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HYDROLOGY OF LAKE CARROLL, HILLSBOROUGH COUNTY, FLORIDA

By

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INTRODUCTION

Lake Carroll, the fourth largest natural lake in Hillsborough County, Florida, is the fourteenth lake to be studied in a series of hydrologic investigations of lakes in west-central Florida. The lake is north of Tampa in one of the most rapidly developing areas of Hillsborough County (fig. 1). The design and fill operation that accompanied residential development, primarily in the early 1960's, increased the surface area of the lake from 186 to 195 acres. Urban development in lake basins and resultant demands on area water resources can affect lake levels and cause degradation of lake water quality. Existing or impending problems with the quality or quantity of lake water can be dealt with more effectively if management planning and actions are based on a thorough understanding of the hydrology of the lake. This report, prepared by the U.S. Geological Survey in cooperation with the Southwest Florida Water Management District (SWFWMD), describes the hydrology of Lake Carroll and how the lake responds to natural variations in climate and to development in the surrounding area.

Lake Carroll was one of the first lakes in Hillsborough County to undergo extensive residential development. The eastern side of the lake was inhabited before 1940. Development on this side can be generally characterized by large residential lots and low population density. In 1959, the Carrollwood subdivision was started on the west and south sides of the lake. As part of this development, low-lying swampy areas adjacent to the lake were deepened by dredging to provide additional lakeshore property and to provide fill for adjacent lots. Four shoreline inlets in the southwestern part of the lake (fig. 2) resulted from this development. The stormwater drainage system for the Carrollwood area discharges into the lake. A private utility company provides water and wastewater treatment facilities for the Carrollwood area. Residents of lakefront properties on the eastern half of the lake obtain their water from city utilities or private wells and their wastewater is treated by septic tanks. The 1.66-mi^2 surface area that drains water to Lake Carroll (fig. 1) has been altered by urban growth from Tampa, but does not include any heavy industry.

Several Geological Survey reports have discussed the Lake Carroll area, but detailed studies of the lake basin have not been done. Lake Carroll is in the western part of an area where a general hydrogeologic investigation is being conducted by Stewart and Mills (J. W. Stewart, U.S. Geological Survey, oral commun., 1983). Stewart (1966) also investigated the hydrologic effects of pumping from the Floridan aquifer in northwest Hillsborough County, and Stewart and Hughes (1974) studied the effects of maintaining lake levels by water pumped from wells in the Floridan aquifer near the Section 21 well field (fig. 1). Sinclair (1974) reported on the hydrogeology of the surficial aquifer of an area about 5 miles northwest of Lake Carroll. Sinclair (1977) also investigated alternatives for artificial recharge of the Floridan aquifer in northwest Hillsborough County, as well as sinkhole development in the same area (Sinclair, 1981). Lake Magdalene, 7 miles north of Lake Carroll, is the subject of an earlier description of lake hydrology by Hunn and Reichenbaugh (1972). Murphy and others (1984) included Lake Carroll in a report on the 1979 flooding in northwestern Hillsborough and southern Pasco Counties.

The Geological Survey publishes annual reports that include data on water levels for lakes, ground-water levels, streamflow, and water-quality data for many surface-water and ground-water sites. Semiannual water-level maps that show the regional configuration of the water table and potentiometric surface of the Floridan aquifer are also produced by the Geological Survey. Climatological data published by the National Oceanic and Atmospheric Administration (NOAA) were also used in the study. Additional rainfall data were provided by the SWFWMD, the city of St. Petersburg, and the U.S. Forest Service. Chemical and biological data were provided by the SWFWMD, Hillsborough County, the Florida Department of Environmental Regulation (DER), and the Florida Department of Natural Resources (DNR).

Data for nearby lakes, ponds, wells, and climatological stations were used to assess the relation of the lake to ground-water levels, the levels of other lakes, rainfall, and evaporation. The lake bottom was sounded by fathometer and by hand-sounding weights in January 1981 and contours of the lake bottom were drawn (fig. 2). A network of 17 shallow wells was installed in November 1980 to help define water-level altitudes in the surficial aquifer adjacent to the lake. Included in this network for monitoring water levels in the surficial aquifer were 12 ponds and lakes in the surrounding area. Existing water-level and water-quality data were analyzed and additional water-quality samples were obtained between September 1980 and April 1981 to help assess the chemical and biological characteristics of the lake.

AREA DESCRIPTION

Lake Carroll is in northwest Hillsborough County adjacent to the northern city limits of Tampa (fig. 1). Almost all lakefront property on Lake Carroll has been developed, and future growth in areas adjacent to the lake will probably be slight. Residential areas adjacent to the lake consist entirely of single-family residences, but apartment or condominium development has occurred on several nearby lakes.

