DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

Prepared in cooperation with the
TENNESSEE WILDLIFE RESOURCES AGENCY and the
TENNESSEE DEPARTMENT OF HEALTH AND ENVIRONMENT, DIVISION OF WATER MANAGEMENT

WATER-RESOURCES INVESTIGATIONS REPORT 85-4284

INTRODUCTION

Reelfoot Lake in northwestern Tennessee (fig. 1), with a surface area of 15,500 acres at normal pool elevation, is the largest natural lake in Tennessee. It was formed by the New Madrid earthquake of 1811-12 (Killebrew, 1874, p. 1154). Over the years, the lake has become an important economic, environmental, and recreational resource to the people in the area, and to the State of Tennessee. The natural eutropic succession rate of the lake has apparently been accelerated by land-use practices within the Reelfoot Lake drainage basin during the past several decades. The potential loss of Reelfoot Lake has prompted the State to make management and restoration of the lake and its resources a priority objective.

The U.S. Geological Survey entered into a cooperative study in May 1984 with the Tennessee Wildlife Resources Agency and the Tennessee Department of Health and Environment, Division of Water Management, to collect and analyze hydrologic data and prepare an annual water budget for Reelfoot Lake. The purpose of the water budget is to provide an analysis of the surface water-ground water-lake-atmospheric water relation at Reelfoot Lake. Results of the analysis can be used by lake managers to evaluate the potential effects of proposed lake management strategies upon the lake and surrounding hydrologic system. The water budget for the 12-month study period (May 1, 1984 through April 30, 1985) is presented in this report. In addition, estimates of suspended-sediment discharge from tributary streams in the Reelfoot Lake basin and an analysis of concentrations of constituents in stream-bottom material at three inflow sites are also presented.

PREVIOUS INVESTIGATIONS AND AVAILABLE DATA

The hydrology of the Reelfoot Lake area is described by Robbins (1985). The report presents data and analyses on the surface-water and ground-water resources of the area including recorded extremes of stage for Reelfoot Lake. It also includes an analysis of the hydrologic effects of lowering Reelfoot Lake 5.8 feet below normal pool and an estimate of the length of time required to refill the lake to normal pool under normal hydrologic conditions. Effects of the Mississippi River on streamflow and lake levels are analyzed and discussed.

Hydrologic data collected during the term of this study are presented in a report by Robbins and others (1985). The report includes lake-level, streamflow, rainfall, and suspended-sediment discharge data, along with analyses of stream-bottom material samples collected at streamflow-monitoring stations. Water levels for Reelfoot Lake are published annually in the series "Water Resources Data for Tennessee."

These reports are available for inspection at the District Office of the U.S. Geological Survey, A-413 Federal Building - U.S. Courthouse, Nashville, TN 37203. Additionally, these reports can be purchased from: Open-File Services Section, Western Distribution Branch, U.S. Geological Survey, Box 25425, Federal Center, Denver, CO 80225.

AREA DESCRIPTION

The Reelfoot Lake drainage basin covers 240 mi², including a small area in Kentucky, and lies within the Mississippi embayment section of the Gulf Coastal Plain. Topographically the area is characterized by several prominent physiographic features: Reelfoot Lake, Mississippi River and flood plain, Tiptonville Dome, a bluff line which bisects the Reelfoot Lake basin along a northeast-southwest axis, and uplands east of the bluffs (fig. 1).

Of the 240 mi² drainage area, approximately 24.2 mi² (10 percent) are covered by the lake at normal pool (282.2 feet above sea level). Approximately 167 mi² (70 percent) are in the bluff and upland area to the east and northeast of the lake. The remaining 48.8 mi² (20 percent) are in the Mississippi River flood-plain area and streamflows are affected by water seeping from the Mississippi River through shallow aquifers during the months of December through May (Robbins, 1985).

During December through May, the water-surface elevation of the Mississippi River is normally 10 to 20 feet higher than the water-surface elevation of Reelfoot Lake and its tributaries draining the Mississippi River flood plain. Seepage from the Mississippi River through shallow aquifers sustains flows in the flood-plain tributary streams at a higher volume than can be attributed to rainfall during these months.

Reelfoot Lake and the surrounding area are underlain by a layer of Mississippi River alluvium (water-table aquifer) ranging in thickness from about 100 to 200 feet. Average thickness of the alluvium is about 140 feet. This surficial layer is underlain by approximately 250 feet of less permeable clay and fine sand which form a ground-water confining unit. This unit in turn is underlain by an aquifer in the Eocene Memphis Sand which consists of approximately 600 feet of highly permeable sand (Strausberg and Schreurs, 1958).

The alluvium consists of a sequence of sedimentary deposits which grade irregularly upward from gravel and coarse sand into progressively finer grained deposits of sand, silt, and clay. This alluvium may be divided into a lower permeable sand and gravel unit and an upper, less permeable, unit because of the general upward decrease in grain size. Ground water in the alluvium generally is under water-table conditions; however, localized artesian conditions may exist where the upper unit contains significant amounts of clay (Strausberg and Schreurs, 1958).

The report by Robbins (1985) describes the ground-water flow patterns around Reelfoot Lake. Ground water, on a regional scale, generally moves westward towards the Mississippi River. However, locally in the Reelfoot Lake area, when the water-surface elevation of the Mississippi River is higher than the adjacent water-table (generally during December to May), the river contributes to ground-water recharge. The rate of ground-water flow to or from the river is dependent on the gradient between the water table and the river. Ground water is also discharged to Reelfoot Lake, tributary streams, and as evapotranspiration by phreatophytes.

LAKE CHARACTERISTICS

Bathymetric contour maps of Reelfoot Lake (U.S. Army Corps of Engineers, 1956) were updated from depth sounding surveys made in 1983 by the Water Quality and Watershed Research Laboratory of the Agricultural Research Service, Durant, Okla., and in 1984 by the Tennessee Wildlife Resources Agency. These updated maps were digitized to obtain a stage-volume relation (fig. 2). At normal pool (282.2 feet above sea level), Reelfoot Lake has a surface area of approximately 15,500 acres, a volume of approximately 80,300 acre-ft, and a mean depth of approximately 5.2 feet. About 43 percent of the total lake area has a depth of 3.0 feet or less at normal pool.

Stage records of Reelfoot Lake have been collected by the U.S. Geological Survey since July 23, 1940. The maximum water-surface elevation of record, 287.2 feet above sea level based on surveyed high-water marks, occurred in January 1937. The minimum water-surface elevation of record, 279.59 feet above sea level, occurred on November 20-21, 1953. Daily mean lake stages and the mean lake stage for the study period are shown in figure 3. Maximum and minimum daily and monthly mean stages for Reelfoot Lake for the study period are shown in figure 4. The monthly mean stage was lowest for September and highest for May. Maximum daily mean stages occurred in May, December, and January.

The volume of water in Reelfoot Lake varies with lake stage as indicated by the stage-volume curve in figure 2. Because of the flatness of the surrounding topography and the shallowness of the lake, a small increase in lake stage results in a relatively large increase in surface area and in the volume of water in the lake (fig. 2). For example, a 1-foot increase in lake stage above normal pool results in an increase in lake volume of 19,400 acre-ft.

Running Reelfoot Bayou (fig. 1) is the outflow stream for Reelfoot Lake. Outflow from the lake into Running Reelfoot Bayou is regulated by a low-head multiple-gate spillway. Operation of the spillway to control lake stage is generally dependent on current lake stage and weather conditions. Records of daily discharge for Running Reelfoot Bayou (station 07027010), show a mean daily discharge of 374 ft³/s for the study period. The maximum daily mean discharge during the study period, 1,690 ft³/s, occurred on May 8, 1984. Maximum and minimum daily and monthly mean discharges for station 07027010 for the study period are shown in figure 5.

