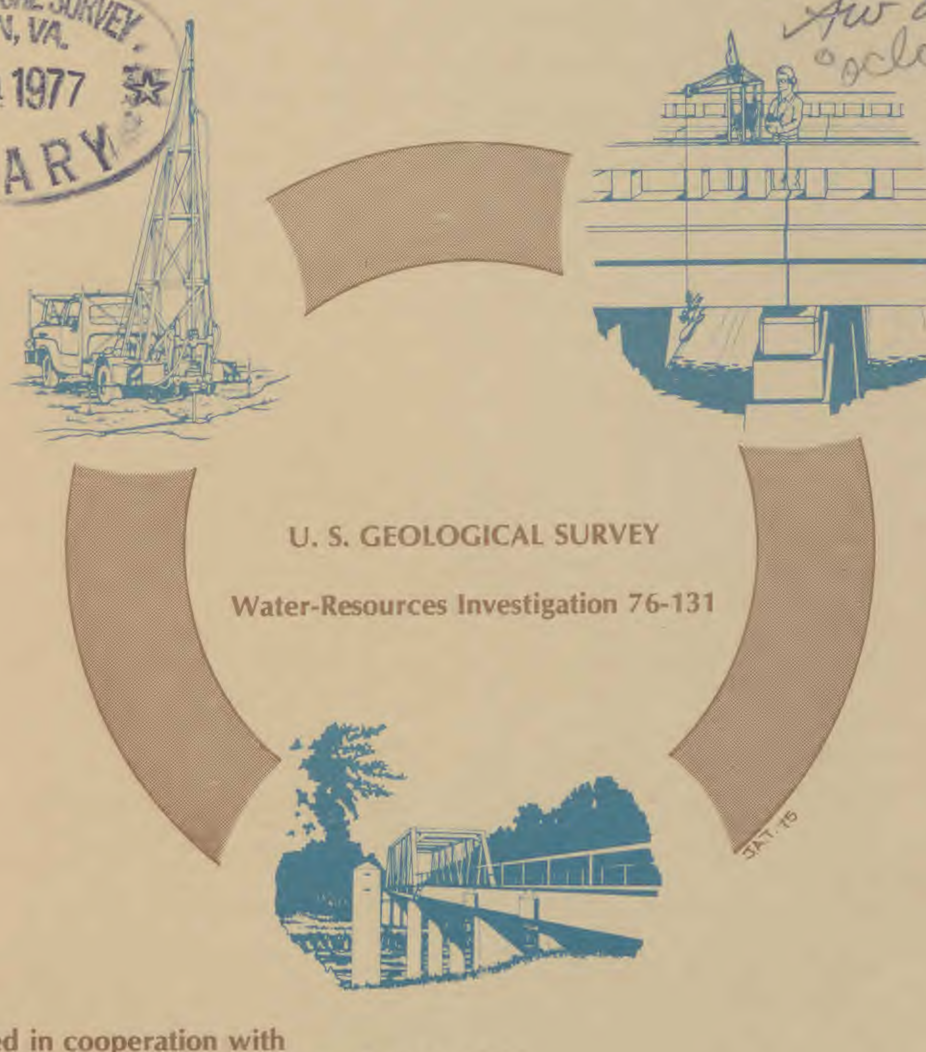
HYDROLOGIC CONSIDERATIONS IN DEWATERING AND REFILLING LAKE CARLTON, ORANGE AND LAKE COUNTIES, FLORIDA



U. S. GEOLOGICAL SURVEY

Water-Resources Investigation 76-131

Prepared in cooperation with
STATE OF FLORIDA GAME AND FRESHWATER FISH COMMISSION
and
BOARD OF COUNTY COMMISSIONERS
LAKE COUNTY, FLORIDA
and
BOARD OF COUNTY COMMISSIONERS
ORANGE COUNTY, FLORIDA

WRI 76-131 HYDROLOGIC CONSIDERATIONS IN DEWATERING AND REFILLING LAKE CARLTON, ORANGE AND LAKE COUNTIES, FLORIDA

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16. Abstracts Lake Carlton, a 382-acre (155 hectare) lake in Lake and Orange Counties in central Florida is highly eutrophicated and subject to algal blooms. It is proposed to correct this problem by dewatering the lake long enough to allow the muck on its bottom to dry and compact, which will allow seed believed to exist in the muck on the lake bottom to germinate. The predicted time required to dewater the lake at a pumping rate of 50,000 gallons (190 cubic meters) per minute is 21 days. The average pumping rate required to maintain the lake in a dewatered condition is computed to be 2,400 gallons (9.08 cubic meters) per minute. The natural average rate of input between May 31 and October 31 is enough to cause the lake to rise from 48 feet (15 meters) to 56 ft (17 meters) above mean sea level. Supplementing the natural input between May 31 and October 31 at a rate of 4,800 gallons (18.4 cubic meters) per minute will cause the lake level to rise from 48 feet (15 meters) to 63 feet (19 meters).

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February 1977

UNITED STATES DEPARTMENT OF THE INTERIOR

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HYDROLOGIC CONSIDERATIONS IN DEWATERING AND REFILLING LAKE CARLTON, ORANGE AND LAKE COUNTIES, FLORIDA

By

Warren Anderson and G. H. Hughes

ABSTRACT

Lake Carlton straddles the line between Lake and Orange Counties in central Florida. The 382-acre (155-hectare) lake is highly eutrophic and subject to virtually perpetual algal blooms. The Florida Game and Fresh Water Fish Commission has proposed to restore the lake to a less eutrophic state by dewatering the lake long enough to allow the muck on its bottom to dry and compact. Lake Carlton would be permanently sealed off from Lake Beauclair which presently serves as a source of nutrient enriched water for Lake Carlton. On the assumption that the seasonal rainfall would be normal, and that the dewatering phase would begin on March 1, the predicted time required to dewater the lake at a pumping rate of 50,000 gallons (190 cubic meters) per minute is 21 days. The average rate of pumping required to maintain the lake in a dewatered condition is computed to be 2,400 gallons (9.08 cubic meters) per minute. If pumping is ended May 31, the predicted altitude to which the lake would recover by October 31 as a result of net natural input is 56.2 feet (17.1 meters) above sea level. Raising the lake level to 63 feet (19.2 meters) above sea level by October 31 would require that the net natural input be supplemented at an average rate of about 4,860 gallons (18.4 cubic meters) per minute between May 31 and October 31.

INTRODUCTION

Lake Carlton in Orange and Lake Counties, Florida, is one of, though not a link in, a chain of lakes in the headwaters of the northward flowing Oklawaha River (fig. 1). Since the mid-1940's, these lakes have been undergoing increasing eutrophication, which is manifested mainly by steadily increasing frequency and duration of algal blooms. Lake Carlton has suffered more from this problem than any lake in the chain (Holcomb, D. E., oral commun., 1975). As a result, the lake has degenerated from one of clear water and excellent sports fishing, to one of pea green water and virtually no sports fishing.

The Florida Game and Fresh Water Fish Commission (Holcomb, D. E., oral commun., 1975) feels that the primary cause of the algal blooms in Lake Carlton is nutrient enriched water introduced from Lake Beauclair through a channel that connects the two lakes. The Commission believes that by permanently sealing off Lake Carlton from Lake Beauclair and dewatering Lake Carlton long enough to compact the muck on its bottom, the lake upon refilling would be restored to and remain in a relatively uneutrophicated condition.

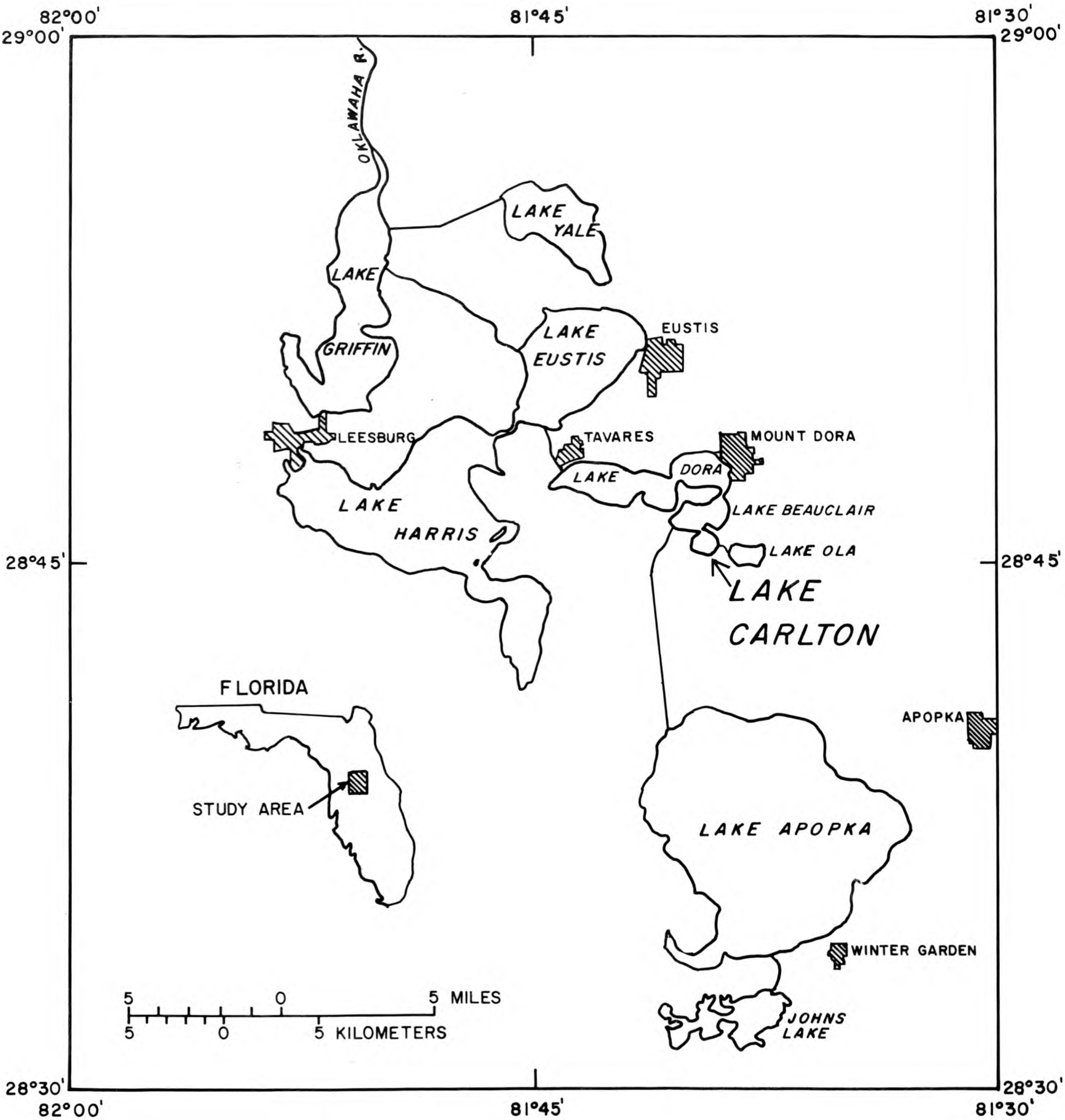

FIGURE 1.--LOCATION OF LAKE CARLTON AND OTHER FEATURES IN THE UPPER OKLAWAHA BASIN.