Land surrounding Lake Carroll is a karst topography of unconsolidated sands and clays underlain by thousands of feet of permeable limestone and dolomite. Much of the surrounding land is internally drained and is pitted with sinkholes and sinkhole lakes that were formed by collapse or subsidence of surficial sands and clays into solution cavities in the underlying rock (Sinclair, 1981). Lake Carroll was probably formed by coalescence of several eroded depressions caused by this dissolution activity. Typical sinkhole depressions are discernible in the lake bottom.

Land-surface altitudes in the Lake Carroll drainage basin range from about 23 to 60 feet above sea level. The land surface north of the lake slopes generally toward the lake. Surface drainage to the west of Lake Carroll is to Sweetwater Creek (fig. 1). Areas to the east of the basin generally drain internally into several sinkholes (J. W. Stewart, oral commun., 1982).

Lake Carroll has no streams flowing into it. Surface inflow to the lake is limited to intermittent storm-sewer drainage from the north, west, and south and to overland flow during periods of heavy precipitation. Almost all surface drainage is from residential areas. Only a few small citrus groves remain near the lake on the east side. Commercial development in the basin is very limited and there are no industrial areas. Surface drainage to the lake from most of the northern part of the basin would occur only during extreme storm periods.

Surface outflow from Lake Carroll is southward through culverts, ditches, and ponds to Willow Creek Lake (fig. 1). Surface outflow from Willow Creek Lake enters Channel H and travels southwest about 4 miles to the confluence of Channel H and Sweetwater Creek. Channel G then conducts surface flow west and south for 4.3 miles to Old Tampa Bay.

CLIMATE

The study area has a subtropical climate characterized by mild, dry winters and warm, rainy summers. Average monthly temperatures range from 60°F in January to 82°F in August. The average annual temperature is 72°F. Average relative humidity in the study area is about 74 percent. Rainfall during winter months is generally the result of broad cold fronts that move south or southeast across the study area. Rainfall during summer months is usually the result of convective thunderstorms and is of greater magnitude than rainfall in the winter. These frequent, rapidly moving thunderstorms often generate heavy rainfall that may differ substantially for areas only a few miles apart.

In choosing data from rainfall stations for use in this investigation, proximity of the stations to Lake Carroll was considered more important than length of record or the continuity offered by more distant, long-term stations. Rainfall data for 1947–80—the period of stage record for Lake Carroll—are from several sources. Rainfall data for 1947-66 are from the NOAA station operated at Sky Lake, 3.5 miles northwest of Lake Carroll. Rainfall records from the U.S. Forest Service station 1.0 mile northeast of the lake were used for the period 1970–80. For the intervening years, 1967–69, the closest available rainfall stations were the St. Petersburg Coone rainfall station, 7.5 miles northwest of Lake Carroll, and the NOAA station at Tampa, 6.0 miles southwest of the lake. Rainfall at Lake Carroll for those 3 years (1967–69) was estimated by regression of rainfall data at the Coone and Tampa stations with data at the Bay Lake and U.S. Forest Service stations.

Average annual rainfall in the Lake Carroll area from 1947 to 1980 was 55.82 inches. Figure 3 lists the annual precipitation and shows departures from the average for each year. Precipitation was below average for the first 24 years. The driest year was 1956, with only 36.06 inches of precipitation. The wettest year was 1979, with 87.40 inches of precipitation. Approximately 60 percent of the rainfall occurred from June through September each year when rainfall from the typical afternoon thunderstorms averaged about 5 inches per month. Rainfall during the rest of the year averaged less than 3 inches per month. The greatest rainfall recorded in a single month was 19.55 inches in August 1979. Several months during 1947-80 had no rainfall.

Estimated evaporation from the lake is based on data from class A evaporation pans at several NOAA climatological stations. Pan-evaporation data for 1952-58 are from the NOAA station at Sky Lake. Pan-evaporation data for 1959-80 are the average of five NOAA stations throughout Florida, chosen for their distribution and consistency of data: Gainesville, Lisbon, Lake Alfred, Vero Beach, and Belle Glade. Two of the stations are north of Lake Carroll, two are south of the lake, and one is approximately the same latitude east of the lake. Variability and magnitude of pan evaporation was not dependent on latitude. Average evaporation from these stations was within 5 percent of the Bay Lake data. A coefficient of 0.78 was used to estimate annual lake evaporation at Lake Carroll from pan-evaporation data. Monthly pan-to-lake coefficients ranged from 0.67 in February to 0.88 in July and were based on pan-to-lake coefficients for Lake Okeechobee, Fla. (Kohler, 1954, p. 128).

Estimated lake evaporation for 1952-80 ranged from 44.8 inches in 1957 to 53.4 inches in 1977. The average lake evaporation was 49.81 inches per year. This amount is in agreement with the estimated 50 inches per year evaporation from shallow lakes in Florida by Kohler and others (1959). Monthly average evaporation losses from the lake range from about 6.0 inches in May to about 2.3 inches in January and December (fig. 4).

