HYDROLOGY OF THE OKLAWAHA LAKES AREA OF FLORIDA

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Prepared by
UNITED STATES GEOLOGICAL SURVEY
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INTRODUCTION

Lakes Apopka, Carlton, Beauclair, Dora, Eustis, Harris, Little Harris, Griffin, and Yale are part of a chain of lakes that is the most prominent feature of the upper Oklawaha River drainage basin in central Florida. For convenience, this chain of lakes is called the Oklawaha lakes in this report, and the lakes in conjunction with their environs, the Oklawaha lakes area. The main use of the lakes is recreation, but the desirability of most of the lakes for recreation has decreased in recent years. Certain land-use practices have caused the lake water quality to deteriorate to the point that swimming, boating, and fishing are better elsewhere. To date, much hydrologic data have been collected in the Oklawaha lakes area. This report, prepared by the U.S. Geological Survey in cooperation with the Southwest Florida Water Management District, summarizes hydrologic knowledge in the area. It provides hydrologic information for the public, and a base for future hydrologic studies pertaining to specific problems, such as water-quality improvement.

DESCRIPTION OF THE AREA

Limestone of the Floridan Aquifer underlies the Oklawaha River drainage basin. Twenty-five to 200 feet (8 to 61 meters) of sand, clayey sand, and clay covers the limestone and constitutes the water- table aquifer in the area of the basin that contains the chain of lakes. (See fig. 1.) The undulating topography, dotted with hundreds of lakes, is largely the result of subsidence of the land surface caused by differential solution by water of the underlying limestone and subsequent collapse of the surficial deposits.

Landforms of generally north-south orientation characterize the Oklawaha lakes area (Puri and Vernon, 1964). Relief is generally greatest (75-210 feet, 23-94 meters) in the ridge areas. Lowest altitudes occur in the valleys where relief (55-165 feet, 17-50 meters) is also least in the area. In addition to these physiographic differences, there are also geologic and hydrologic differences among the ridges, valleys, and uplands.

The lithology of the water-table aquifer of the ridges and uplands is one of generalized type, and that of the water-table aquifer of the valleys is of a second generalized type (Knochenmus, written communication, 1973). The first type consists of three subunits. The upper–beginning at land surface–is a thin mantle of fine sand (0-15 feet, 0-5 meters). The middle subunit is a thicker stratum of fine clayey sand. The lowermost subunit consists of interbedded and intermixed sand and clay and overlies the Floridan Aquifer. The permeability of the water- table aquifer decreases with increasing depth, so that the lowermost subunit acts as a confining layer and restricts the movement of water from one aquifer to the other.

The second generalized type, characteristic of the water-table aquifer in the valleys, is one heterogeneous unit made up of medium sand and interbedded clay layers. Enough clay probably exists in this unit near the top of the Floridan Aquifer to restrict the hydraulic connection between aquifers.

GEOHYDROLOGIC RELATIONS

Categorization of the geohydrologic differences among landforms in the Oklawaha lakes area stems mainly from what happens to the estimated annual 49.9 inches (1,270 millimeters) of rainfall (30-year average of annual rainfall from National Oceanic and Atmospheric Administration stations at Eustis, Leesburg, and Clermont). The part of this rainfall that ends up in surface streams, percolates to the Floridan Aquifer, evaporates, or is transpired varies with the type of landform.

On the Lake Wales Ridge, runoff is low. High sand hills and a water table far below land surface readily allow most of the rainfall to seep into the ground. The confining layer under the Lake Wales Ridge is very thin or missing, so that the water-table aquifer is in hydraulic connection with the Floridan Aquifer. Consequently, recharge to the Floridan Aquifer is high. Knochenmus (written communication, 1973) estimates annual runoff on the Lake Wales Ridge to be 0-4 inches (0-100 millimeters), and annual recharge to be 12-16 inches (300-400 millimeters). The remaining 30+ inches (760+ millimeters) of rainfall is evapotranspired. Citrus trees, which cover most of the non-swamp and non-urban land in the Oklawaha lakes area, transpire about 30 inches (760 millimeters) of water annually (Lichtler, 1972, p. 25). About 48 inches (1,220 millimeters) per year is evaporated from lakes (Kohler and others, 1959).

According to Knochenmus (written communication, 1973), the Sumter and Lake Uplands in the Oklawaha lakes area are moderately good recharge areas(8-12 inches, 200-300 millimeters annually). Runoff estimated to be 0-4 inches (0-100 millimeters) from the Lake Upland. Recharge through the Mount Dora Ridge is hindered by a relatively thick confining layer, but still averages 4-8 inches (100-200 millimeters) annually. Runoff from the Mount Dora Ridge is estimated to be 4-8 inches also.

The Central Valley and the Lake Harris Cross Valley are different from the ridge and upland areas. In much of the valley area, the water table is within a few feet of land surface; thus, the potential for evapotranspiration is greater than elsewhere in the Oklawaha lakes area. The potentiometric surface (surface defined by the levels to which water will rise in wells cased into an aquifer) of the Floridan Aquifer is also close to or even above the land surface in much of the valley area. When the water table and the potentiometric surface of the Floridan aquifer nearly coincide, little vertical gradient exists between aquifers. Consequently, movement of water between the two aquifers is low. Knochenmus (written communication, 1973) estimates annual recharge to the Floridan aquifer in the valley area to be 0-4 inches (0-100 millimeters).

The stated geologic and hydrologic differences among landforms are necessarily generalized to represent average conditions over the Oklawaha lakes area. Certain areas of the Central Valley are relatively high and vertical gradients are probably sufficient to allow recharge. On the Lake Wales Ridge along the south edge of Lake Harris, the potentiometric surface of the Floridan aquifer is as high as or higher than the water table, so no recharge can occur there.