The hydrologic feasibility of draining and refilling Lake Carlton was investigated as part of the U.S. Geological Survey's cooperative program of water-resources investigations. The investigation was made in financial cooperation with the Boards of County Commissioners of Lake and Orange Counties, and was carried out in technical coordination with the Florida Game and Fresh Water Fish Commission. This report summarizes the results of the investigation. The time required to empty the lake by pumping water out at 50,000 gal/min (190 m^3/min) and the effect of dewatering the lake, both on ground-water seepage rates into the lake and on the downstream flow system are discussed. The project would be scheduled during the frost-free months, March through October. The altitude that the lake would reach as a result of the net natural input and the amount that the net natural input would have to be supplemented to bring the lake to a near-normal stage of 63 ft (19 m) by the end of the refill period are also indicated.

The report is based on data gathered October 1, 1974 through March 31, 1975 (hereinafter called the "study period").

For the convenience of those who perfer to use metric units, a table for converting English to metric units is given below:

English units	Multiply by	To obtain Metric units
acres	0.405	hectares (ha)
acre-feet (acre-ft)	1233.6	cubic meters (m^3)
cubic feet per second (ft^3/s)	.028	cubic meters per second (m^3/s)
feet (ft)	.3048	meters (m)
gallons per minute (gal/min)	.0038	cubic meters per minute (m^3/min)
inches (in)	25.4	millimeters (mm)
miles (mi)	1.609	kilometers (km)
square miles (mi^2)	2.59	square kilometers (km^2)

THE HYDROLOGIC ENVIRONMENT

Lake Carlton is the last lake in a system of lakes tributary to Lake Beauclair, one of the chain of lakes in the headwaters of the Oklawaha River (figs. 1 and 2). The Lake Carlton system is connected to Lake Beauclair by a channel which is about 30 ft (9 m) wide and 2 ft (0.6 m) deep at lake stage 61 ft (19 m) above mean sea level and 80 ft (24 m) wide and 6 ft (2 m) deep at lake stage 65 ft (20 m) above mean sea level. At the average stage of 63 ft (19 m), the area of Lake Carlton is about 382 acres (155 ha) and its volume is about 4,600 acre-

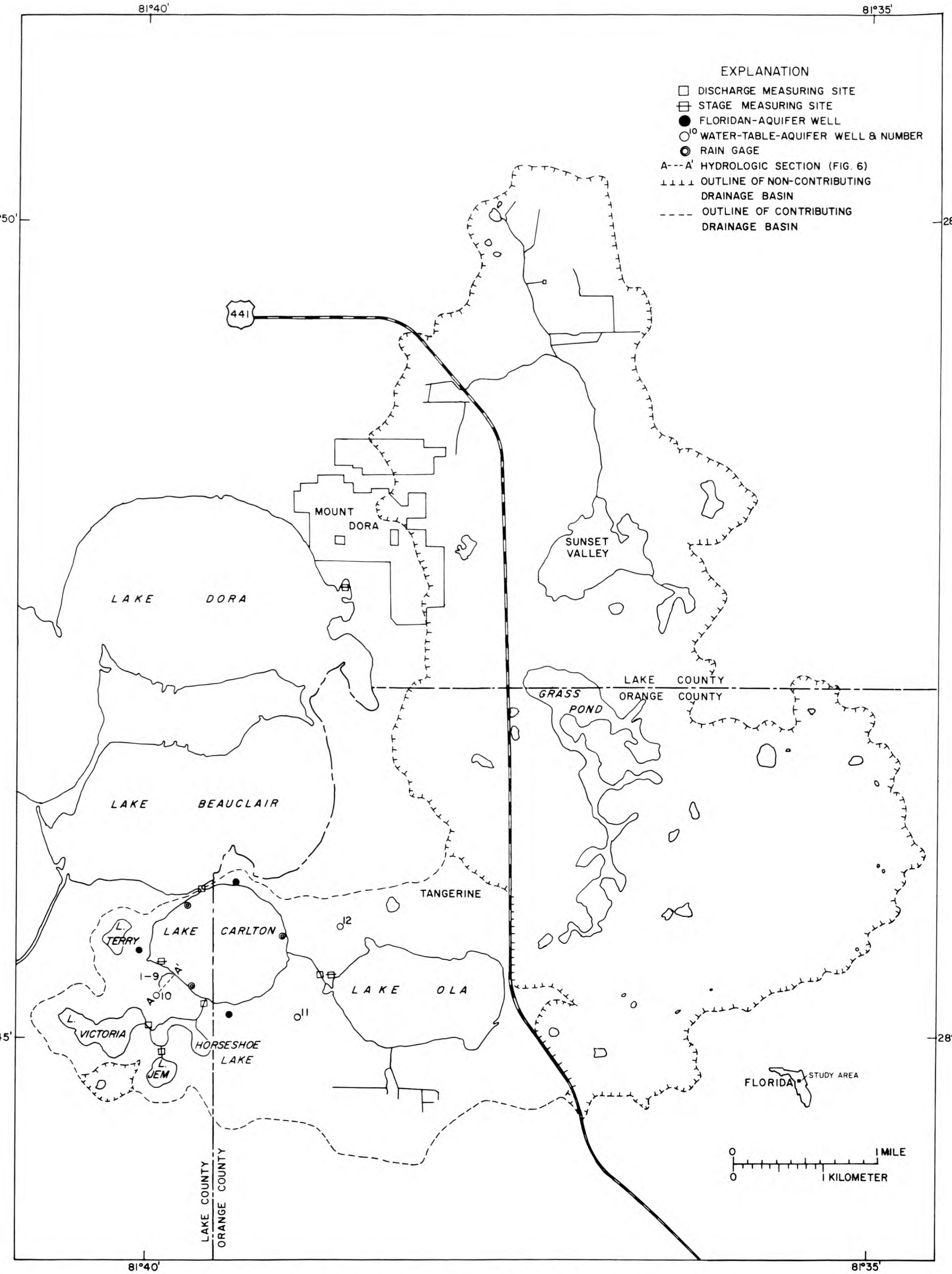

FIGURE 2.--DATA SITES AND OTHER FEATURES IN THE LAKE CARLTON DRAINAGE BASIN.

feet (5,670,000 m^3). The area of the drainage basin of Lake Carlton as delineated on the 7½-minute topographic map is 18.5 mi^2 or 47.9 km^2 (fig. 2). However, only 5.06 mi^2 (13.1 km^2) of the basin contributes surface flow to Lake Carlton. In the rest of the basin, rainfall either returns to the atmosphere by evapotranspiration or infiltrates to the artesian Floridan aquifer, and, therefore does not enter Lake Carlton.

A well drilled to the top of the Floridan aquifer at a site on the north shore of the lake shows that about 130 ft (40 m) of unconsolidated materials overlie the limestone of the Floridan aquifer. Samples of the materials penetrated by this well show about the top 25 ft (8 m) to be layered black, brown, and green fine to coarse sands with some fine gravel. A layer of creamy white fine-to-coarse sand lies between the 25- and 50-foot (8- and 15-m) depths. At depths between 50 and 75 ft (15 and 23 m), gray to green clayey fine sand occurs. From 75 ft (23 m) below the surface to the top of the limestone at 130 ft (40 m), the materials grade from dense green clay with medium-to-coarse sand and some limestone fragments to dense blue-gray phosphatic silt. This lower layer of materials is very impervious as it appears to be dry in places according to the samples recovered. These impermeable materials may or may not extend as a continuous layer completely around Lake Carlton and may or may not extend continuously beneath Lake Carlton. In some parts of Florida the hydraulic conductivity of the confining bed between the Floridan and water-table aquifers differs substantially over relatively short distances. The confining bed appears to have collapsed completely beneath some sinkholes and sinkhole lakes.

At normal stages, Lake Carlton is slightly lower than the surrounding water table and a few feet higher than the potentiometric surface of the Floridan aquifer under the lake. Thus, water is assumed to seep into the lake from the shallow water-table aquifer and out of the lake to the Floridan aquifer.

Water flows in both directions through the channel connecting Lake Carlton to Lake Beauclair. On a short-term basis, the amounts and direction of flow in the channel are controlled by oscillations of the lake surfaces set up by wind. These oscillations cause a difference in the altitudes of the lake surfaces, first in one direction and then in the other. When Lake Carlton is higher than Lake Beauclair at the connecting channel, water flows out of Lake Carlton into Lake Beauclair. When Lake Beauclair is higher, water flows from Lake Beauclair into Lake Carlton. But, on a long-term basis, the net direction of flow depends on whether input to Lake Carlton from rainfall, subsurface flow, and surface flow other than in the connecting channel, is greater or less than output by evaporation and subsurface flow.

METHOD OF ANALYSIS

The determination of the quantity of water to be pumped from Lake Carlton during the dewatering and hold-down periods, and the quantity of water available for refilling the lake by natural processes requires measurements or estimates of rainfall, evaporation, surface flow to the lake, and subsurface flow to the lake from the water-table aquifer and the Floridan aquifer. Sufficient data were available, or obtainable, to make direct estimates of all factors except the subsurface exchange of water between the lake and the Floridan aquifer. This factor can be determined indirectly as a residual by solution of a water-budget equation for Lake Carlton. Once, the amount of water exchanged between the lake and the Floridan aquifer is determined for one condition, the amount exchanged under other conditions can be estimated on the basis of head relationships which can be established.

WATER BUDGET OF LAKE CARLTON

The water budget of Lake Carlton was determined for the study period, October 1, 1974 to March 31, 1975. The factors included in the water budget were determined or estimated as follows.

Rainfall

Rainfall was measured in three rain gages spaced evenly around Lake Carlton (fig. 2). The total catch in these gages during the study period was 8.32 in (211 mm) in the east gage, 9.45 in (240 mm) in the northwest gage and 8.62 in (219 mm) in the southwest gage. The average of the three totals was 8.80 in (224 mm). Thus, the contribution to the 382-acre (155-hectare) lake from rainfall was 280 acre-ft or (345,000 m^3) during the study period.

Evaporation

Evaporation from Lake Carlton during the study period was assumed to be the same as that given for the same months by Lichtler and others (1968, p. 74) for lakes in Orange County. Total evaporation for the 6 months was thus assumed to be 17 in (432 mm). This amounts to 540 acre-ft (666,000 m^3) of output from Lake Carlton during the study period.

Change in storage

Lake Carlton declined in stage 0.1 ft (0.03 m) during the study period according to records for Lake Dora at Mount Dora which is considered to be at the same level as Lake Carlton. This is equivalent to about 40 acre-ft (49,300 m^3) of output from Lake Carlton during the study period.

Surface flow

Surface flow into and out of Lake Carlton was evaluated by periodic discharge measurements or observations of no flow at the outlets of Lakes Ola, Victoria, and Horseshoe and by use of a continuously recording deflection vane at Lake Carlton outlet.

