Water-Quality Assessment of Lakes Maumelle and Winona, Arkansas, 1991 Through 2003

Prepared in cooperation with
CENTRAL ARKANSAS WATER

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U.S. Department of the Interior
U.S. Geological Survey

Front Cover: View of Lake Maumelle from the summit of Pinnacle Mountain. Photograph provided by Richard Ates, Pinnacle Mountain State Park.

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By Joel M. Galloway and W. Reed Green

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Conversion Factors and Datum and Abbreviations

Multiply	By	To obtain
Length		
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
Area		
square kilometer (km^2)	0.3861	square mile (mi^2)
Volume		
cubic meter (m^3)	35.31	cubic foot (ft^3)
Flow rate		
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
Mass		
kilogram (kg)	2.205	pound avoirdupois (lb)
kilogram per year (kg/yr)	2.205	pound per year (lb/yr)

Degrees Celsius (° C) may be converted to degree Fahrenheit (° F) by using the following equation:
° F = 1.8(° C) + 32

In this report vertical coordinate information is referenced to the National Geodetic Vertical datum of 1929 (NGVD of 1929). Horizontal coordinate information is referenced to North American Datum of 1983 (NAD 83).

Constituent concentrations in water are in milligrams per liter (mg/L), micrograms per liter (µg/L), and colonies per 100 milliliters

mg/L, milligrams per liter

µg/L, micrograms per liter

mL, milliliters

Water-Quality Assessment of Lakes Maumelle and Winona, Arkansas, 1991 Through 2003

By Joel M. Galloway and W. Reed Green

Abstract

Lakes Maumelle and Winona are water-supply reservoirs for the Little Rock and North Little Rock metropolitan areas in central Arkansas. In addition to water supply, the reservoirs are used for recreation and fish and wildlife habitat. The purpose of this report is to describe the hydrology and water quality of Lakes Maumelle and Winona and their inflows from data collected by the U.S. Geological Survey in cooperation with Central Arkansas Water for calendar years 1991 through 2003.

The main inflows into Lakes Maumelle and Winona, the Maumelle River and Alum Fork Saline River, exhibited typical seasonal variability in streamflow with high flows usually occurring in the late fall, winter, and early spring, and low or no flow in the summer and early fall. The highest annual mean streamflow occurred in 1991 and the lowest annual mean streamflow occurred in 1992 for the Maumelle River and 1995 for the Alum Fork Saline River.

Water quality measured in Lakes Maumelle and Winona varied spatially and temporally. Although total phosphorus concentrations were substantially higher at the upper ends of the lakes than at the lower ends of the lakes, nitrogen and orthophosphorus concentrations were not significantly different among the sampling sites on each lake. The highest concentrations of nitrogen generally were measured in 1991 and from 1998 through 2003 at all of the sampling sites. The highest total phosphorus concentrations were measured from 1994 to 1996 and from 1998 to 2001 on Lake Maumelle and from 1993 to 1994 on Lake Winona. Total and dissolved organic carbon concentrations were similar among sites on each lake and the greatest concentrations were measured in 1996 and 1997 at all of the sites. The chlorophyll *a* concentrations varied seasonally, with the highest concentrations in October and November, but were relatively uniform spatially and annually in Lakes Maumelle and Winona for 1991 through 2003. Water clarity was greater at the lower ends of the lakes than at the upper ends. Secchi depth varied seasonally, with the greatest depth from July to September and the least depth during October through December. There was no apparent trend in Secchi depth over the entire sampling period.

The trophic state indices calculated from near-surface concentrations of total phosphorus and chlorophyll *a* for Lakes Maumelle and Winona indicated that they generally were oligotrophic although they fluctuated in time between mesotrophic and oligotrophic conditions.

Water-quality concentrations generally were less for the main inflow to Lake Winona, the Alum Fork Saline River, than for the Maumelle River, Bringle, Yount, and Reece Creeks, which flow into Lake Maumelle. Nutrient concentrations for the Maumelle and Alum Fork Saline Rivers remained fairly uniform from 1991 through 2003. Suspended-sediment concentrations generally were greatest at Bringle Creek. Concentrations of fecal streptococci measured at the Alum Fork Saline River were similar to concentrations measured at the Maumelle River, and fecal coliforms concentrations for the Alum Fork Saline River were approximately half the concentration measured at the Maumelle River. Bringle and Reece Creeks had greater concentrations of fecal coliforms and fecal streptococci than the Maumelle River, and Yount Creek had the lowest concentration of fecal streptococci among all the sites.

Annual loads of nutrients, dissolved organic carbon, and suspended sediment estimated for the Maumelle River and the Alum Fork Saline River were similar between sites and varied with time from 1991 through 2003. Annual loads were greatest in 1991 for the Maumelle and Alum Fork Saline Rivers and the least in 2000 for the Maumelle River and 1995 for the Alum Fork Saline River. Estimated loads also demonstrated seasonal trends with the highest daily loads in the winter and fall and lowest daily loads in the summer for both sites.

Annual yields of nutrients and dissolved organic carbon computed for the Maumelle River were similar to yields for the Alum Fork Saline River and suspended-sediment yields were less for the period of 1991 through 2003. The Alum Fork Saline River had a mean total nitrogen yield that was slightly greater than the mean total nitrogen yield for Maumelle River and more than three times greater than yields for selected undeveloped sites across the Nation.

Annual flow-weighted concentrations of nutrients and dissolved organic carbon for the Alum Fork Saline River generally were similar to those computed for the Maumelle River. Suspended-sediment flow-weighted concentrations for the Alum Fork Saline River were approximately one-half those computed

for the Maumelle River. The Alum Fork Saline River generally had flow-weighted nutrient concentrations similar to the mean flow-weighted concentrations for selected undeveloped basins across the Nation.

Introduction

Lakes Maumelle and Winona are water-supply reservoirs for the Little Rock and North Little Rock metropolitan areas in central Arkansas. In addition to water supply, the reservoirs are used for recreation and fish and wildlife habitat. As the urban and agricultural development of the basins has increased in the last 20 years, concerns about the sustainability of the quality of the water supply also have increased. Monitoring changes in the hydrology and water quality of the basin as the land use changes is critical to managing the resource.

A long-term water-quality database is important to accurately assess present water-quality conditions, trends, and sensitivity to change. Hydrologic and water-quality data have been collected on Lakes Maumelle and Winona and their inflows from 1991 through 2003 by the U.S. Geological Survey (USGS) in cooperation with Central Arkansas Water (CAW), the utility that owns and operates the two water-supply reservoirs.

Purpose and Scope

The purpose of this report is to describe the hydrology and water quality of Lakes Maumelle and Winona and their inflows from calendar years 1991 through 2003. Samples were collected at four locations in Lake Maumelle and at three locations in Lake Winona. Samples also were collected at four inflow sites to Lake Maumelle and one inflow site to Lake Winona. Water samples were analyzed for several field parameters and constituents, including specific conductance, pH, water temperature, dissolved oxygen, nutrients, organic carbon, suspended sediment, chlorophyll *a*, Secchi depth, and fecal indicator bacteria. Annual and seasonal loads of nutrients, dissolved organic carbon, and suspended sediment were estimated for the main inflows into Lakes Maumelle and Winona, the Maumelle River at Williams Junction, Arkansas (Lake Maumelle), and the Alum Fork Saline River near Reform, Arkansas (Lake Winona). Yields and flow-weighted concentrations were calculated from estimated annual loads and compared with selected sites representing undeveloped basins across the Nation and one site representing a developed basin in Arkansas.

Study Area Description

Lakes Maumelle and Winona are located in central Arkansas, west of the city of Little Rock (fig. 1). Construction of Lake Maumelle on the Maumelle River was completed in 1956 (Green, 2001). Lake Maumelle contains 2.70 x 10^8 m^3 of water at the spillway elevation (88.4 m above NGVD of 1929) and has 2.31 x 10^8 m^3 of usable water (Green, 2001). The surface area of Lake Maumelle at the spillway elevation is approximately 36 km^2, the maximum length of the reservoir is 19 km, and maximum depth is 14 m with an average depth of 7.5 m. The reservoir has a drainage area of 355 km^2 at the dam. The Lake Maumelle watershed consists mainly of forested land (91 percent, not including the reservoir area) and pasture (8 percent, not including the reservoir area). The land use for the Maumelle River watershed upstream from the reservoir is approximately 98 percent forested land (fig. 2).

Construction of Lake Winona on the Alum Fork Saline River was completed in 1938 (Green, 1994). Lake Winona contains 5.10 x 10^7 m^3 at the spillway elevation (225.6 m above NGVD of 1929) with 4.69 x 10^7 m^3 of usable water (Green, 1994). The surface area of Lake Winona at the spillway elevation is 4.1 km^2. The maximum length of Lake Winona is 7.2 km, with a maximum depth of 30 m and an average depth of 10.6 m. Lake Winona has a drainage area of 115 km^2 that is mainly forested land (94 percent, not including the reservoir area) (fig. 2). The Alum Fork Saline River above the reservoir has a watershed consisting of nearly 100 percent forested land.

Previous Investigations

USGS and CAW have collected reservoir elevation, streamflow, and water-quality data for Lakes Maumelle and Winona and the main inflows, the Maumelle River and Alum Fork Saline River, respectively, since 1989 as part of an ongoing monitoring program. Data are stored in the USGS National Water Information System database and published annually (Moore and others, 1992; Porter and others, 1993; Westerfield and others, 1994; Evans and others, 1995; Porter and others, 1996; 1997; 1998; 1999; 2000; 2001; 2002; Brossett and Evans, 2003; Evans and others, 2004). Hydrologic data collected in Lakes Maumelle and Winona from May 1989 to October 1992 (Green and Louthian, 1993) were used to assess water quality (Green, 1994). Green (1994) concluded that the water quality of Lakes Maumelle and Winona and the Maumelle River and Alum Fork Saline River are more pristine than other reservoirs and streams in the region. Green (2001) concluded that nutrient concentrations in Lake Maumelle and the Maumelle River were one to two orders of magnitude lower than estimates of national background nutrient concentrations.

Green (2001) developed and calibrated a hydrodynamic and water-quality model of Lake Maumelle to simulate the temperature, dissolved oxygen, nutrient, and algal biomass dynamics in the reservoir from 1991 to 1992. The model also was used to evaluate reservoir response to a spill of a conservative material at the upper end of Lake Maumelle. The model simulated the release of a nearby nursery pond into a tributary of Lake Maumelle (Green, 2001). Simulation results showed elevated concentrations of some nutrients, organic carbon, iron, and manganese during simulated releases in 1991 through 1994 and 1996 (Green, 1998). In addition, model simulations of the algal response to increases of nitrogen and phosphorus loads demon-

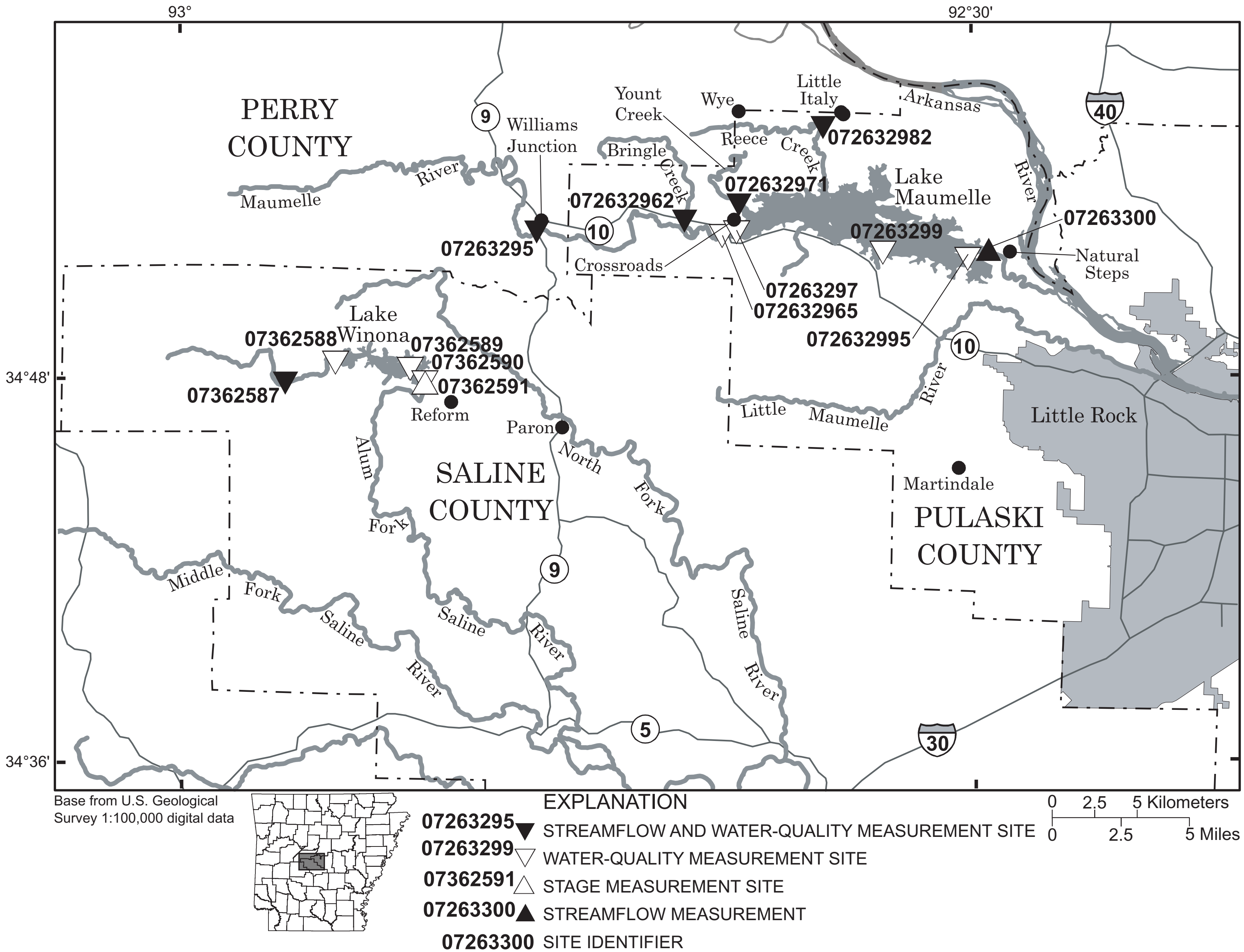


Figure 1. Location of Lakes Maumelle and Winona.

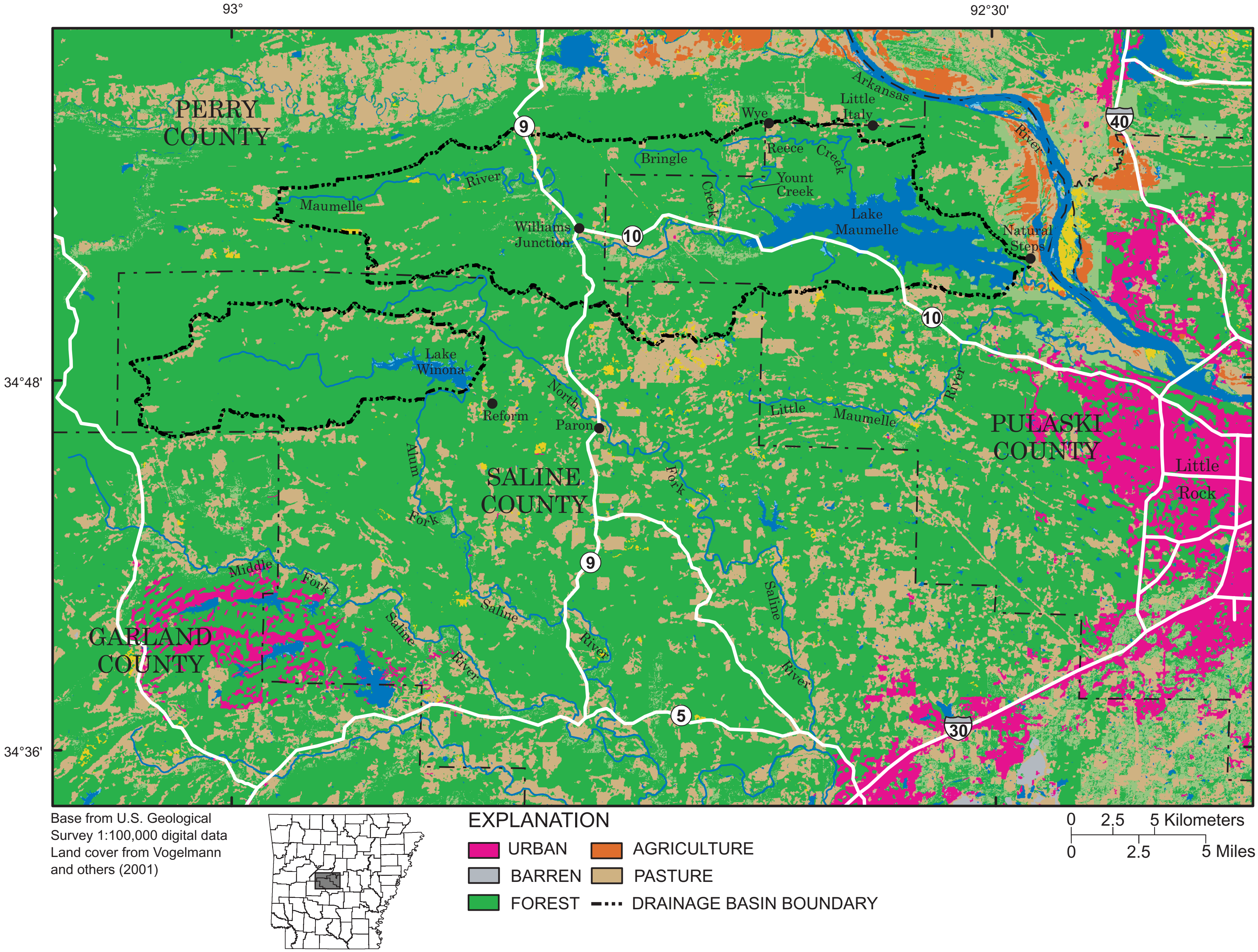


Figure 2. Land use in the Lakes Maumelle and Winona watersheds.

strated phosphorus limited conditions in Lake Maumelle (Green, 2001).

Pomes and others (1997; 1999) evaluated the sources of disinfection byproduct precursors in Lakes Maumelle and Winona. Aquatic humic substances in water that generate potentially harmful disinfection byproducts and dissolved organic carbon concentrations were found to be higher in Lake Winona than in Lake Maumelle and likely originate from deciduous leaf litter, twigs, and grass leachates (Pomes and others, 1997; 1999).