FLOW, STAGE CHARACTERISTICS, AND REGULATION OF THE OKLAWAHA LAKES SYSTEM

Of the nine lakes in the hydrologic system discussed in this report, Lake Apopka has the largest surface area; however, it is also the shallowest. Lake Harris and Little Lake Harris combined contain the largest volume of water. Figure 2 is a diagram of the direction and average measured or estimated rate of flow in the channels connecting the lakes, and the volume of water stored in the lakes at the indicated stages.

Lake levels are usually lowest in the spring, when rainfall is low, and highest in late summer and early fall, when rainfall is high. Above-average or below-average rainfall over a period of months can noticeably affect lake levels. For example, figure 3 shows that during the drought period of 1954-56, lake levels declined almost continuously toward record lows. Again in 1961-62, deficient rainfall over an extended period resulted in very low lake levels. Above-average rainfall in 1953, and in 1959-60, produced unusually high lake levels. Over the periods of record, the largest range in lake level fluctuation has been about 6 feet (2 meters) in Lakes Eustis and Harris, and the smallest, about 4 feet (1.3 meter), in Lakes Griffin and Yale.

Lake Griffin has been regulated to some extent for more than 30 years by a control in the Oklawaha River at Moss Bluff, about 8 miles (13 kilometers) downstream from the lake. The other Oklawaha lakes have been regulated for somewhat shorter periods. A timber control was placed in Apopka-Beauclair Canal in 1950, and the present lock and dam, about halfway between Lake Apopka and Lake Beauclair (fig. 1) was opened in 1956. Also in 1956, the present lock and dam in Haines Creek at Lisbon was opened. Haines Creek was straightened and enlarged about the same time. A non-adjustable control in Yale-Griffin Canal for many years was replaced recently by a 30-inch (760 millimeter) culvert about 0.3 mile (0.5 kilometer) from Lake Yale. The level of Lakes Dora, Beauclair, and Carlton seems to more closely match the level of lakes Eustis and Harris after Dora Canal was enlarged about 1958. Apopka-Beauclair Canal was also deepened in 1958.

Flow- and stage-duration curves show how the natural regimen of discharge through Haines Creek and Apopka-Beauclair Canal and fluctuations in the levels of lakes in the chain have been altered by regulation. The flow-duration curves of Apopka-Beauclair Canal and Haines Creek for the unregulated periods (figs. 4 and 5) have fairly flat slopes because the large volume of storage in the upstream lakes tends to equalize flow. The slopes of the curves representing the regulated periods are steeper because regulation has caused considerably more variation in extremes of flow. More water was released during wet periods, and less water released during dry periods, than would have flowed from the lakes under pre-regulation channel conditions.

Comparison of the stage-duration curves for Lake Apopka and Lake Eustis for the regulated and unregulated periods (figs. 6 and 7) does not reveal the seemingly drastic changes in the flow regimen of Apopka-Beauclair Canal and Haines Creek. The shape of the curves for the regulated periods is similar to that for the unregulated periods. Increasing the range of discharge variation in the two channels did not noticeably reduce the range of fluctuation of Lake Apopka and Lake Eustis, and also Lakes Harris, Little Harris, Dora, Beauclair, and Carlton for the periods of record compared. But it is likely that lake stages higher than those recorded during the 1959-60 wet period would have occurred if channel improvements had not been made. Similarly, the drought of 1961-62 would probably have caused lower lake levels than those that occurred if discharge had not been controlled.

LAKE BOTTOM CONFIGURATION AND COMPOSITION

The most prominent features of the lake bottoms are the relatively deep trenches in Lakes Harris, Eustis, Griffin, Yale, and Apopka. The trenches occur to some degree in each of the larger lakes along the south or west shore parallel to the widest expanse of water.

The physical characteristics of bottom deposits in all the Oklawaha lakes are similar: spot samples of bottom materials throughout the lake system were almost always unconsolidated jelly-like muck. However, in the trenches of Lakes Harris, Eustis, Griffin, and Yale, most spot samples were fine to coarse sand rather than muck. The bottom deposits of Lake Apopka were sampled extensively by Schneider and Little (1969). They report soft, unconsolidated muck over 90 percent of the lake bottom, consisting of approximately 99 percent water at the surface, and about 90 percent water at a depth of 1 meter. Unconsolidated deposits of muck are at least 40 feet (12 meters) thick in some areas of the lake. Where water depths permitted in Lakes Griffin, Harris, Little Harris, and Eustis, a 14- foot (4.3-meter) rod was pushed into the muck. Penetration ranged from less than 1 foot (0.3 meter) to more than 7 feet (2 meters).

One explanation for the existence of trenches along the south or west shores of the larger lakes is that wind-generated currents have prevented the deposition of sediment in these areas. Winds blowing across the surface of a body of water create a surface current, which results in the piling-up of the surface water toward the leeward shore. The pressure thus exerted on the water immediately underneath the piled-up water induces a flow there in a direction opposite to that of the surface current (Ruttner, 1969, p. 50; Reid, 1961, p. 112). In general, prevailing winds over Florida, other than the southern peninsula, are from the north in winter (Bradley, 1972).