North and South Reelfoot Creek, Running Slough, and Indian Creek (fig. 1) are the principal tributaries that provide inflow to Reelfoot Lake. Records of daily discharge at North Reelfoot Creek (station 07026370), South Reelfoot Creek (station 07026400), Running Slough (station 07026640), and Indian Creek (station 07026795) for the study period show a range in monthly mean discharge from 227 ft³/s at station 07026400 for May, to 0 ft³/s at station 07026640 for August and September. Maximum and minimum daily, and monthly mean discharges for the study period for the four inflow monitoring sites are shown in figures 6, 7, 8, and 9.

WATER BUDGET

The volume of water in Reelfoot Lake fluctuates in response to surface-water inflow, surface-water outflow, precipitation, evaporation, and ground-water inflow and outflow. This relation can be expressed by the following water-budget equation:

$$\text{Net change in lake contents} = \text{Precipitation} - \text{Evaporation} + \text{Surface-water inflow} - \text{Surface-water outflow} + \text{Net ground-water flow}$$

The quantity of water in each hydrologic component of the water budget was evaluated by month, for the period May 1, 1984, through April 30, 1985, to provide a basis for understanding the hydrology of the lake system. No other factors, such as diversions and consumptive use, are known to significantly affect Reelfoot Lake.

The volume of water in Reelfoot Lake is a function of lake stage. Monthly changes in volume (fig. 10) were determined from lake-stage data (fig. 3) and the stage-volume relation (fig. 2). Net change in lake contents for the 12-month study period was an increase of 1,950 acre-ft.

Monthly precipitation data (fig. 11) were computed by the Thiessen method (Linsley and others, 1975, p. 78-83) using rainfall data from two Geological Survey stations at Reelfoot Lake and the National Weather Service station at Samburg (fig. 1). During the study period, monthly precipitation in May, September, October, and December exceeded the 30-year (1951-80) standard normal monthly precipitation (fig. 12). The cumulative total precipitation on the lake surface during the study period was 49.76 inches (64,800 acre-ft), which was 4 percent above normal (47.89 inches).

Monthly free water-surface evaporation for the study period was estimated using monthly pan evaporation data from National Weather Service stations at Martin, Tenn. (approximately 28 miles east southeast of Reelfoot Lake), and Jackson, Tenn. (approximately 62 miles south southeast of Reelfoot Lake), and a pan coefficient of 0.76 (U.S. Department of Commerce, 1982). Although evaporation from a lake surface may differ significantly from free water-surface evaporation during a given month because of changes in heat storage in the lake, it was assumed for the purposes of this study that free water-surface evaporation and lake-surface evaporation were equivalent. Estimated evaporation from the surface of Reelfoot Lake ranged from 0.52 inch (760 acre-ft) in January 1985 to 5.82 inches (7,490 acre-ft) in June 1984 (fig. 13). The cumulative total estimated evaporation loss from the lake surface during the budget period was 37.05 inches (46,200 acre-ft), which was 74 percent of the total precipitation during the same period.

Monthly surface-water inflow (fig. 14) was calculated from daily discharge records (Robbins, 1985) on the three major tributaries to Reelfoot Lake and a weighted average unit runoff coefficient for the 103 mi² of ungaged drainage area. Monthly surface-water outflow (fig. 15) was calculated from daily discharge records (Robbins, 1985) for Running Reelfoot Bayou (station 07027010) (fig. 1).

Net ground-water flow represents the difference between ground-water inflow and outflow. Ground-water inflow and outflow were not measured directly. The net monthly exchange between Reelfoot Lake and the ground-water system was estimated by solving the water-budget equation for net ground-water flow (fig. 16). Because it is computed as a residual, the accuracy of the net ground-water term in the equation is dependent upon the cumulative errors of the other water-budget components. The estimated potential error associated with the net ground-water term at Reelfoot Lake was determined by methods described by Winter (1981) and is approximately 40 percent (Robbins, 1985).

Water levels for a network of 31 observation wells (fig. 1) were measured periodically throughout the study period, and a ground-water flow simulation model was developed to independently check the net ground-water flow into or out of Reelfoot Lake (Robbins, 1985). Net ground-water flow estimates derived by each method (water budget and flow simulation model) were compared for two periods, August to September and November to December 1984. The model-calculated net ground-water flow for the two simulated periods was 7,250 acre-ft of inflow, whereas the residual of the water-budget equation (net ground-water flow) for the two periods was 8,530 acre-ft of inflow. The water-budget value was considered as being within the same accuracy range as the value derived by the ground-water flow simulation model. Therefore, the water-budget method was considered to be an appropriate estimate of net ground-water flow and was used for calculation of the study period net ground-water flow.

Results of the water-budget calculation are listed below. All values are in acre-feet.

[Data rounded to three significant figures and may not add to totals because of independent rounding]

Period	Change in volume	= Precipitation	- Evaporation	+ Surface-water inflow	- Surface-water outflow	+ Net ground-water flow
5/1/84 to 4/30/85	1,950	64,800	46,200	234,000	270,000	19,300

The water-budget analysis indicates there is a net gain of water from the ground-water system to the lake. Additionally, if there had been no surface-water outflow from the lake during the study period, the net excess water (272,000 acre-ft) could have filled Reelfoot Lake to 282.2 feet above sea level 3.4 times. The relative contribution of each hydrologic component to the study period water budget is illustrated in figure 17. Surface-water inflow accounted for 74 percent of the total inflow to Reelfoot Lake and evaporation accounted for 15 percent of the total outflow.

SEDIMENT INFLOW

At Reelfoot Lake, the natural eutropic succession rate has apparently been accelerated during the past several decades by land-use practices within the drainage basin, which may have increased sediment inflow to the lake. Eutrophication is generally considered to be undesirable because it reduces the aesthetic qualities of lakes. The aesthetic value of Reelfoot Lake is declining (Tennessee Department of Health and Environment, 1984, p. 52-53) because large areas of the lake bottom are covered by a thick layer of organic material and fine-grained sediments, algal blooms are a frequent occurrence, and growth of aquatic vegetation creates dissolved-oxygen and user-access problems. In addition, wave action and wind generated currents stir up bottom material causing the lake to become turbid.

Suspended-sediment discharge data were collected at three of the surface-water inflow sites, North Reelfoot Creek (station 07026370), South Reelfoot Creek (station 07026400), and Running Slough (station 07026640) (fig. 1). The relation between suspended-sediment discharge and water discharge at each of the three sites is shown in figures 18, 19, and 20, respectively. Data obtained at each surface-water inflow site for the study period (Robbins and others, 1985) indicate 85,200 tons (3.4 tons/acre) of suspended sediment were discharged from the South Reelfoot Creek basin, 67,800 tons (1.9 tons/acre) from the North Reelfoot Creek basin, and 3,550 tons (0.5 tons/acre) from the Running Slough basin. The combined total suspended sediment discharged from these three basins (105.7 mi²) was 157,000 tons as measured at the gage on each tributary.

Suspended-sediment discharge from the remaining ungaged area (111.1 mi²) was assumed to be similar to that at the three monitoring stations. Based upon the areal extent of the two source areas (the Mississippi River flood plain and the Mississippi River bluff and uplands) and using a weighted average suspended-sediment discharge coefficient, suspended-sediment discharge from the ungaged area was estimated to be 136,000 tons for the study period. Total suspended-sediment discharge from the Reelfoot Lake drainage basin (gaged area plus ungaged area totals) for the study period was estimated to be 293,000 tons.