The flow from Lake Ola and the stage of Lake Ola for the period August 26, 1974 through May 30, 1975 are shown by figure 3. The total input to Lake Carlton from Lake Ola during the study period is estimated as 30 acre-ft (37,000 m^3). No water flowed from Lake Victoria to Horseshoe Lake during the period. The amount of flow from Horseshoe Lake to Lake Carlton could not be determined precisely by periodic measurements because flow in the connecting channel periodically reverses. However, flow from Horseshoe Lake to Lake Carlton during the study period is estimated to be about 10 acre-ft (12,000 m^3) since the drainage area of Horseshoe Lake is about one third that of Lake Ola.

Water enters and leaves Lake Carlton through its connection with Lake Beauclair. To determine the rate and direction of flow in this connecting channel, an aluminum plate or vane, connected to a continuous recorder, was suspended in the channel. This device was arranged to indicate the rate of flow in the channel by recording the amount the vane was deflected by the current (fig. 4). The relation between the amount of deflection and the rate of flow in the channel was established by measuring the velocity of the current with a standard current meter and relating the results to the simultaneous vane deflection. The deflection vane indicates that the rate of flow can approach 200 ft^3/s (5.66 m^3/s) in either direction. However, the deflection vane indicated that the net flow averaged 3.48 ft^3/s (0.10 m^3/s) into Lake Carlton during the study period. This is the average of the daily net flows for the 156 days for which complete data were available out of the 182 days in the study period and amounts to a total of 1,260 acre-ft (1,550,000 m^3).

The rapid fluctuation from inflow to outflow and back to inflow, as indicated by the sample deflection vane record shown in figure 4, makes it very difficult to accurately determine the net flow for windy days. Therefore, limited confidence can be placed on the accuracy of this average net flow. Nevertheless, as this is the only value available, it was used as a factor in the water budget. Thus, the total surface input to Lake Carlton from Lake Ola, Horseshoe Lake and Lake Beauclair during the study period was about 1,300 acre-ft (1,600,000 m^3).

Subsurface flow

The amount of subsurface flow to Lake Carlton from the water-table aquifer depends on how much of the rainfall that infiltrates to the water-table aquifer can escape by means other than lateral seepage into

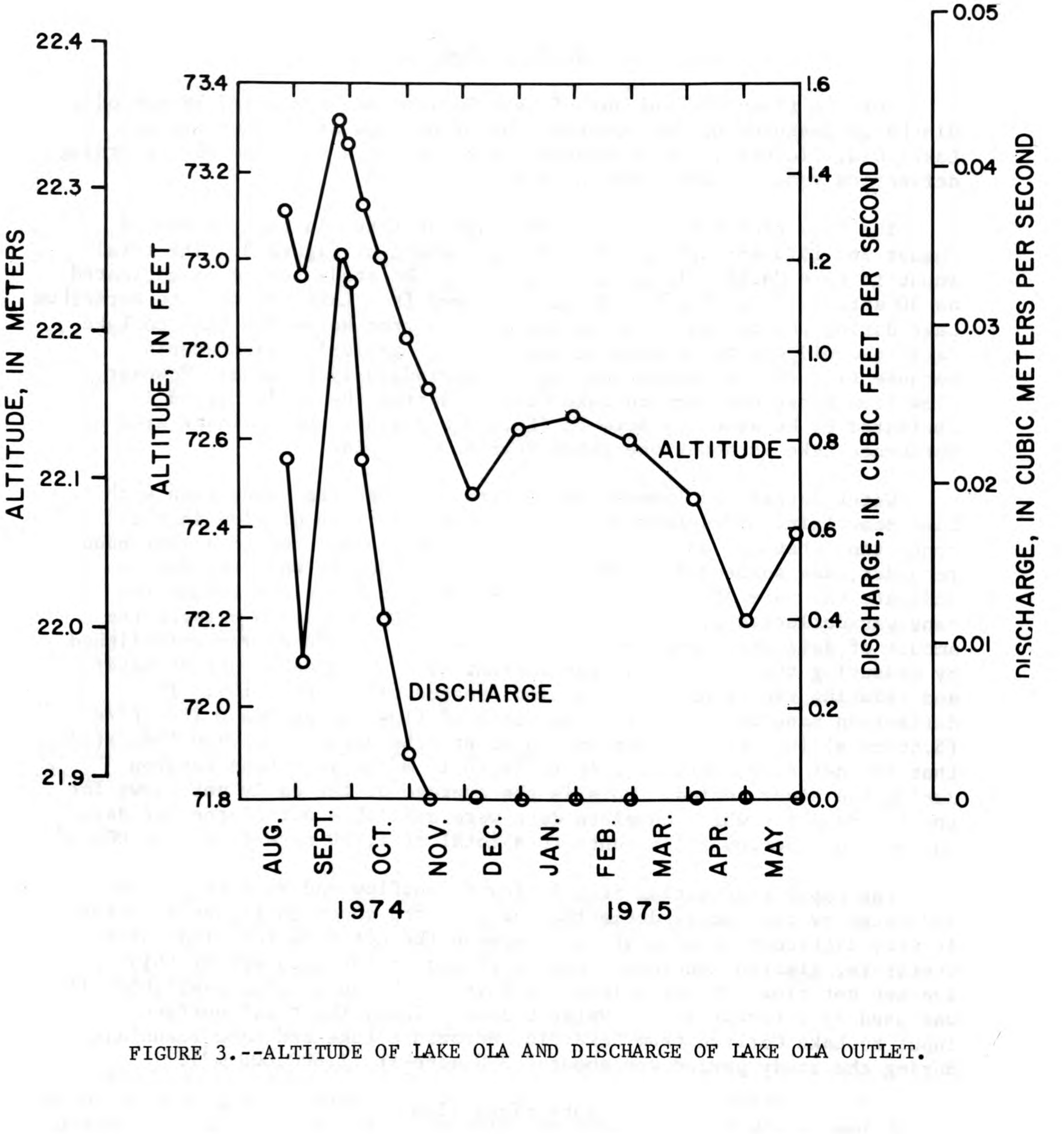

FIGURE 3.--ALTITUDE OF LAKE OLA AND DISCHARGE OF LAKE OLA OUTLET.

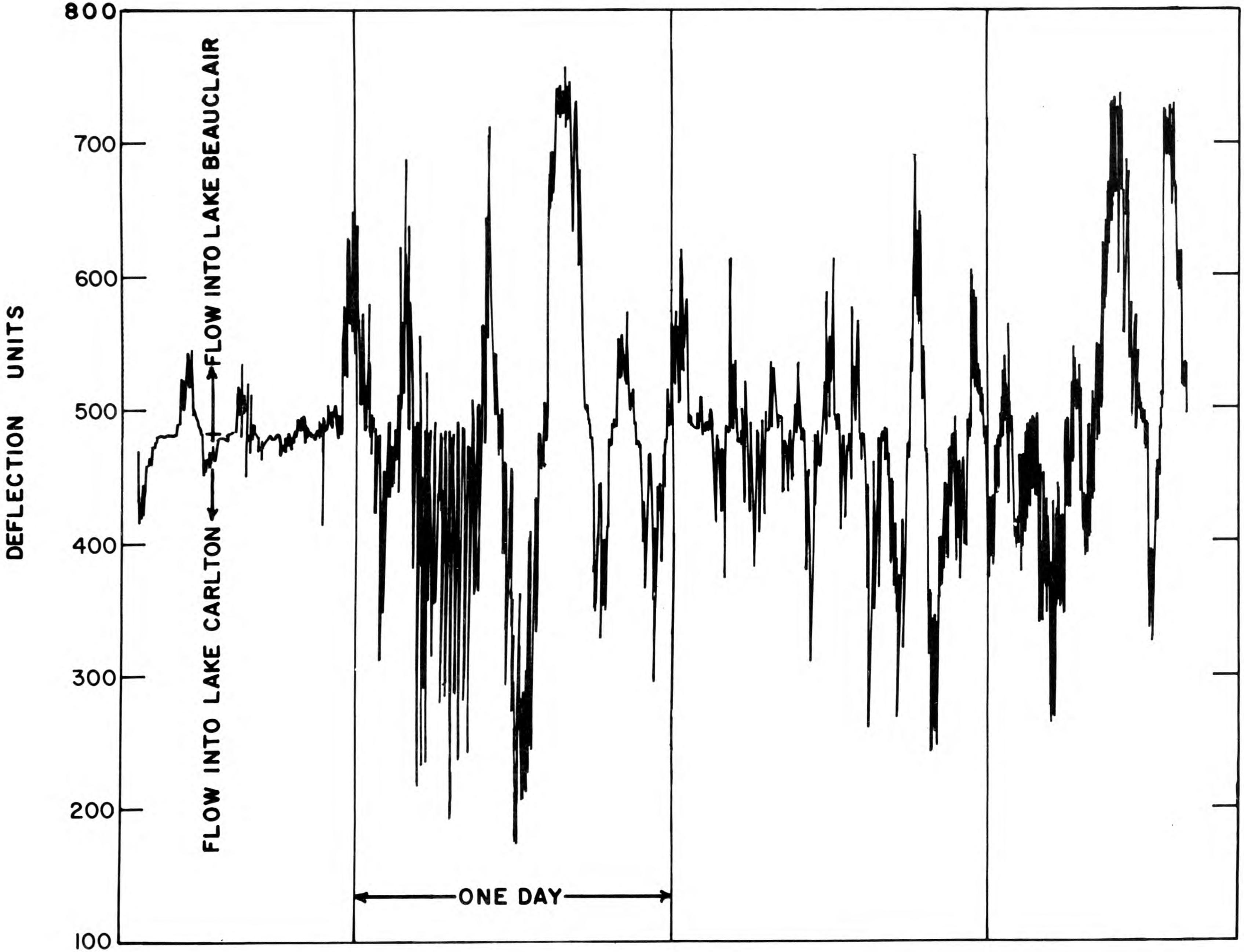

FIGURE 4.--SAMPLE OF VANE DEFLECTION RECORD FOR LAKE CARLTON OUTLET.

the lake. The only other means of escape are evapotranspiration and seepage to the Floridan aquifer.

The land surface adjacent to the lake along section A-A' (fig. 2) slopes far more steeply than the water table so the thickness of the unsaturated materials is 30 ft (9 m) or more within 200 ft (60 m) of the lake. Consequently, even though the potential for soil moisture depletion is large, losses from the water-table aquifer by evapotranspiration are probably small. Water levels in wells 9, 10, 11, and 12 continued to decline steadily in January when rainfall was 2.3 in (58 mm), the highest monthly total during the study period. Therefore, none of the rain was assumed to have reached the water-table aquifer.

Although the 55 ft (17 m) of blue-gray phosphatic silt penetrated in the well on the north side of Lake Carlton may not exist all around Lake Carlton, it is presumed to do so in this analysis. Hence, on the basis of this assumption the leakage from the water-table aquifer to the Floridan aquifer can be considered very small. The effect of this assumption is to maximize the computed subsurface flow into Lake Carlton from the water-table aquifer. To the extent that the subsurface flow is a factor, therefore, the final estimate of pumping time required to lower the level of Lake Carlton could be considered conservative. Because it was assumed that no significant amount of water was lost from the water-table aquifer by evapotranspiration and leakage to the Floridan aquifer or gained by recharge from rainfall, all of the decline in the water table surrounding the lake during the study period was considered change in storage caused by lateral seepage toward the lake. In this analysis, all of the water was assumed to have entered the lake.

