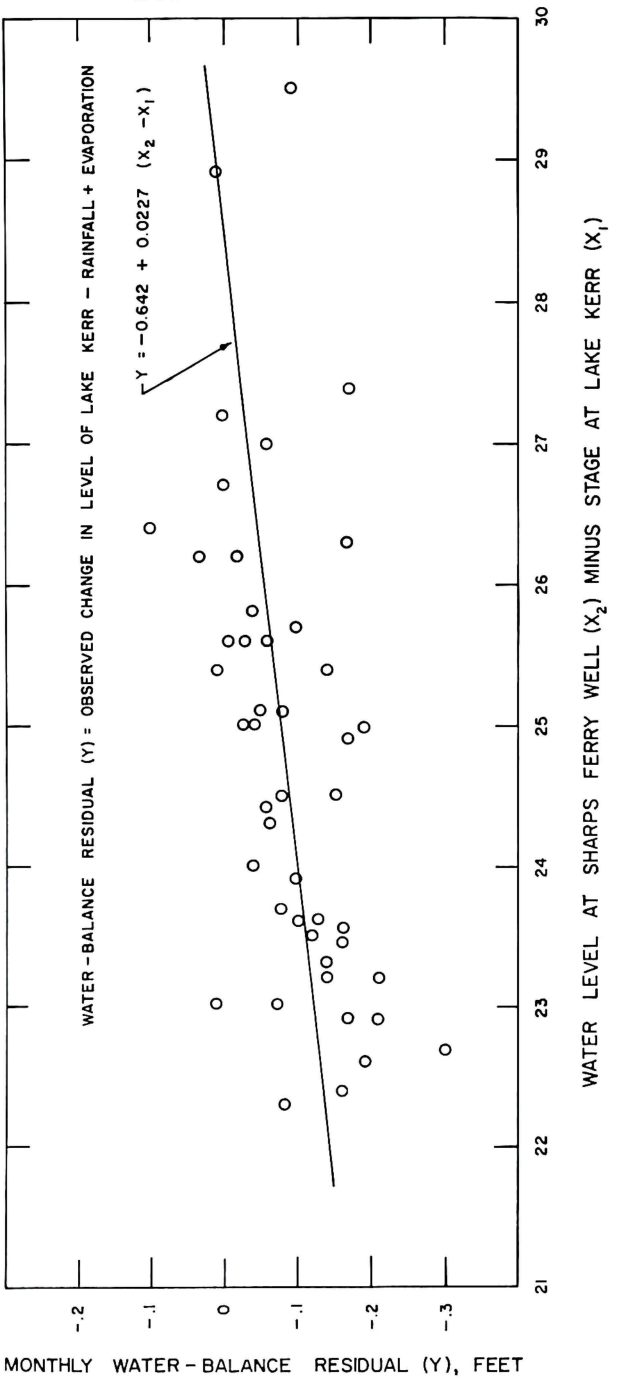


Figure 17. Graph showing relation between monthly water-balance residual of Lake Kerr and difference in water levels at Lake Kerr and Sharps Ferry well for month when estimated rainfall was less than 0.30 foot.

rainfall. Consequently, when the potential for leakage to the Floridan aquifer is small, the potential for ground-water inflow from the shallow aquifer is large, and vice versa. Thus, variations in ground-water inflow also are related to the $X_2 - X_1$ term but in the opposite way that variations in leakage are related to the term. The $X_2 - X_1$ term therefore reflects the combined effect of variations in leakage from Lake Kerr to the Floridan aquifer and ground-water inflow to Lake Kerr from the shallow aquifer.

The data used to determine the regression coefficients of equation 2 were restricted to that for months having estimated rainfall less than 0.30 foot because (a) errors due to the estimate of surface-water inflow (estimated as zero) would have minimal effect; (b) the selected data provided a fairly large sample (about half the available data) consisting of data for 47 months that were widely enough dispersed in time to be fairly representative of both wet and dry periods; (c) data for months having rainfall greater than 0.30 foot per month lacked the homogeneity required for valid regression analyses because of large and apparently uncompensated errors in the estimates of rainfall for some months. The resulting regression equation was

$$Y = -0.642 + 0.0227\ (X_2 - X_1). \qquad (3)$$

Figure 17 shows a plot of the data.