INFLOW-OUTFLOW RELATIONS

To show inflow-outflow relations, a water-budget study was made of Lakes Carlton, Beauclair, Dora, Harris, Little Harris, and Eustis taken as a hydrologic unit. These lakes were chosen for a water budget because streamflow into and out of the six-lake system is gaged. (See fig. 1.) The January 1970-December 1971 time period was selected because the discharge record for the Palatlakaha River at structure M-1 begins in January 1970. The water budget is shown graphically in figure 8. Storage in the lakes was 28,800 acre-feet (35.6 cubic hectometers) less on December 31, 1971, than on January 1, 1970. This change in storage accounts for the difference between total input and total output. Gaged inflow and known spring discharges, 48 percent of the total input over the 2-year period, consists of water entering through Apopka-Beauclair Canal, through structure M-1 on the Palatlakaha River, and from Bugg, Blue, and Holiday Springs. The input from the springs was estimated on the basis of discharge measurements. Estimated rainfall on the 49 square miles (127 square kilometers) of water surface area, 35 percent of the total input over the 2-year period, is the average of rainfall at Clermont, Eustis, and Leesburg. Gaged outflow, 66 percent of the total output, is the volume of water released through Haines Creek over the 2 years. Estimated evaporation, 34 percent of the total output, is pan evaporation at the National Oceanic and Atmospheric Administration Lisbon station for 1970-71 adjusted for lakes by the factor 0.81 (Kohler, 1954). Algebraically combining inputs and outputs and the change in storage leaves a residual input of 17 percent derived from ungaged runoff, subsurface flow from the water-table aquifer, and the net exchange of water between the lakes and the Floridan Aquifer.

The weighted difference between the altitude of the potentiometric surface of the Floridan Aquifer and the levels of the six lakes shows the potentiometric surface to have been 1.92 feet (0.585 meter) higher, on the average, than the lake levels in May 1971; at this time the potentiometric surface was at or near its lowest level relative to the lake surfaces during the 2-year period. (See fig. 9.) Thus, if the permeability of the deposits between the lakes and the Floridan Aquifer, exclusive of the vents at the springs, is uniform, the net exchange of water between the lakes and the Floridan Aquifer must have been into the lakes. If the lower limit on net exchange of water is assumed to be zero, then the entire 17 percent residual was ungaged runoff and subsurface flow from the water-table aquifer, fixing the upper limit of these factors at 5.86 inches (149 millimeters) per year. From an analysis based on estimates of water-table aquifer permeability, average gradient toward the lakes, and area of subsurface flow to the lakes, ungaged runoff to the lakes is appreciably greater than subsurface flow from the water-table aquifer. Knochenmus (written communication, 1973) suggests that runoff and subsurface flow from the water-table aquifer in the ungaged area are at least 2 inches (51 millimeters) per year. If these factors were a minimum of 2 inches (51 millimeters) per year, or 6 percent of the total input, then the contribution from the Floridan Aquifer was a maximum of 11 percent of the total input. On the hypotheses that the net exchange of water between the lakes and the Floridan Aquifer cannot be to the aquifer and that ungaged runoff and subsurface flow from the water-table aquifer were at least 2 inches, (51 millimeters) the most that can be deduced is that runoff and subsurface flow accounts for 6 to 17 percent of the total input, and that seepage from the Floridan Aquifer to the lakes accounts for 0 to 11 percent of the total input.

A water budget for Lake Apopka, to the extent possible with available data, has been calculated by Anderson (1971). A potential for seepage from the Floridan Aquifer to the lake exists. The flow from Apopka (Gourd Neck) Springs in the southwest part of Lake Apopka was measured to be 28 cubic feet per second (18 million gallons per day, 0.79 cubic meter per second) in May 1971. It is estimated that flow from the spring is equivalent to about 30 percent of the average net outflow from the lake.

WATER QUALITY

The Florida Game and Fresh Water Fish Commission studied 104 Florida lakes and ranked them according to the degree of eutrophication of each (East Central Florida Regional Planning Council, 1972). Lakes Apopka, Carlton, Beauclair, and Dora are among the 10 most eutrophic of the 104 lakes studied. Lakes Eustis, Griffin, Harris, and Yale are ranked 94, 89, 75, and 72 respectively; the higher the rank the greater the degree of eutrophication. Eutrophication of a lake is the natural process of enrichment with nutrients. The Oklawaha chain of lakes is a prime example of "cultural eutrophication"–that is, eutrophication greatly accelerated by certain activities of man.

The main cause of cultural eutrophication in the Oklawaha lakes is muck farming of the reclaimed marsh and wetlands along the north shore of Lake Apopka (P.R. Edwards, former Director, Lake County Pollution Control Department, oral communication, 1973). To maintain optimum water levels while growing crops, water is pumped from the farms to Lake Apopka and to Apopka-Beauclair Canal when water is in excess, and allowed to flow by gravity from the lake to the farms when water is deficient. Water from the farms is rich in nutrients dissolved from the highly organic muck and from fertilizers. Since Lake Apopka and Apopka-Beauclair Canal are at the head of the chain of lakes, nutrient- rich water flows to the down-stream lakes. Smaller muck farms are adjacent to Lakes Harris and Griffin.

Other sources of the nutrients that enter the lakes are sewage treatment plants and industrial plants, primarily citrus processing plants. Sewage treatment plants for years have discharged waste to Lakes Yale, Dora, Eustis, Griffin, and Apopka. Sewage waste from private treatment facilities has also been discharged to the lakes. Citrus processing plants have discharged waste water to Lakes Yale, Griffin, Harris, and Apopka.

Both the Lake and Orange County Pollution Control Departments now prohibit the discharge of any type of waste to surface waters. Several municipal, private, and industrial sources have been granted temporary permits to continue discharging waste to the lakes until facilities for other methods of disposal can be completed. The muck farms also continue to discharge nutrient-laden water to the lakes, but only under temporary permits. Agricultural interests are developing plans to control the discharge of waste into surface waters.

No single characteristic can satisfactorily define the trophic state of a lake. Several physical, chemical, and biological criteria are usually used to indicate the degree of eutrophication. Eutrophic lakes have high nutrient concentrations of nitrogen and phosphorus, high chlorophyll levels, high production of plankton and large plants, low water transparency, high algal populations distributed among few species, and are usually shallow (Brezonik and others, 1969). Based on analyses of water samples by the Lake and Orange County Pollution Control Departments, the Environmental Engineering Department of the University of Florida, and the U.S. Geological Survey, these characteristics generally describe the Oklawaha chain of lakes. Probably the worst lakes in terms of water quality are Carlton, Beauclair, and Dora, followed closely by Lake Apopka. The quality of Lakes Eustis and Griffin is somewhat better. Lakes Harris and Little Harris contain water of considerably better quality than that in Lakes Carlton, Beauclair, Dora, and Apopka. Lake Yale is the best in the chain because of relative lack of nutrient sources. The quality of Lakes Eustis and Griffin is better than that of the lakes upstream of Dora Canal because water of relatively good quality from Lake Harris dilutes the water of poorer quality from Lake Dora. Lakes Harris and Little Harris contain water of better quality than those upstream of Dora Canal because their main source. of water, the Palatlakaha River, is relatively free of nutrients.