As a consequence of the foregoing assumptions, the quantity of subsurface flow to Lake Carlton from the water-table aquifer during the study period is represented by the volume of the aquifer dewatered (with appropriate adjustment for specific yield) as the water table declined between October 1, 1974 and March 31, 1974. The volume of the aquifer dewatered can be determined from the area of the aquifer extending from the lake to the water-table divide and the average decline of the water table over that area.

In evaluating subsurface flow to the lake from the water-table aquifer, the area surrounding the lake was considered in two segments as indicated in figure 5. One of the segments is typified by high sand hills and the other, by little topographic relief.

In the sand-hill area, 10 wells (numbered 1 through 10) were installed on the southwest shore of Lake Carlton in a line extending from the lake to near the topographic divide, as shown by section A-A' in figure 6. (See figure 2 for location of section A-A'.) Two additional wells were installed near the topographic divide, one (well 11) on the

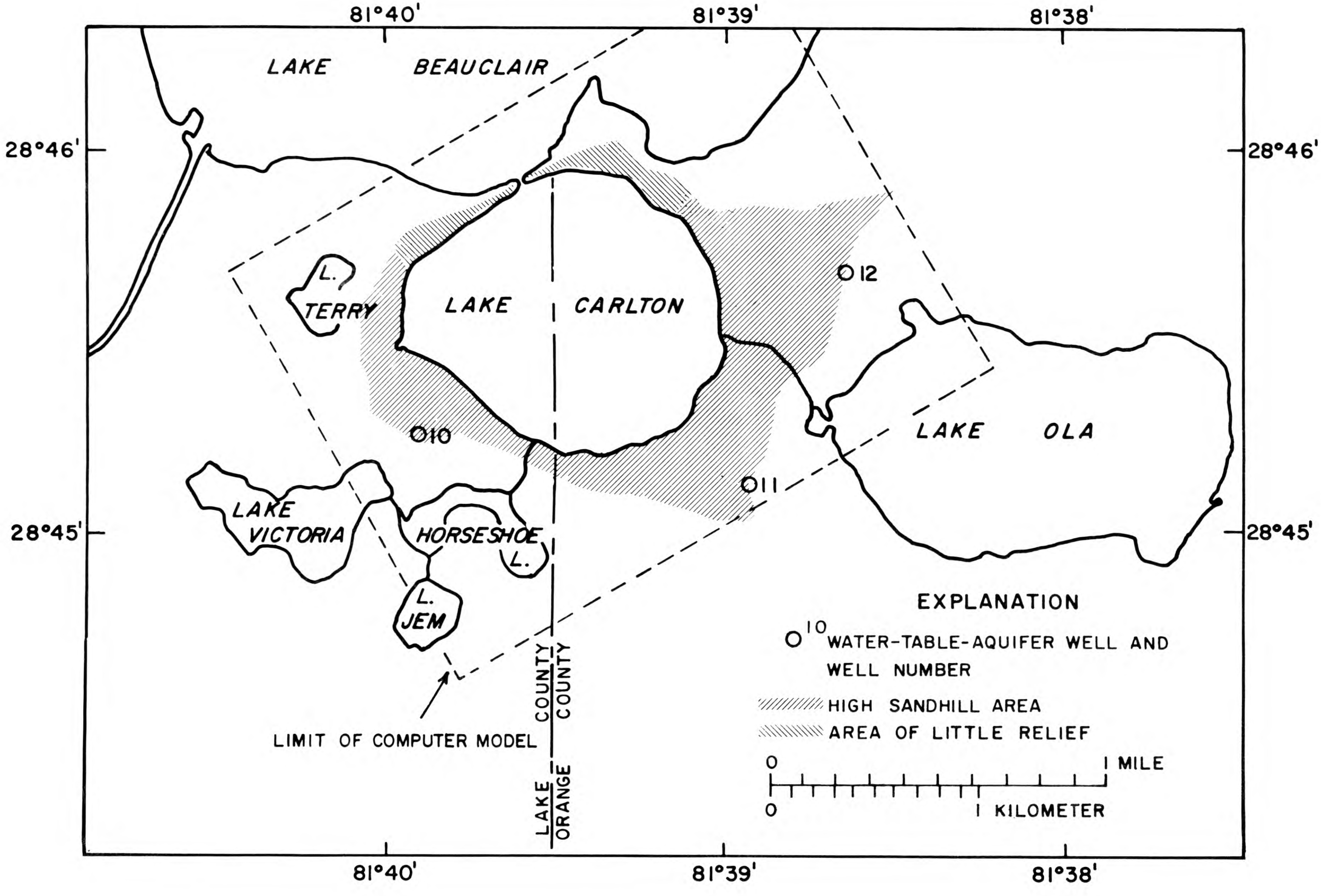

FIGURE 5.--AREAL EXTENT OF SEGMENTS OF THE WATER-TABLE AQUIFER BETWEEN LAKE CARLTON AND THE TOPOGRAPHIC DIVIDE AND THE AREA OF THE WATER-TABLE AQUIFER MODELED.

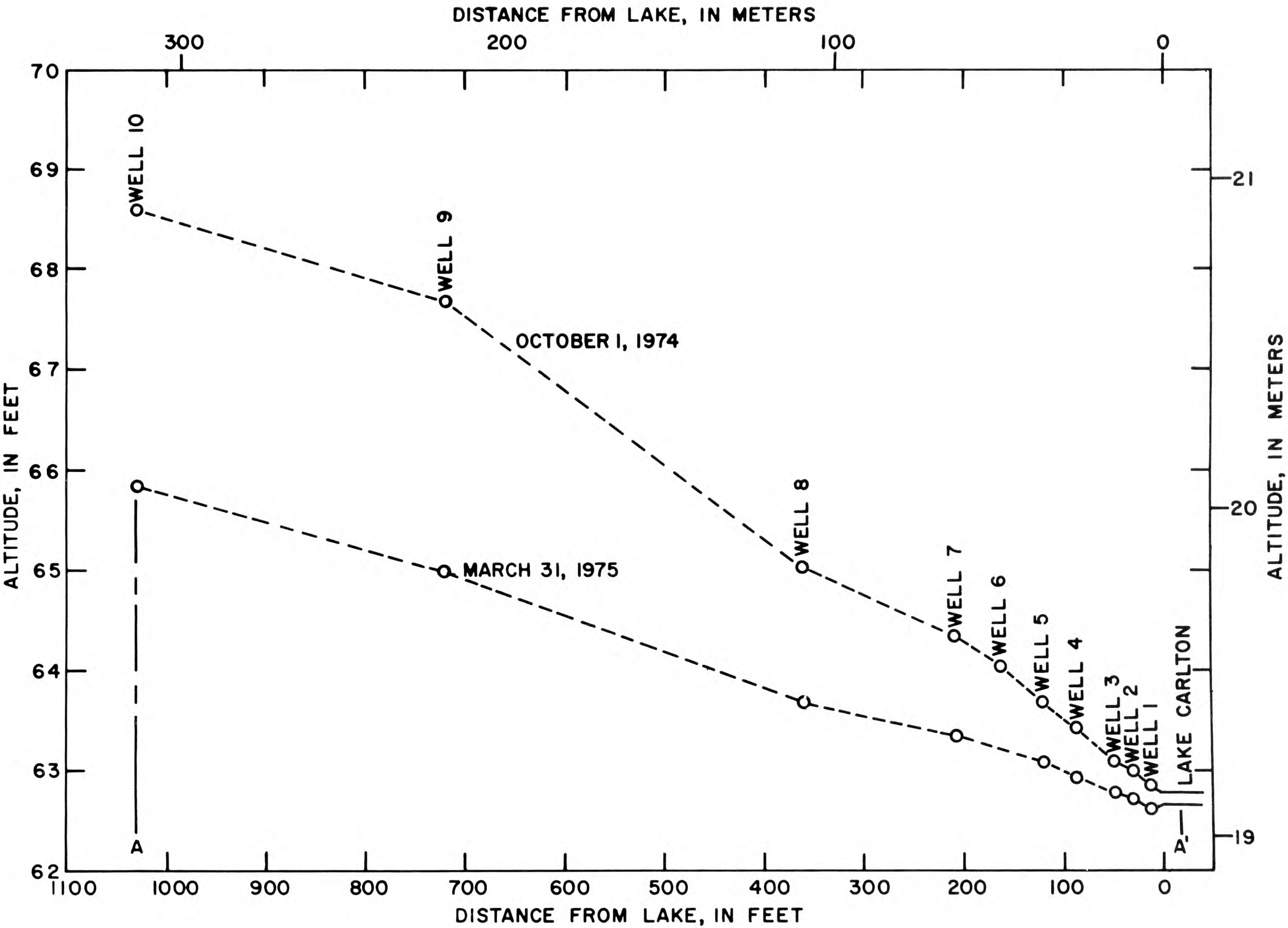

FIGURE 6.--PROFILES OF THE WATFR TABLE ALONG HYDROLOGIC SECTION A-A' FOR OCTOBER 31, 1974 AND MARCH 31, 1975

southeast side and the other (well 12) on the east side of the lake (figs. 2 and 5). The decline in lake level between the start and end of the study period was averaged with the water-level decline in each of wells 10, 11, and 12. The average of the three determinations was assumed to represent the average decline of the water table over the sand-hill area.

Although section A-A' indicates that the slope of the water table is not precisely uniform between well 10 and the lake, the departure from uniformity is not excessive. Inasmuch as the slope of the water table had to be assumed uniform between the lake and wells 11 and 12, because the configuration of the water table was not defined, the assumption of uniform slope seemingly would be justified for all three wells. Some additional error would result if the water-table divide is not coincident with the topographic divide throughout the sand-hill area; however, the accuracy of the computed average decline in the water table is considered adequate for the purposes of this study.

For the area of little relief (fig. 5) the average water-table decline during the study period was arbitrarily estimated as 0.2 ft (0.06 m).

The dewatered volume of the water-table aquifer was determined by multiplying the average declines of the water table for the two segments by the respective areas of the two segments. The specific yield of the water-table aquifer was estimated as 10 percent for each segment. Thus, the total volume of subsurface flow into the lake from the water-table aquifer during the study period was computed as one-tenth the total volume of dewatered aquifer, or about 60 acre-ft (74,000 m^3).

The amount of subsurface flow out of Lake Carlton can only be evaluated as the residual of the water budget of the lake. The water budget for Lake Carlton for the study period can be used to evaluate the amount of subsurface flow out of the lake by substituting the values indicated in the foregoing section in the following formula:

$$gwo = gwi + p + si - so - e + \Delta s$$

in which:

gwo = subsurface flow out of the lake
gwi = subsurface flow into the lake
p = total rainfall into the lake
si = surface flow into the lake
so = surface flow out of the lake
e = evaporation from the lake
Δs = change in storage in the lake

Thus,

$$gwo = 60 + 280 + 1300 - 0 - 540 + 40 = 1140 \text{ acre-ft } (1{,}410{,}000 \text{ m}^3).$$

The rate of subsurface flow fron Lake Carlton to the Floridan aquifer is directly proportional to the head difference between the lake and the potentiometric surface of the Floridan aquifer. Therefore, in order to make use of the computed value for subsurface flow out of the lake during the study period, the average head difference between the lake and the potentiometric surface of the Floridan aquifer must be evaluated for both the study period and the periods of project implementation. Direct knowledge of this head relation is available only for the period January 1 to March 31, 1975. Thus, it was necessary to estimate the head differences for the other periods in question. The estimate of the average daily altitude of the potentiometric surface is shown by figure 7. This estimate is based on several sources of information. The seasonal trend is based on the average seasonal trend in the water level in a well in Orange County (Lichtler and Joyner, 1966, fig. 4). The approximate average altitude was determined on the basis of the probable minimum given for the Lake Carlton area by Lichtler and others (1968, fig. 49) and the range of fluctuation for this area given by Lichtler and Joyner (1966, fig. 5).