Methods

Streamflow and Lake Volume

Stream stage was measured continuously at the main inflow to Lake Maumelle, the Maumelle River at Williams Junction, Arkansas (07263295); at Lake Maumelle dam near Natural Steps, Arkansas (07263300); the main inflow to Lake Winona, the Alum Fork Saline River near Reform, Arkansas (07362587); and at Lake Winona dam at Reform (07362591) (fig. 1). Stage and instantaneous discharge were measured to compute the continuous streamflow from stage-discharge rating curves using methods described in Rantz and others (1982) for the Maumelle River and Alum Fork Saline River inflows to Lakes Maumelle and Winona. The stage data from Lake Maumelle dam and Lake Winona dam were used to compute daily mean lake volume from stage-capacity curves (Central Arkansas Water, written commun., 1990).

Lake Sampling

Fixed sampling sites were established along the downstream gradient of Lakes Maumelle and Winona. Sample sites in the lakes were located along the original stream channel, the deepest location within the lake cross section. The four sampling sites on Lake Maumelle were west of Highway 10 Bridge (upper end; 072632965), east of Highway 10 Bridge (upper end; 07263297), near Little Italy (middle; 07263299), and near Natural Steps (lower end; 072632995) (fig. 1 and table 1). The three sampling sites on Lake Winona were downstream from Stillhouse Branch (upper end; 07362588), downstream from Gillis Branch (middle; 07362589), and at Reform (lower end; 07362590) (fig. 1 and table 1). Samples were collected from 1991 to 1998 using a 1-m by 5-cm bailer to collect depth-integrated composite samples representing the entire water column when isothermal conditions were present. During thermal stratification, depth-integrated samples were collected representing the epilimnion (near-surface) and hypolimnion (near-bottom). Samples were collected after 1998 using a peristaltic pump, instead of a bailer, in the epilimnion and hypolimnion during thermal stratification, and only in the epilimnion during isother-

Table 1. Water-quality and streamflow sites for Lakes Maumelle and Winona.

Station number	Station name	Station type	Period of data
07263295	Maumelle River at Williams Junction	Discharge, Water Quality	1989 through 2003
072632962	Bringle Creek near Crossroads	Water Quality	1998, 2000, 2003
072632965	Lake Maumelle west of Highway 10 Bridge	Water Quality	1991 through 1992, 2000, 2002 through 2003
07263297	Lake Maumelle east of Highway 10 Bridge	Water Quality	1989 through 2000, 2002 through 2003
072632971	Yount Creek near Martindale	Water Quality	1998, 2000, 2003
072632982	Reece Creek near Little Italy	Water Quality	1998, 2000, 2003
07263299	Lake Maumelle near Little Italy	Water Quality	1989 through 2000, 2002 through 2003
072632995	Lake Maumelle near Natural Steps	Water Quality	1989 through 2000, 2002 through 2003
07263300	Maumelle River at Maumelle Dam near Natural Steps	Discharge, Lake Stage	1989 through 2003
07362587	Alum Fork Saline River near Reform	Discharge, Water Quality	1989 through 2003
07362588	Lake Winona downstream from Stillhouse Branch	Water Quality	1995 through 2000, 2002 through 2003
07362589	Lake Winona downstream from Gillis Branch	Water Quality	1995 through 2000, 2002 through 2003
07362590	Lake Winona at Reform	Water Quality	1989 through 2000, 2002 through 2003
07362591	Lake Winona Dam at Reform	Lake Stage	1989 through 2003

mal conditions. Water-quality samples were analyzed for nutrients (dissolved orthophosphorus, total phosphorus, total ammonia plus organic nitrogen, dissolved ammonia, and dissolved nitrite plus nitrate), total and dissolved organic carbon, and chlorophyll *a*. All sample analyses were conducted at USGS laboratories following USGS procedures (Fishman, 1993). Field parameters (water temperature, dissolved-oxygen concentration, pH, and specific conductance) were measured at various depths. When thermal stratification was present, measurements were made at depth intervals where the change in temperature was 1 °C or at 0.3-m intervals, whichever was greater. Secchi depth also was measured at each site as an indicator of water clarity.

Samples were collected at various time intervals in Lakes Maumelle and Winona from 1989 through 2003 (table 1). Samples were collected from Lake Maumelle east of Highway 10 Bridge, near Little Italy, and near Natural Steps and Lake Winona near Reform several times each year from 1989 through 2003. A period of more intensive sampling was conducted on Lake Maumelle in 1991 and 1992 to develop a hydrodynamic and water-quality model of the reservoir (Green, 2001). Samples were collected from Lake Maumelle west of Highway 10 Bridge in 1991, 1992, 2000, 2002, and 2003. Sample sites downstream from Stillhouse Branch and downstream from Gillis Branch on Lake Winona were collected only from 1995 through 2000 and 2002 through 2003. Samples were not collected at any of the sites on Lakes Maumelle and Winona during 2001. Although data has been collected since 1989, only data for 1991 through 2003 are described in this report because different sampling methods were used prior to 1991.

Inflow Sampling

Water-quality samples were collected from fixed sampling sites at the Maumelle River at Williams Junction (07263295) and the Alum Fork Saline River near Reform (07362587) from May 1989 to December 2003. Samples also were collected from three smaller tributaries to Lake Maumelle in 1998, 2000, and 2003; Bringle Creek near Crossroads (072632962), Yount Creek near Martindale (072632971), and Reece Creek near Little Italy (072632982) (fig. 1 and table 1). Water-quality samples were collected following equal-width increment methods using depth-integrated samplers. Samples were collected and processed using protocols described in Wilde and Radke (1998), Wilde and others (1998a, 1998b, 1998c, 1999a, and 1999b), and Meyers and Wilde (1999). Samples were analyzed for nutrients and dissolved organic carbon by the USGS Ocala Water Quality and Research Laboratory in Ocala, Florida, following procedures described in Fishman (1993). Suspended sediment was analyzed by the USGS Missouri District laboratory following procedures described in Guy (1969). Fecal indicator bacteria (fecal coliform and fecal streptococci) were analyzed in the field by USGS personnel following procedures in Meyers and Wilde (1999). Field parameters, including water temperature, dissolved-oxygen concentration, pH, and specific conductance, also were measured with each sample collected. Water-quality samples generally were collected four times a year from 1991 through 2003 and during high-flow events in 1991, 1992, 1996, 2002, and 2003 at the Maumelle River and Alum Fork Saline River. Samples were collected only during high-flow events at Bringle, Yount, and Reece Creeks.

Data Analysis

Streamflow and water-quality data (inflow and lake samples) were analyzed or summarized using several statistical and graphical techniques. Boxplots and time-series plots were used to compare concentrations of selected water-quality constituents among sites for data collected from 1991 through 2003. Concentrations reported as less than a laboratory reporting limit were converted to one-half the reporting limit for preparation of boxplots, calculation of total nitrogen concentrations (the sum of nitrite plus nitrate and ammonia plus organic nitrogen), and statistical analyses. The Wilcoxon rank sum test (Helsel and Hirsch, 1992) was used to test for differences in selected water-quality constituents between sites. The Wilcoxon rank sum test is a nonparametric test that determines the probability (p) that the mean of a dataset is similar to the mean of another dataset within a 95 percent confidence interval. A locally weighted smooth (LOWESS) line was included in scatter plots of constituent concentrations with time. The LOWESS line is a locally weighted polynomial regression, where at each point along the line, a low-degree polynomial is fit to a subset of the data. The polynomial is fit using weighted least squares, giving more weight to points near the point whose response is being estimated and less weight to points further away.

Trophic State Indices

One method of classifying the water quality of a lake is by computing water-quality or Trophic State Index (TSI) values based on near-surface total phosphorus and chlorophyll *a* concentrations (Carlson, 1977). TSI values based on phosphorus concentrations (TSI_P) and chlorophyll *a* concentrations (TSI_C) were computed for each sampling by means of equations 1-3:

$$TSI_P = 10[6\text{-}\log_2 0.048/\text{total phosphorus (in milligrams per liter)}] \tag{1}$$

$$TSI_C = 10[6\text{-}\log_2 7.7/(\text{chlorophyll } a)^{0.68} \text{ (in micrograms per liter)}] \tag{2}$$

Trophic state indices can range on a gradual scale from 0 to 100. Trophic state indices less than 30 are commonly considered oligotrophic conditions, indices ranging from 50 to 70 are indicative of eutrophic conditions, and values greater than 70 are commonly considered hypereutrophic conditions (Wetzel, 2001).

Loads and Yields

Water-quality constituent loads and yields were calculated from concentrations and streamflow measured at the main inflow sites including the Maumelle River at Williams Junction and the Alum Fork Saline River near Reform. The S-LOAD-EST computer program (David Lorenz, U.S. Geological Survey, written commun., 2003) was used to estimate annual and seasonal constituent loads at the two sites for 1991 through 2003. Constituent load (*L*) is a function of the volumetric rate of water passing a point in the stream (*Q*) and the constituent concentration within the water (*C*). Regression methods used to estimate constituent loads use the natural logarithm (ln) transformed relation between *Q* and *C* to estimate daily *C* (or *L*) of the constituent. The regression method can account for non-normal data distributions, seasonal and long-term cycles, censored data, biases associated with using logarithmic transformations, and serial correlations of the residuals (Cohn, 1995). The regression method uses discrete water-quality samples often collected over several years and a daily streamflow hydrograph. The complete model includes relations between natural logarithmic-transformed *L* and *Q*, time (*T*) and seasonality:

$$\ln(L) = \beta_o + \beta_1 \ln Q) + \beta_2 \ln(Q^2) + \beta_3 T + \beta_4 T^2 + \beta_5 \sin(2\pi T) + \beta_6 \cos(2\pi T) \quad (3)$$

where L represents the constituent load, in kilograms per day;
β_o is the regression constant;
β_1, β_2, β_3, β_4, β_5 and β_6 are regression coefficients;
Q represents daily streamflow, in cubic meters per second; and
T represents decimal time.

Substantial relations were not found between L and Q^2, seasonality, and time for the data sets, and were not included in the regression analysis described in this report. Therefore, only the relations between natural logarithmic-transformed L and Q were used to estimate annual and seasonal constituent loads:

$$\ln(L) = \beta_o + \beta_1 \ln(Q) \quad (4)$$

Transforming the results of the model from logarithmic space to real space was accomplished using two methods; an adjusted maximum likelihood estimator (AMLE) (Cohn and others, 1992) and a least absolute deviation (LAD) (David Lorenz, U.S. Geological Survey, written commun., 2003). The AMLE method was used to transform the results if the constituent had censored values and the LAD method was used if no censored values were included in the data or if outliers in the residuals were present.

Annual yields (kilograms per square kilometer) were calculated from estimated annual loads at each site. The yield was calculated by dividing the annual load (kilograms per year) by the drainage area contributing flow to the location of the sampling site (square kilometers).

Flow-Weighted Concentrations

Flow-weighted concentrations also were calculated from the estimated annual loads. Flow-weighted concentrations were calculated by dividing the annual load by the annual mean streamflow, and applying appropriate conversion factors for dimensional units:

$$C_{FW} = \left[\frac{L}{Q_{annual}}\right] \times 3.171 \times 10^{-5} \quad (5)$$

where C_{FW} represents the flow-weighted concentration, in milligrams per liter,
L represents the annual constituent load in kilograms per year, and
Q_{annual} represents the annual mean streamflow, in cubic meter per second.

Water-Quality Assessment

Hydrologic Conditions

Hydrologic conditions were monitored at the main inflows and outflows of Lakes Maumelle and Winona. Streamflow was continuously monitored at a station on the main inflow, the Maumelle River, upstream from Lake Maumelle at Williams Junction (07263295) (fig. 1). Continuous lake stage was recorded and reservoir outflow was measured at a station at Lake Maumelle dam at Natural Steps (07263300). Continuous streamflow was recorded upstream from Lake Winona at a station on the main inflow, the Alum Fork Saline River near Reform (07362587). Continuous lake stage was recorded at Lake Winona dam at Reform (07362591).

Lake Maumelle

At the station at Williams Junction, the Maumelle River has a drainage area of 119.4 km^2, which accounts for approximately 37 percent of the Lake Maumelle watershed at the dam. The Maumelle River exhibits typical seasonal variability with high-flows usually occurring in the winter (January through March), and spring (April through June), and low or no flow in the summer (July through September) and fall (October through December) (fig. 3). The mean annual streamflow for 1991 through 2003 for the Maumelle River at Williams Junction was 1.64 m^3/s. The highest annual mean streamflow for the period of 1991 through 2003 was 2.51 m^3/s in 1991 and the lowest annual mean streamflow was 1.11 m^3/s in 1992 (fig. 3). The maximum instantaneous streamflow for the Maumelle River for the period of record (October 1989 through December 2003) was 183 m^3/s that occurred on December 3, 1993 (Brossett and Evans, 2003).

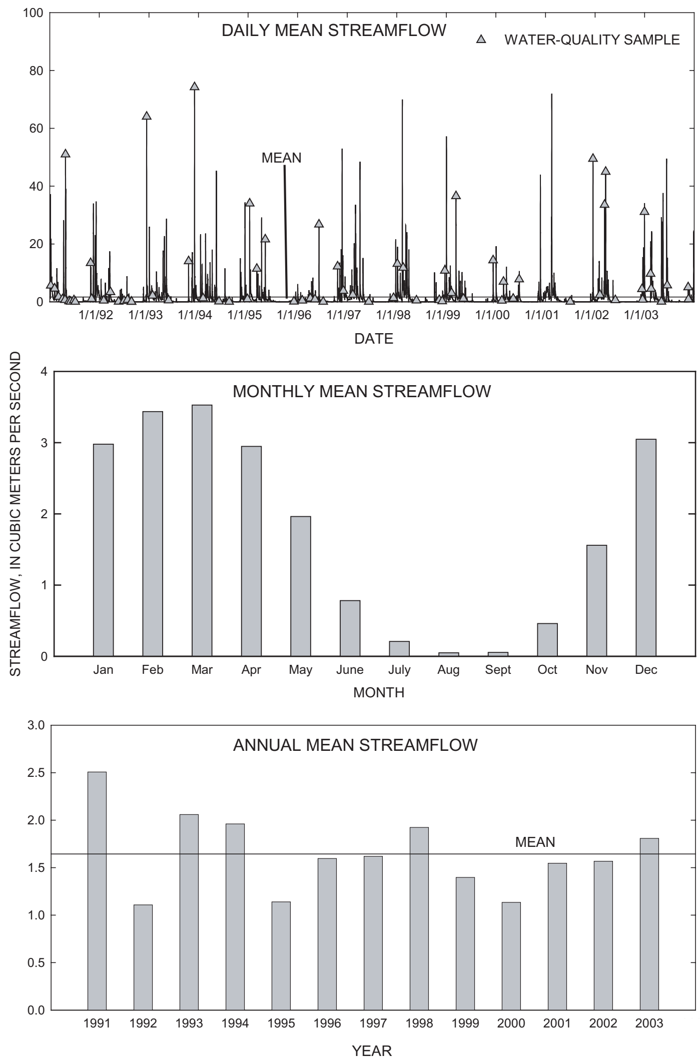


Figure 3. Daily, monthly, and annual mean streamflow, and water-quality sampling times for the Maumelle River at Williams Junction, Arkansas, 1991 through 2003.

Much of the total streamflow in the Maumelle River during 1991 through 2003 occurred during relatively few days (fig. 4). For example, 50 percent of the total streamflow (which delivers most of the constituent load to the reservoir) passed the station in about 18 days (5 percent of the year) in a typical year.

The water-level elevation (stage) and volume in Lake Maumelle demonstrated seasonal fluctuations resulting from seasonal inflows (fig. 5). Maximum volumes generally occurred in the fall and winter and minimum volumes occurred in late summer and fall. Lake volumes ranged from 224 million m^3 (1.2 m below the spillway elevation) to 299 million m^3 (0.8 m above the spillway elevation). The mean lake volume was 262 million m^3 with a corresponding stage of 88.2 m above NGVD of 1929 (0.2 m below the spillway elevation).

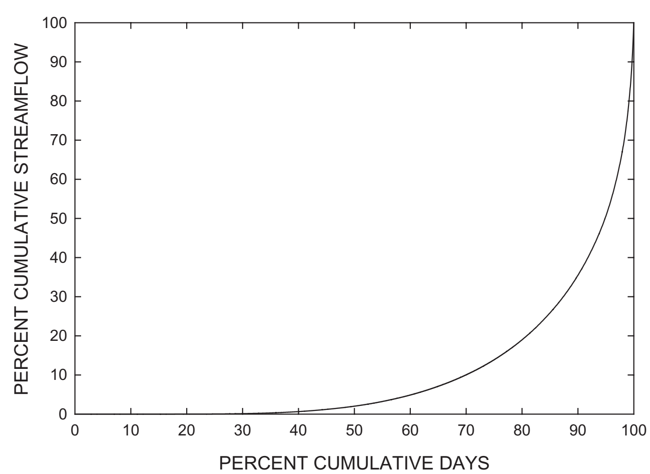


Figure 4. Flow accumulation curve for the Maumelle River at Williams Junction, Arkansas, 1991 through 2003.

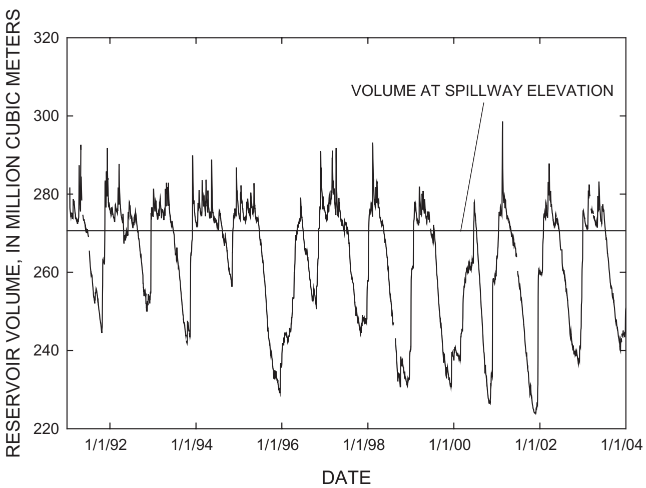


Figure 5. Daily mean reservoir volumes for Lake Maumelle from stage recorded at Lake Maumelle at Natural Steps, Arkansas (07263300), 1991 through 2003.

Lake Winona

The Alum Fork Saline River upstream from Lake Winona has a drainage area of 69.9 km^2, or approximately 65 percent of the Lake Winona watershed at the dam. Similar to the Maumelle River, the Alum Fork Saline River demonstrates seasonal fluctuations with high flows in the late fall, winter, and early spring and low or no flows in the summer and early fall (fig. 6). The mean annual streamflow for the Alum Fork Saline River near Reform was 1.28 m^3/s for 1991 through 2003. The highest annual mean streamflow was 2.32 m^3/s that occurred in 1991 and the lowest annual mean streamflow was 0.91 m^3/s in 1995 (fig. 6). The maximum instantaneous flow recorded at the Alum Fork Saline River for the period of record (October 1989 through December 2003) was 382 m^3/s on December 21, 1990 (Brossett and Evans, 2003).