HYDROGEOLOGY AND GROUND WATER

Lake Carroll and the surrounding area are underlain by three principal hydrogeologic units: a surficial aquifer system that is a permeable layer of sand, clay, and organic material, referred to as the surficial aquifer; a discontinuous layer of relatively impermeable material that act as a confining layer beneath the surficial aquifer; and the extensive series of permeable limestone formations beneath the confining layer, known collectively as the Floridan aquifer. The physical characteristics of these units and their relation to each other and Lake Carroll determine the quantity of ground water that flows into the lake or the amount lost by the lake to the ground-water system.

The materials that extend from land surface and lake bottom to the underlying confining bed comprise the surficial or water-table aquifer (fig. 5). The thickness of the surficial aquifer in the Lake Carroll area ranges from 0 to 50 feet and averages about 35 feet adjacent to the lake. The fine to very fine, well-sorted sand near the land surface contains some organic materials and ranges in color from white to dark brown depending on the degree of organic staining. Clayey sands and thin lenses of clay are encountered at most sites, with a general increase in clay content with depth (Sinclair, 1974).

Underlying the surficial aquifer is a layer of dense clay, marl, sand, and limestone (Sinclair, 1974). The low permeability of this clay-predominant material causes it to act as a confining bed between the surficial aquifer and the underlying Floridan aquifer and retards vertical movement of water between the two aquifers. Where the layer is thin or absent, the potential for exchange of water between the aquifers is increased. Thickness of the clay layer may be more than 40 feet, but average thickness near the lake is about 8 feet (fig. 5). Generally, the thickness of the confining bed increases from west to east. Test borings about 4 miles northwest of Lake Carroll confirmed the presence of the confining bed at 47 of 59 test holes (Sinclair, 1974). The configuration of the confining bed beneath the lake is not known. The configuration suggested in figure 5 could result from collapse or subsidence of surficial materials caused by dissolution of underlying limestone.

Underlying the confining bed is a series of permeable limestone and dolomite formations that extend for several thousand feet below land surface. The uppermost formation is the Tampa Limestone, followed by the Suwannee, Ocala, Avon Park, Lake City, Oldsmar, and Cedar Keys Limestones (Menke and others, 1961). These deposits range in geologic age from Miocene to Paleocene and are known collectively as the Floridan aquifer.

The water table, or top of the saturated zone in the surficial aquifer, ranges from 1 to 39 feet below land surface in the vicinity of the lake. Regional movement of water in the surficial aquifer is from north to south (Yobbi and Woodham, 1981; Yobbi and Barr, 1983). The configuration of the water table generally follows the topography. Recharge of water to the surficial aquifer is primarily by rainfall, but water is also supplied by lateral movement from lakes, by infiltration of irrigation water, and by septic-tank drain fields. Water movement from the surficial aquifer is by evapotranspiration, lateral movement to lakes and streams, withdrawals from wells, and downward leakage through the confining bed to the Floridan aquifer. Water in the surficial aquifer often contains objectionable concentrations of iron and is subject to contamination by drainage from streets or septic tanks. Because of these factors, water from shallow sand-point wells that are open to the surficial aquifer is generally used for lawn irrigation and not for domestic supply.

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Seventeen shallow wells were installed during the investigation to define and monitor water levels in the surficial aquifer. Wells ranged from 9.3 feet to 24.0 feet in depth and were constructed of 1¼-inch PVC casing with 4 feet of slotted well screen. Water-level data collected at 12 area lakes, including Lake Carroll, indicate that water levels of nearby ponds and lakes are contiguous with the water table. Data for the 12 lakes were used with the data for the 17 wells in estimating the configuration of the water table. Two wells open to the Floridan aquifer were measured periodically to determine the altitude of the potentiometric surface of that aquifer. Water levels from these two wells were used in construction of maps showing the altitude of the potentiometric surface of the Floridan aquifer in west-central Florida for May and September 1981 (Yobbi and Woodham, 1981; Yobbi and Barr, 1982). Measurements made from November 1980 to September 1981 indicate that the water levels in both aquifers were lowest in May 1981 and highest in September 1981. The configuration of the water table and the potentiometric surface of the Floridan aquifer for May and September 1981 are shown in figures 4 and 7, respectively.

The Floridan aquifer is the primary source of ground water in the Lake Carroll area. Water from the aquifer is a calcium bicarbonate type. Private residential wells are generally cased less than 100 feet and are usually less than 200 feet deep. They obtain water from the Tampa or Suwannee Limestones. The three public-supply wells west of Lake Carroll (fig. 6) are about 500 feet deep and are open to the Suwannee, Ocala, and Avon Park Limestones. Total pumpage from the wells exceeded 0.77 Mgal/d in 1980 and served about 1,150 homes (George Garland, Florida Cities Water Company, oral commun., 1981).