The process of eutrophication is irreversible because the life processes going on in a lake are such that nutrients are not lost from the system but are largely recycled. The excessive quantities of algae (algal blooms) that result from abundant nutrients die, sink to the lake bottoms, and decompose. As the algae decompose, they release some of the nutrients back to the water to be used for continued growth of algae. Decomposition, which requires oxygen, and the oxygen demands of the living algae, can reduce dissolved oxygen levels to near zero so that fish die. The dead fish sink to the bottom where they decay and contribute more organic matter to the lake bottom. The soft, unconsolidated bottom deposits of the Oklawaha lakes result from a gradual build-up of decayed organic matter. Loose bottom conditions make spawning difficult for those gamefish that require a firm bottom upon which to lay eggs, and also retard the growth of rooted aquatic plants, which provide shelter for the fish, take up nutrients, and produce oxygen. Once a lake is overly enriched with nutrients, the damage cannot be overcome in a short time by eliminating the source of nutrients. Restoration requires drastic and costly measures.

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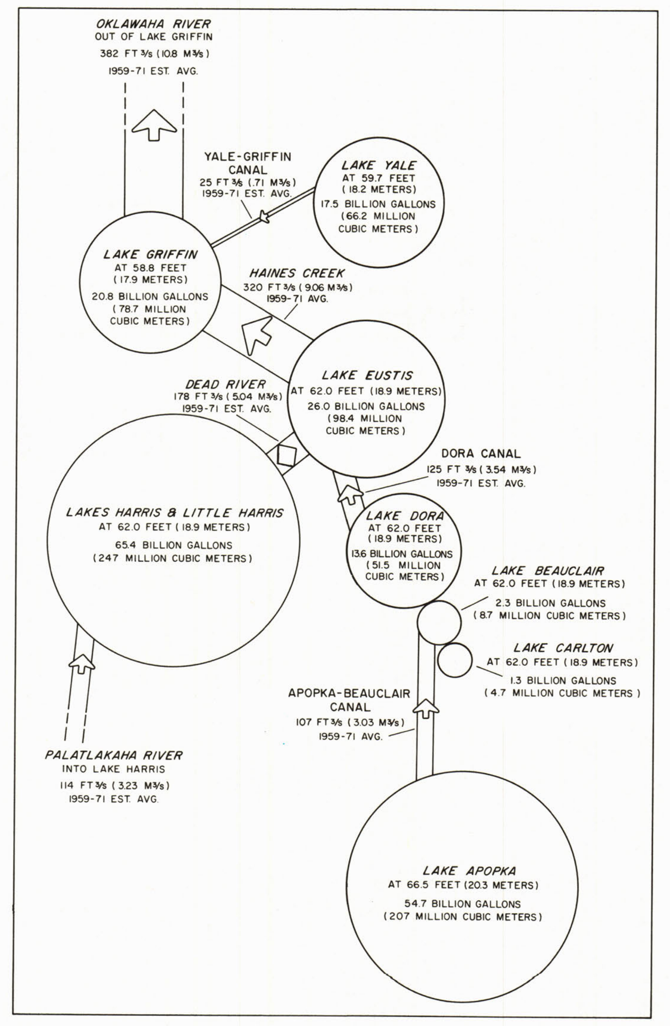
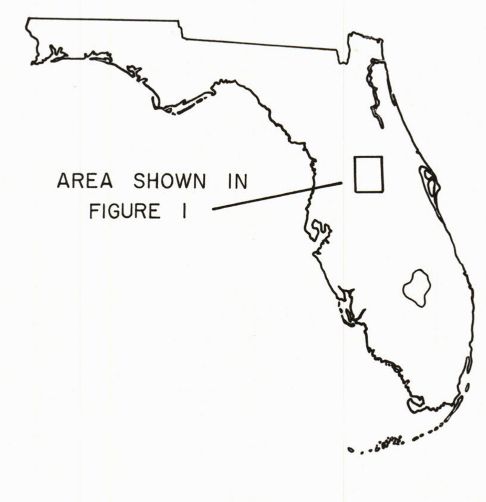


Figure 2. Volumes and flows in the Oklawaha lakes system.