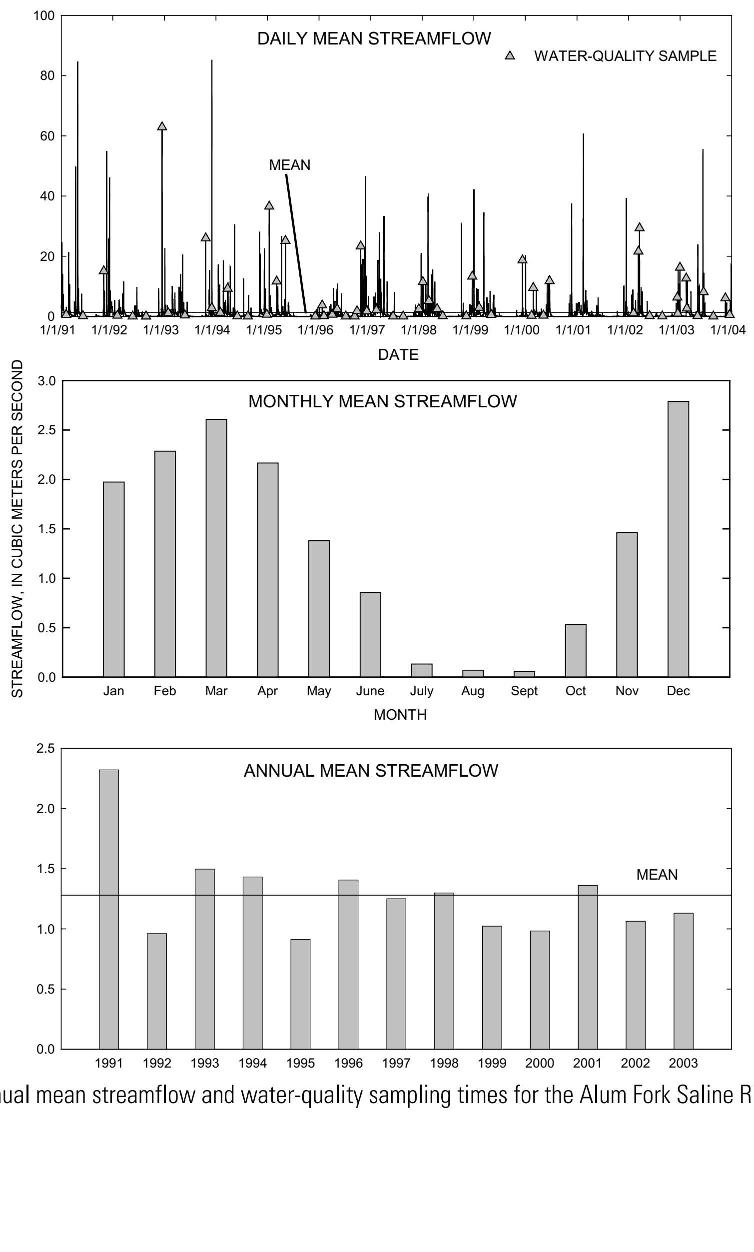


Figure 6. Daily, monthly, and annual mean streamflow and water-quality sampling times for the Alum Fork Saline River near Reform Arkansas, 1991 through 2003

Similar to the Maumelle River, much of the total streamflow in the Alum Fork Saline River during 1991 through 2003 occurred during relatively few days (fig. 7). Fifty percent of the streamflow passed the station in 193 days (or 4 percent of the 12-year period). This suggests that annually the upper 50 percent of the streamflow passes the station in about 15 days (4 percent of the year) in a typical year.

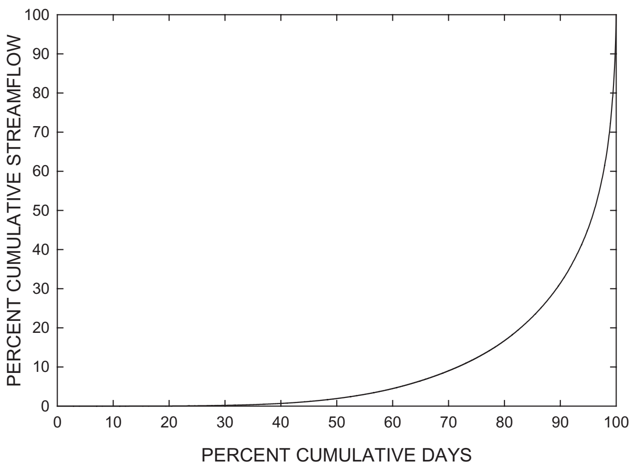


Figure 7. Flow accumulation curve for the Alum Fork Saline River near Reform, Arkansas, 1991 through 2003.

Seasonal fluctuations in the water level and volume occurred in Lake Winona from 1991 through 2003 as a result of seasonal fluctuations of the inflows and drinking-water withdrawals (fig. 8). Lake volumes ranged from 32.8 million m^3 (4.3 m below the spillway elevation) to 53.9 million m^3 (0.6 m above the spillway elevation). On average, the reservoir volume for the period was 46.1 million m^3, with a stage of 224.4 m above NGVD of 1929 (1.1 m below the spillway elevation).

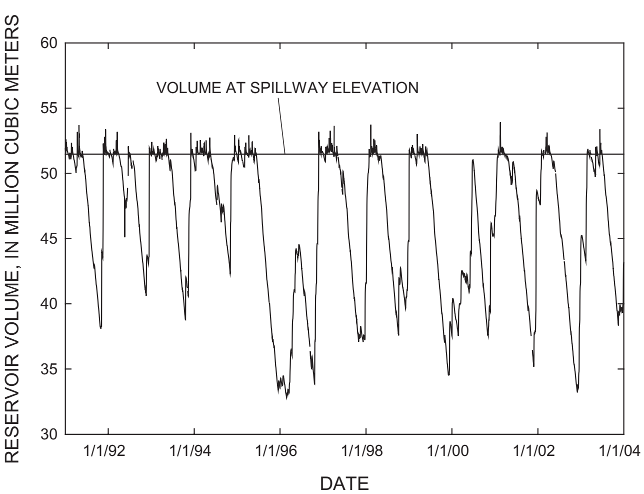


Figure 8. Daily mean reservoir volumes for Lake Winona from stage recorded at Lake Winona dam at Reform (07362591), Arkansas, 1991 through 2003.

Lake Water Quality

This section describes the water-quality conditions monitored in Lakes Maumelle and Winona from 1991 through 2003 (excluding 2001) pertaining to temperature, dissolved oxygen, nutrients, chlorophyll *a*, water clarity, and trophic status. Data were collected and analyzed for samples collected at four sites on Lake Maumelle and three sites on Lake Winona.

Lake Maumelle

Lake Maumelle was sampled at three locations from 1991 through 2003 (excluding 2001) including sites east of Highway 10 Bridge (07263297), near Little Italy (07263299) and near Natural Steps (072632995) (fig. 1). Lake Maumelle west of Highway 10 Bridge (072632965) was sampled only in 1991, 1992, 2000, and 2003.

Temperature

The temperature distribution in Lake Maumelle exhibits typical seasonal cycles of lakes and reservoirs located within similar latitudes (Wetzel, 2001) (fig. 9). Lake Maumelle is a monomictic system, in which thermal stratification occurs annually during the summer and complete mixing occurs in the fall. Isothermal conditions exist throughout the winter and early spring.

Thermal stratification begins in the lower end of Lake Maumelle during May and June and generally becomes established by July (fig. 9). Thermal stratification is fully developed by late summer. Stratification occurs as the layer of water near the surface heats up during the spring, more rapidly than the heat is distributed throughout the water column, causing temperature or density gradients to develop. The warm, less dense water remains near the surface and the cooler, more dense water remains near the bottom. As a result of the density gradients, thermal resistance to mixing becomes established, physically isolating the epilimnion or mixing layer from the hypolimnion (Green, 1994). The thermocline usually is established at approximately 6 to 9 m depth in Lake Maumelle, with bottom temperatures ranging from 16 to 20 °C in the hypolimnion (fig. 9).

Dissolved-Oxygen Concentrations

The distribution of dissolved oxygen in Lake Maumelle exhibits seasonal changes mainly because of the thermodynamics in the hypolimnion of the reservoir (fig. 10). Because the hypolimnion is isolated from the surface during periods of thermal stratification, reaeration from surface mixing is eliminated and very little, if any, oxygen input from photosynthetic activity from algae occurs below the thermocline (Green, 1994). Dissolved-oxygen concentrations during the winter remain uniform and near saturation levels because of complete water column mixing and isothermal conditions. As thermal stratification becomes established, dissolved-oxygen concentrations

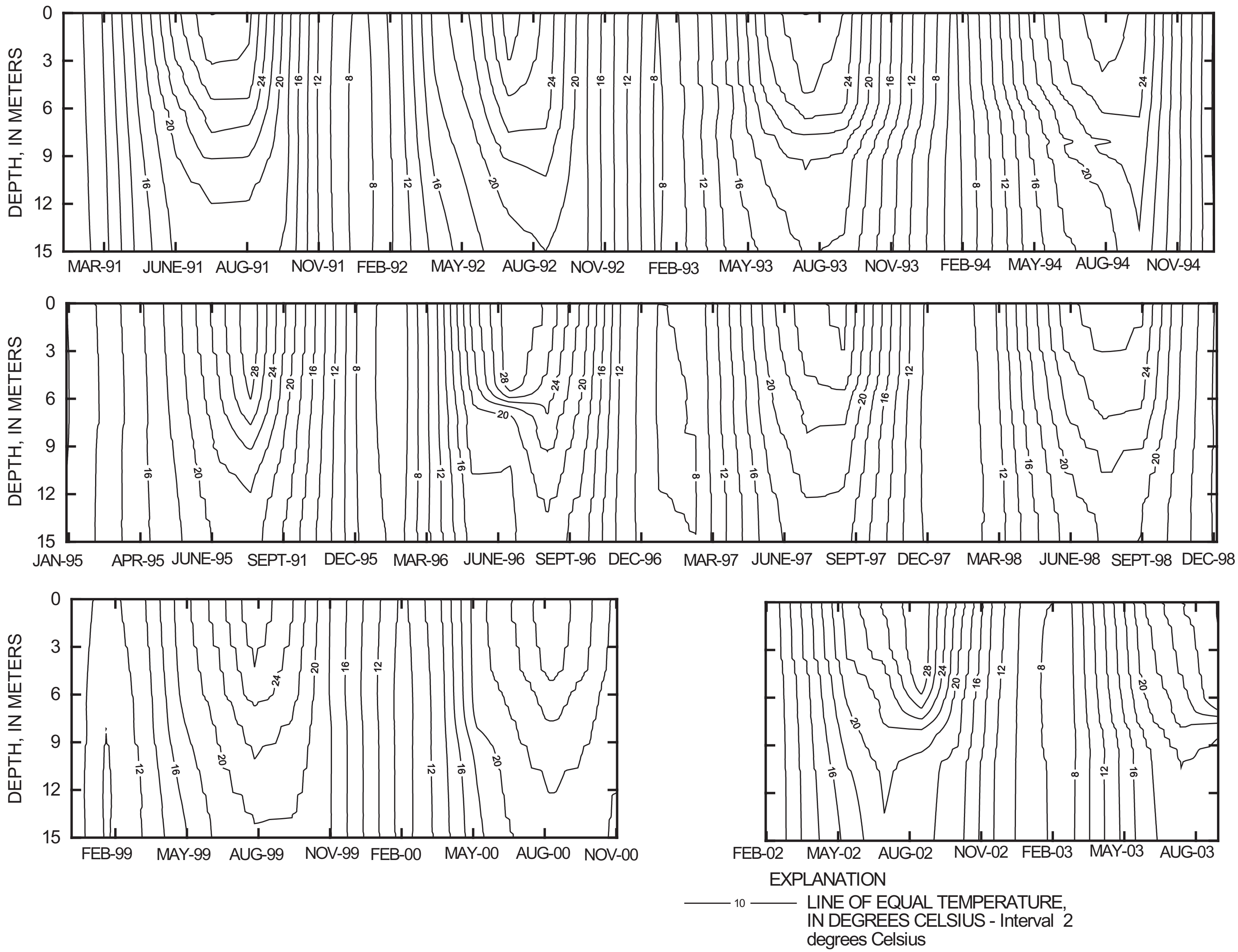


Figure 9. Distribution of temperature with depth and time in Lake Maumelle near Natural Steps, Arkansas.

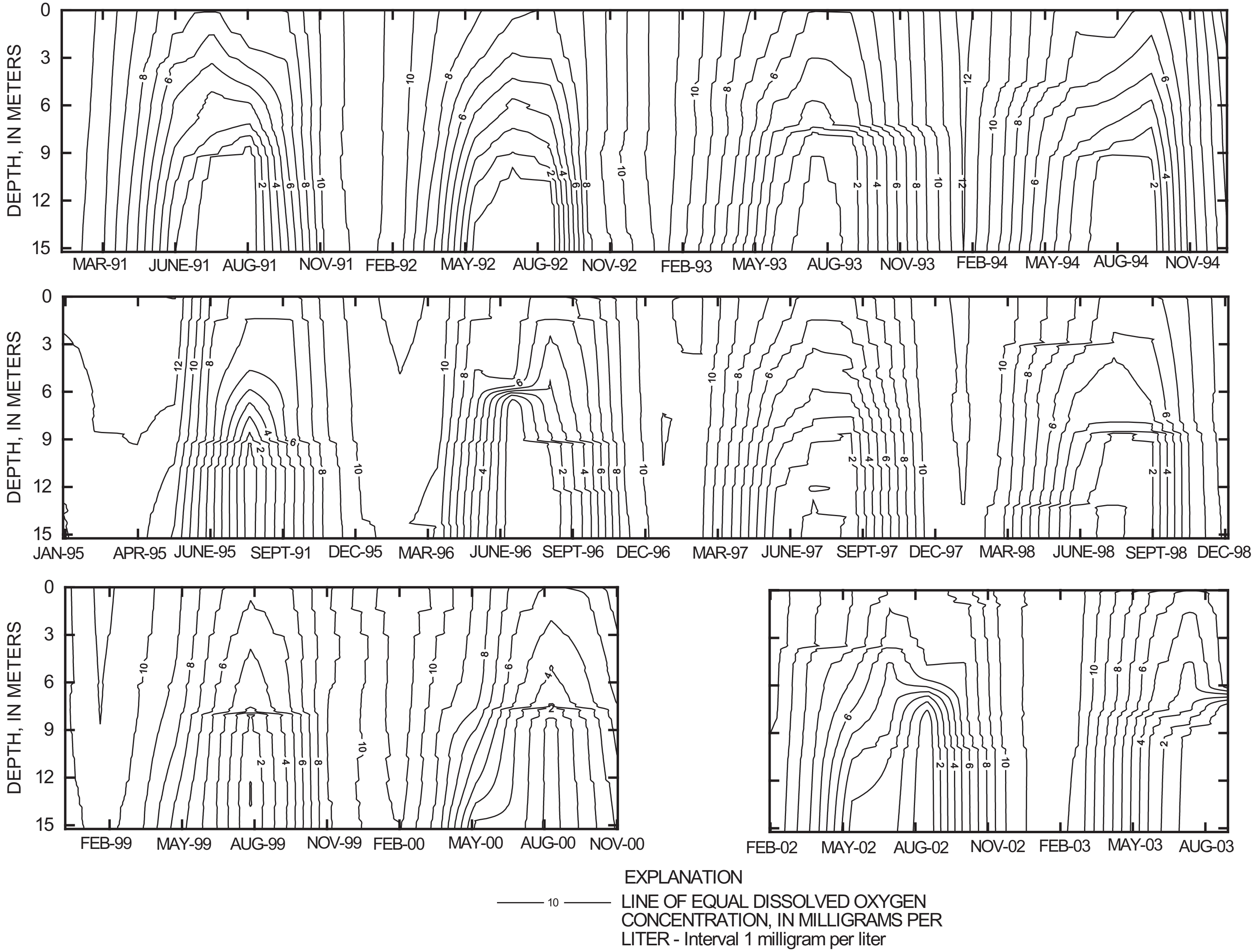


Figure 10. Distribution of dissolved oxygen concentration with depth and time in Lake Maumelle near Natural Steps, Arkansas.

in the hypolimnion decrease because of sediment and biochemical oxygen demand, and by summer, conditions in the hypolimnion are nearly anoxic (devoid of dissolved oxygen). In addition to sediment oxygen demand, Green (1994) suggests four possible factors contributing to the anoxic conditions in the hypolimnion in Lake Maumelle. First, the volume of water in the hypolimnion is relatively small, and as a result, the total mass of oxygen is limited. Second, the temperature of the hypolimnic water is relatively warm, further reducing the amount of oxygen that the water can contain because colder water can hold more dissolved oxygen than warmer water. Third, as phytoplankton and other particulate matter settles out of the water, oxygen is consumed by decay and chemical reduction within the hypolimnion. And fourth, once the surface water begins to heat up in the spring, the cooler inflow from the Maumelle River and other tributaries would tend to sink below the surface water because of the temperature related difference in water density. As a result, the organic and chemical load is displaced into the hypolimnion and adds to the consumption of oxygen.

Nutrient and Organic Carbon Concentrations

The nutrient concentrations measured in the epilimnion varied both spatially and temporally in Lake Maumelle. Total ammonia plus organic nitrogen, nitrite plus nitrate, total nitrogen, and orthophosphorus measured in the upper reservoir (east of Highway 10) were not significantly different ($p>0.05$) than concentrations measured at the lower end (near Natural Steps) (figs. 1 and 11). Total phosphorus concentrations were significantly ($p<0.05$) less at the lower end of the lake than concentrations measured in the upper end of the lake for the period of 1991 through 2003. Orthophosphorus concentrations were generally near or below laboratory detection limits for most of the samples.

The greatest concentrations of total nitrogen generally occurred in 1991 and from 1998 through 2003 at the three sites that were sampled since 1991 (fig. 12). Total ammonia plus organic nitrogen and nitrite plus nitrate concentrations generally were greatest in 1991. Nitrite plus nitrate concentrations in both ends of the lake were greatest from 1991 to 1992 and 1998 through 2003. Total ammonia plus organic nitrogen concentrations increased from 1999 through 2003 in both ends of the lake.