Water levels shown in figure 6 represent lower than average levels in the surficial and Floridan aquifers. Rainfall for the previous 3 months was about 6 inches below average. Water levels in the shallow wells ranged from 2.6 to 19.7 feet below land surface and averaged about 9.9 feet below land surface. Water from the surficial aquifer flowed into Lake Carroll along most of the lake perimeter. Water-table gradients toward the lake ranged from 0.008 ft/ft on the north and west sides of the lake to 0.002 ft/ft on the south side. Water from the lake flowed laterally in the surficial aquifer toward Boat Lake in the southeast and toward Lake Eckles east of Lake Carroll. Maximum water-table gradients were toward Lake Eckles and were about 0.002 ft/ft. The surficial aquifer supplied water to the lake through more than 90 percent of the lake perimeter. The altitude of the potentiometric surface in the Floridan aquifer beneath Lake Carroll ranged from about 19 feet above sea level at the south end of the lake to about 35 feet above sea level at the north end. Throughout the study area, the altitude of the potentiometric surface of the Floridan aquifer was lower than the water level of lake Carroll or the water table in the surficial aquifer.

Figure 7 presents altitudes of the water table in the surficial aquifer and the potentiometric surface of the Floridan aquifer for September 25, 1981. Water levels in the surficial aquifer ranged from 1.2 to 15.2 feet below land surface and averaged about 6.2 feet below land surface. In September, water from Lake Carroll was still flowing outward in the surficial aquifer in the vicinity of Boat Lake, as it was in May 1981. The water-table gradient between Lake Carroll and Lake Eckles, however, reversed. Summer rainfall recharged the surficial aquifer and formed higher water levels at well nest number 12, adjacent to Lake Carroll. Because of the higher levels, ground water in the surficial aquifer flows toward Lake Carroll west of well number 12 and toward Lake Eckles east of the well. The altitude of the potentiometric surface of the Floridan aquifer beneath Lake Carroll ranged from about 25 to 30 feet above sea level and remained lower than the water level of Lake Carroll or the surficial aquifer.

Because water levels in the lake and surficial aquifer are higher than the potentiometric surface of the Floridan aquifer, leakage through the confining layer is from the lake and the surficial aquifer downward to the Floridan aquifer. Upward leakage from the Floridan aquifer generally does not occur in the vicinity of Lake Carroll. The rate of downward leakage from the lake and surficial aquifer is dependent on the permeability and continuity of the confining layer and the relative altitudes of the lake and surficial aquifer and the potentiometric surface. Lowering the potentiometric surface by pumping or deficient recharge would increase downward leakage and possibly result in lowered levels for the lake and surficial aquifer. Lakes within 5 miles of Lake Carroll have been significantly affected by large withdrawals of water from the Floridan aquifer. Long-term water levels for the Floridan aquifer adjacent to the lake are not available, so changes in relation between the lake and potentiometric surface cannot be evaluated directly. However, changes in downward leakage can be estimated indirectly by means of water-balance analyses as shown in a later section of this report.

LAKE CHARACTERISTICS

The bottom configuration of Lake Carroll was mapped January 1981 using data obtained by recording fathometer and physical soundings. The lake stage during collection of bathymetric data was 34.68 feet above sea level. Depths shown in figure 2 and discussed in the following paragraphs have been adjusted to represent lake depths at a stage of 35.46 feet—the average stage of the lake since 1947.

The bottom of Lake Carroll is characterized by a number of irregular, natural depressions with a maximum measured depth of about 21.2 feet below altitude, 14.2 feet above sea level. Figure 2 shows four depressions that are greater than 20 feet in depth. Samples of bottom material collected throughout the lake reveal a firm bottom of fine sand where depths are less than about 10 feet. A thin, black layer of very fine, loose silt and organic material is found below depths of 10 feet. The layer increased to unknown thickness in deeper areas.

Areas of apparent dredging were detected along much of the lake shoreline during collection of bathymetric data. These areas are indicated by cross-hatching in figure 2, but some were not contoured because of the highly irregular bottom elevation. Many small dredged areas were probably undetected during collection of data. The dredged areas were generally at least 30 feet, but not more than 100 feet, from the shore. The dredged areas comprise a small percentage of the lake bottom and range in depth from less than 10 feet to about 26 feet. Maximum detected depths in these dredged areas are noted by spot depth readings shown in figure 2. The inlets in the southwest part of the lake were excavated from marshy ground in about 1962 to a maximum depth of about 10 feet.

Comparison of 1958 and 1969 Geological Survey topographic maps and aerial photographs taken in 1957, 1960, and 1963 indicates that the lake shoreline was altered during residential development in 1959-60. The size of Lake Carroll was increased from 186 acres to about 195 acres. Increase in area, as a result of excavation of inlets in the southwest and southeast areas of the lake, was partially offset by filling lakeshore property with material dredged from the lake bottom. Creation of the inlets did not significantly affect lake size, but increased the length of the lake shoreline from 3.2 miles prior to development to about 4.3 miles by 1963. Increasing the shoreline length-to-area ratio may increase the potential for degradation of the aquatic environment (Gaggiani and McPherson, 1976).