CONCENTRATIONS OF PESTICIDES IN STREAM-BOTTOM MATERIAL

Agricultural runoff from Reelfoot Lake basin watersheds contains pesticides which adhere to soil particles. In order to determine the potential concentrations and types of pesticides entering Reelfoot Lake, stream-bottom material samples were analyzed once during the study period at North Reelfoot Creek (station 07026370), South Reelfoot Creek (station 07026400), and Running Slough (station 07026640). Analysis results are listed in table 1 and indicate that all pesticides tested for were at concentrations below detectable limits except DDE at the North Reelfoot Creek and Running Slough sites.

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Winter, T. C., 1981, Uncertainties in estimating the water balance of lakes: Water Resources Bulletin, v. 17, no. 1, 34 p.

CONVERSION FACTORS

For readers who may prefer to use the International System of Units (SI) rather than the inch-pound units used herein, the conversion factors are listed below:

Multiply	By	To obtain
cubic foot per second (ft³/s)	0.02832	cubic meter per second (m³/s)
acre-foot (acre-ft)	1,233	cubic meter (m³)
foot (ft)	0.3048	meter (m)
ton, short	0.9072	megagram (Mg)
acre	0.4047	hectare (ha)
inch (in.)	25.40	millimeter (mm)
square mile (mi²)	2.590	square kilometer (km²)
micromho per centimeter at 25°Celsius (µmhos/cm at 25°C)	1.0	microsiemens per centimeter at 25°Celsius (µS/cm at 25°C)

All elevations and water levels in this report are referenced to NGVD of 1929 (National Geodetic Vertical Datum of 1929), a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "mean sea level." NGVD of 1929 is referred to as sea level in this report.

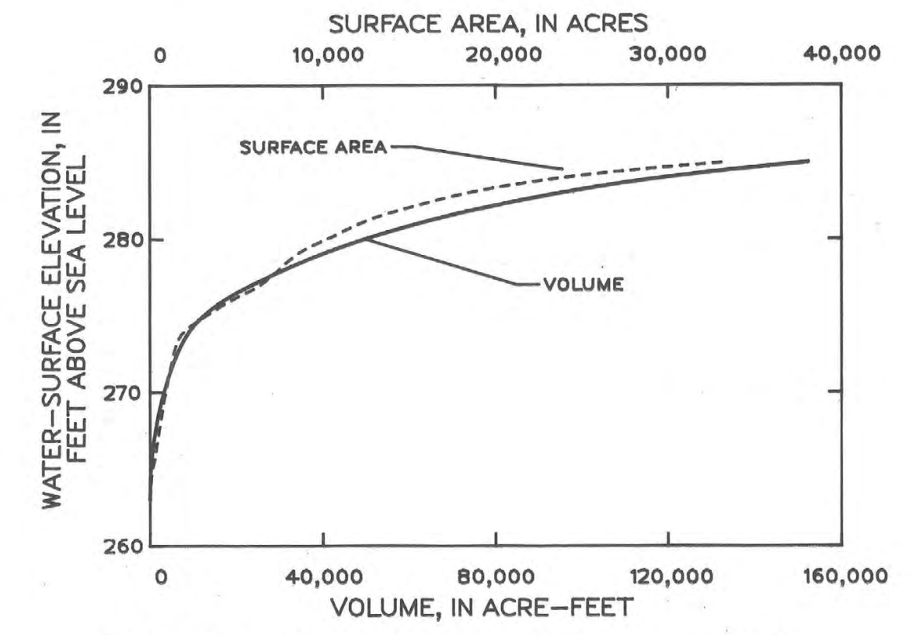

Figure 2.-- Stage-volume and stage-area relations for Reelfoot Lake.

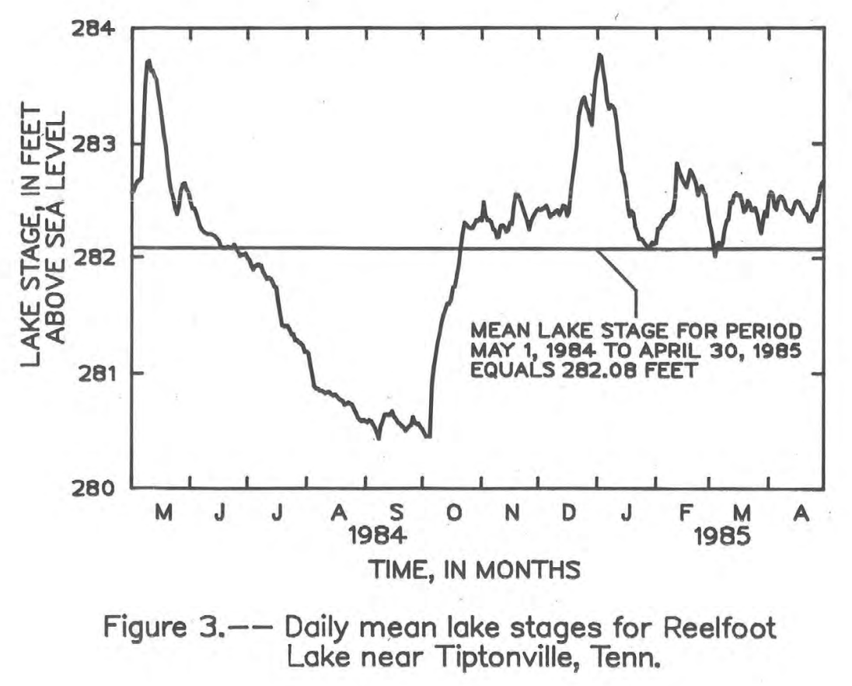

Figure 3.-- Daily mean lake stages for Reelfoot Lake near Tiptonville, Tenn.

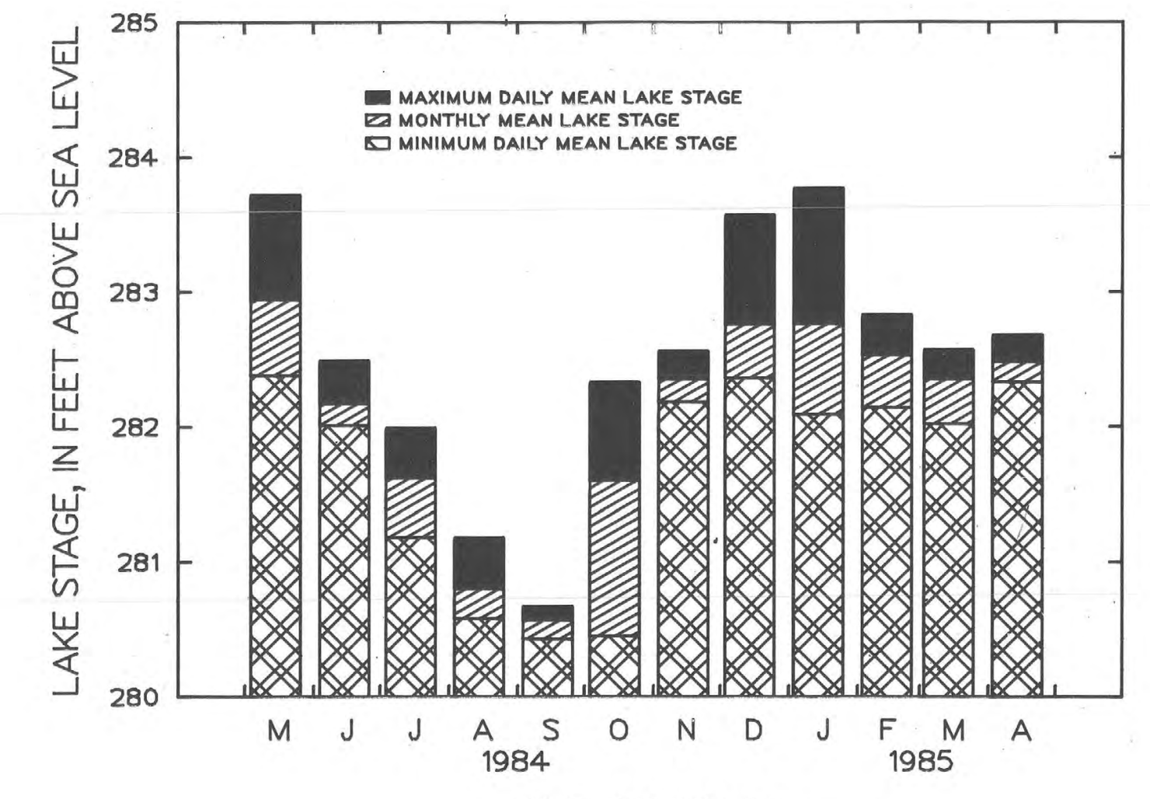

Figure 4.-- Lake-level statistics for Reelfoot Lake near Tiptonville, Tenn.