For the period January to March 1975, the average level of the potentiometric surface along the southwest shore of Lake Carlton was 57.1 ft (17.4 m) based on water levels in wells on the southwest shore. The potentiometric surface on the northeast shore of the lake is estimated to be about 1.5 ft (0.46 m) lower than that on the southwest shore from the general decline of the potentiometric surface at the lake shown by several maps given by Lichtler and others (1968, fig. 46-49). Thus, the average level under the lake in the first quarter of 1975 was estimated to be about 0.7 ft (0.21 m) lower than that on the southwest shore or about 56.4 ft (17.2 m) above mean sea level.

Figure 7 indicates that the average level of the potentiometric surface is about 2.7 ft (0.82 m) higher in the last quarter of an average year than in the first quarter. Hence, the level of the potentiometric surface in the last quarter of 1974 (the first half of the study period) was assumed to be about 2.7 ft (0.82 m) higher than the average in the first quarter of 1975 or about 59.1 ft (18.0 m). Thus, the average level of the potentiometric surface under the lake during the study period is estimated to have been about 57.8 ft (17.6 m). The average level of the lake during the study period was 62.5 ft (19.0 m) so the average head difference during the study period was about 4.7 ft (1.4 m) which is rounded to 5 ft (1.5 m).

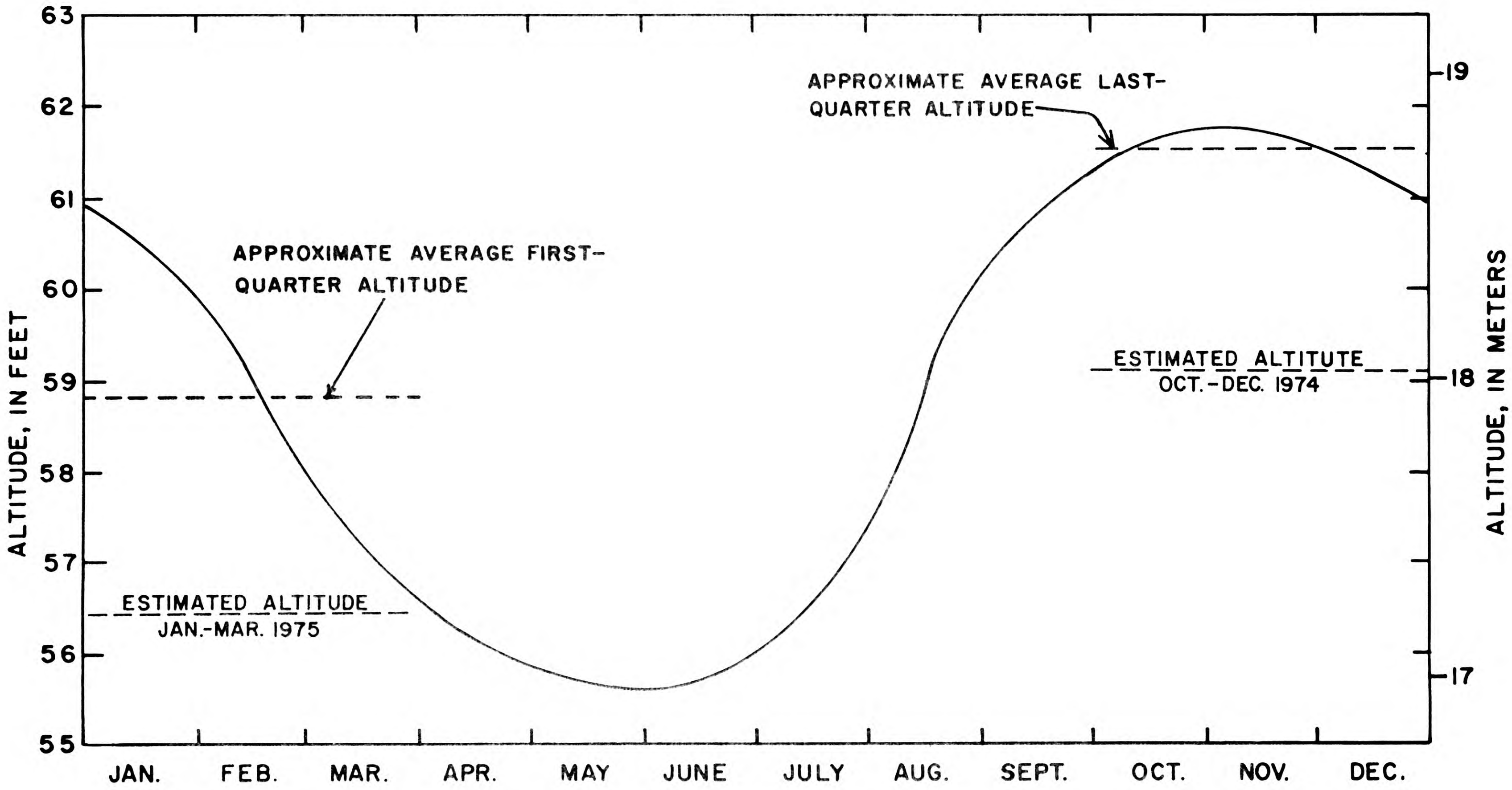

FIGURE 7.--ESTIMATED ALTITUDE OF THE POTENTIOMETRIC SURFACE OF THE FLORIDAN AQUIFER UNDER LAKE CARLTON DURING AN AVERAGE YEAR.

The computed subsurface flow out of the lake of 1,140 acre-ft (1,410,000 m^3) in 182 days at an average head difference of 5 ft (1.5 m) gives a unit rate of 1.25 (acre-ft/d)/ft or 5,060 (m^3/d)/m of head difference between the lake surface and the potentiometric surface of the Floridan aquifer.

Error analysis

In the foregoing analysis, the magnitude of the subsurface flow from Lake Carlton to the Floridan aquifer was determined to be about 1,140 acre-ft (1,410,000 m^3) as a residual term of a water-budget equation. Because the residual term includes the net of errors in determinations of the magnitudes of all the other factors involved, its significance depends largely on the relation between its magnitude and the magnitude of the possible errors in the estimates of the other factors.

The computed evaporation (540 acre-ft or 666,000 m^3) and rainfall (280 acre-ft or 345,000 m^3) are sizeable quantities, but the estimates of these quantities probably are correct within 10 to 20 percent. The computed change in storage in Lake Carlton (40 acre-ft or 49,000 m^3) is small and also is probably determined correctly within 10 to 20 percent. The computed subsurface inflow to Lake Carlton from the water-table aquifer (60 acre-ft or 74,000 m^3) is subject to large errors, but, in view of its small magnitude, even an error as great as 50 to 100 percent would not seriously affect the apparent significance of the residual term. Inasmuch as the residual term is much larger than the probable error in any of the above mentioned terms, and inasmuch as the errors of all the individual terms would not likely fall in the same direction, the significance of the residual term evidently would be determined by the accuracy of the computed surface flow into Lake Carlton (1,300 acre-ft or 1,600,000 m^3).

The computed surface inflow to Lake Carlton consists of flow from Lakes Ola and Horseshoe (40 acre-ft or 49,000 m^3) and from Lake Beauclair (1,260 acre-ft or 1,550,000 m^3). Obviously, even a large error in the estimate of flow from Lakes Ola and Horseshoe would not seriously affect the accuracy of the total computed surface inflow. Hence, the meaning of the residual term of the water-budget equation depends almost entirely on the accuracy of the computed surface flow from Lake Beauclair. Because of the rapid fluctuation and reversal of flow between the two lakes on windy days, which prevailed during much of the study period, the computed net surface flow from Lake Beauclair to Lake Carlton is subject to a substantial error which cannot be evaluated. Consequently, the residual term, which is considered to represent subsurface flow from Lake Carlton to the Floridan aquifer, could contain a substantial error. Although the determination of subsurface flow from Lake Carlton to the

Floridan aquifer is considered to be sufficiently accurate for the purpose of this report, inferences based on this computed flow for any other purpose should be viewed with caution.

ANALYSIS OF THE DRAWDOWN

The drawdown of Lake Carlton will occur in 3 phases: dewatering, hold down, and refilling. Some basic estimates or assumptions required for determining the amount of input or output of water by the various means during these phases follow.

1. The channel between Lake Carlton and Lakes Beauclair will be blocked, and, if necessary, those between Lake Ola and Horseshoe Lake will also be blocked during the project except during the refill period when the channels may be unblocked; or in the case of the Carlton-Beauclair channel, partially unblocked.

2. Dewatering will begin March 1 and will continue until the lake surface is lowered to 48 ft (15 m) above mean sea level.

3. The lake surface will be held down until the beginning of the rainy season, which in this analysis is considered June 1.

4. The method of refill will depend on the adequacy of the natural net input to raise the lake surface to 63 ft (19 m) above mean sea level by October 31.

5. Total rainfall and evaporation from March through October, while the lake is drawn down, will be near normal and the daily distribution during the refill period will be as in 1964, when the total June through October rainfall was near normal.

6. The rate of pumping will be 50,000 gal/min (190 m^3/min) or 221 acre-ft/d (273,000 m^3/d) during the dewatering period and as required during the hold-down period.

7. The lake surface will be at its average March 1st level of 63 ft (19 m) above mean sea level when pumping begins.

8. An iterative digital model for aquifer evaluation programmed by Trescott (1973) and modified by A. L. Putnam and H. F. Grubb for application to Lake Carlton was used to determine subsurface flow to the lake from the water-table aquifer during the dewatering and hold-down phases of the project. The limits of the area represented by the model are shown in figure 5. Lakes within the area were treated as constant-head sources.