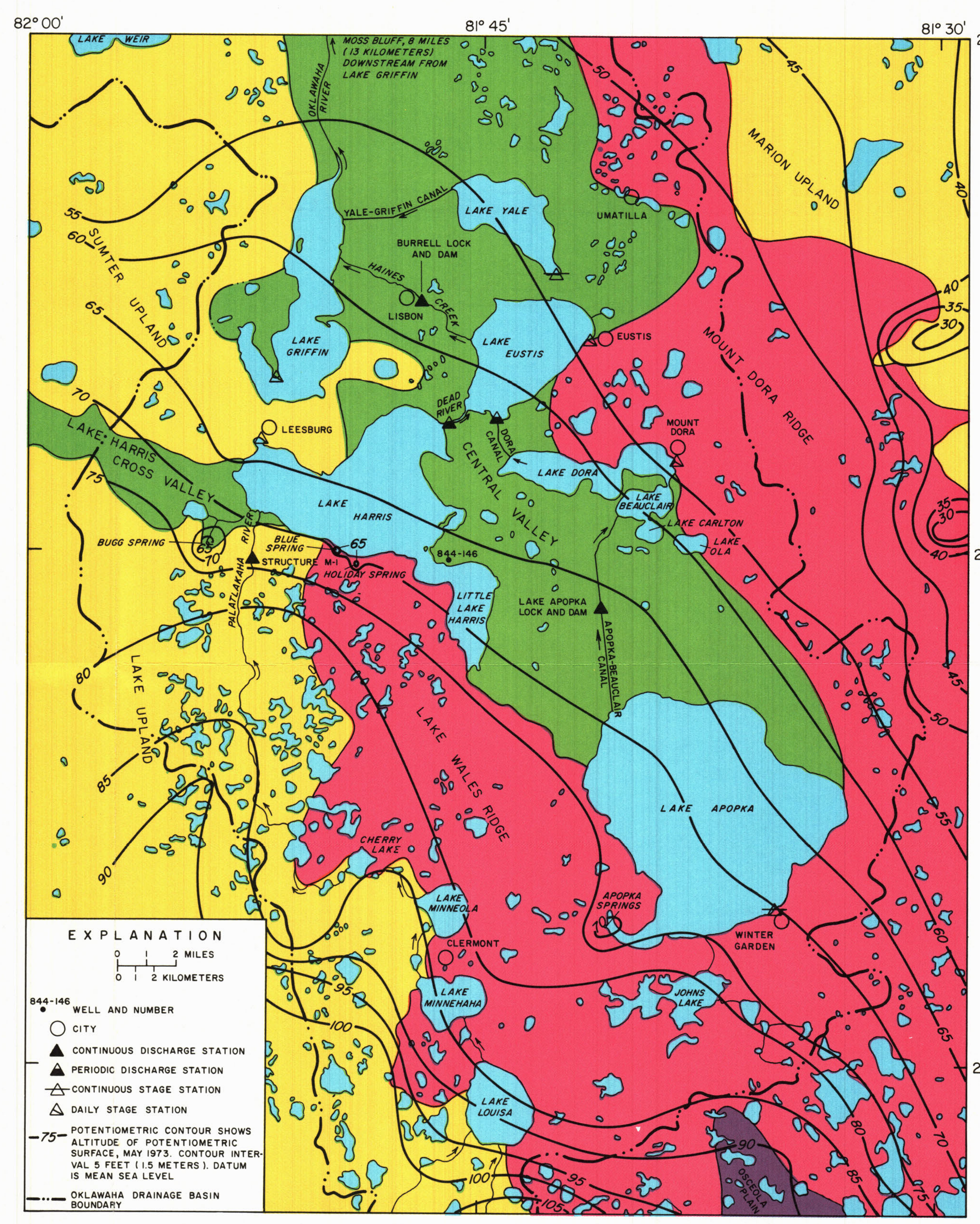
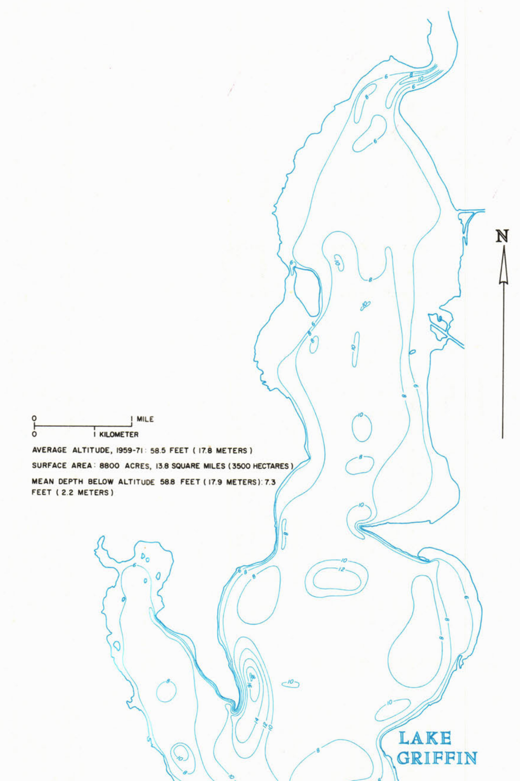
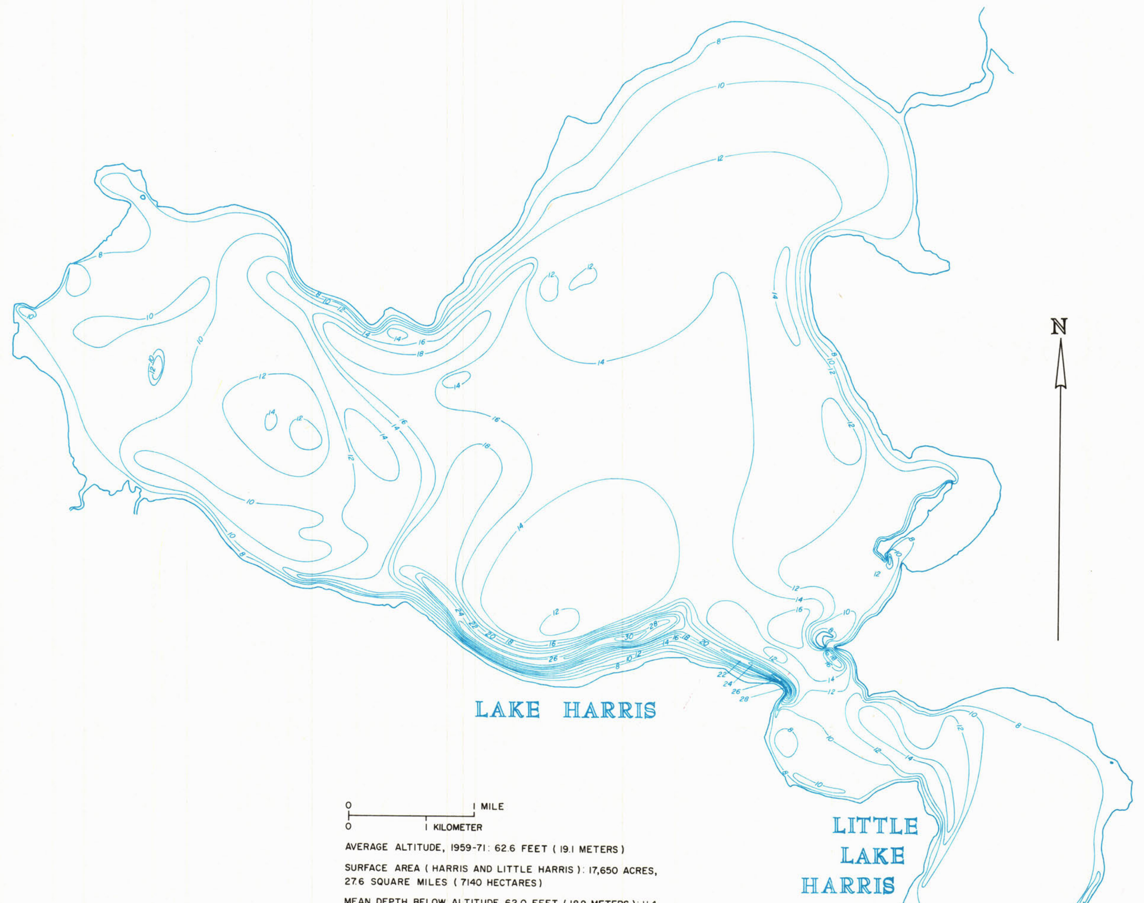
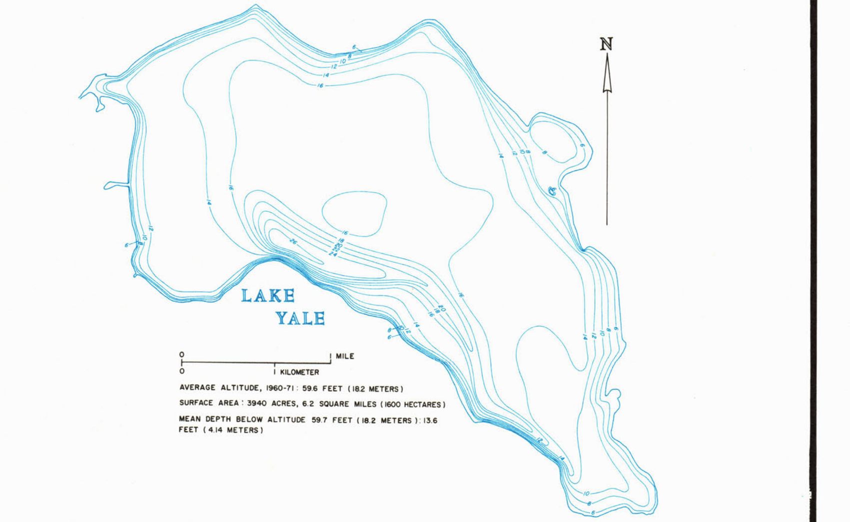
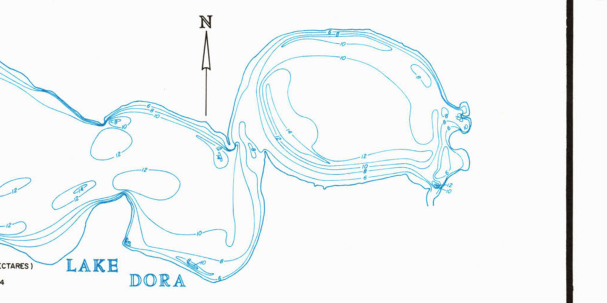