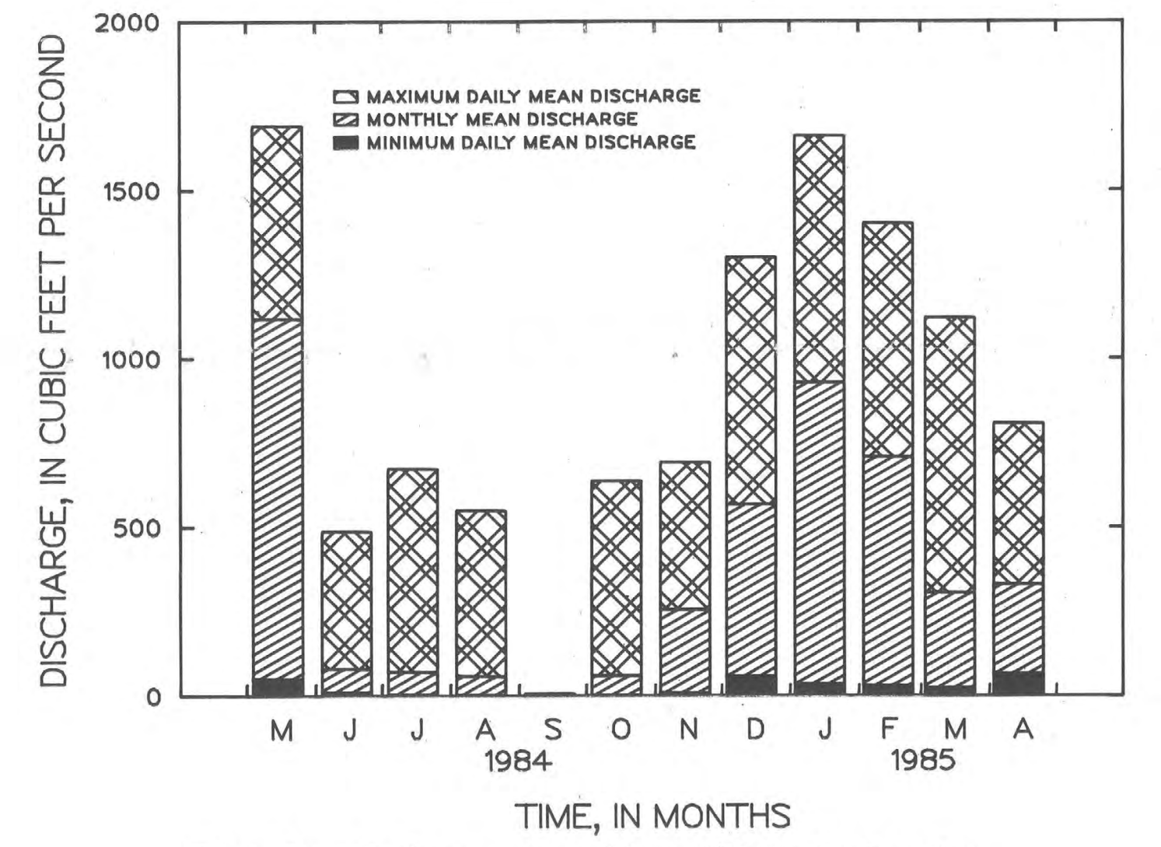

Figure 5.--Surface-water outflow statistics for Running Reelfoot Bayou (station 07027010).

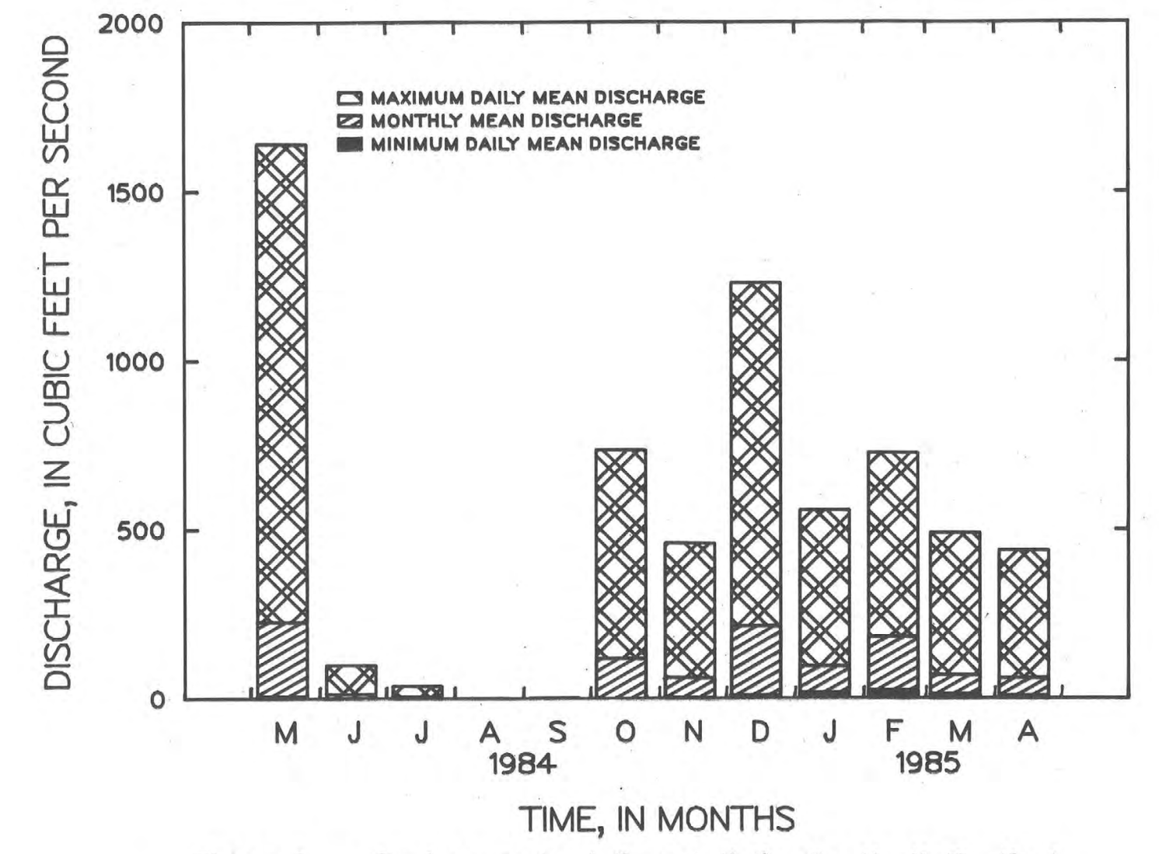

Figure 6.-- Surface-water inflow statistics for North Reelfoot Creek (station 07026370).