Two of the parameters required for operation of the modified model were the hydraulic condictivities of the water-table aquifer and of the sediments on the lake bottom between the lake and the water-table aquifer. The hydraulic conductivity of the water-table aquifer was determined to be 1.3 ft/d (0.4 m/d) on the basis of the 60 acre-ft (74,000 m^3) of subsurface flow from the water-table aquifer to the lake--as computed for the study period--an aquifer width of 18,600 ft (5,670 m), an aquifer depth of 80 ft (24 m), and a hydraulic gradient of 0.0075. The thickness and hydraulic conductivity of the sediments on the lake bottom could not be determined within the scope of this investigation. However, in a study of Bay Lake of Disney World in Orange County about 23 mi (37 km) south of Lake Carlton, calibration of the same modified model was achieved when a hydraulic-conductivity value of 0.013 ft/d (0.004 m/d) was assigned to lake-bottom sediments which were assumed to cover the entire lake bottom uniformly at a thickness of 1 ft (0.3 m) (A. L. Putnam, oral commun., 1975). Consequently, these same values of hydraulic conductivity and sediment thickness were assumed to apply to the lake-bottom sediments of Lake Carlton. Under the conditions at Lake Carlton, the output of the modified model proved to be relatively insensitive to the assumed value of hydraulic conductivity of the lake-bottom sediments. For example, a 30-fold increase in the hydraulic-conductivity value was found to cause an increase in the computed subsurface inflow to the lake from the water-table aquifer of only 4 acre-ft (4,900 m^3) during the drawdown period and only 10 acre-ft (12,300 m^3) during the holddown period. Thus, in view of the large quantity of water to be pumped from storage in Lake Carlton, any error in the computed subsurface inflow to the lake from the water-table aquifer that might result from assumptions about the lake-bottom sediments probably would not have an appreciable effect on the outcome of this investigation.

9. Execution of the computer program required an input of estimated daily stages. On the assumption that input and output components would be about equal during the dewatering period, the stage at the end of each day was computed for a pumping rate of 50,000 gal/min (190 m^3/min) and using the relation between lake stage and lake volume. This indicated that the lake level would be lowered to a stage of 48 ft (15 m) in 21 days. If the initial execution of the computer program with estimated lake stages resulted in a computed pumping time appreciably different from 21 days, lakes stages would have to be adjusted taking into account the computed components of inflow and outflow; then the program would have to be rerun. In this study, however, the estimated pumping time and the computed pumping time were so nearly equal that recomputation was not necessary.

Dewatering the Lake

Dewatering Lake Carlton will require sufficient pumpage to remove the water stored in the lake plus rainfall and surface and subsurface flow into the lake minus evaporation and surface and subsurface flow out of the lake. These factors are evaluated below and the approximate time needed to dewater the lake is verified.

Storage in the Lake

Depth contours for Lake Carlton (Bush, 1974) at a surface altitude of 62 ft (19 m) are shown by figure 8. The relation between lake surface altitude and surface area of Lake Carlton based on these contours is shown by figure 9. Using the stage-area relation in figure 9 the volume of water stored by the lake at altitude 63 ft (19 m) is computed to be 4,600 acre-ft (5,670,000 m^3).

Surface Flow

Normally, there is no surface flow from Lake Ola or Horseshoe Lake to Lake Carlton in March. However, if the channel between Lake Carlton and Horseshoe Lake is not blocked, about 2 ft (0.6 m) of water (64 ac-ft) (79,000 m^3) can be expected to drain from Horseshoe Lake to Lake Carlton. This would add 0.29 day to the pumping time computed at the end of this section of this report. No significant overland flow into Lake Carlton normally occurs in March.

Surface flow out of Lake Carlton will be 50,000 gal/min (190 m^3/min or 221 acre-ft/d (273,000 m^3/d) of pumpage to Lake Beauclair.

Subsurface flow

Subsurface flow to Lake Carlton from the water-table aquifer was determined by use of a computer model of the lake and its surroundings (fig. 5). Between the time pumping begins on March 1 and the time the lake stage reaches 48 ft (15 m) on March 21, subsurface flow to the lake from the water-table aquifer is shown by the model to total about 30 acre-ft (37,000 m^3).

After the first 9.5 days of pumping, the head difference between the lake surface and the potentiometric surface of the Floridan aquifer will change from positive, which tends to cause water to flow from the lake to the Floridan aquifer, to negative, which tends to cause water to flow into the lake from the Floridan aquifer. From the daily differences between the two curves in figure 10 and the unit subsurface flow into the lake from the Floridan aquifer of 1.25 (acre-ft/d)ft (5,060 m^3/d)/m of head difference, a total of 50 acre-ft (62,000 m^3) of subsurface flow to the lake from the Floridan aquifer was computed for the period March 10-21.

Figure 10, which shows the approximate altitudes of Lake Carlton and potentiometric surface of the Floridan aquifer under the lake during the dewatering period, indicates water will tend to flow from the lake to the Floridan aquifer for the first 9.5 days. The altitude of the potentiometric surface was taken from figure 7. The average head

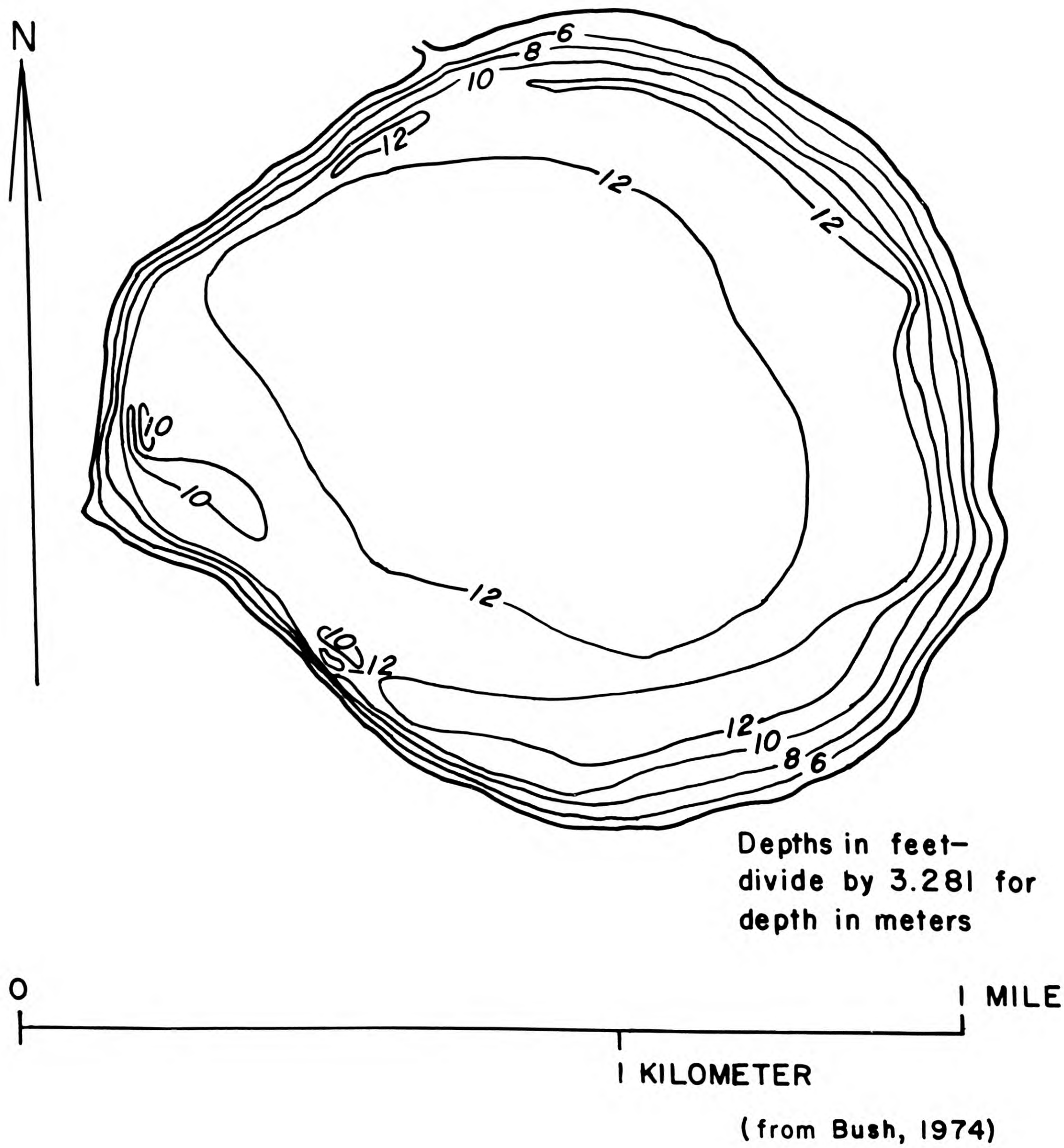

FIGURE 8.--DEPTH CONTOURS OF LAKE CARLTON FOR SURFACE ALTITUDE OF 62 FEET (19 METERS).

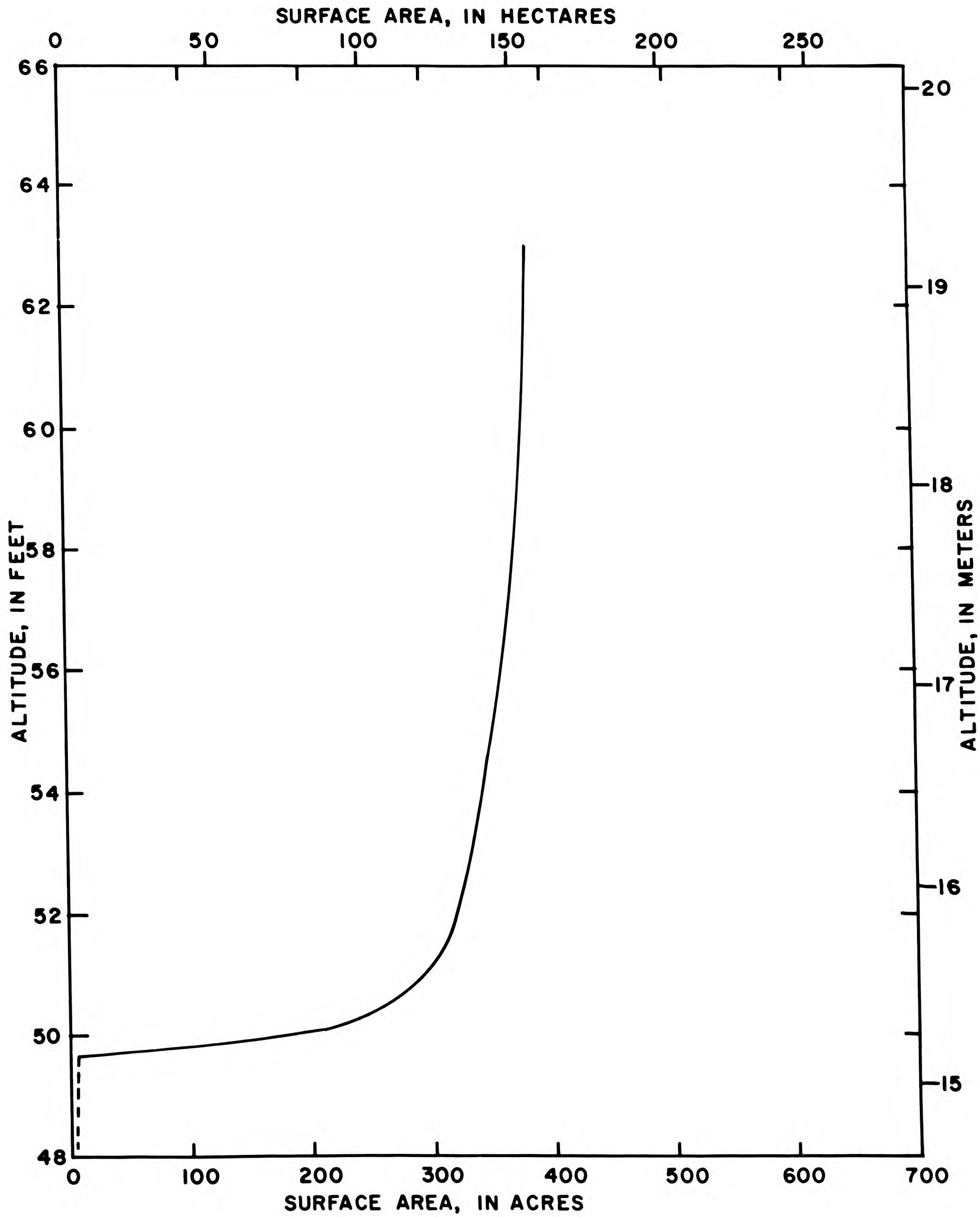

FIGURE 9.--RELATION OF ALTITUDE TO SURFACE AREA OF LAKE CARLTON.