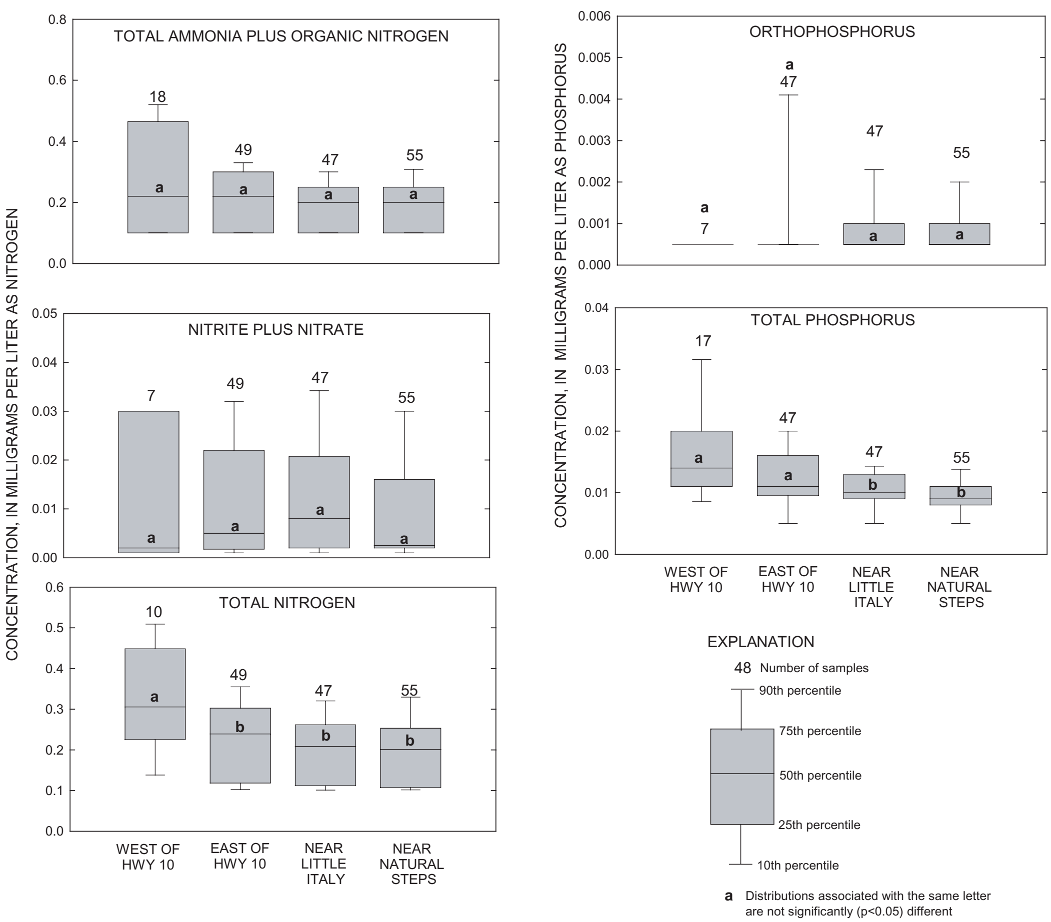


Figure 11. Distribution of nutrient concentrations for four sites on Lake Maumelle, Arkansas.

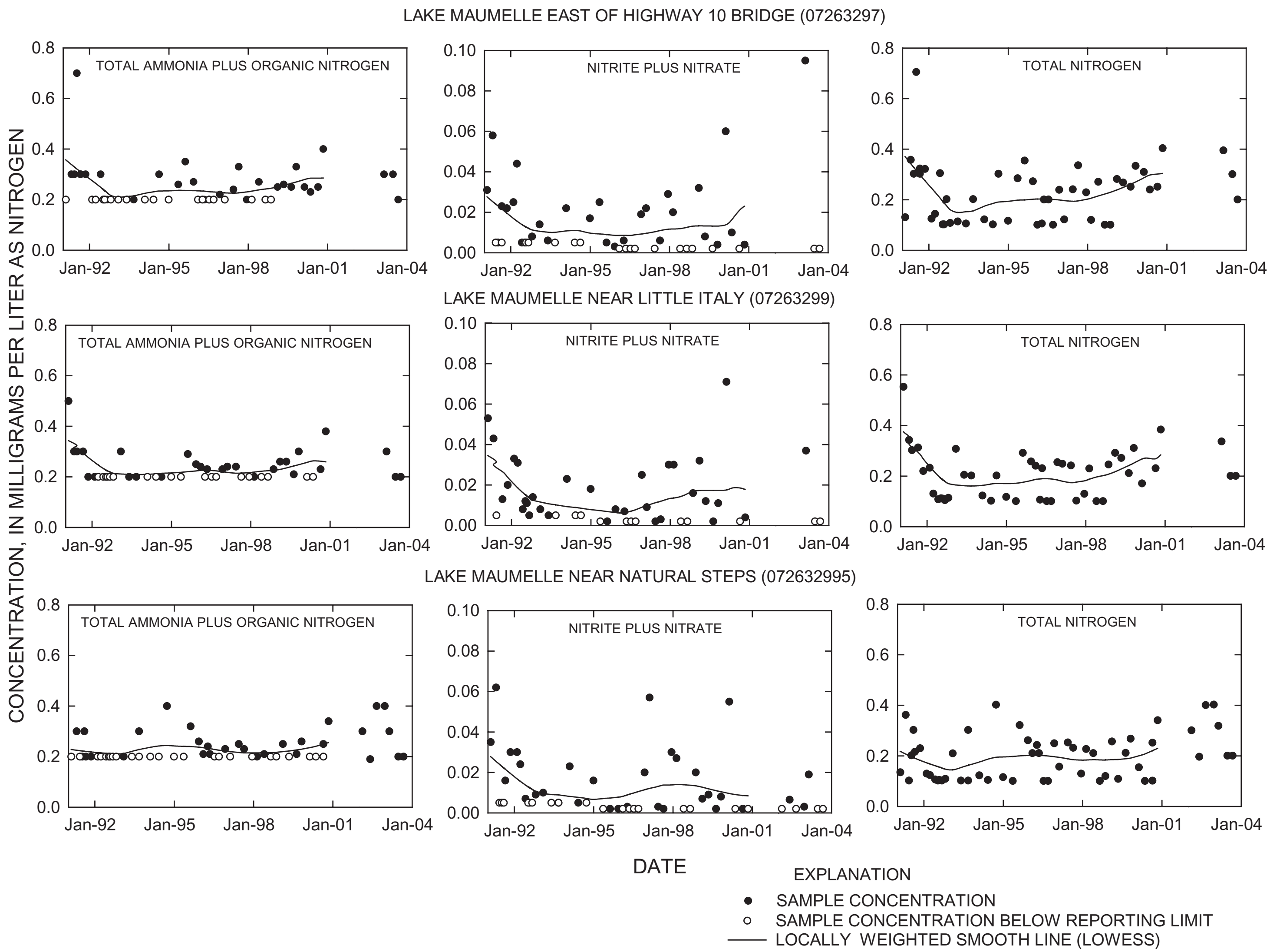


Figure 12. Time series of nitrogen concentrations for three sites on Lake Maumelle, Arkansas, 1991 through 2003.

Total phosphorus concentrations generally were greatest from 1994 to 1996 and from 1998 to 2001 and lowest from 2002 through 2003 at all three sampling sites (fig. 13). Orthophosphorus concentrations did not show any noticeable trends and generally were near or below laboratory detection limits from 1991 through 2003.

Dissolved and total organic carbon concentrations measured in the epilimnion of Lake Maumelle were similar among sites (fig. 14). The median concentrations of dissolved organic carbon in Lake Maumelle west of Highway 10 Bridge, east of Highway 10 Bridge, near Little Italy, and near Natural Steps were 2.85 mg/L, 2.90 mg/L, 2.90 mg/L, and 2.70 mg/L as carbon, respectively. The 75th percentile of concentrations from samples collected at Lake Maumelle west of Highway 10 Bridge in 2000 and 2003 was higher than the 75th percentile of concentrations of all samples collected at the other sampling sites. The greatest concentrations of dissolved and total organic carbon in the upper, middle, and lower parts of the lake occurred in 1996 and 1997 (fig. 15). Green (2001) indicated that the residence time in 1996 for Lake Maumelle was nearly four times greater than other years from 1990 to 1997, which suggest that greater dissolved and total organic carbon concentrations may have occurred because of internal loading within the reservoir.

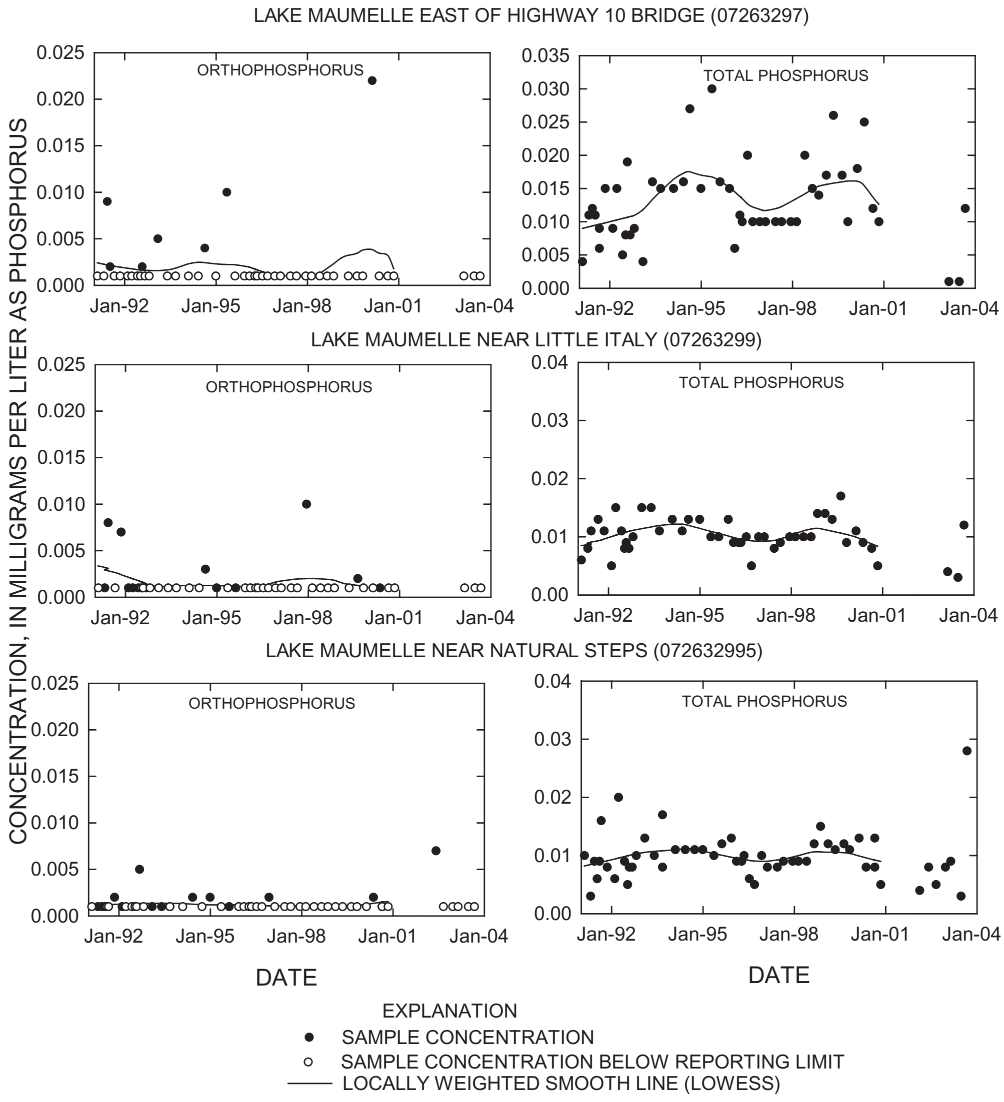


Figure 13. Time series of phosphorus concentrations for three sites on Lake Maumelle, Arkansas, 1991 through 2003.

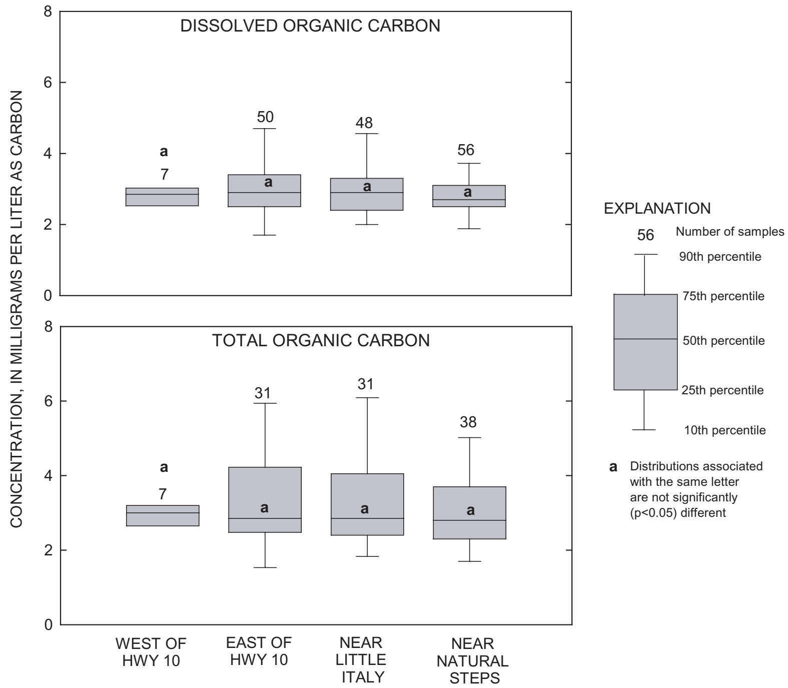


Figure 14. Distribution of organic carbon concentrations for four sites on Lake Maumelle, Arkansas.

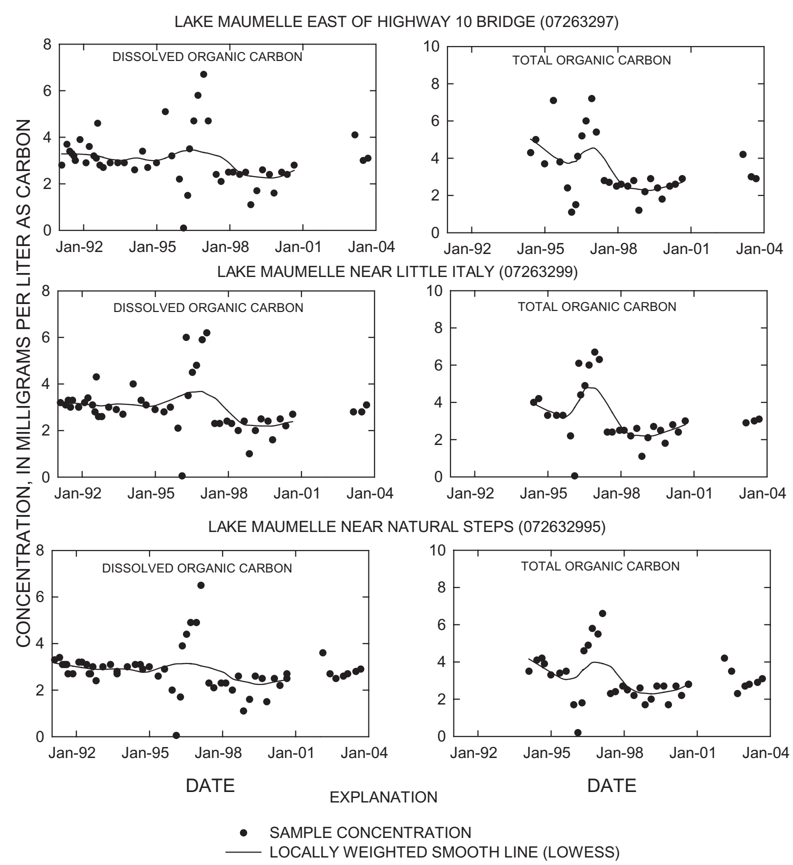


Figure 15. Time series of organic carbon concentrations for three sites on Lake Maumelle, Arkansas, 1991 through 2003.

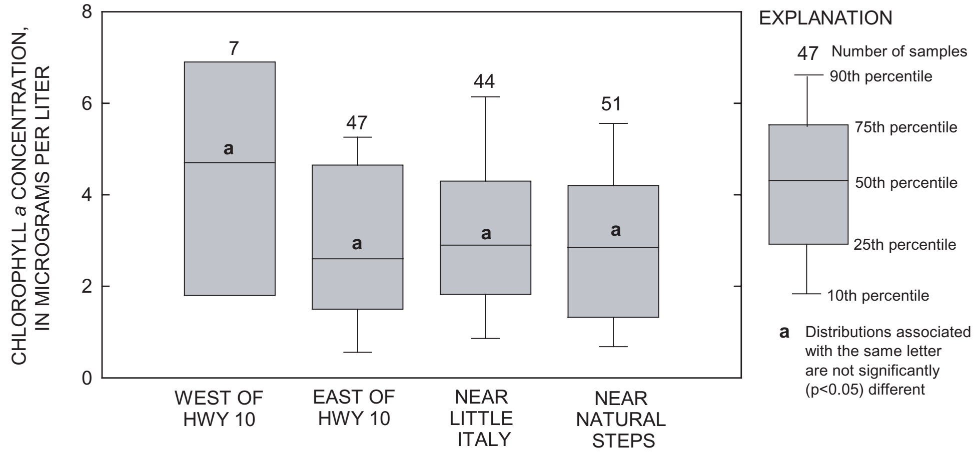


Figure 16. Distribution of chlorophyll *a* concentrations or four sites on Lake Maumelle, Arkansas.

Chlorophyll *a* Concentrations

Concentrations of chlorophyll *a* were relatively uniform spatially and temporally in Lake Maumelle. Chlorophyll *a* is a photosynthetic pigment found in algae and other green plants. The concentration of chlorophyll *a*, therefore, is commonly used as a measure of the density of the algal population of a lake. The chlorophyll *a* concentrations east of Highway 10 Bridge (upper end of the lake) had a median value of 2.60 μg/L, while concentrations from samples collected at the lower end of the lake (near Natural Steps) had a median concentration of 2.85 μg/L for the period of 1991 through 2003 (fig. 16). Concentrations of chlorophyll *a* remained fairly uniform from 1991 through 2003, although slightly higher concentrations were evident in 1998 to 2000 at all the sampled sites (fig. 17). The chlorophyll *a* concentrations varied seasonally, with the highest median concentrations generally during August through November, and the lowest concentrations during March through July (fig. 18).

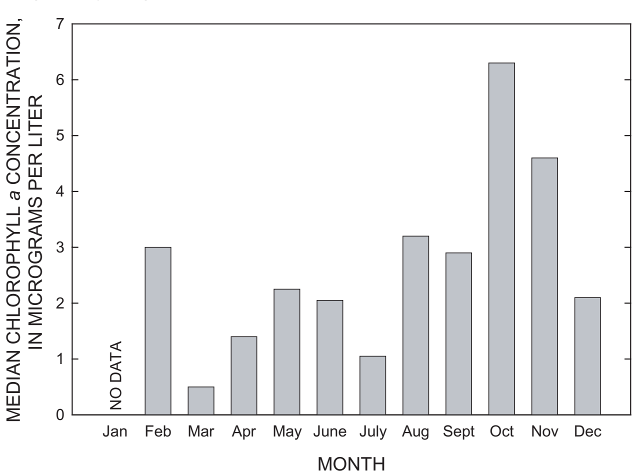


Figure 18. Median monthly chlorophyll *a* concentrations for Lake Maumelle near Natural Steps, Arkansas, 1991 through 2003.