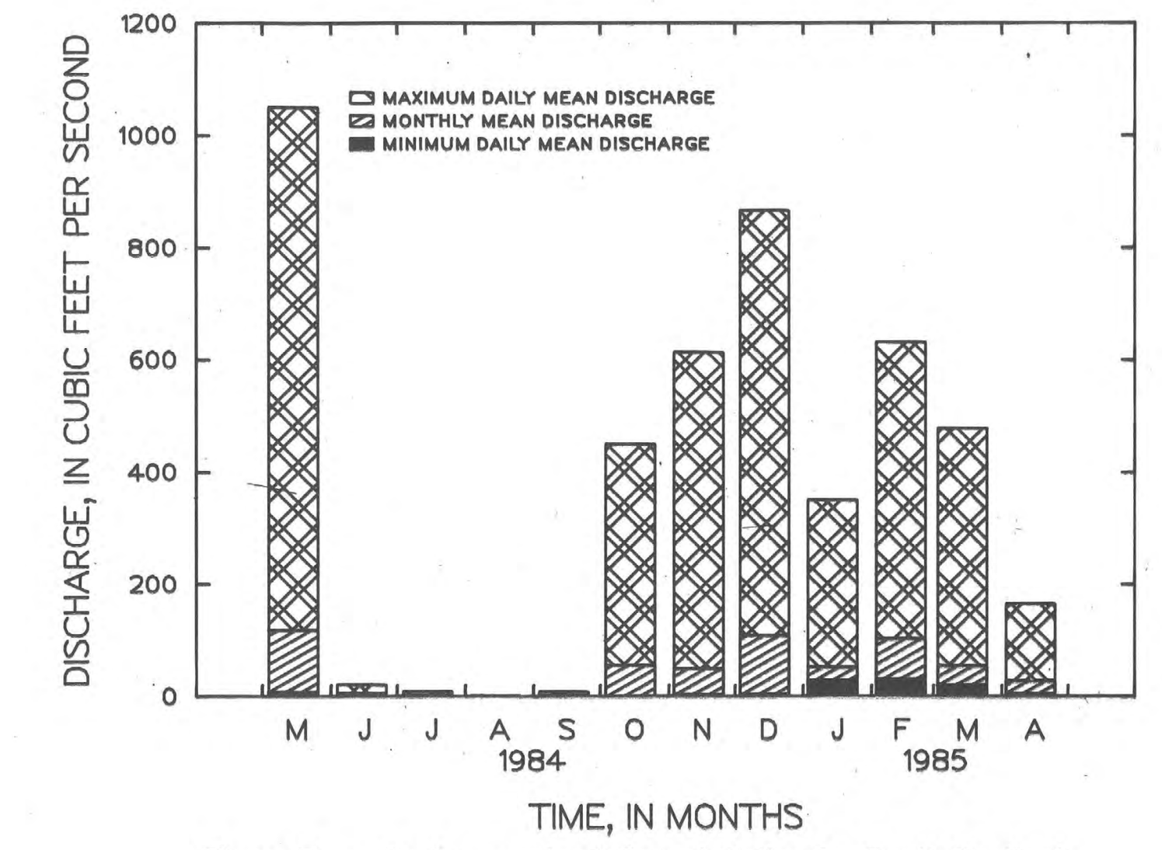

Figure 7.-- Surface-water inflow statistics for South Reelfoot Creek (station 07026400).

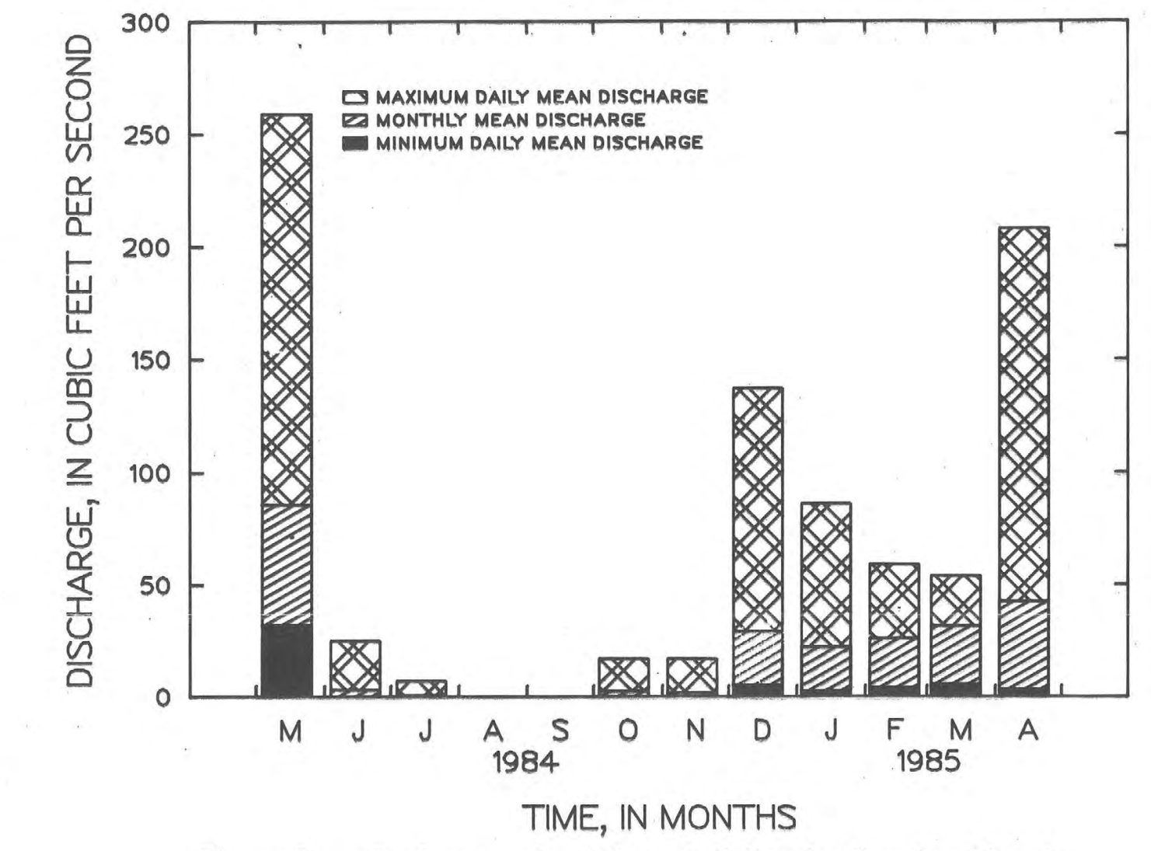

Figure 8.--Surface-water inflow statistics for Running Slough (station 07026640).

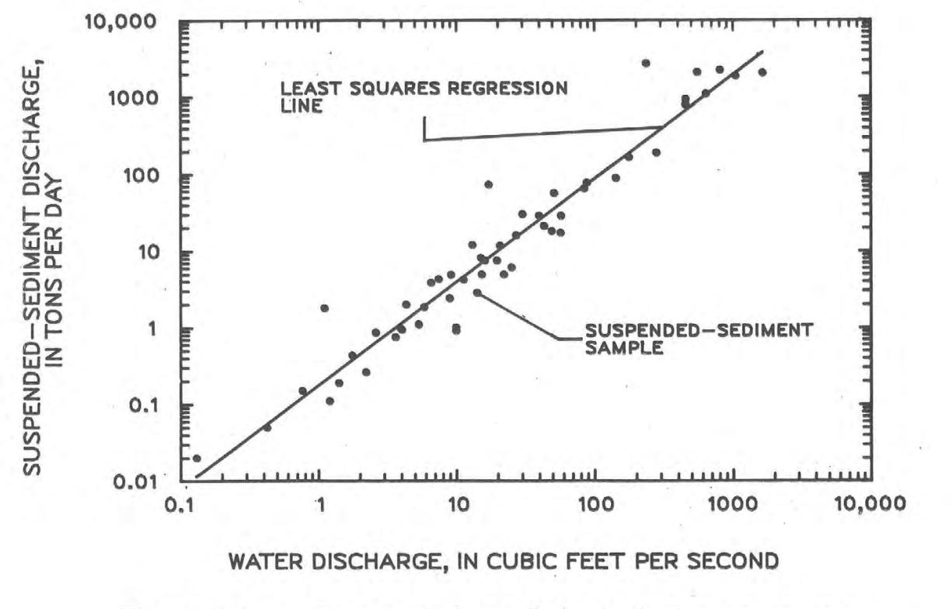

Figure 18.-- Suspended-sediment discharge versus water discharge for North Reelfoot Creek (station 07026370).