The stage of Lake Carroll has been monitored since mid-1946. Month-end lake stages for 1946-80 are presented on figure 3. Daily stage readings are available from 1965 to the present (1982). The frequency of readings from 1946 to 1965 ranges from daily to irregular monthly readings. Mean stage of Lake Carroll for the period 1947-80 is 35.46 feet above sea level. Maximum stage of Lake Carroll since 1946 is 40.08 feet above sea level, which occurred in September 1947 (from floodmark). Minimum daily stage of the lake occurred on March 30, 1957, when the lake stage was 32.35 feet above sea level. Thus, the range in stage since 1946 has been 7.73 feet.

Figure 8 represents stage-duration curves for the period of record 1947-80 and for the period 1971-78, a period of low lake levels. For the period 1947-80, the lake was higher than 35.00 feet 62 percent of the time, whereas during the 1971-78 period, it was higher than 35.00 feet only 19 percent of the time. The median stage for 1947-80—the level exceeded 50 percent of the time—was about 35.3 feet above sea level and coincides closely with the mean, or average, stage of 35.46 feet above sea level.

Figure 9 presents the frequency distribution of annual maximum stages for Lake Carroll based on peak stages for 1946-80. The curve was computed by the log Pearson Type III frequency analysis (U.S. Water Resources Council, 1976). As the example in figure 9 indicates, a flood stage of 37.7 feet above sea level will be equaled or exceeded on an average of about once every 5 years.

A culvert at the Lake Carroll outlet has stop logs to control outflow, but they are currently (1982) effective only during periods of above-average lake stage. Outflow occurs only when Lake Carroll and the two ponds between Lake Carroll and White Trout Lake rise above an altitude of about 35.5 feet above sea level. Outflow during periods of higher stages is controlled by constrictions at culverts and ditches and by the water levels of the two downstream ponds and White Trout Lake. Manipulation of the outflow control on White Trout Lake can also affect outflow from Lake Carroll.

Peak stages and stage-duration curves for Lake Carroll are dependent on the amount of surface outflow from Lake Carroll toward White Trout Lake. The outflow culvert from Lake Carroll was enlarged and lowered approximately 1 foot in 1965, but outflow prior to this time may have been dependent on conditions downstream from the culvert. Other changes in the outflow system have probably occurred since 1947 as residential development progressed. The effects of these changes on the duration of daily stages or on annual maximum stages of Lake Carroll are not known.

Stage-area and stage-volume relations for Lake Carroll are shown in figures 10 and 11, respectively. Data for these relations are from fathometer data and Geological Survey topographic maps of the surrounding land surface. At the mean stage of 35.46 feet above sea level, Lake Carroll has a surface area of about 195 acres and contains approximately 2,080 acre-feet of water. Area and volume relations do not include the pond that is connected to Lake Carroll by a canal in the southeast corner of the lake.

WATER BALANCE

Evaluation of major sources of inflow to and outflow from a lake provides an understanding of the relation between the lake and its environment. This water-balance analysis indicates the relative importance of various components of the hydrologic cycle and how natural variations or manmade changes can affect the quantity of water entering and leaving the lake. The chemical and biological characteristics of the lake can be altered by the relative quantities of each component of the hydrologic cycle.

The stage and volume of water in Lake Carroll fluctuates in response to precipitation, evaporation, surface-water inflow and outflow, exchange of water between the lake and surficial aquifer, and downward leakage to the Floridan aquifer. The water balance of Lake Carroll can be expressed by the following equation:

Change in volume	=	Precipitation	−	Evaporation	+	Surface-water inflow	−	Surface-water outflow
	+	Ground-water inflow	−	Ground-water outflow	−	Downward leakage		

Precise information on each of these components would require a more intensive investigation over a longer period of time and is beyond the scope of this report. Complete definition of the ground-water flow components, for example, would require a more extensive network of deep and shallow wells, as well as laboratory and aquifer testing to more accurately define the material and hydraulic characteristics of the surficial and Floridan aquifers. By relying on accepted techniques and findings from other hydrologic investigations, however, estimates of the water-balance components can be made. The following results should provide valuable information to both water managers and users. Prudent readers should realize the limitations of the data used in the analyses and should conduct future data collection, management actions, or investigations accordingly.

Surface-water inflow to Lake Carroll is intermittent and dependent on antecedent conditions and the magnitude and intensity of precipitations. Surface-water outflow is also intermittent and is dependent on lake stage and physical controls in the outflow channel. Ground-water inflow and outflow refer to water exchanged between the lake and the surficial aquifer. Downward leakage refers to water leaking downward through the underlying confining bed to the Floridan aquifer. Upward leakage from the Floridan aquifer to the surficial aquifer and the lake does not occur because the water level in Lake Carroll is higher than the potentiometric surface in the Floridan aquifer.