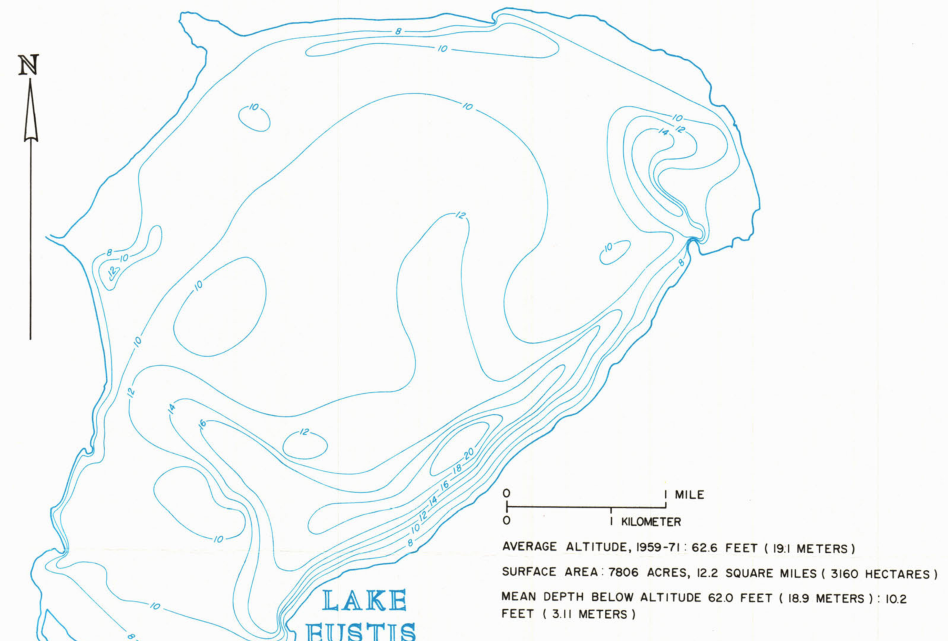
Figure 1. Map of the Oklawaha lakes area.