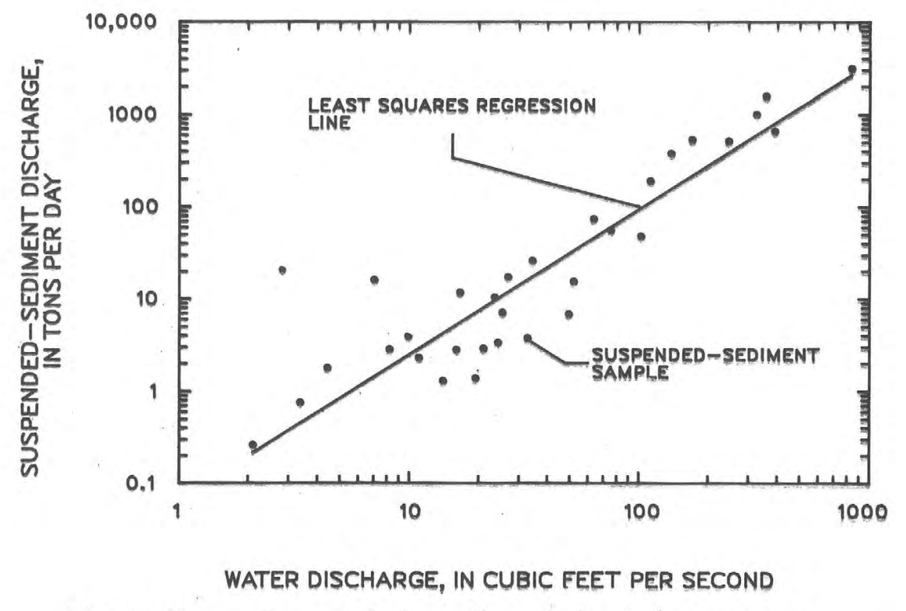

Figure 19.-- Suspended-sediment discharge versus water discharge for South Reelfoot Creek (station 07026400).

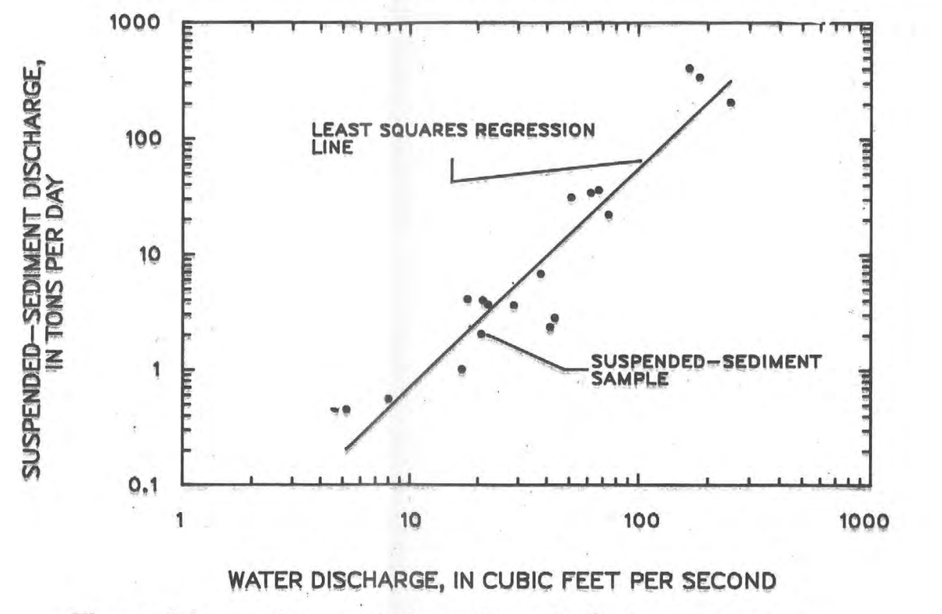

Figure 20.-- Suspended-sediment discharge versus water discharge for Running Slough (station 07026640).

Base from U.S. Geological Survey 1:24,000, Hornbeak, Ridgely, 1964; Clayton, 1966; Bondurant, Hubbard Lake, 1969, Samburg, Tiptonville, 1964, revised 1981; Mooring, Point Pleasant, 1971, Hickman, 1970, revised 1983

Hydrology by C.H. Robbins, 1985

Figure 1.--Location of Reelfoot Lake, streamflow-monitoring stations, lake-stage gages, observation wells, rainfall stations, and physiographic features.

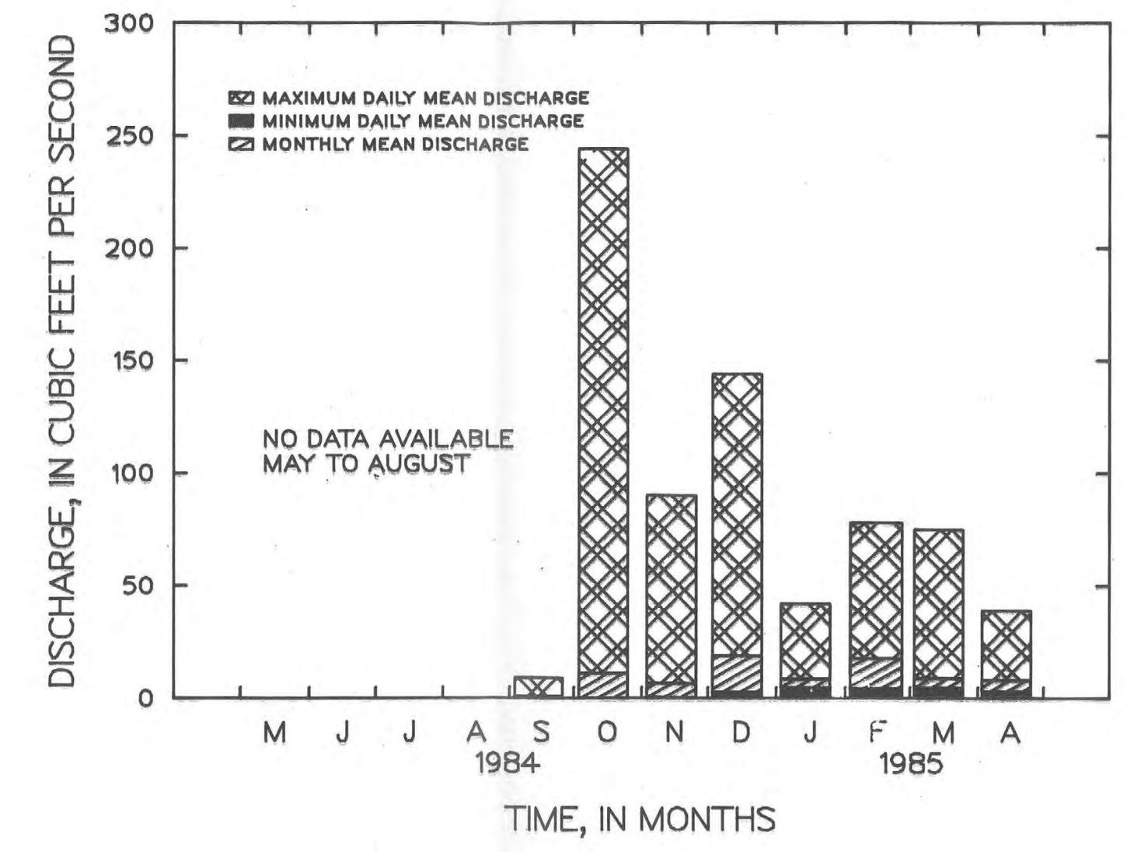

Figure 9.-- Surface-water inflow statistics for Indian Creek (station 07026795).