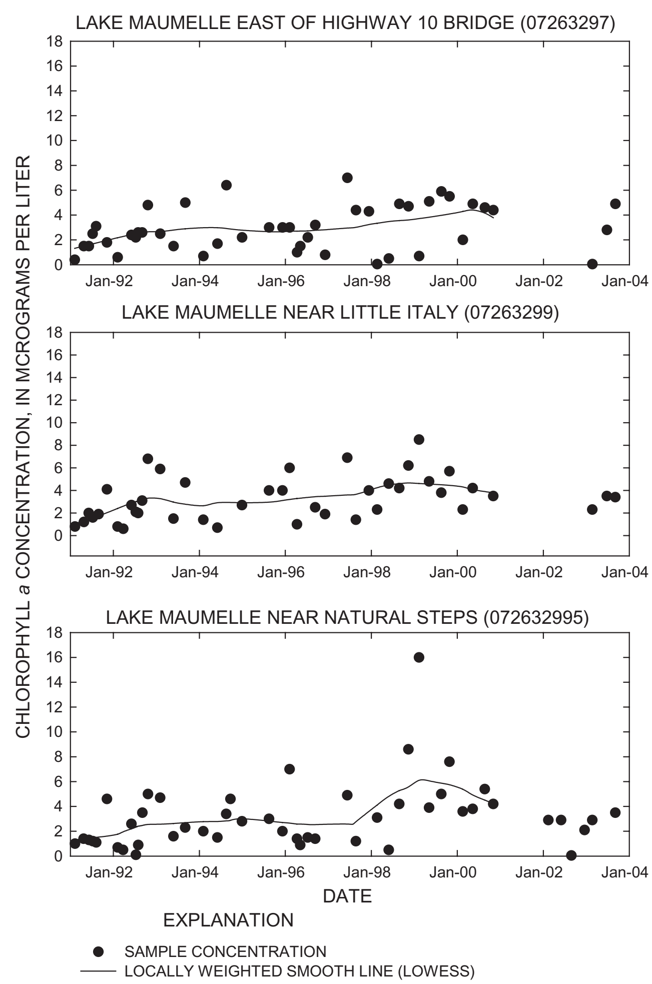


Figure 17. Time series of chlorophyll *a* concentrations for three sites on Lake Maumelle, Arkansas, 1991 through 2003.

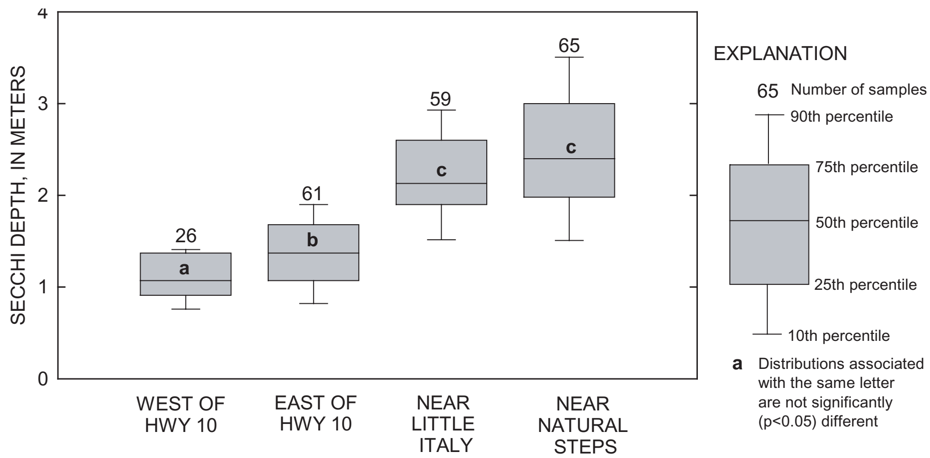


Figure 19. Distribution of Secchi depths for four sites on Lake Maumelle, Arkansas.

Water Clarity

During the study period, water clarity measured in Lake Maumelle was significantly greater at the lower end than in the upper end of the lake (fig. 19). The median Secchi depth measured in the upper end (west of Highway 10 Bridge) was 1.1 m, and median Secchi depth at the lower end was 2.4 m for the period of 1991 through 2003. Secchi depth varied seasonally, with the greatest median depth from July through September and the least median depth during October through December (fig. 20). However, no apparent trends during 1991 through 2003 were observed at sites in the reservoir (fig. 21).

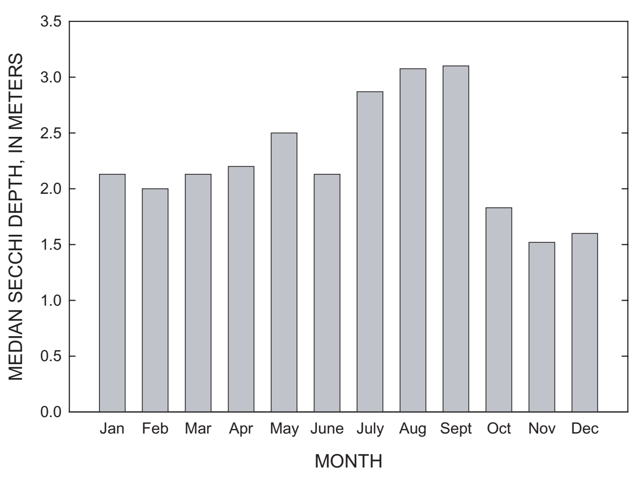


Figure 20. Median monthly Secchi depths for Lake Maumelle near Natural Steps, Arkansas, 1991 through 2003.

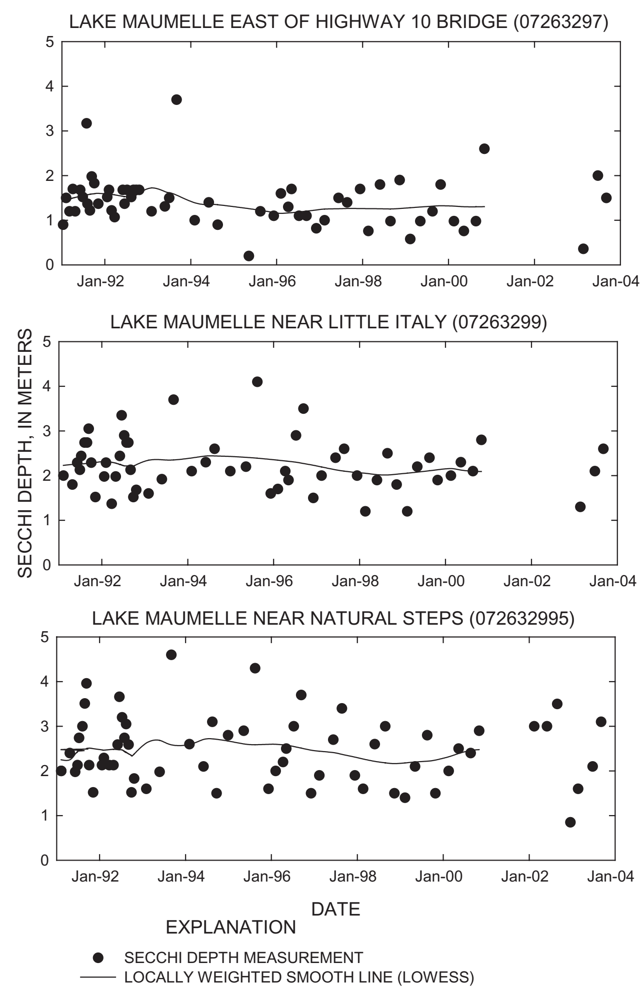


Figure 21. Time series of Secchi depth for three sites on Lake Maumelle, Arkansas, 1991 through 2003.

Trophic Status

The trophic status of a reservoir is an indicator of the age of a reservoir as it progresses towards physical, chemical, and biological equilibrium. In general, as a reservoir matures, the trophic condition evolves from oligotrophy to mesotrophy, mesotrophy to eutrophy, and eutrophy to hypereutrophy. Oligotrophy is considered the most pristine water-quality condition, and hypereutrophy is the poorest water-quality condition (Wetzel, 2001). Influences from cultural activities can accelerate the natural progression of the reservoir towards equilibrium from hundreds of years to a few decades.

The Trophic State Indices (TSI) indicated conditions ranging from oligotrophic to mesotrophic for three sites on Lake Maumelle. Epilimnetic TSI values for total phosphorus and chlorophyll *a* for three sites on Lake Maumelle indicated the lake is generally oligotrophic although some fluctuations between mesotrophic and oligotrophic conditions were observed over time (fig. 22).

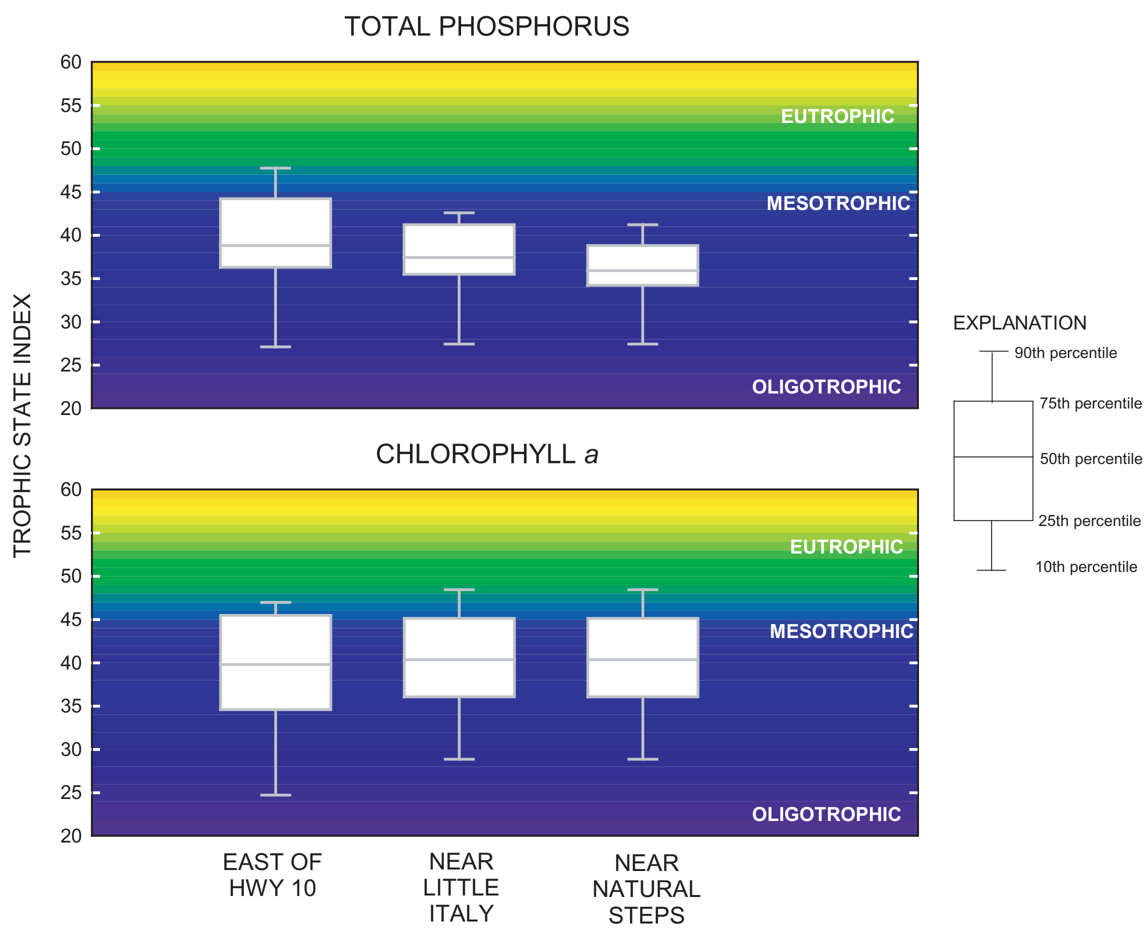


Figure 22. Trophic state indices for three sites on Lake Maumelle, Arkansas, 1991 through 2003.

Lake Winona

Lake Winona was sampled downstream from Stillhouse Branch (upper end of lake) (07362588) and downstream from Gillis Branch (middle) (07362589) from 1995 through 2003 (excluding 2001). Lake Winona at Reform (lower end of the lake) (07362590) was sampled from 1991 through 2003 (excluding 2001) (fig. 1).

Temperature

Lake Winona is representative of a monomictic system similar to Lake Maumelle that has a temperature distribution with seasonal cycles of thermal stratification occurring annually during the summer, complete mixing in the fall, and isothermal conditions in the winter (fig. 23). At the lower end of Lake Winona, mixing in the winter is not as complete as observed in Lake Maumelle, although the thermocline, which usually occurs at 3 to 6 m in depth, is more pronounced than in Lake Maumelle in the summer. Temperatures below a depth of 12 m in Lake Winona ranged from 8 to 13 °C during the summer.

Dissolved-Oxygen Concentrations

The distribution of dissolved-oxygen concentrations in Lake Winona differed from those observed at Lake Maumelle (fig. 24). Dissolved-oxygen concentrations in the hypolimnion generally were higher in Lake Winona than in Maumelle, because of the cooler temperatures in Lake Winona (fig. 23). The cooler temperatures in the hypolimnion allow inflow from the Alum Fork Saline River and other tributaries to move through the metalimnion (middle layers) of the lake, and the associated organic and chemical load would consume the oxygen in the metalimnion (Green, 1994). The volume of water in the hypolimnion also is greater in Lake Winona than in Lake Maumelle, allowing for greater concentrations of oxygen. During stratification, approximately 58 percent of the reservoir volume in Lake Winona is below the thermocline, whereas in Lake Maumelle, only about 28 percent of the reservoir volume is below the thermocline. The greater volume of water in the hypolimnion allows for more dissolved oxygen to be available for chemical and biological demand.

Nutrient and Organic Carbon Concentrations

Nitrogen concentrations were not significantly different among sampling sites for the period of 1991 through 2003 (fig. 25). Median total nitrogen concentrations ranged from 0.150 mg/L in the middle of Lake Winona to 0.240 mg/L at the upper end of the lake. Nitrate plus nitrite concentrations were slightly greater at the lower end of the lake with a median value of 0.014 mg/L, compared to median concentrations of 0.009 mg/L measured in the middle and upper end of the lake. Total ammonia plus organic nitrogen concentrations were mostly near or below detection limits at all three sampling sites.

Temporal differences were observed in nitrogen concentrations in Lake Winona. Total nitrogen concentrations generally were greater in 2000 through 2003 than in previous years at all three sampling sites and concentrations measured at the lower end of the lake also were greater in 1991 than subsequent years (fig. 26). Nitrite plus nitrate concentrations generally were greatest in 1995 through 1999 at all three sampling sites.

Phosphorus concentrations in Lake Winona varied spatially and temporally. Median total phosphorus concentrations were significantly greater at the upper end of Lake Winona than at the middle and lower ends of the lake (fig. 25). Total phosphorus concentrations measured at the lower end of Lake Winona generally were less in 1991, 1992, 2002, and 2003, and greater concentrations were measured in 1993 and 1994 (fig. 27). Concentrations of total phosphorus generally were greatest in 1995 through 1997 in the upper and middle portions of the lake. Orthophosphorus concentrations mostly were near or below the laboratory detection limits at all three sampling sites for the period.

Concentrations of total and dissolved organic carbon were not significantly different among sampling sites but did vary temporally. The highest concentrations of organic carbon were observed at the lower end of Lake Winona with median concentrations of 3.40 mg/L as carbon for total organic carbon and 3.20 mg/L as carbon for dissolved organic carbon (fig. 28). The upper end of Lake Winona had similar values, and the middle had the lowest values with median concentrations of 3.00 mg/L as carbon for total organic carbon and 2.80 mg/L as carbon for dissolved organic carbon. The highest concentrations of organic carbon were measured in 1996 and 1997 (fig. 29). Similar to Lake Maumelle, high concentrations in 1996 and 1997 for Lake Winona may have occurred because of internal loading within the reservoir. At the lower end of Lake Winona, where samples were analyzed for dissolved organic carbon since 1991, concentrations of dissolved organic carbon also were relatively higher in 1991 compared to subsequent years.

Chlorophyll *a* Concentrations

Chlorophyll *a* concentrations in Lake Winona were not significantly different among sampling sites, although the concentrations generally decreased from the upper end of the lake to the lower end (fig. 30). The median concentrations of chlorophyll *a* measured in the upper end, middle, and lower end of Lake Winona were 2.00 μg/L, 1.70 μg/L, and 1.3 μg/L, respectively.

Chlorophyll *a* concentrations varied annually and seasonally in Lake Winona. The greatest concentrations of chlorophyll *a* were observed in 1997 and 2000 at all three sampling sites (fig. 31). Concentrations of chlorophyll *a* did not have as noticeable of a seasonal trend as observed in Lake Maumelle, with the highest concentrations occurring in October and November (fall) and the lowest concentrations occurring in December, January, and February (winter), and June (early summer) (fig. 32).

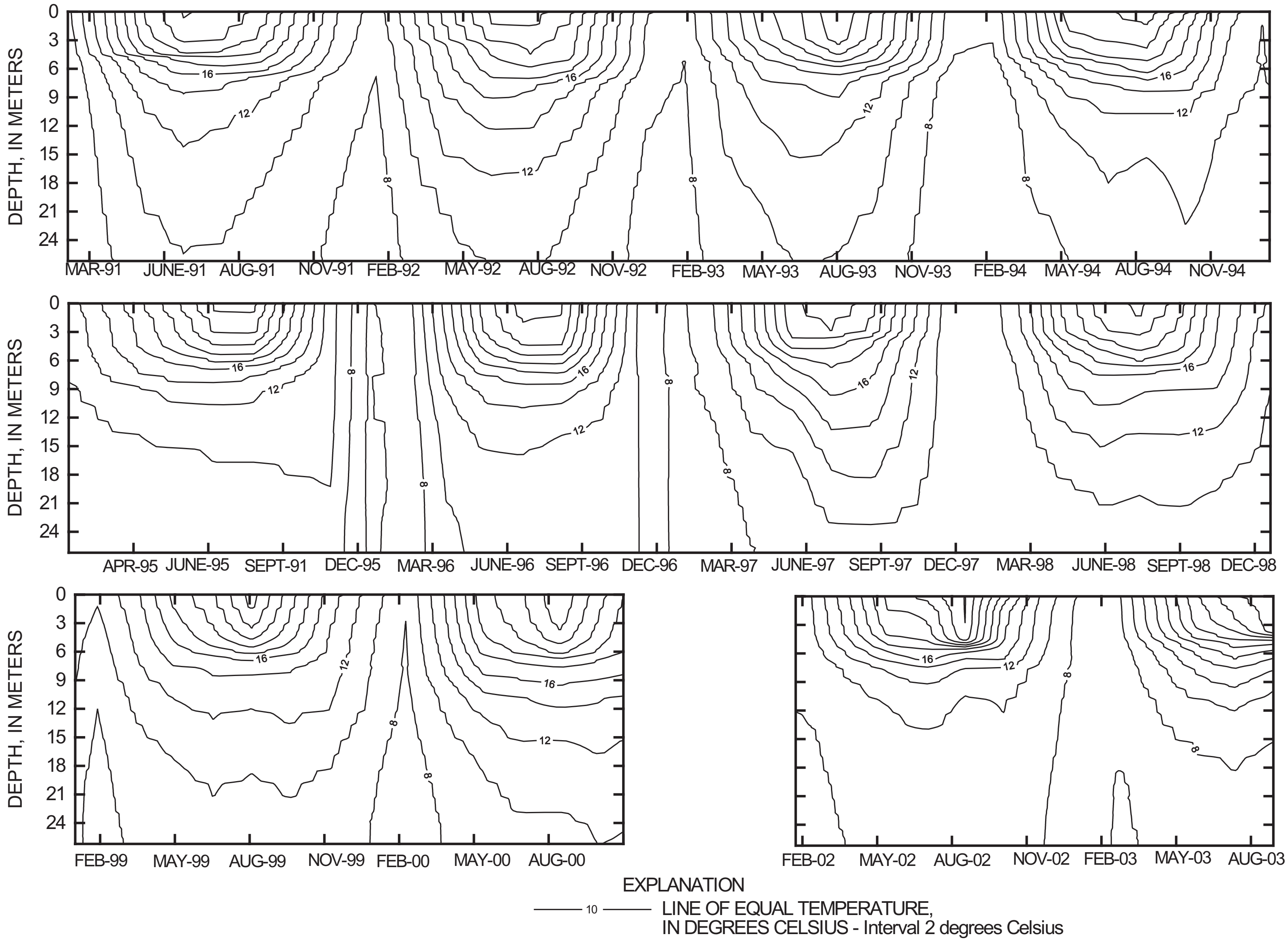


Figure 23. Distribution of temperature with depth and time in Lake Winona at Reform, Arkansas.