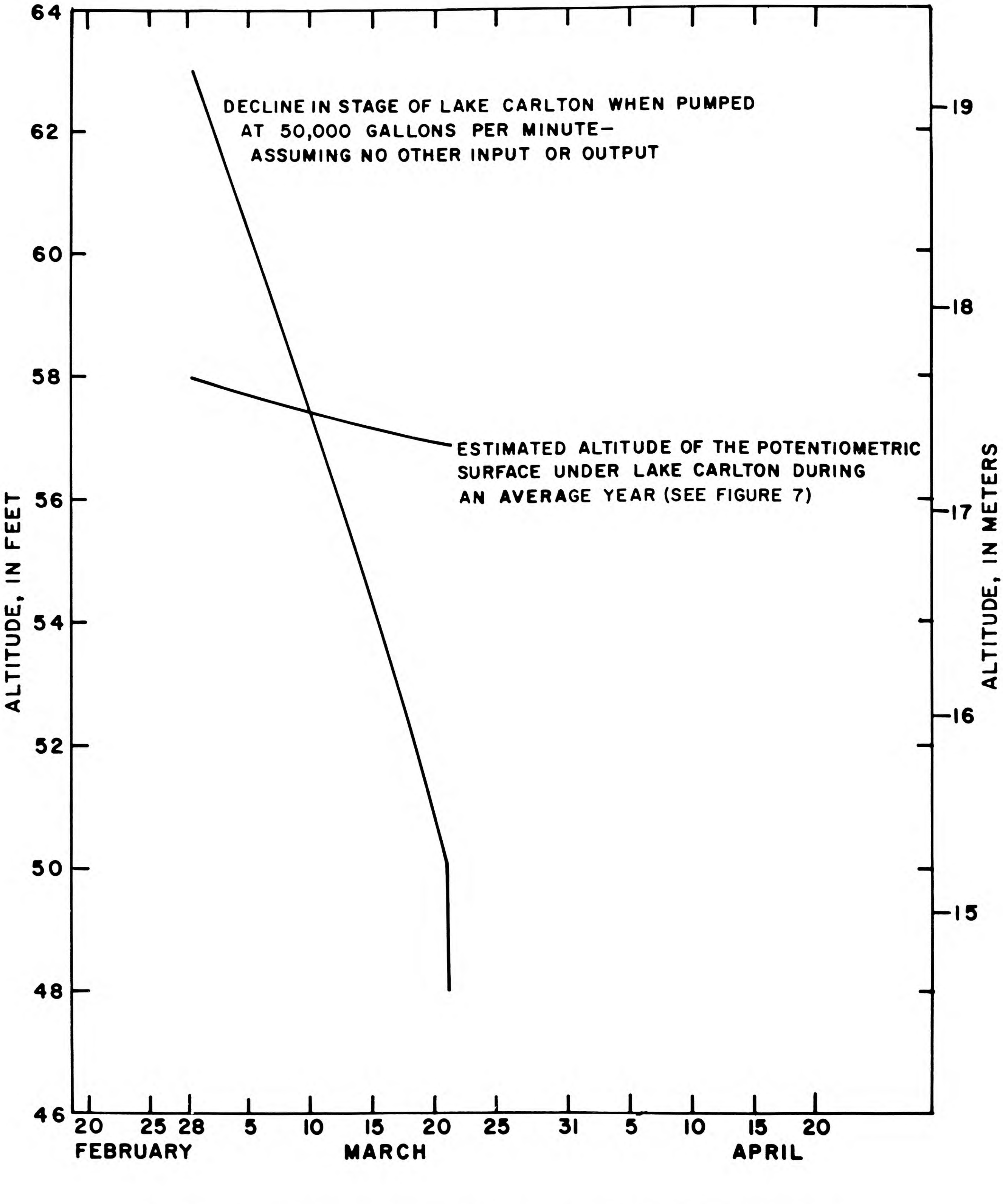

FIGURE 10.--APPROXIMATE LEVELS OF LAKE CARLTON AND THE POTENTIOMETRIC SURFACE OF THE FLORIDAN AQUIFER UNDER THE LAKE DURING DEWATERING.

difference between the lake and the potentiometric surface indicated by figure 10 during this 9.5 days is 2.53 ft (0.77 m). Thus, if the unit flow out of the lake to the Floridan aquifer is 1.25 (acre-ft/d)/ft (3,060 m^3/d)/m, total subsurface flow from the lake to the Floridan aquifer for the 9.5 days will be 2.53 x 1.25 x 9.5 = 30 acre-ft (37,000 m^3).

Rainfall

Average rainfall in Orlando for March is 3.41 in (86.6 mm) (Butson, 1962) of which 2.3 in (584 mm) is estimated to fall in the first 21 days. This is equivalent to about 70 acre-ft (86,000 m^3) of input.

Evaporation

Average evaporation from lakes in Orange County for March is 3.9 in (99 mm) (Lichtler and others, 1968, p.75). If 2.0 in (51 mm) of this occurs within the first 21 days, average output from the lake by evaporation is about 60 acre-ft (74,000 m^3).

Time required for dewatering

The values, in acre-feet, determined in this section of this report are summarized as follows:

Storage	4,600
Surface flow into lake	0
Subsurface flow into lake	80
Rainfall	70
Subsurface flow out of lake	30
Evaporation	60

Thus, the amount to be pumped will be 4,600 + 0 + 80 + 70 - 30 - 60 = 4,660 acre-ft (5,750,000 m^3). At a pumping rate of 221 acre-ft/d (273,000 m^3/d) the adjusted approximate time needed to dewater the lake is 4,660 ÷ 221 = 21 days.

Holding the Lake Level Down

As indicated in the previous section, drawdown of the lake should be accomplished by March 21, if the conditions assumed are extant. Thus, the hold-down period will extend from March 22 through May 31, 1976, a period of 71 days.

Factors to be considered during this period are subsurface flow into the lake, rainfall, evaporation and pumpage. It is assumed there will be no surface flow into the lake or subsurface flow out of the lake.

Subsurface flow

During the hold-down period, subsurface flow into the lake will be derived from both the water-table aquifer around the lake and from the Floridan aquifer through materials under the lake. The amount of subsurface flow into the lake from the water-table aquifer was determined by the computer model and amounts to 100 acre-ft (123,000 m^3). The amount of subsurface flow to the lake from the Floridan aquifer depends on how high the potentiometric surface is above the lake surface. The level of the lake will, of course, be held at or close to 48 ft (15 m) during the hold-down period. The estimated average level of potentiometric surface of the Floridan aquifer during the hold-down period (fig. 7) will be 56 ft (17 m) above mean sea level or 8.0 ft (2.4 m) higher than the lake level. Thus, if the rate of subsurface flow into the lake from the Floridan aquifer is 1.25 (acre-ft/d)/ft or 5,060 (m^2/d)/m during the 71 day hold-down period, the total flow through the lake bottom into the lake from the Floridan aquifer will be 8 x 1.25 x 71 = 710 acre-ft (876,000 m^3).

Total subsurface flow into the lake from both aquifers will be about 810 acre-ft (999,000 m^3).

Rainfall

Records of rainfall at Orlando indicate the average rainfall in the months of March, April and May is 3.41, 3.42 and 3.57 in (87, 87 and 91 mm), respectively. Assuming that 1.11 in (28.2 mm) of the rain in March will occur after the 21st, total normal rainfall for the period March 22 to May 31 is 8.10 in (206 mm). This amount of rainfall is equivalent to about 260 acre-ft (321,000 m^3) into Lake Carlton.

Evaporation

Using the estimates of monthly evaporation from Orange County lakes (Lichtler and others, 1968, p.75) and assuming that 1.9 in (4.8 mm) of the March evaporation occurs the last 10 days of March, then normal evaporation from a free lake surface from March 22 through May 31 is 14.1 in (358 mm). However, most of the lake bottom will be dewatered so the water table is expected to be 2 ft or more (0.6 m or more) below most of the lake bottom. Thus, only about 9.9 in (251 mm) of water is expected to evaporate from the lake bottom during the hold-down period. This is equivalent to about 310 acre-ft (382,000 m^3) of water loss from the lake bottom.

Pumpage Requirements

Summing the inputs and outputs for the hold-down period gives a net of 760 acre-ft (940,000 m^3) to be pumped during the hold-down period. This is equivalent to 84 hours of pumping at 50,000 gal/min (190 m^3/min) or 2,400 gal/min (9.08 m^3/min) of continuous pumping.

The input from rainfall during the hold-down period will occur intermittently in varying amounts some of which could be very large. For instance, should 7 in (178 mm) of rain occur in 24 hours during the period, the entire 50,000 gal/min (190 m^3/min) capacity of the pumps would be required for 24 hours to forestall a large rise in the lake level. Thus, it would be better to operate the pumps intermittently at full capacity to maintain the lake level near 48 ft (15 m) than to pump continuously at the lower rate.

Refilling the Lake

Sources of water for refilling Lake Carlton include flow in the channels from the connecting lakes, overland flow, natural flow from the water-table aquifer and the Floridan aquifer, rainfall, and pumpage from the Floridan aquifer. Use of water from the Floridan aquifer to help refill the Lake is not now planned. Currently, plans call for supplementing the net amount of input from all sources other than surface flow from Lake Beauclair with just enough water from Lake Beauclair to bring the lake level back to 63 ft (19 m) above mean sea level by October 31. The only means of water loss from the lake during the refill period are evaporation and subsurface flow to the Floridan aquifer through the bottom during the latter part of the refill period since the water table adjacent to the lake is expected to rise at least as fast as the lake rises and to maintain a gradient toward the lake.

If conditions during the 153-day refill period (June through October) are as assumed for this analysis and if natural input to the lake is not supplemented with water from the Floridan aquifer or Lake Beauclair, the level of Lake Carlton will stay below that of the potentiometric surface of the Floridan aquifer during the entire refill period and water loss from the lake will be by evapotranspiration only. If, however, input to the lake is supplemented during the refill period, water could be lost through the lake bottom if the supplementation were enough to raise the lake higher than the potentiometric surface. In the analysis, the rate of refill was computed assuming no supplementation.