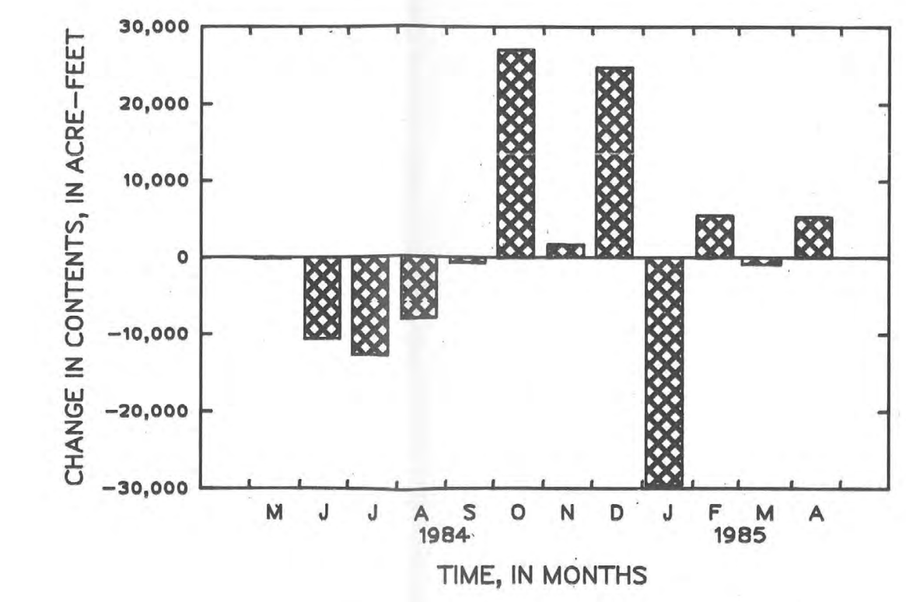

Figure 10.-- Net monthly change in contents of Reelfoot Lake.

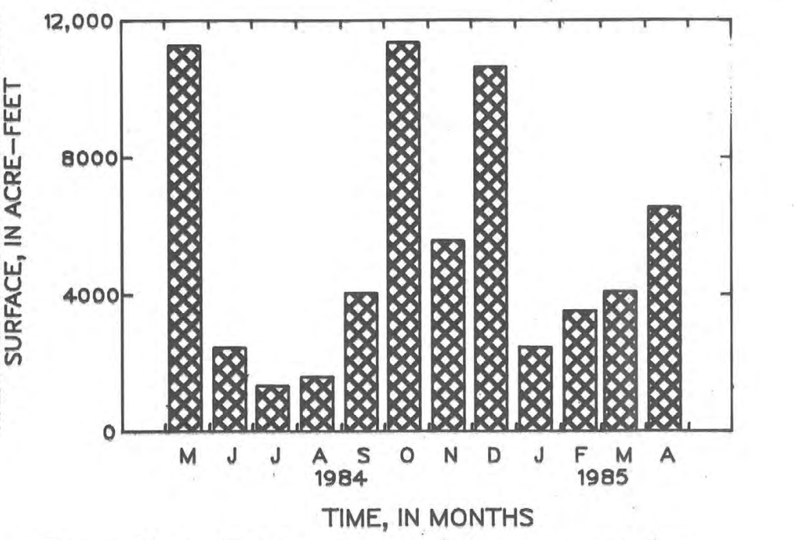

Figure 11.-- Total monthly rainfall accumulation on lake surface.

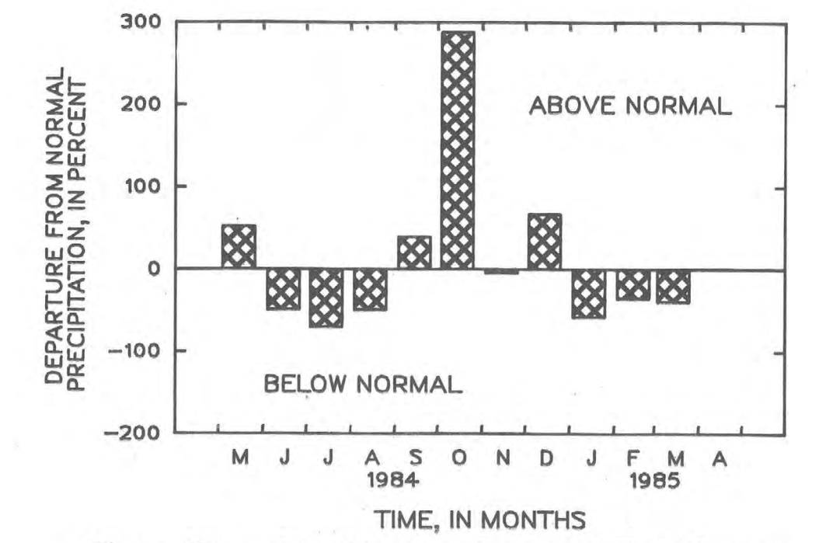

Figure 12.-- Monthly departure from the 30-year (1951-80) standard normal monthly precipitation at Reelfoot Lake.

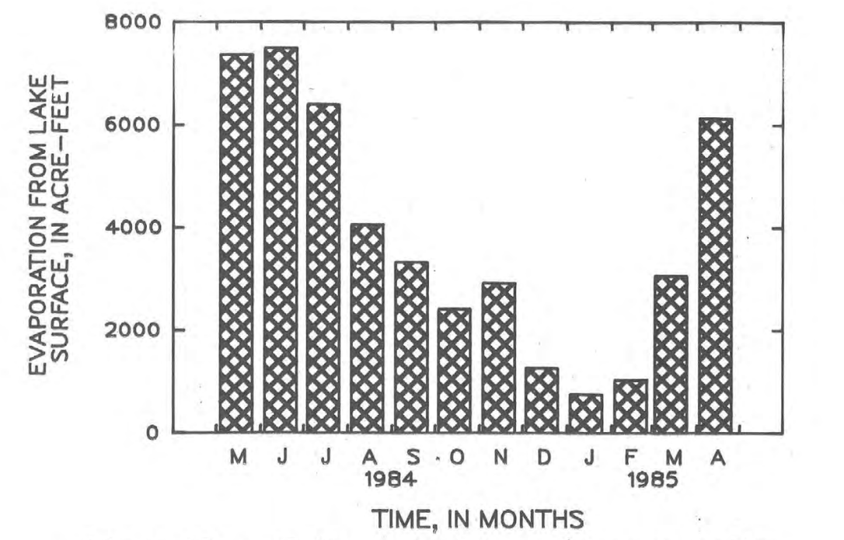

Figure 13.-- Estimated total monthly evaporation from lake surface.