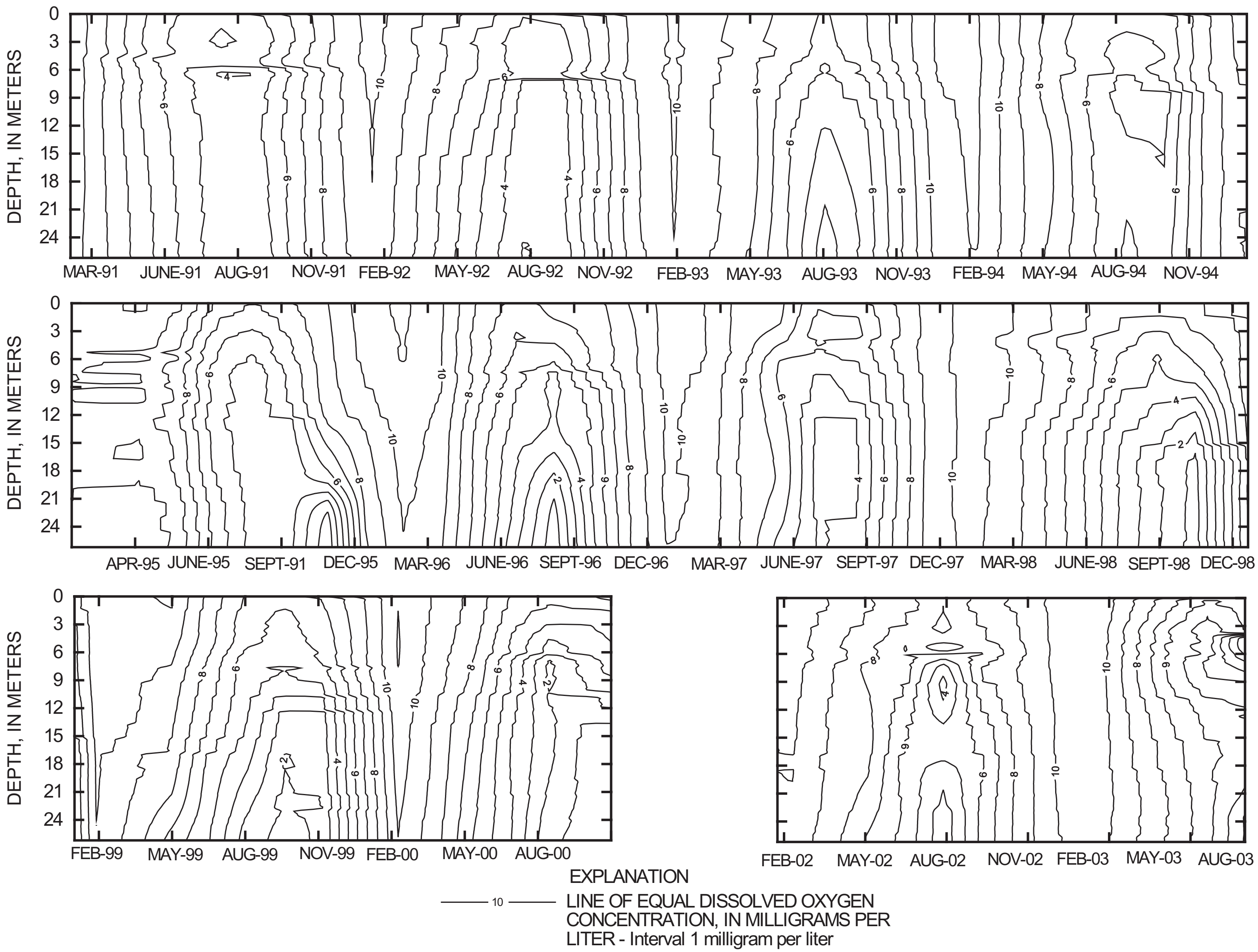


Figure 24. Distribution of dissolved oxygen concentration with depth and time in Lake Winona at Reform, Arkansas.

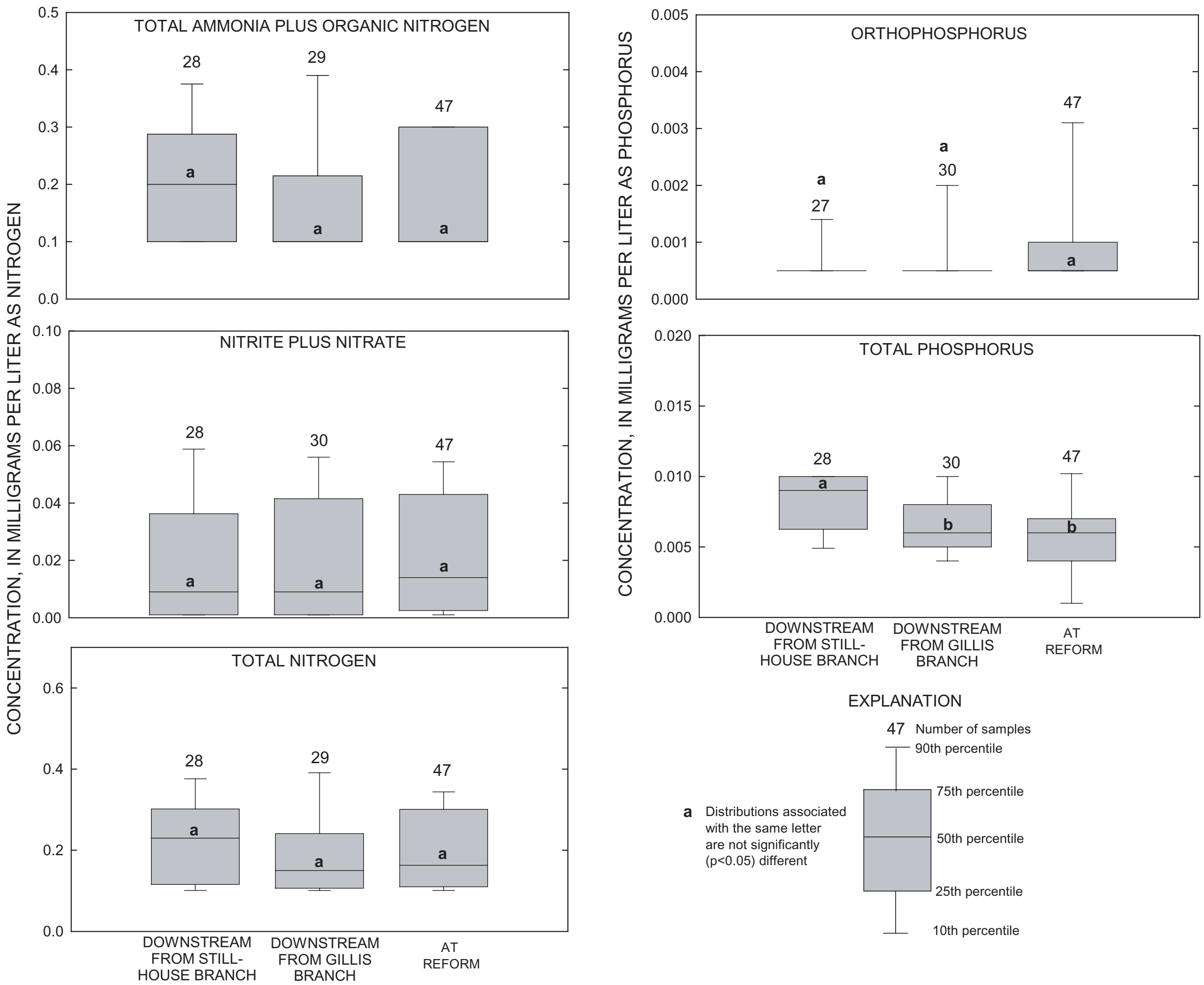


Figure 25. Distribution of nutrient concentrations for three sites on Lake Winona, Arkansas.

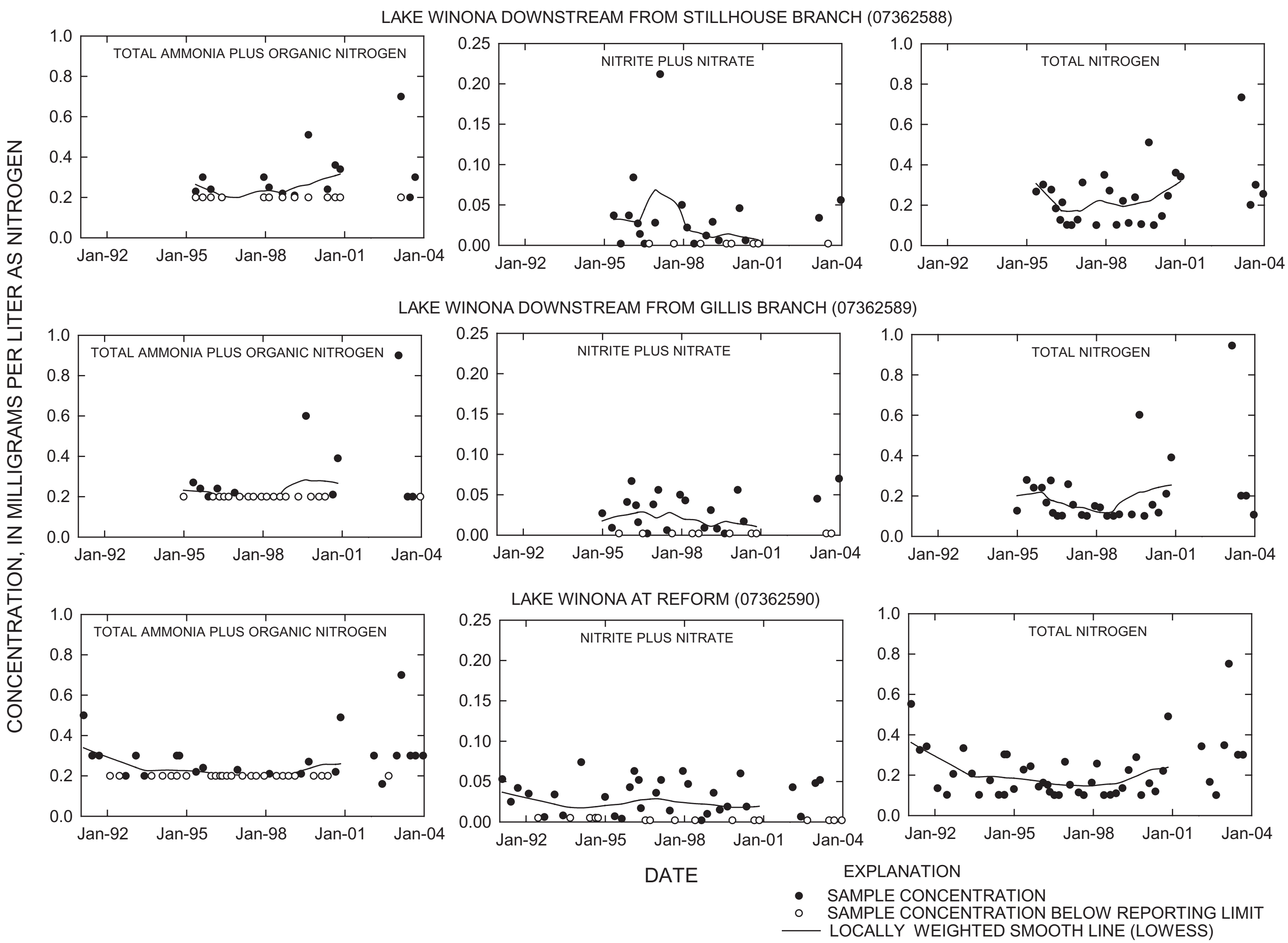


Figure 26. Time series of nitrogen concentrations for three sites on Lake Winona, Arkansas.

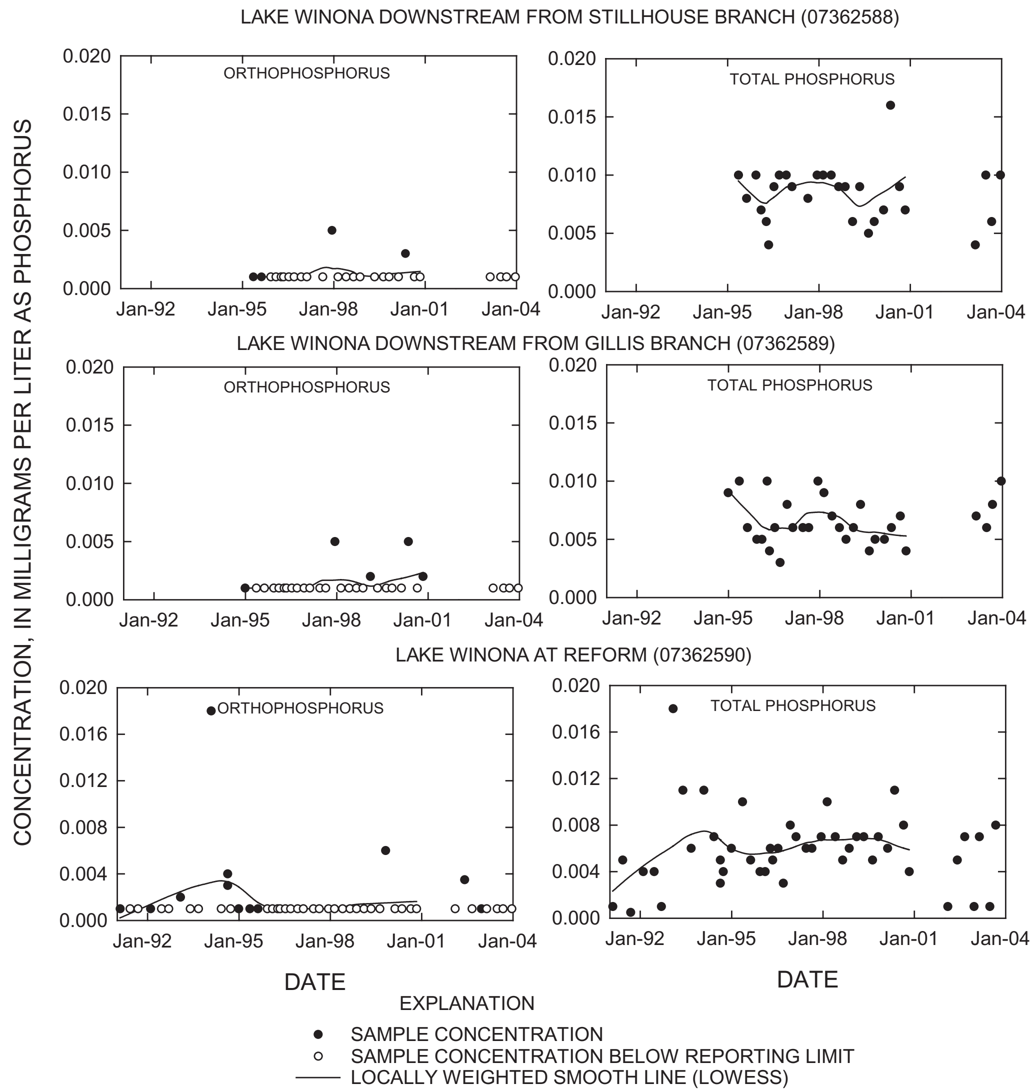


Figure 27. Time series of phosphorus concentrations for three sites on Lake Winona, Arkansas.

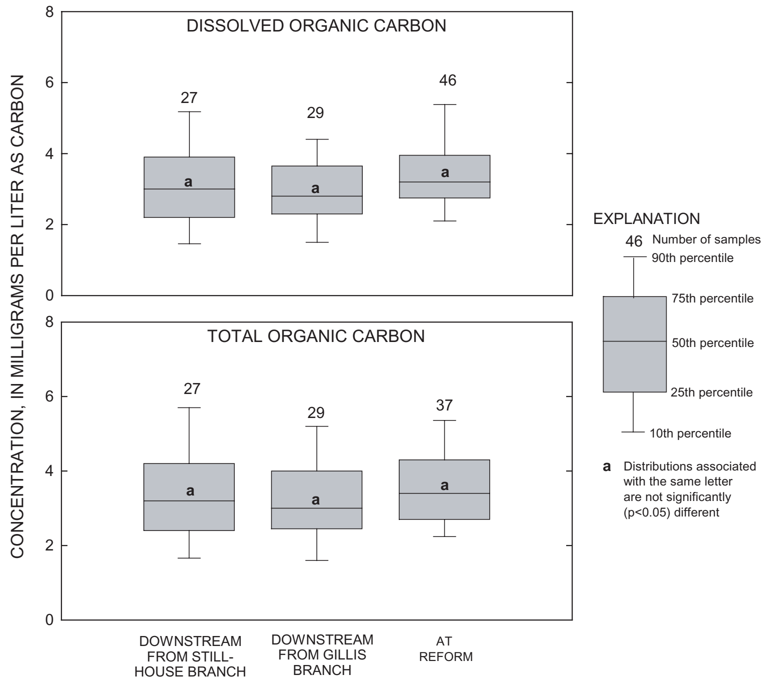


Figure 28. Distribution of organic carbon concentrations for three sites on Lake Winona, Arkansas.