The monthly water balance of Lake Carroll was evaluated for the period 1952-80. Incomplete stage record and lack of appropriate evaporation data prior to 1952 made water-balance analysis prior to this date impractical. Two periods were selected to evaluate possible changes in the water balance of the lake caused by lakeside and area development. The first period, 1952-80, was considered to be a predevelopment period. The second period, 1961-80, was during a period of residential development.

Stage and climatic criteria were established to insure that unmeasured components of the water budget would be negligible. Based on knowledge of outflow controls, for example, surface-water outflow was negligible if lake stages were less than 36.5 feet above sea level through 1960 and less than 35.5 feet after 1960. Initially, surface-water inflow from storm-drainage systems or overland flow was assumed to be negligible if monthly precipitation was less than 2.0 inches. This precipitation criteria was increased gradually to 6.0 inches per month without any significant change in water-balance computations. Approximately 40 percent of all months in each of the two periods of analyses met these stage and precipitation criteria set to assess negligible surface-water flow.

The amount of ground-water flow to or from the lake from the surficial aquifer can be estimated by use of Darcy's equation for flow through porous media:

$$Q = KIA$$

where

Q = Discharge, in cubic feet per day,
K = Horizontal conductivity, in feet per day,
I = Hydraulic gradient, in feet per foot,
A = Cross-sectional area through which the water passes, in square feet.

Horizontal conductivity of the surficial aquifer in northwest Hillsborough and south Pasco Counties was estimated by Sinclair (1974) to be about 13 feet per day. Hydraulic gradients in the surficial aquifer were computed from water-table contours (figs. 6 and 7). Cross-sectional areas of ground-water flow were determined from water-level data (figs. 6 and 7) and bathymetric data (fig. 2). Computations indicate that net ground-water flow from the surficial aquifer to the lake in May 1981 was about 0.2 ft^3/s. This rate of ground-water inflow would cause a rise in lake stage of about 0.06 foot per month (ft/mo) over a lake surface of 195 acres. For September 1981, net ground-water flow to Lake Carroll was computed to be about 0.8 ft^3/s, or about 0.24 ft/mo over the average lake surface.

Because historical data on water-table altitudes in the surficial aquifer were not available, ground-water flow to the lake was estimated from the computed values of flow for May and September 1981. Analyses of water levels in the surficial aquifer and in Lake Carroll indicate that wet periods which cause relatively higher stages in the lake also cause greater ground-water gradients toward the lake, resulting in higher ground-water flow. Conversely, dry periods cause both lower lake stages and lower ground-water gradients toward the lake. Estimates of net ground-water flow to the lake were varied with lake stage and ranged from 0.03 to 0.31 ft/mo. The average lake stage during 1952-80 was higher than for 1961-80, so the method of estimating ground-water flow resulted in higher estimates of flow for the first period. Available water-level data indicate that the four closest gaged lakes—all upgradient from Lake Carroll—also had lower water levels during the latter period. These data indicate that water levels in the surficial aquifer would also be lower during the 1961-80 period, with a subsequent decreased flow from the surficial aquifer to the lake. Estimated net flow to the lake from the surficial aquifer averaged about 0.15 ft/mo for the 1952-60 and about 0.17 ft/mo for 1961-80.

Downward leakage from the lake to the Floridan aquifer was computed as the residual from the water-balance equation for months of negligible surface-water inflow and outflow. Computed rates of downward leakage varied seasonally; they increased during the dry spring months when the differential in head between the water table and Floridan aquifers was greatest and decreased during the wet summer months when the differential was the least. For 1952-60, downward leakage ranged from 0.03 to 0.43 ft/mo and averaged about 0.23 ft/mo over the lake surface. Downward leakage to the Floridan aquifer during 1961-80 ranged from 0.04 to 0.44 ft/mo and averaged about 0.27 ft/mo. The average values of downward leakage were considered to be representative of all months during each of the time periods analyzed.

Net surface-water flow was estimated as the residual component in the water-balance equation using the average values of ground-water flow and downward leakage computed for periods of no surface flow. All months in both time periods were considered. Attempts to separate the net surface-water flow into inflow and outflow components were not successful. Such computations would require daily information on rainfall intensity and downstream water levels. Calculations indicate that surface-water outflow from Lake Carroll during 1952-60 averaged 0.31 ft/mo more than surface-water inflow. After 1960, surface-water inflow increased and surface-water outflow decreased, which resulted in more water flowing into the lake than out of the lake. For 1961-80, net surface-water flow to the lake averaged about 0.72 ft/yr.

Results of water-balance computations are presented below for 1952-60 and 1961-80. As noted previously, values below are estimates based on climatic and hydrologic data available at the time (1981) of the investigation. Values are yearly averages for each component. Volumes are expressed as feet of water over the average lake surface of 195 acres.