Surface flow

Little basis exists for evaluating surface flow to Lake Carlton for the refill period. The most analagous hydrologic system to that of Lake Carlton for which long-term data are available is Cypress Creek basin in southwest Orange County. Average rainfall during the refill months as indicated by records at Orlando is 33.09 in (840.4 mm). Rainfall during these months was very near normal in 1964. Therefore, flow records for Cypress Creek in 1964 reduced by the ratio of the square miles of drainage area (5.06/30.3) were used as surface input during the refill period. This resulted in an estimated surface input of 450 acre-ft (550,000 m^3).

Subsurface flow

Subsurface flow to Lake Carlton from the water-table aquifer will depend on the relative rate of rise of the water table and the lake surface. If the water table rises faster than the lake, subsurface flow to the lake will be more than that on the last day of the hold-down period. If the lake surface rises faster than the water table, the flow will be less than on the last day of the hold-down period.

Output from the computer model indicated that the average decline in the water table in the area modeled was about 20 in (500 mm). This is equivalent to 2 in (50 mm) of water over the area at the assumed specific yield of 10 percent for the water-table aquifer. Average recharge to the water-table aquifer during the refill period is estimated to be about 8 in (200 mm). Thus, the water table will probably rise more than the lake surface and the average rate of subsurface flow into the lake will, therefore, be more than that on the last day of the hold-down period. However, as seepage from the water-table aquifer will be a minor part of the total refill input, a flat rate of 1.1 acre-ft (1,400 m^3) per day was used, giving a total of about 170 acre-ft (210,000 m^3).

Subsurface flow from the Floridan aquifer to the lake through its bottom during the refill period was computed by multiplying the daily difference in feet between the lake stage and estimated altitude of the potentiometric surface by (1.25 acre-ft/d)/ft or 5,060 (m^3/d)/m. The estimated input to the lake from the Floridan totaled about 1,120 acre-ft (1,380,000 m^3).

Rainfall

Input from rainfall was computed by multiplying the daily rainfall in feet at Orlando in 1964 by 382 acres, the area of the lake bed. This was done to present an actual example of distribution of about normal total rainfall during the refill period and also to conform to the condition that ostensibly caused the runoff from Cypress Creek basin. The input from rainfall during the refill period thus computed amounts to 1,050 acre-ft (1,300,000 m^3).

Evaporation

Daily evaporation in acre-feet from the lake was computed by multiplying the daily pan evaporation in feet at Lisbon in 1964 by an appropriate pan-to-lake coefficient and appropriate pan to lake coefficient and multiplying that product by 382 acres. No reduction in evaporation for less than total inundation of the lake bottom was made because subsurface flow into the lake through its bottom exceeded evaporation throughout the period and as a result it was felt the opportunity for evaporation plus transpiration, from the lake bottom might be nearly as much as for evaporation from a free water surface. Total evaporation computed for the refill period is 790 acre-ft (970,000 m^3).

Effects of natural inputs and outputs

The total rise in the lake surface caused by the net natural input to the lake under average conditions, similar to those in 1964, was determined by computing the net input in acre-feet from surface flow, subsurface flow, rainfall and evaporation for each day of the refill period. The net input for each day was divided by the area of the lake at the initial stage for that day to determine the change in stage for that day. Beginning with 48 ft (15 m) at midnight of May 31, the daily computed changes in stage were cumulatively added to determine the stage that would be reached by midnight on October 31.

The results of this procedure is shown by figure 11 as a hydrograph which also covers the drawdown and hold-down periods. Of course, the hydrograph for the refill period is valid only if all of the assumptions and estimates on which it is based are valid. As indicated by figure 11, under the conditions specified, the lake stage would recover to only 56.2 ft (17.1 m) above mean sea level by October 31.

Additional Input Required for Total Recovery

The normal stage of Lake Carlton at the end of October is 63 ft (19 m) above mean sea level. The storage capacity of the lake between 56.2 ft (17.1 m) and 63 ft (19 m) is 2,600 (acre-ft) (3,210,000 m^3). However, if the natural input were supplemented in a manner to cause the lake level to rise from 48 ft (15 m) to 63 ft (19 m) during the refill period as shown by figure 11, net subsurface flow to the lake would be

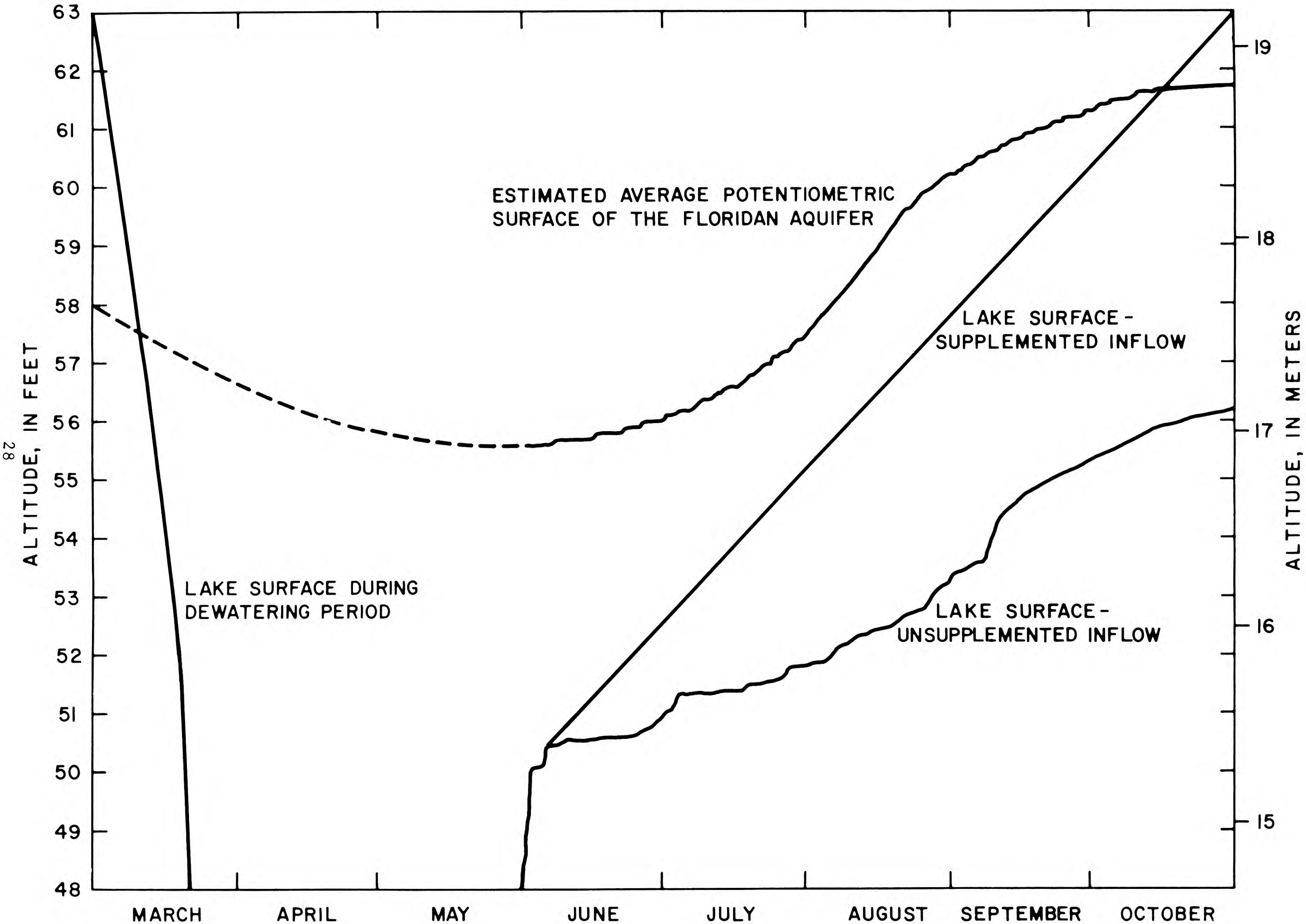

FIGURE 11.--COMPUTED ALTITUDE OF LAKE CARLTON AT END OF EACH DAY OF DEWATERING AND REFILL PERIODS OF THE LAKE DRAWDOWN (INPUT UNSUPPLEMENTED).

about 680 acre-ft (839,000 m^3) less than that computed for unsupplemented conditions because the more rapid rise of the lake would decrease the head difference between the lake and the potentiometric surface. In fact, after about 140 days, the head relation between the two would actually reverse. Thus, 2,600 + 680 acre-ft (4,050,000 m^3), equivalent to about 4,860 gal/min (18.4 m^3/min) would be needed in addition to the natural input to cause the lake to rise to 63 ft (19 m) above mean sea level by October 31.

The various estimated quantities of water that would enter or leave Lake Carlton during the three phases of the drawdown project are given in table 1.

DOWNSTREAM EFFECTS

If conditions during the drawdown and hold-down periods are as specified and suitable for execution of the project, no signigicant adverse impact on the downstream part of the system will occur. If the entire 5,420 acre-ft (6,690,000 m^3) of water pumped from the lake were stored in the system between Apopka control and lock and Burrell control and lock, the water level in the system would be raised by only 0.20 ft (0.06 m).

CONCLUSIONS

If the connections between Lake Carlton and Lake Beauclair, Lake Ola, and Horseshoe Lake were blocked off, the stage of the 382-acre (155-ha) Lake Carlton could be lowered from 63 ft (19 m) to 48 ft (15 m) in about 21 days by pumping out water at 50,000 gal/min (190 m^3/min) under normal weather and hydrologic conditions for March.

A pump capable of removing 50,000 gal/min (190 m^3/min) would have to operate a total of 82 hours in order to hold the level of Lake Carlton at a stage of 48 ft (15 m) above mean sea level from March 22 through May 31 under normal conditions.

If pumping is stopped May 31, and near-normal weather occurs from June through October, the natural input would cause the level of Lake Carlton to rise from 48 ft (15 m) to 56.2 ft (17.1 m) by October 31. If the lake is to reach 63 feet (19 m) by October 31, the natural input would have to be supplemented at an average rate of about 4,860 gal/min (18.4 m^3/min) or a total of about 3,280 acre-ft (4,050,000 m^3).

Table 1.--Water budget of Lake Carlton for assumed conditions during the three phases of the drawdown (acre-feet).

Water budget item	Dewatering March 1-21	Hold-down March 22-May 31	Refill June 1-October 31 Unsupplemented	Refill June 1-October 31 Supplemented
Rainfall	70	260	1,050	1,050
Evaporation	60	310	790	790
Surface inflow	0	0	450	3,730
Surface outflow	[a]4,660	[a]760	0	0
Water-table inflow[b]	30	100	170	170
Water-table outflow[c]	0	0	0	0
Artesian inflow[d]	50	710	1,120	450
Artesian outflow[e]	30	0	0	10
Change in storage	[f]4,600	0	[g]2,000	[g]4,600
Supplement needed	-	-	-	3,280

Note.--Multiply by 1,233.64 to convert to cubic meters.

a. Pumpage
b. Subsurface flow from the water-table aquifer to Lake Carlton
c. Subsurface flow to the water-table aquifer from Lake Carlton
d. Subsurface flow from the Floridan aquifer to Lake Carlton
e. Subsurface flow to the Floridan aquifer from Lake Carlton
f. Decrease in storage
g. Increase in storage

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