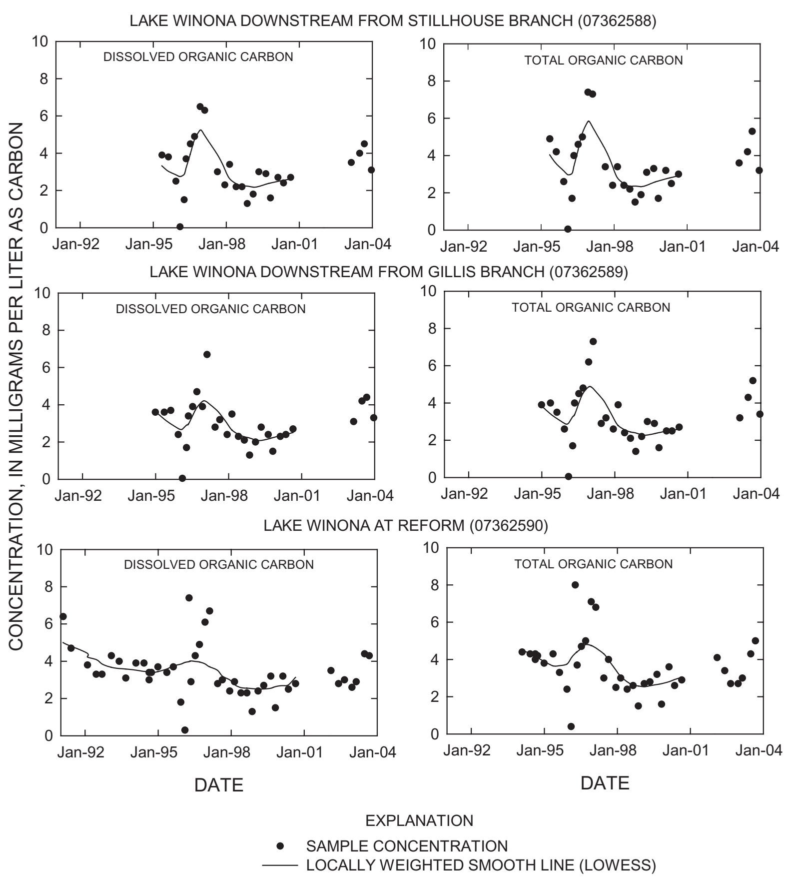


Figure 29. Time series of organic carbon concentrations for three sites on Lake Winona, Arkansas.

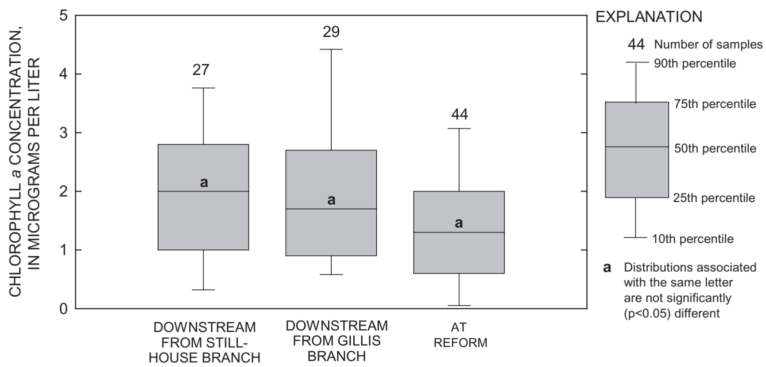


Figure 30. Time series of chlorophyll *a* concentrations for three sites on Lake Winona, Arkansas.

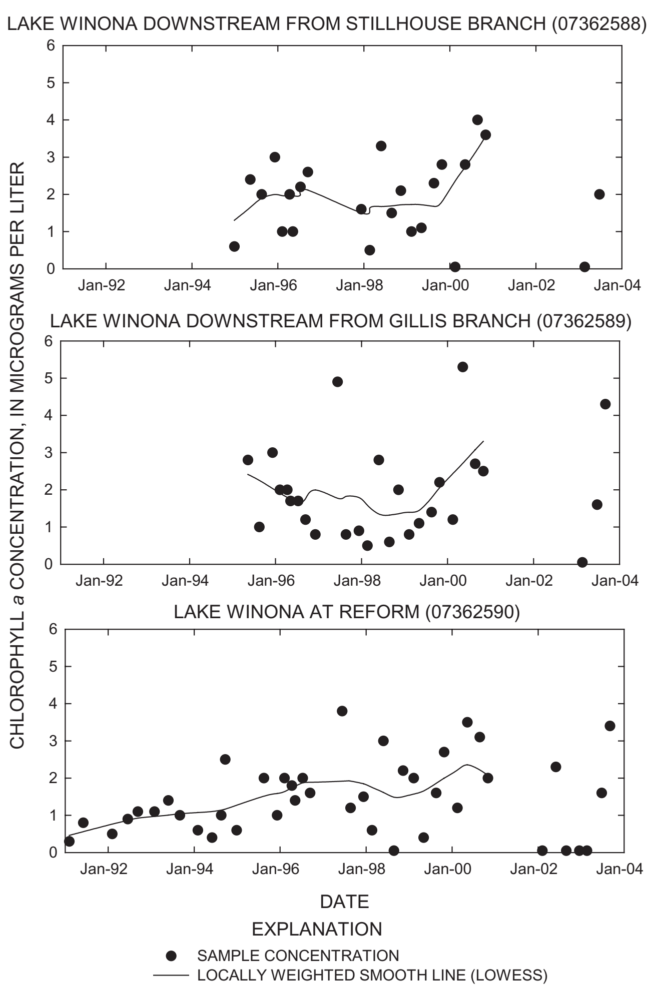


Figure 31. Time series of chlorophyll *a* concentrations for three sites on Lake Winona, Arkansas.

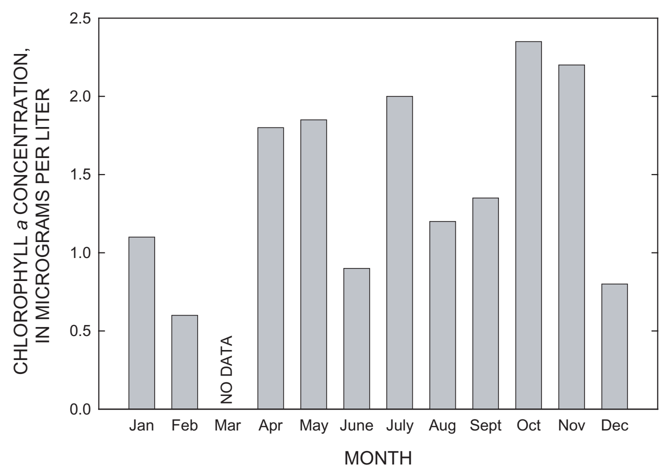


Figure 32. Median monthly chlorophyll *a* concentrations for Lake Winona at Reform, Arkansas, 1991 through 2003.

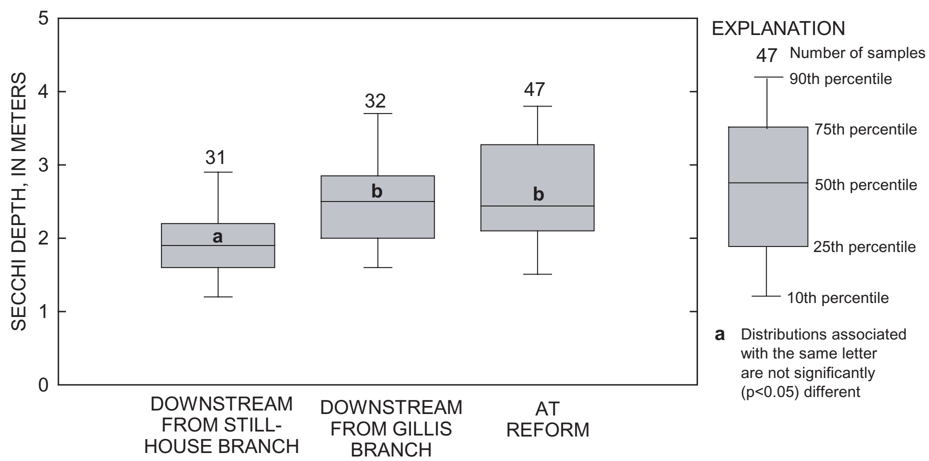


Figure 33. Distribution of Secchi depths for three sites on Lake Winona, Arkansas.

Water Clarity

The water clarity in Lake Winona varied spatially and temporally. The Secchi depth measured in the upper lake generally was significantly less than Secchi depth measured in the middle and lower lake (fig. 33). The median Secchi depth for the upper lake was 1.90 m and for the lower lake was 2.44 m. The water clarity in the middle of the lake was slightly greater than measured in the lower lake with a median Secchi depth of 2.50 m. Although water clarity changes seasonally throughout a given year (fig. 34), no noticeable trend was observed for the entire study period (fig. 35). However, Secchi depth measurements made in 2002 and 2003 were slightly less than previous years.

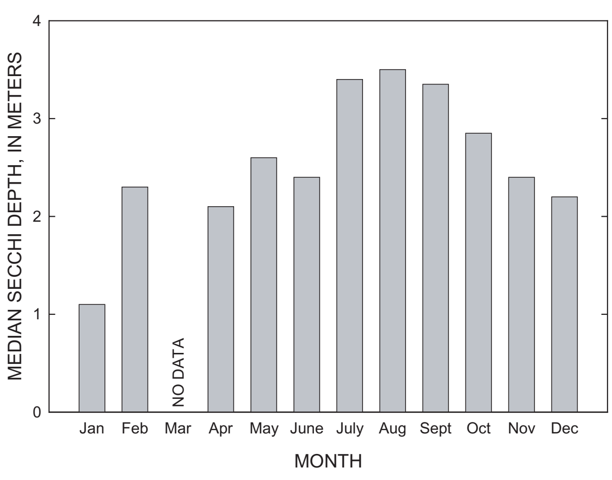


Figure 34. Median monthly Secchi depths for Lake Winona at Reform, Arkansas, 1991 through 2003.

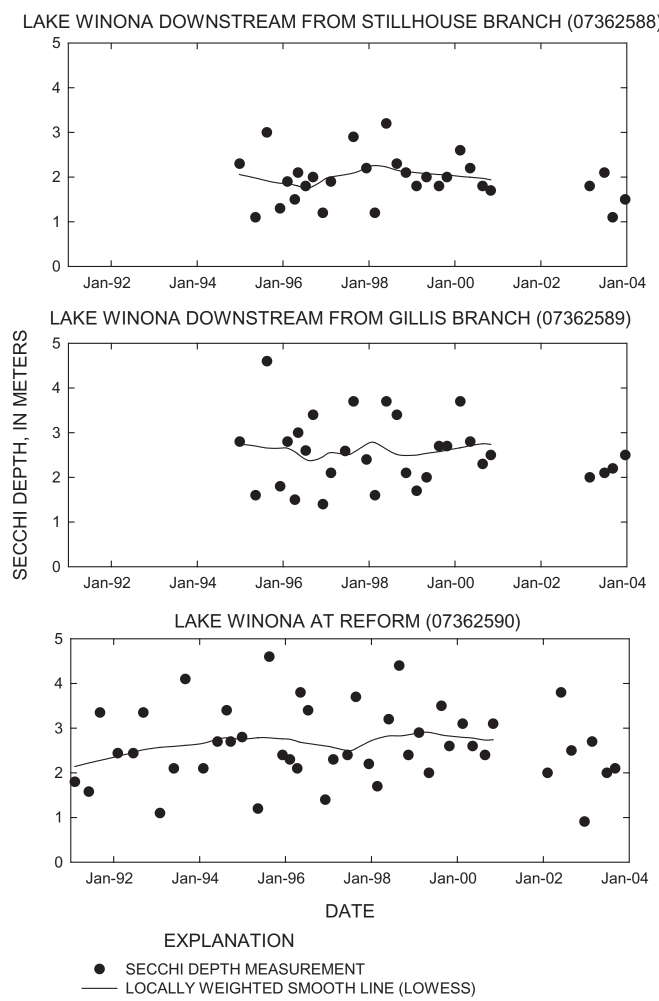


Figure 35. Time series of Secchi depth for three sites on Lake Winona, Arkansas.

Trophic Status

TSI calculated from near-surface concentrations of total phosphorus and chlorophyll *a* classify Lake Winona as mainly oligotrophic. Green (1994) presented similar conditions using data from 1989 through 1992, which indicates that little change in the trophic status of Lake Winona has occurred from 1989 through 2003.

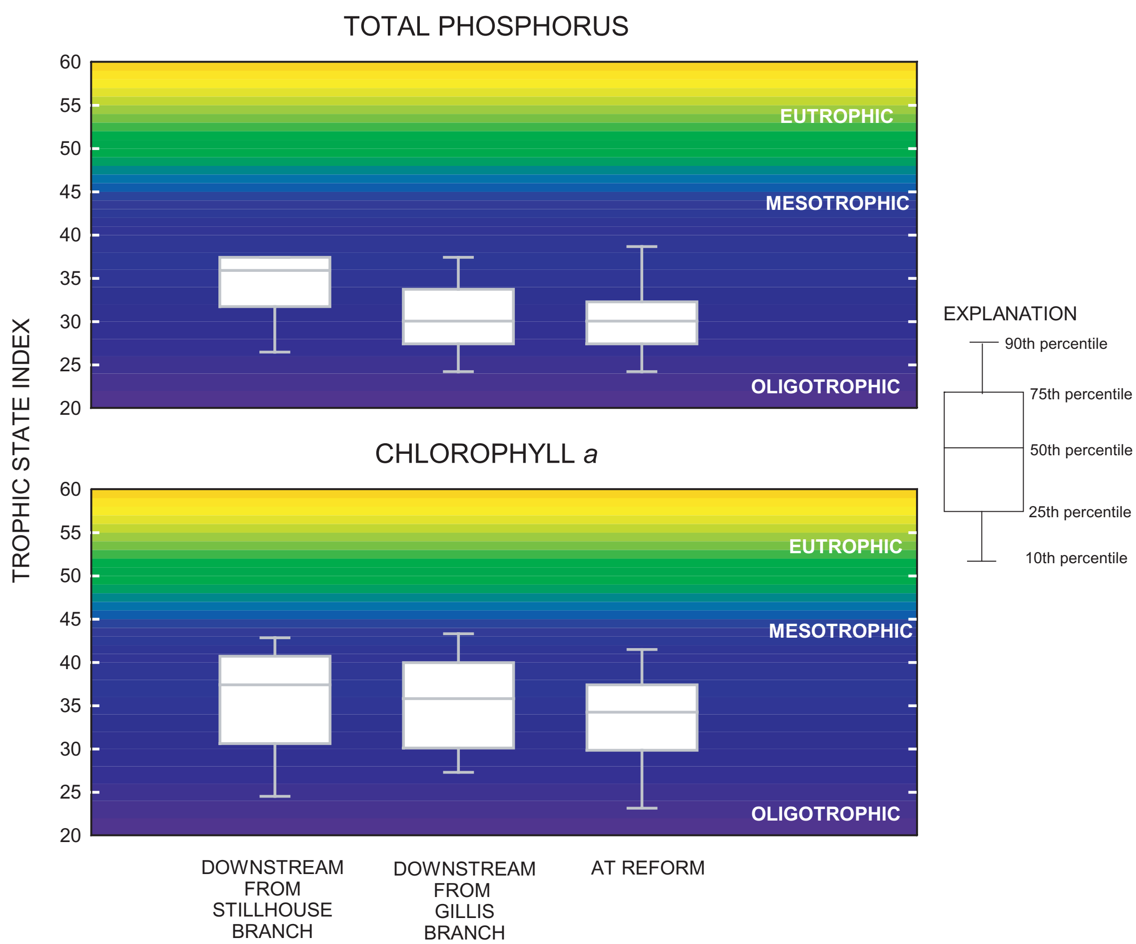


Figure 36. Trophic state indices for three sites on Lake Winona, Arkansas.

Inflow Water Quality

Lake Maumelle

Samples were collected at four inflow sites on Lake Maumelle. The Maumelle River at Williams Junction (fig. 1) is the main inflow and was sampled from 1991 through 2003 (excluding 2001). Bringle, Yount, and Reece Creeks (fig. 1) were sampled only in 1998, 2000, and 2003 during high-flow events because these creeks are intermittent. This section summarizes the constituent concentrations for the four inflows, and presents the estimated annual and seasonal loads, yields, and flow-weighted concentrations for the Maumelle River.

Constituent Concentrations

Nutrient concentrations generally were lower in samples from the Maumelle River than in samples from the smaller inflows (Bringle, Yount, and Reece Creeks) (fig. 37). However, samples were collected only during high-flow events at all of the smaller inflows and mostly during base-flow conditions on the Maumelle River. Median concentrations of total ammonia plus organic nitrogen, nitrite plus nitrate, and total nitrogen for the Maumelle River were 0.200, 0.016, and 0.244 mg/L as nitrogen, respectively. Median nitrogen and phosphorus concentrations for Bringle, Yount, and Reece Creeks were approximately double the concentrations measured on the Maumelle River and the median nitrite plus nitrate concentration on Bringle Creek was five times the median concentration for the Maumelle River. Total phosphorus concentrations for the Maumelle River had a median value of 0.012 mg/L as phosphorus and orthophosphorus concentrations were mostly near or below the laboratory detection limit for the period.

The median dissolved organic carbon concentration for the Maumelle River was 3.25 mg/L as carbon. Bringle, Yount, and Reece Creeks had only one sample at each site analyzed for dissolved organic carbon with values of 3.8, 5.6, and 3.8 mg/L as carbon, respectively.