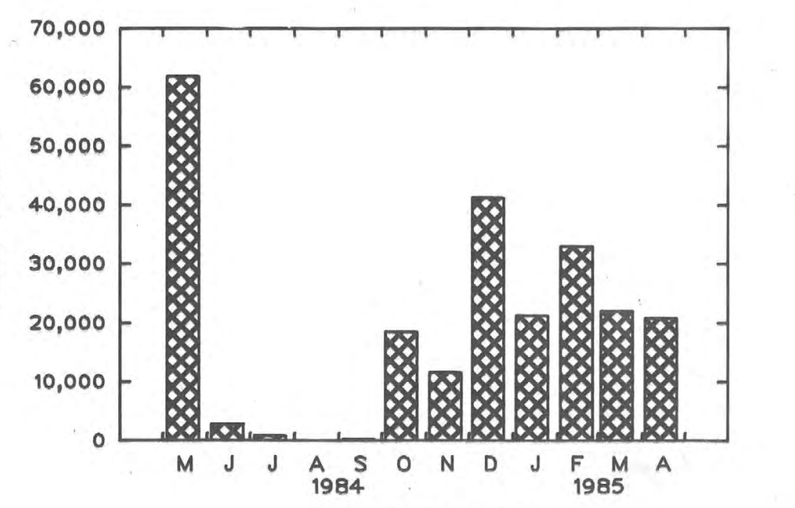

Figure 14.-- Estimated total monthly surface-water inflow to Reelfoot Lake.

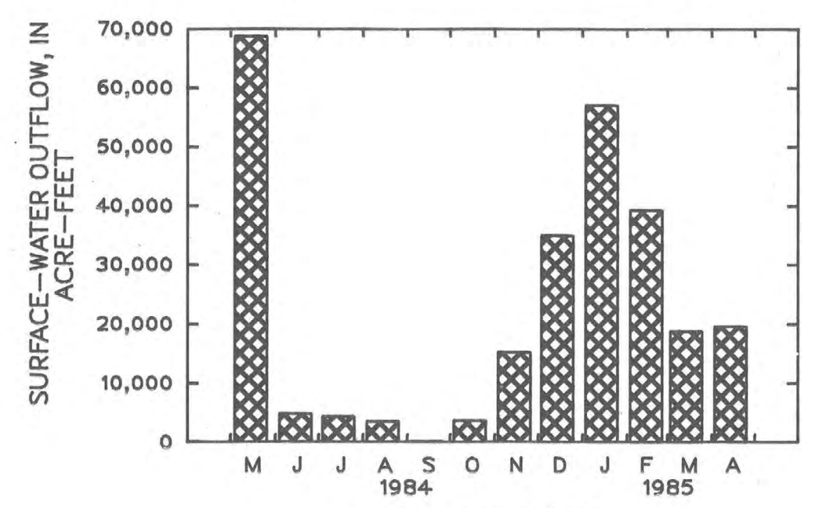

Figure 15.-- Total monthly surface-water outflow from Reelfoot Lake.

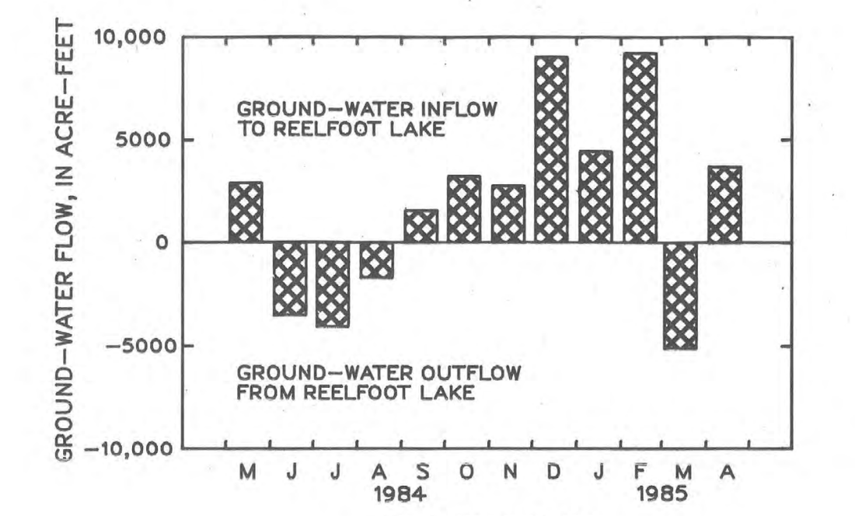

Figure 16.-- Net monthly ground-water flow at Reelfoot Lake.

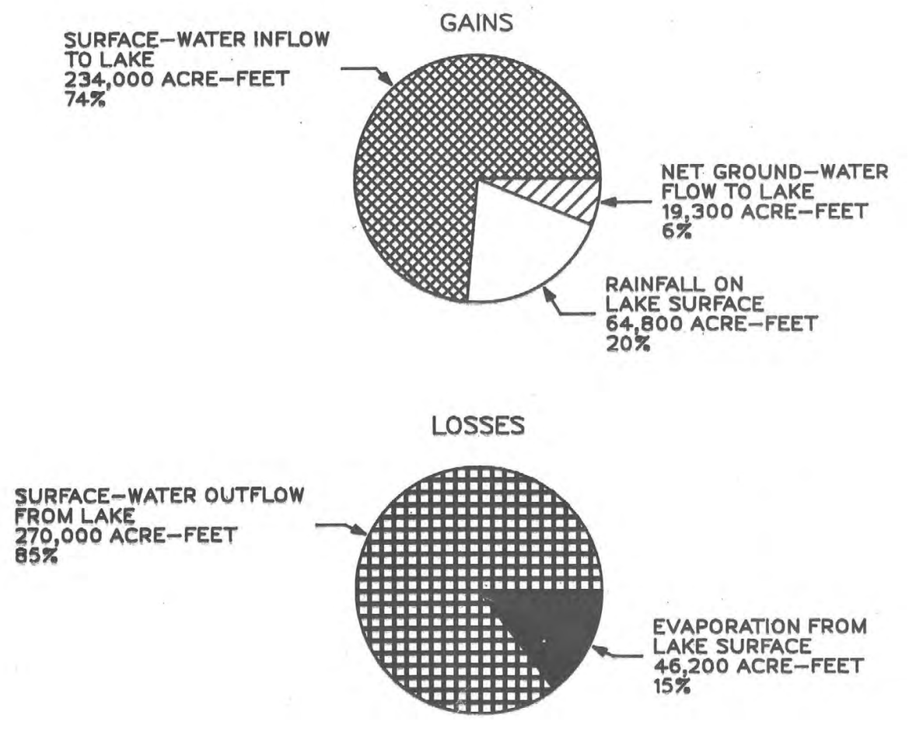

Figure 17.-- Relative contribution of each hydrologic component to the water budget for Reelfoot Lake May 1984-April 1985.

Table 1.--Pesticide concentrations in bottom material at streamflow monitoring stations

[in micrograms per kilogram, except as noted]

Station	Date	Time	Streamflow (ft³/s)	Specific conductance (µS/cm at 25°C)	Temperature (Deg C)	Aldrin	Chlordane	DDD	DDE	DDT	Dieldrin	Endosulfan	Endrin	Heptachlor	Heptachlor epoxide	Lindane	Methoxychlor	Mirex	Perthane	PCB	PCN
North Reelfoot Cr. at Highway 22, near Clayton, Tenn. (07026370)	5/30/84	1630	21	225	19.0	<.1	<1.0	<.1	.4	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<1.00	<1	<1.0
South Reelfoot Cr. near Clayton, Tenn. (07026400)	5/31/84	1310	27	280	16.5	<.1	<1.0	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<1.00	<1	<1.0
Running Slough near Ledford, Ky. (07026640)	5/30/84	1445	38	380	--	<.1	<1.0	<.1	12	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<1.00	<1	<1.0

WATER BUDGET AND ESTIMATED SUSPENDED-SEDIMENT INFLOW FOR REELFOOT LAKE, OBION AND LAKE COUNTIES, NORTHWESTERN TENNESSEE, MAY 1984-APRIL 1985.

By

Clarence H. Robbins

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