The monthly change in level of Lake Kerr was recomputed using the regression equation (equation 3) to determine the net of leakage from Lake Kerr and ground-water inflow to Lake Kerr, hereafter called net ground-water inflow. Monthly values of rainfall, lake evaporation, and surface-water inflow were the same as used in the previous computations. Net ground-water inflow ranged from +0.03 foot per month in October 1964 to -0.14 foot per month in April - June 1968, and averaged -0.083 foot per month overall. The range of variation of net ground-water inflow (0.17 foot) agrees closely with the range of 0.16 foot deduced previously from the analysis of the observed lake-level declines during rainless periods (table 3).

The monthly errors - - as indicated by the difference between the observed change in lake level and the recomputed change in lake level - - differed somewhat from the errors of the results of the previous computations, the maximum difference being 0.13 foot in October 1964. For the most part, however, monthly errors that were large in the previous computations remained large and those that were small in the previous computations remained small. In general appearance, the time distribution of the monthly errors shown in figure 18 is about the same as the distribution shown in figure 13.

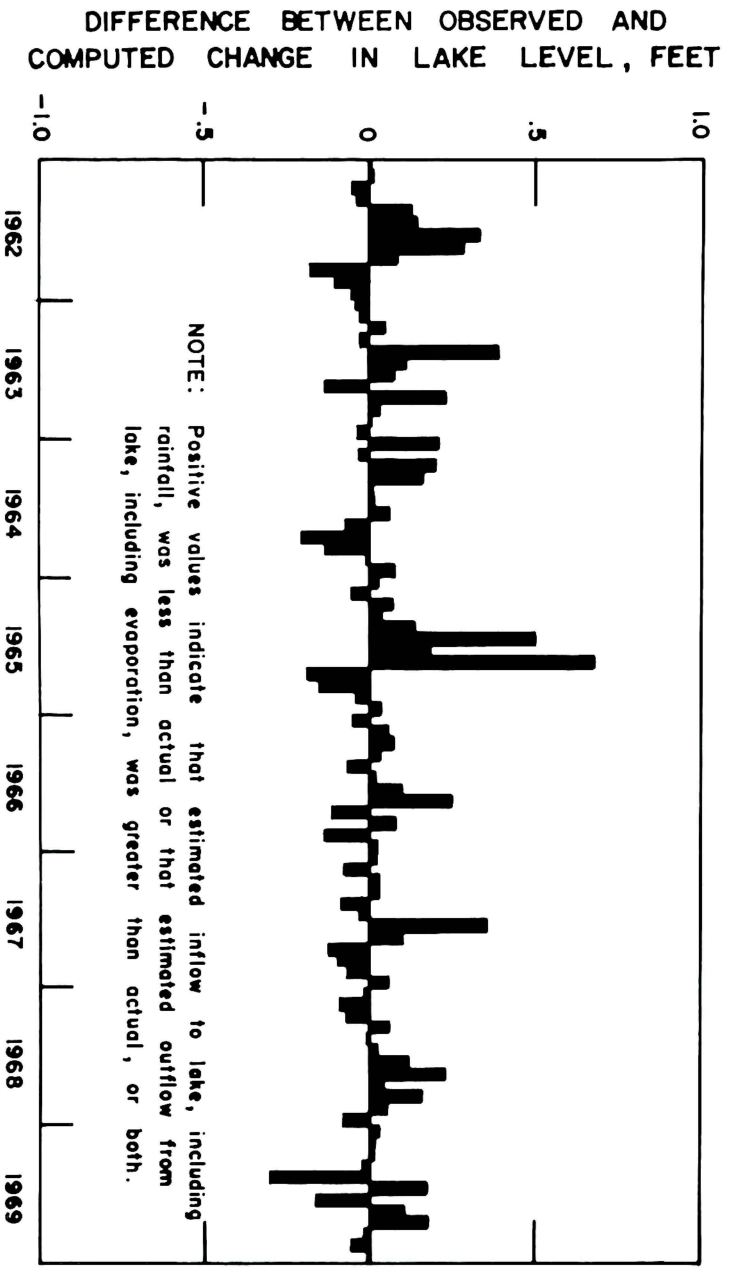


Figure 18. Graph showing time distribution of difference between observed and computed change in level of Lake Kerr wherein the net of leakage and ground-water inflow is determined by regression equation.