Period	Change in stage	=	Precipitation	−	Evaporation
1952-60	+0.17	=	4.85	−	4.02
1961-80	0.00	=	4.85	−	4.02

Period	+	Net ground-water flow	−	Downward leakage	±	Net surface-water flow
1952-60	+	2.41	−	2.76	−	0.31
1961-80	+	2.02	−	3.24	+	.72

The above water-balance estimations indicate a general lowering of lake stage after 1960. Average annual decline in lake stage was 0.09 foot after 1960, but the decline was not continuous during the 20-year period. Precipitation after 1960 averaged 0.23 foot less for each year than in the earlier period, while evaporation from the lake averaged 0.19 foot more. Ground-water inflow to the lake decreased while downward leakage increased. Ground-water flow to the lake after 1960 averaged about 0.39 foot less each year than in the 1952-60 period, and downward leakage from the lake averaged 0.48 foot more than during the earlier period. Net surface-water flow to the lake increased by more than 1 foot per year, but was not sufficient to maintain lake stages at the 1952-60 altitudes because of the combined effects of climate, decreased ground-water inflow, and increased downward leakage.

Although lake stages declined after lakeside development began, there is no indication that this development caused the lower stages. Development of storm-drainage systems and impervious areas probably accounts for part of the net increase in surface-water inflow. These impervious areas may also have caused a decrease in infiltration of rainfall to the surficial aquifer that resulted in lowered ground-water levels and less ground-water flow to the lake. The lower rainfall and higher evaporation after 1960 affected lake stages directly, but also affected water levels in the surficial aquifer and Floridan aquifer. As mentioned previously, the four closest gaged lakes to Lake Carroll were also lower after 1960. Although long-term water levels in the Floridan aquifer near Lake Carroll are not available, data indicate that the increase in downward leakage from the lake is probably a result of regionally lower altitudes of the potentiometric surface of the Floridan aquifer, rather than a condition specific to the Lake Carroll area (Stewart and others, 1971; Mills and Laughlin, 1976). Ground-water withdrawals from the Floridan aquifer throughout the region have increased since 1960, but the relative effects of a drier climate and increased ground-water withdrawals on water levels throughout the entire region is beyond the scope of this report. Lakeside development may have increased surface-water inflow to the lake, but this inflow had less effect on the stage of Lake Carroll than did regional changes in climate and ground-water levels.

WATER QUALITY

Water-quality data for Lake Carroll have been collected intermittently since June 1965. Periodic samples collected from 1965 to 1971 were analyzed for nutrient and major ion concentrations. Specific conductance and temperature data have been collected periodically since June 1967. Water-quality data prior to 1980 are not available to assess possible changes that resulted from lakeside residential development. To assess the present physical, chemical, and biological characteristics of the lake, water-quality samples were collected three times during the 1980-81 period of investigation (tables 1 and 2). Results of those analyses were compared with previous water-quality data to evaluate possible changes or trends in chemical characteristics since 1965. The samples collected in September 1980 and January and April 1981 were analyzed for a much broader range of constituents than previous samples and provided a more comprehensive data base for Lake Carroll water.

In September 1980, water-quality samples were collected from two sites in the lake to assess variability of water-quality characteristics (sites C1 and C2, fig. 2). Samples from each site were analyzed for concentrations of nutrients, phytoplankton, chlorophyll-a and -b, chemical and biochemical oxygen demand, major ions, metals, and selected pesticides and herbicides. Vertical profiles of conductivity, temperature, dissolved oxygen, and pH were also determined. Results of the analyses indicated that differences between water-quality parameters at the two sites were insignificant, and subsequent samples were collected only at site C2. The sampling site did not have a permanent marker, and measured depths varied from one sampling date to the next, which indicates the samples were obtained from slightly different locations.

Vertical profiles of dissolved oxygen, temperature, pH, and conductivity were collected on each sampling date. Temperature, pH, and dissolved oxygen decreased with depth. Decreases of pH and concentrations of dissolved oxygen with depth are expected because of decreasing photosynthetic activity with depth and absence of air-water contact. In September 1980, temperature readings decreased from 31°C to 28°C; pH decreased from 8.3 to 6.8 units, and concentrations of dissolved oxygen decreased from 8.4 to 4.4 milligrams per liter (mg/L) with depth. Specific conductance (micromhos per centimeter (µmho/cm) and dissolved solids varied little variation with depth. Temperature, conductivity, and dissolved oxygen profiles for January 1981 showed relatively constant values of 12°C, 185 µmho/cm, and 10.0 mg/L, respectively; pH was 7.2 units at the surface and 7.0 units near the bottom. In April 1981, concentrations of dissolved oxygen ranged from 9.1 mg/L near the surface to 7.1 mg/L near the 15-foot depth. Temperature decreased with depth from 26°C to 24°C, and pH ranged from 7.3 units near the surface to 6.7 units near the bottom. Conductivity decreased slightly but averaged about 200 µmho/cm throughout the profile. Based on these vertical profile data, water in Lake Carroll appears to be well mixed vertically.