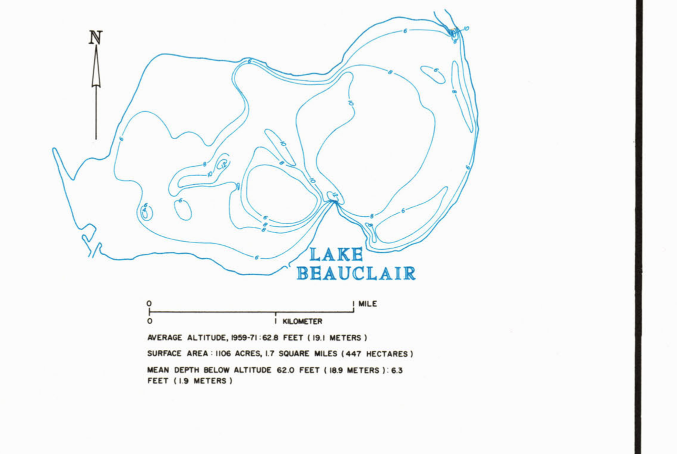


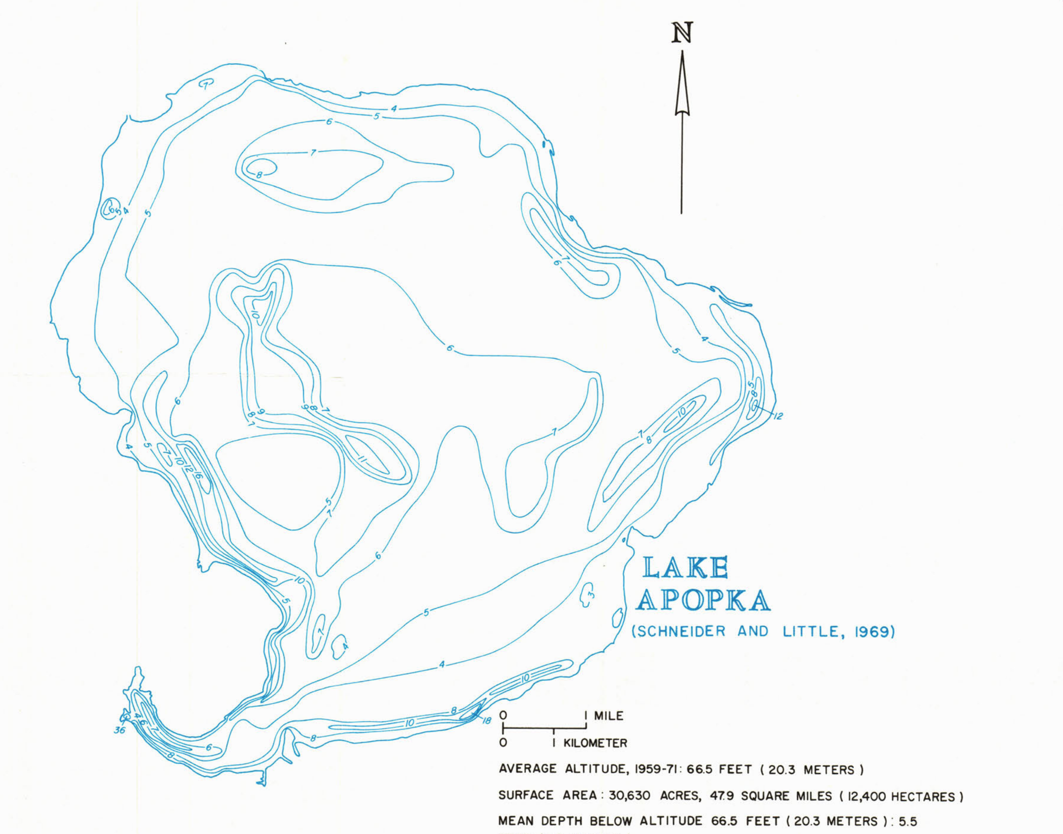


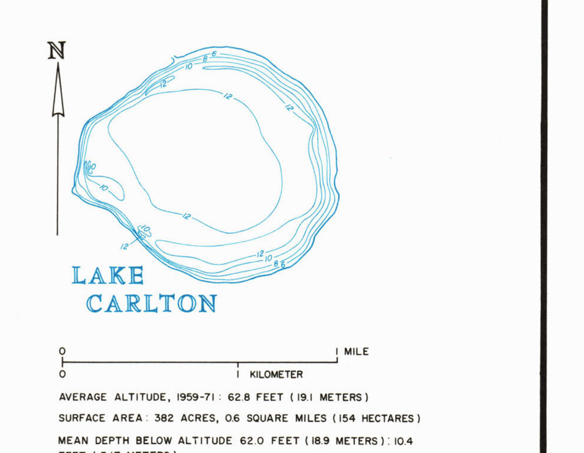












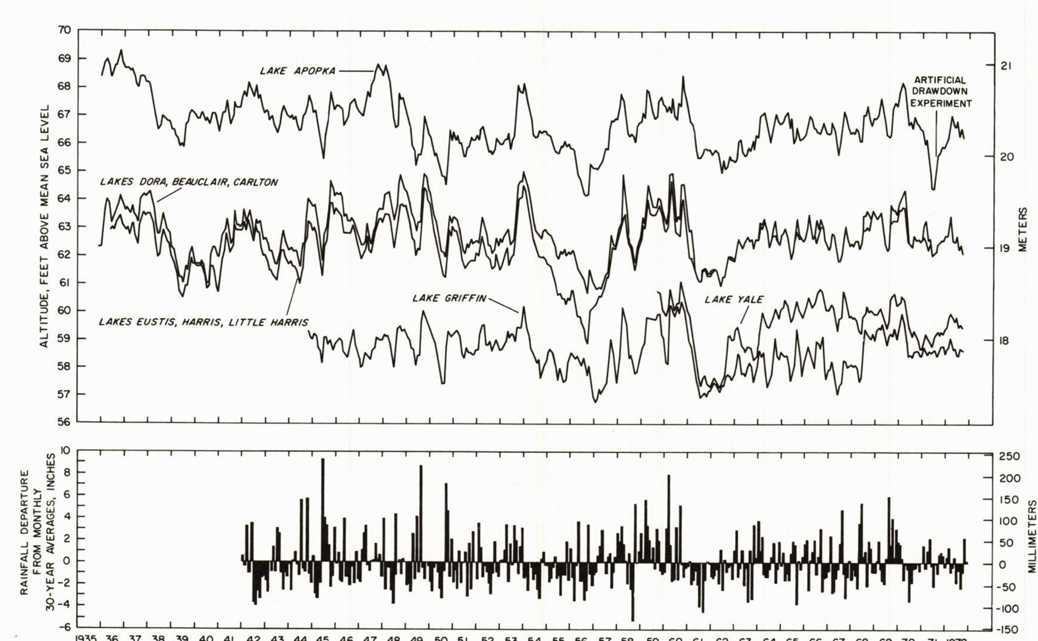


Figure 3. Month-end water levels, rainfall departure from 30-year averages from National Oceanic and Atmospheric Administration stations at Eustis, Leesburg, and Clermont.

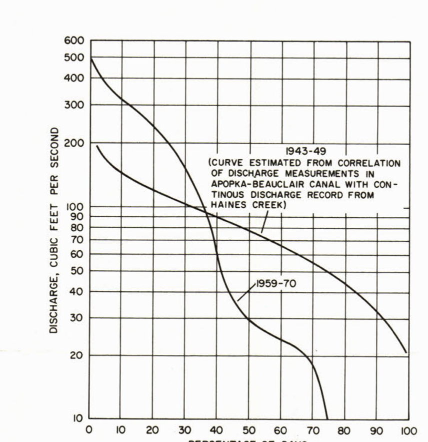


Figure 4. Flow-duration curves for Apopka-Beauclair Canal for unregulated period 1943-49, regulated period 1959-70.

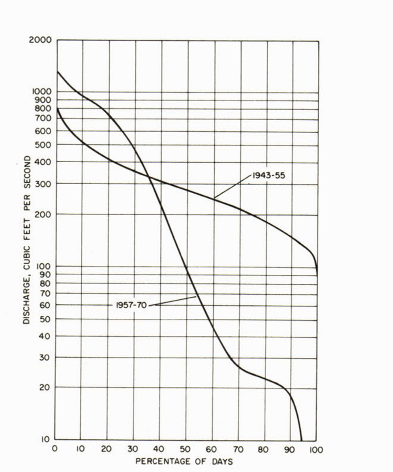


Figure 5. Flow-duration curves for Haines Creek for unregulated period 1943-55, regulated period 1957-70.