TABLE 6
APPROXIMATE YEARLY WATER BALANCE OF LAKE KERR, 1962 - 69, IN FEET;
NET OF LEAKAGE AND GROUND-WATER INFLOW DETERMINED BY REGRESSION EQUATION

Calendar year	Estimated rainfall	Estimated lake evaporation	Estimated leakage minus ground-water inflow	Estimated surface-water inflow	Change in lake level		Error [1]
					Computed	Observed	
1962	3.37	3.83	1.43	0	- 1.89	- 1.32	+0.57
1963	4.40	3.92	1.37	0	- .89	- .23	+ .66
1964	6.04	3.88	.55	0	+1.61	+1.92	+ .31
1965	4.57	3.87	.43	0	+ .27	+1.52	+1.25
1966	4.60	3.75	.78	0	+ .07	+ .35	+ .28
1967	3.70	3.99	1.07	0	- 1.36	- 1.20	+ .16
1968	4.75	3.84	1.25	0	- .34	+ .10	+ .44
1969	5.12	3.76	1.08	0	+ .28	+ .26	- .02
Total	36.55	30.84	7.96	0	- 2.25	+1.40	+3.65
Average	4.57	3.86	1.00	0	–	–	+ .46

[1] Error is difference between observed and computed change in lake level.

When the monthly water-balance results based on the regression equation are summed by years (as shown in table 6) the resulting error is reduced for some years - - in relation to the errors shown in table 5 - - and increased for others. The reduction in error was greatest for years when the level of Lake Kerr rose the most. The cumulative error for 1962 - 69 was appreciably reduced from +5.29 feet to +3.65 feet.

As was true in table 5, the persistency of the positive sign of the yearly errors in table 6 again indicates that estimated inflow to Lake Kerr was less than actual or that estimated outflow from Lake Kerr was greater than actual. Part of the error doubtlessly can be attributed to surface-water inflow which was estimated as zero. Some surface-water inflow must result from intense rainfalls around the lake. Although the inflow from any one storm might be small and relatively inconsequential, inflow from the several intense storms that occur each year might be expected to add water averaging from 0.2 to 0.3 foot per year.

Although the estimate of yearly lake evaporation conceivably could be incorrect by a few inches, this would not produce a persistent error in the yearly water-balance results because of the computational procedures used. For example, if actual lake evaporation is 43 inches or 49 inches rather than 46 inches per year, as estimated, the difference is distributed almost uniformly among the estimates of monthly lake evaporation. The error in monthly evaporation consequently appears in the monthly water-balance residual - - making them greater or less than they should be - - and, hence, in the regression equation which is based on the residuals. When the regression equation is used to determine net ground-water inflow, therefore, the resulting values are in error in a positive direction if estimated lake evaporation is larger than actual and they are in error in a negative direction if estimated lake evaporation is smaller than actual. Thus, the error in the estimate of lake evaporation is compensated for by an error of the opposite direction in the estimate of net ground-water inflow.

Although in the general area of Lake Kerr errors due to faulty estimates of rainfall normally would be expected to balance closely over a period as long as 8 years, part of the large cumulative error indicated in table 6 probably is attributable to the estimate of rainfall on the lake. The previous analysis of monthly results indicated that the large errors - - substantially greater than 0.1 foot per month - - were primarily attributable to faulty estimates of rainfall. The direction of the large errors indicated that estimated rainfall on the lake frequently was substantially less than actual and seldom was substantially greater than actual. Thus, for 1962 - 69 the yearly rainfall at Lake Kerr may have averaged from 2 to 3 inches more than was indicated by the average of rainfall at Crescent City and Ocala, even though rainfall at the three points may average about the same over the long term.