To assess changes in concentrations of major chemical constituents in Lake Carroll since 1965, the data for these relations are from samples collected in June 1965, May 1970, and April 1981 were graphically compared (fig. 12). Very little difference in relative concentrations of the major constituents for these three samples is evident. The water type is basically calcium bicarbonate sulfate, with sodium and chloride also important components. Concentrations of sulfate in 1981 are slightly higher than in other surface waters in the area, but show little increase over the 1965 and 1970 concentrations. Possible sources of sulfate include wet or dry fallout of atmospheric sulfur dioxide—from combustion of sulfur containing fossil fuels—and surface runoff and ground water from fertilized lakeshore areas. Lake Carroll is in a coastal area and sodium and chloride concentrations in the lake may be due to ocean salts transported inland by wind and precipitation.

Samples collected in September 1980 were analyzed for concentrations of 25 pesticides and herbicides—aldrin, chlordane, DDD, DDE, DDT, dieldrin, endrin, endosulfan 1, endrin, ethion, heptachlor, heptachlor epoxide, heptachlor, malathion, methyl parathion, methyl trithion, methoxychlor, toxaphene, PCN, perthane, silvex, toxaphene, 2, 4-D; 2, 4-DB; and 2, 4, 5-T. Only dieldrin and 2, 4-D, were detected in the samples. Concentrations of total dieldrin were 0.01 microgram per liter (µg/L) at both sites. Concentrations of total 2, 4-D were less than 0.1 µg/L at both sites. Concentrations of 2, 4-D were well below the Florida Department of Environmental Regulation (DER) limit of 100 µg/L (total 2, 4-D for Class III waters—waters that are used for recreation and for propagation and management of fish and wildlife (Florida Department of Environmental Regulation, 1978, Rule 17-3). The Florida DER has not set limits for concentrations of dieldrin.

Samples collected from the lake in September 1980 were also analyzed for concentrations of selected metals (table 1). Concentrations of all metals were below Florida DER limits for Class III waters. Only iron, manganese, and strontium had been sampled previously. The results of the 1980 sample analyses do not show significant change in concentrations of these metals.

The specific conductance of Lake Carroll water has fluctuated between 105 and 311 µmho/cm for the 16 periodic determinations made since June 1965. The mean value of all determinations is 205 µmho/cm. Analyses of the data do not indicate any increase in specific conductance since 1965 nor any correlation with stage or time of year.

Nitrogen and phosphorus are essential nutrients for plant growth. An excess of both nutrients can lead to explosive growth of aquatic plants and algae that cause esthetic and ecological problems. Possible sources of nitrogen and phosphorus species in Lake Carroll water are lakeside septic tanks, runoff from fertilized areas, decomposition of dead phytoplankton, and atmospheric nitrogen that is fixed by blue-green algae.

Concentrations of nitrogen and phosphorus species in Lake Carroll water were determined for samples collected in 1980 and 1981 (table 2). Results of nutrient samples from 1965 to 1971 are insufficient for use in previous nutrient concentrations. Nutrient concentrations in samples collected in 1980 and 1981 are generally within the range of concentrations determined in samples collected from 1965 to 1971. Figure 13 indicates that organic nitrogen dominated the total nitrogen concentrations in samples collected in 1980 and 1981. The ratio of orthophosphorus to total phosphorus was variable.

Taxonomic identification if algal populations was determined for samples collected from Lake Carroll in January and April 1981. Cyanophyta (blue-green algae) constituted 89 percent of the total algal population in January and 99 percent in April. Cyanophyta algae can fix atmospheric nitrogen, increase nitrogen concentrations in the lake, and compound nutrient problems. *Anacystis* (also earlier known as *Microcystis*) was the dominant organism in both samples. Wetzel (1975, p. 299) indicates that dominance of *Anacystis* is a biological characteristic indicative of nutrient excess in lake waters. Total phytoplankton concentrations are presented in table 1.

Aquatic weeds in Lake Carroll have been considered to be a problem by area residents and have been treated by applications of herbicide since at least 1970. In 1970, area residents funded an extensive herbicide application on Lake Carroll. The Hillsborough County Environmental Protection Commission (EPC) sampled several sites in the lake in November 1970 to assess the impact of herbicide treatment. Low concentrations of dissolved oxygen and high concentrations of chlorophyll, orthophosphate, nitrate, and conductivity were found at one of four sampling sites, probably resulting from decomposition of aquatic plants (Roger Stewart, Hillsborough County EPC, oral commun., 1981). This condition appeared to be localized and was probably short term. The Florida DER has permit records for herbicide applications since 1974 when permits were first required.

ABBREVIATIONS AND CONVERSION FACTORS

Factors for converting inch-pound units to International System of units (SI) and abbreviations of units

| *Multiply* | *By* | *To obtain* |