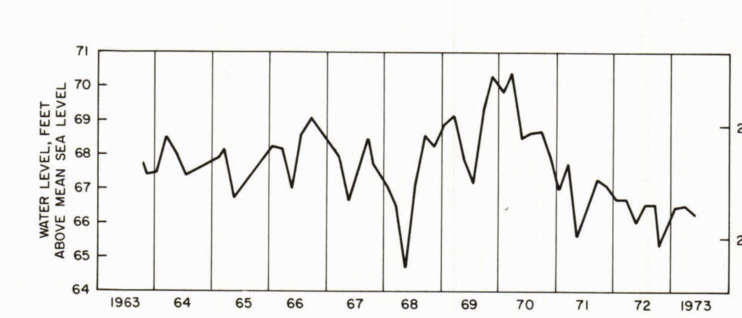


Figure 9. Periodic water level in Floridan Aquifer well 844-146.

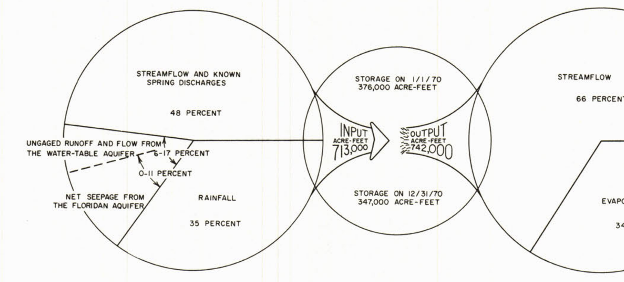


Figure 8. Water budget for Lakes Carlton, Beauclair, Dora, Eustis, Harris and Little Harris, taken as a unit, for the period 1/1/70-12/31/71.

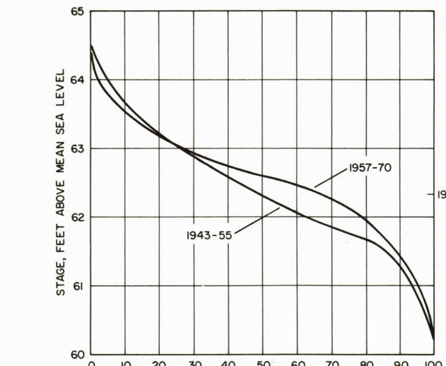


Figure 7. Stage-duration curves for Lake Eustis for unregulated period 1943-55, regulated period 1957-70.

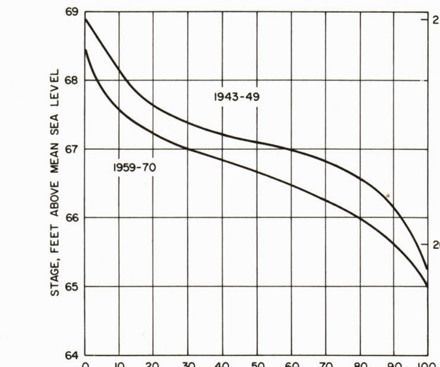


Figure 6. Stage-duration curves for Lake Apopka for unregulated period 1943-49, regulated period, 1959-70.