If an appreciable part of the cumulative error in table 6 is due to faulty estimates of rainfall - - and if over the long term the yearly rainfall averages about the same at Lake Kerr, Crescent City, and Ocala - - then water-balance computations based on factors estimated as described herein (including the use of equation 3 to determine net ground-water inflow) should in time produce a greater proportion of negative errors than was produced for 1962 - 69. An analysis of the monthly water-balance data for 1970 - 71 (not presented herein) indicates that the yearly error in the computed change in level of Lake Kerr is -0.70 foot from 1970 and -0.06 foot for 1971. A similar analysis of the yearly data for 1956 - 61 indicates that the resulting yearly error is positive for 3 years and negative for 3 years and that the cumulative error for the 6 years is only slightly positive. This indicates that a greater proportion of negative yearly errors can be expected over a longer time and that during 1962 - 69 rainfall at Lake Kerr was somewhat anomalously greater than rainfall at Crescent City, Ocala, and other stations in the general area.

SUMMARY

The monthly change in level of Lake Kerr was approximated for 1962 - 69 by use of a water-balance equation and estimates of rainfall, evaporation, leakage, surface-water and ground-water inflow. Rainfall was taken as the average of rainfall at Crescent City and Ocala. Estimated yearly lake evaporation was distributed on basis of the seasonal variation of monthly pan evaporation. Although leakage is known to vary, leakage was assumed to occur uniformly at 0.1 foot per month. Although surface-water and ground-water inflow occur at times, these factors were tentatively estimated as zero.

The computed monthly change in lake level was within 0.10 foot of the observed change in lake level about 70 percent of the time. Because of the distance between the lake and the rainfall stations used for the estimate of rainfall at the lake, some large errors were to be expected. Because of the usual randomness of rainfall, however, errors from this cause were expected to balance one another over a period as long as 8 years. Instead, most of the errors substantially greater than 0.10 foot were of the same direction and indicated inflow to the lake not accounted for by the various estimates. Because of their magnitude and because they were traced to periods of lake-level rise, the large errors presumably were caused by faulty estimates of rainfall or surface-water inflow.

A similar array of large errors resulted when the estimate of rainfall was based on records for other rainfall stations in the vicinity of Lake Kerr, taken singly and in different combinations, both including and excluding those for Crescent City and Ocala. In these computations, for some of the months

associated with large errors the size of the errors varied with the choice of rainfall stations, suggesting that the large errors of the computations based on rainfall at Crescent City and Ocala probably were caused by faulty estimates of rainfall. For 7 months, especially for 1965, but for other years as well, large errors persisted regardless of the choice of rainfall stations used; however, for 1965 rainfall was shown to be substantially greater at Lake Kerr than indicated by rainfall stations in the general area. Thus, it was concluded that all the large errors of the water-balance computations resulted primarily from faulty estimates of rainfall. Surface-water inflow probably is a small contributing factor during the most intensive rainfalls.

The use of a constant rate of leakage from the lake and an estimate of zero for ground-water inflow to the lake did not lead to large cyclical errors in the analysis of the observed lake-level declines during rainless periods involving 54 months in 1962 - 69. Such errors would be expected to occur if either leakage from the lake or ground-water inflow to the lake were both large and highly variable between wet and dry periods. The combined effect of variations in the monthly rates of leakage and ground-water inflow was indicated to be 0.16 foot for 95 percent of the months involved. In a separate analysis, variation in the monthly rate of leakage in 1962 - 69 was indicated to be about 0.04 - 0.06 foot. Thus, the variation in the monthly rate of ground-water inflow apparently fell within a range of about 0.10 foot.

Analysis of the difference between the level of water in a well tapping the shallow aquifer and the level of water in the lake suggested that the relative magnitude of ground-water inflow to the lake from the shallow aquifer varied greatly between wet and dry periods; for this to occur within a variation in the monthly rate of ground-water inflow of about 0.10 foot, the monthly rate of ground-water inflow had to be small (relative to 0.10 foot) during dry periods and not appreciably greater than 0.10 foot during wet periods.

The yearly water-balance data showed that for 1962 - 69 the computed change in lake level was in error by +5.29 feet. The direction of the error indicated inflow to the lake that was not accounted for by the estimates of the various factors involved. Part of the error is easily explained by the fact that both surface-water and ground-water inflows were estimated as zero. The accumulation of small quantities of either could be appreciable over a period of 8 years.

The effect of ground-water inflow to Lake Kerr was investigated by use of regression methods wherein net ground-water inflow (the net of leakage and ground-water inflow) was related to the difference between the lake stage and the level of water in Sharps Ferry well, which taps the same Floridan aquifer

that underlies Lake Kerr. After net ground-water inflow was determined by the regression equation, the cumulative error in the computed change in level for 1962 - 69 was appreciably reduced from +5.29 feet to +3.65 feet. Net ground-water inflow ranged from +0.03 foot per month to -0.14 foot per month, and averaged -0.083 foot per month for 1962 - 69, leakage being greater than ground-water inflow for all but a few months near the end of 1964.

The remainder of the cumulative error in the computed change in level for 1962 - 69 was attributed to faulty estimates of surface-water inflow (estimated as zero) and rainfall. Small quantities of surface-water inflow resulting from the several intensive rainfalls that occur most years conceivably could total, on the average, from 0.2 to 0.3 foot of water per year.

The analysis of large errors in the monthly water-balance results indicated that during 1962 - 69 estimated rainfall at Lake Kerr frequently was substantially less than actual and seldom was substantially greater than actual. Thus, during 1962 - 69 the actual rainfall at Lake Kerr may have averaged 2 to 3 inches more than was estimated on basis of rainfall at Crescent City and Ocala, even though rainfall at these two stations may be closely representative of rainfall at Lake Kerr over a longer period of time. Analyses of water-balance data for 1956 - 61 and 1970 - 71 (not included herein) indicated that rainfall at Lake Kerr was anomalously high in 1962 - 69.

Based on the long-term averages for Crescent City and Ocala, rainfall at Lake Kerr averages about 54 inches per year. Lake evaporation is estimated to average about 46 inches per year. During 1962 - 69, leakage from Lake Kerr was about 12 inches greater than ground-water inflow to Lake Kerr. If this 12-inch difference is representative of the long-term average, surface-water inflow averaging about 4 inches per year is required to maintain the water balance of Lake Kerr. Ground-water inflow is indicated to be relatively small, probably in the same order of magnitude as surface-water inflow.

REFERENCES

Clark, W. E., Musgrove, R. H., Menke, C. G., and Cagle, J. W., Jr.
1963 *Hydrology of Brooklyn Lake near Keystone Heights, Florida:* Florida State Board of Conserv., Div. of Geol., Rept. Inv. 33, 43 p.

Faulkner, G. L.
1970 *Geohydrology of the Cross - Florida Barge Canal area:* U. S. Geol. Survey, Tallahassee, Fla., open-file report, 222 p.

Florida Agricultural Experiment stations
1962 *General soil map of Florida:* Univ. of Florida, Gainesville, 1 sheet.

Hendricks, E. L., and Goodwin, M. H., Jr.
1952 *Water-level fluctuations in limestone sinks in southwestern Georgia* in *Contributions to the hydrology of the United States:* U. S. Geol. Survey Water-Supply Paper 1110, pp. 157-245.

Kenner, W. E.
1964 *Maps showing depths of selected lakes in Florida:* Florida State Board of Conserv., Div. of Geol., Inf. Circ. 40, 82 p.

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

Kohler, M. A.
1954 *Lake and pan evaporation* in *Water-loss investigations - - Lake Hefner studies, technical report:* U. S. Geol. Survey Prof. Paper 269, pp. 127 - 148.

Parker, G. G., Ferguson, G. E., Love, S. K., and others
1955 *Water resources of southeastern Florida:* U. S. Geol. Survey Water-Supply Paper 1255, 965 p.

Riggs, H. C.
1968 *Some statistical tools in hydrology:* U. S. Geol. Survey, Tech. Water-Resources Inv., Book 4, Chap. A1, 39 p.

U. S. Geological Survey
1962-1970 *Water resources data for Florida, part 1, surface-water records, vol. 3, lakes, annual summaries for 1961 - 69 water years:* U. S. Geol. Survey, Water Resources Div., Tallahassee, Fla., ann. ser.

U. S. Weather Bureau
1961-1970 *Climatolotical data, Florida, monthly and annual summaries, 1960 - 69:* U. S. Dept. Commerce, Environmental Sci. Services Adm., Asheville, N. C.

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