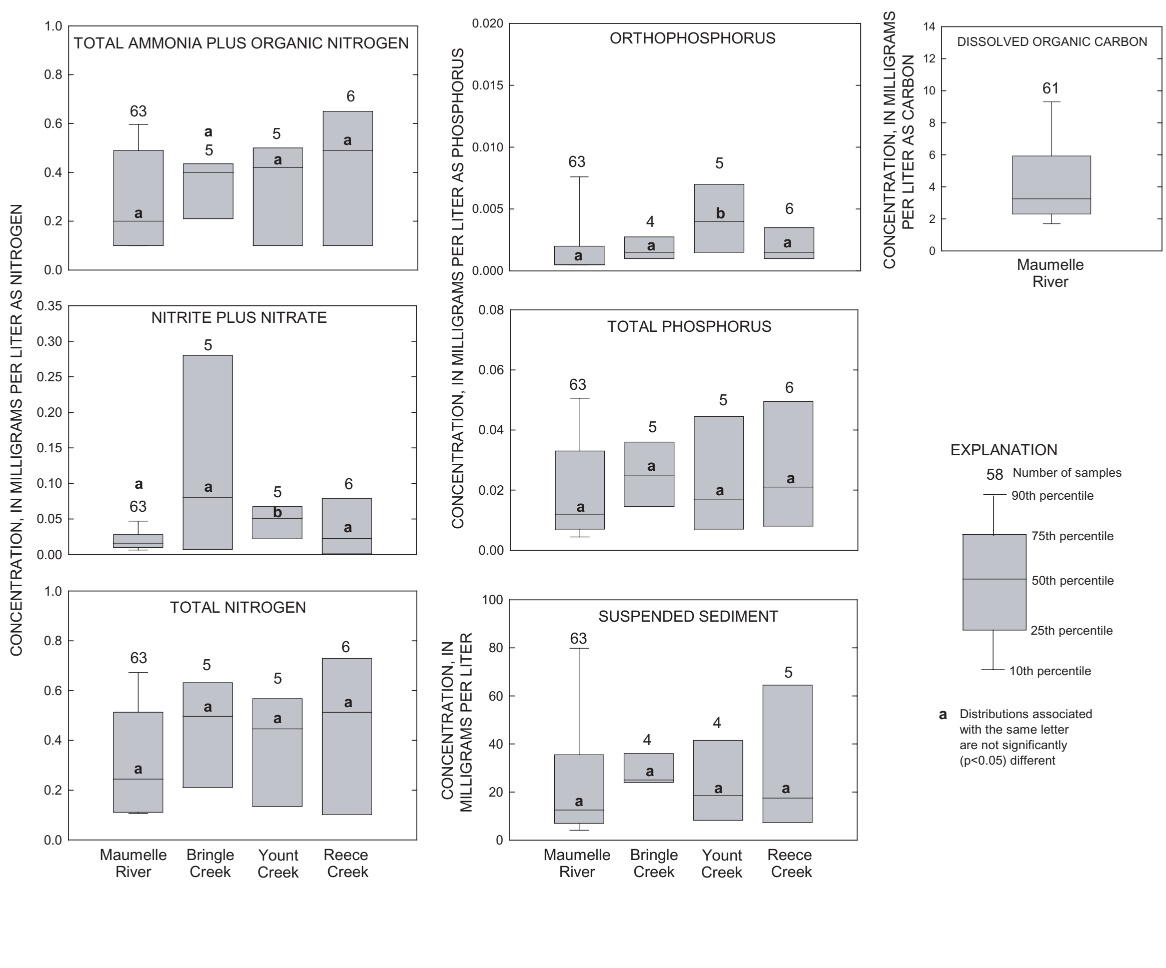


Figure 37. Distribution of nutrient, dissolved organic carbon, and suspended-sediment concentrations for four inflow sites to Lake Maumelle.

Nutrients and dissolved organic carbon concentrations for the Maumelle River generally varied seasonally but remained fairly uniform from 1991 through 2003 (fig. 38). However, samples collected from 2001 through 2003 yielded slightly higher nitrogen and dissolved organic carbon concentrations and slightly lower total phosphorus concentrations than previous years.

Concentrations of suspended sediment remained fairly uniform at the Maumelle River for the entire sample period, although higher concentrations were measured periodically during high-flow events (fig. 38). Suspended-sediment concentrations from samples collected at the inflow sites generally were greatest at Bringle Creek (from samples collected during high-flow events) and lowest at the Maumelle River (fig. 37). However, 10 percent of the samples collected at the Maumelle River had suspended-sediment concentrations that were greater than concentrations at the other inflow sites.

Fecal indicator bacteria are measures of the sanitary quality of water and are correlated to the presence of water-borne pathogens (Hem, 1989). Sources of fecal indicator bacteria can include septic tanks; animal wastes from feedlots, barnyards, and pastures; and manure application areas. Concentrations of fecal coliform bacteria measured in the Maumelle River ranged from less than 1 to 4,900 colonies per 100 mL, with a median concentration of 120 colonies per 100 mL. Bringle, Yount, and Reece Creeks had greater concentrations of fecal coliform bacteria with median values of 120, 370, and 842 colonies per 100 mL, respectively. Bringle and Reece Creeks had greater median concentrations of fecal streptococci than the Maumelle River, and Yount Creek had the least median fecal streptococci concentration (fig. 39).

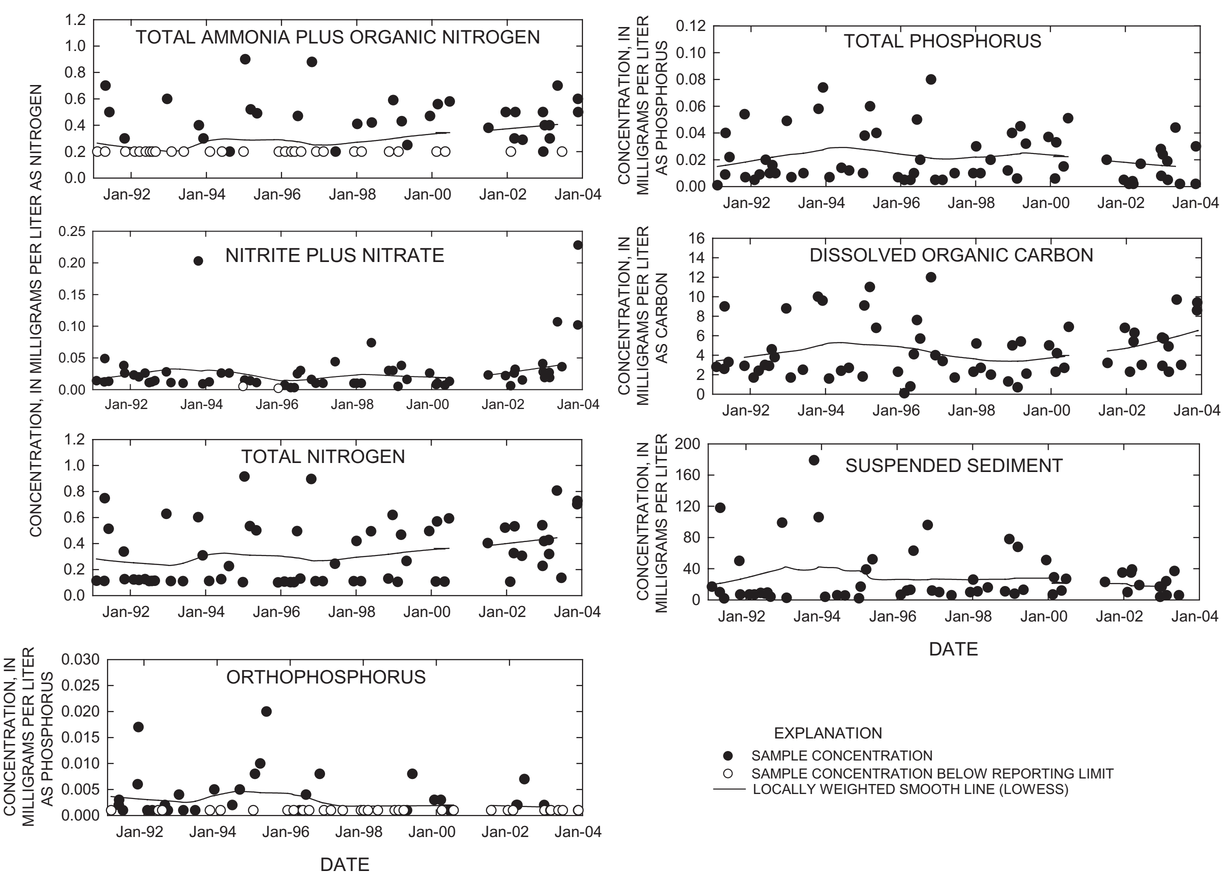


Figure 38. Time series of nutrient, dissolved organic carbon, and suspended-sediment concentrations for the Maumelle River at Williams Junction, Arkansas, 1991 through 2003.

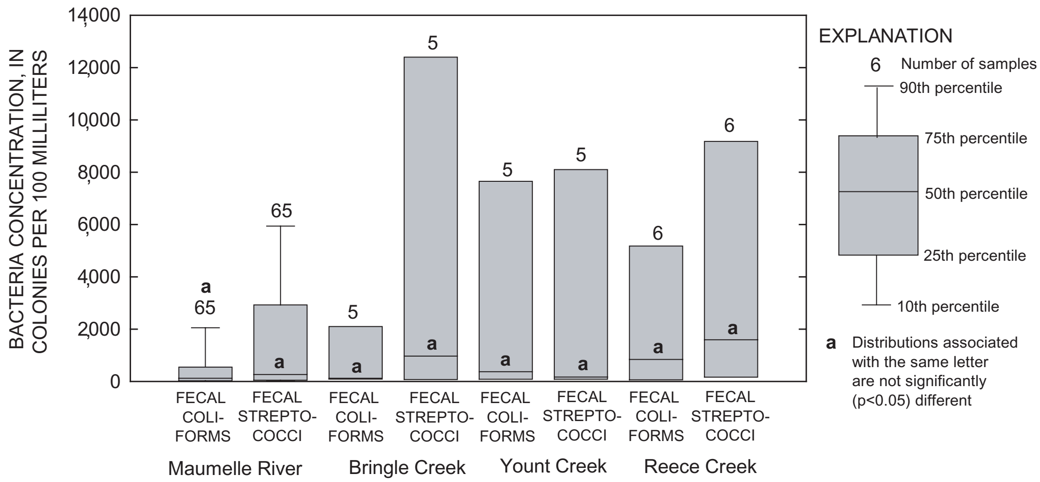


Figure 39. Distribution of fecal indicator bacteria concentrations for four inflow sites to Lake Maumelle.

Loads and Yields of Nutrients, Dissolved Organic Carbon, and Suspended Sediment

Estimated annual loads of nutrients, dissolved organic carbon, and suspended sediment for the Maumelle River varied from 1991 through 2003 (fig. 40 and table 2). Because loads are a function of streamflow, periods of higher streamflow generally produced higher loads. The greatest annual loads occurred in 1991 and the least annual loads occurred in 2000. Annual total nitrogen loads ranged from 18,000 kg/yr in 2000 to 46,500 kg/yr in 1991, and total phosphorus loads ranged from 822 kg/yr in 2000 to 1,960 kg/yr in 1991. The ratio of annual total nitrogen load to total phosphorus load for the Maumelle River ranged from 23 to 24 indicating that loading of nutrients entering Lake Maumelle are phosphorus limited (Redfield, 1958; Wetzel, 2001). Total ammonia plus organic nitrogen loads were approximately 17 times the nitrite plus nitrate loads and composed most of the total nitrogen loads. Dissolved organic carbon loads followed similar trends as the nutrients with loads ranging from 170,000 kg/yr in 2000 to 431,000 kg/yr in 1991. Annual suspended-sediment loads ranged from 1,020,000 kg/yr in 2000 to 2,870,000 in 1991 (fig. 40, table 2).

Estimated loads differed seasonally with the highest daily loads in the winter and fall and the lowest daily loads in the summer for the Maumelle River for 1991 through 2003 (fig. 41). Average daily nitrogen loads in the winter were approximately 27 (nitrite plus nitrate) to 38 (total nitrogen) times the average daily loads estimated for the summer. Average daily total phosphorus loads for the winter were 33 times the average daily loads for the summer. Similarly, daily dissolved organic carbon loads were 38 times higher in the winter than in the summer, and suspended-sediment loads were 48 times higher in the winter than in summer.

Annual nutrient yields computed for the Maumelle River (table 2) were compared to 82 sites representative of undeveloped basins identified across the Nation including two sites in Arkansas (Clark and others, 2000) and to the Illinois River south of Siloam Springs, Arkansas, which is representative of a developed basin (Green and Haggard, 2001) (fig. 42). The mean annual yield of nitrite plus nitrate for the undeveloped sites was twice the yield for the Maumelle River while the mean annual total nitrogen yield for the Maumelle River was 2.8 times greater than for the undeveloped sites. Orthophosphorus and total phosphorus yields for the Maumelle River were similar to the yields for the undeveloped sites. Mean annual yields for the Illinois River (Green and Haggard, 2001) for all nutrients were substantially greater than the yields computed for the Maumelle River. The mean annual yield of nitrite plus nitrate for the Illinois River was 79 times greater than the yield for the Maumelle River, and mean total nitrogen yield for the Illinois River was 6 times greater than the yield for the Maumelle River. Mean annual yields of orthophosphorus and total phosphorus for the Illinois River were 50 times and 17 times greater than the yields for the Maumelle River, respectively.

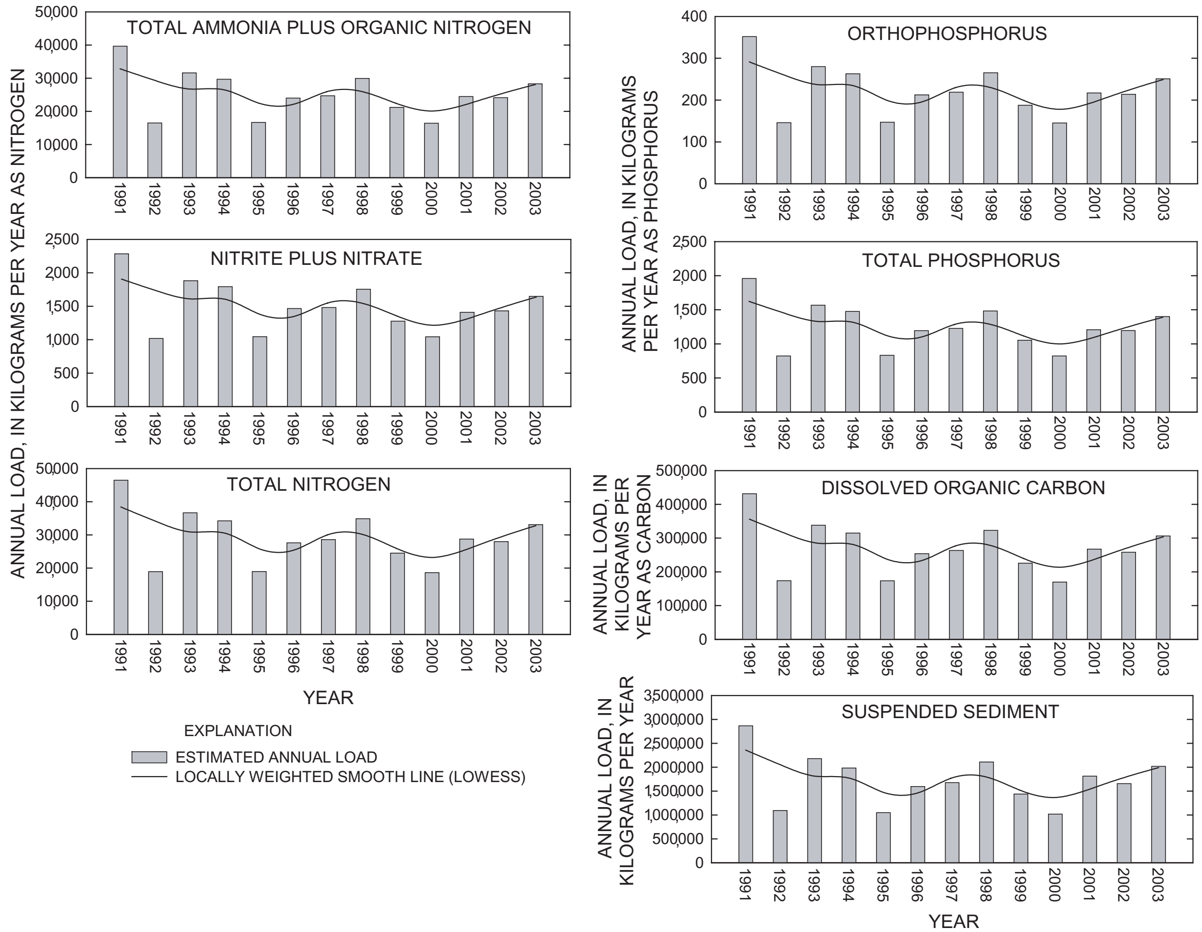
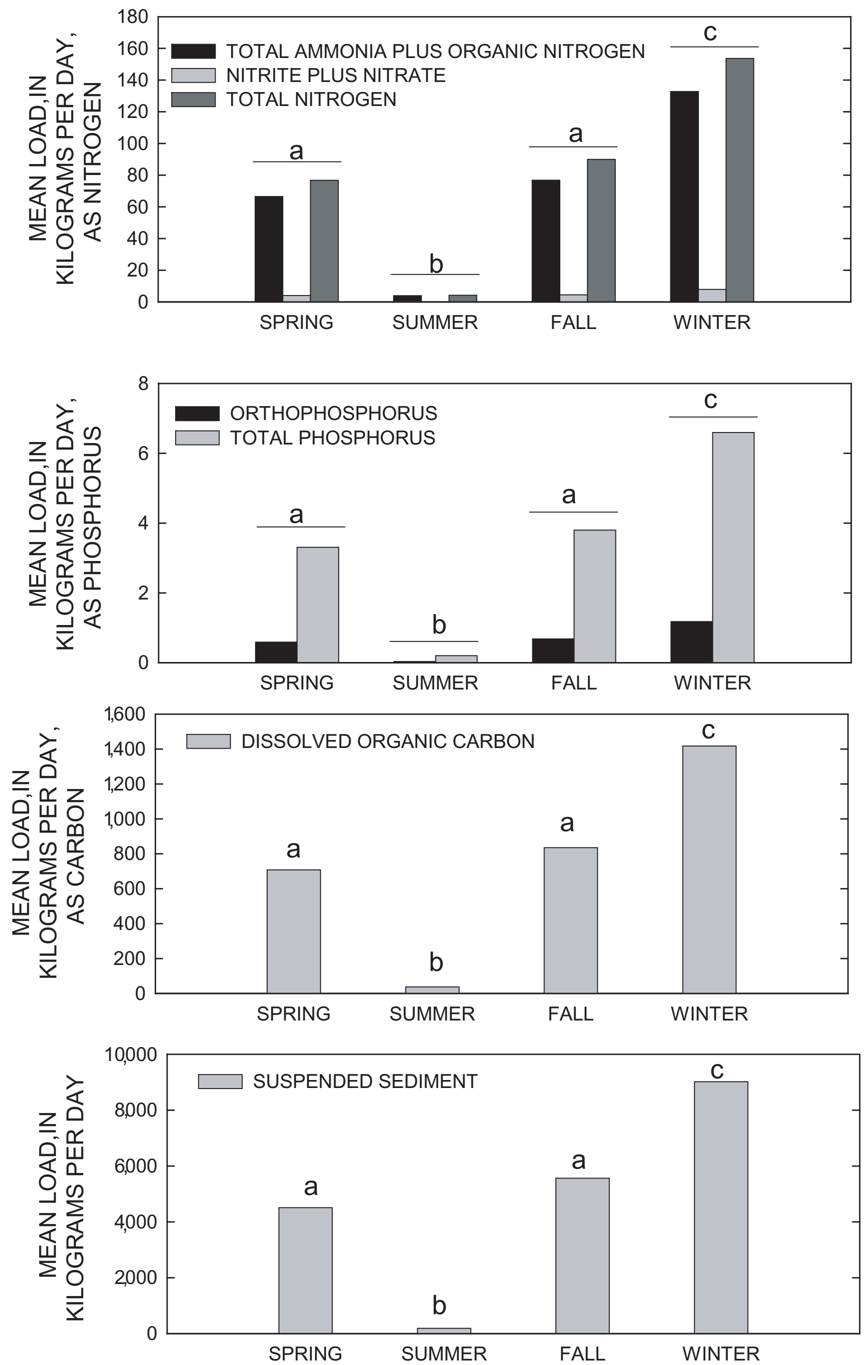


Figure 40. Annual nutrient, dissolved organic carbon, and suspended-sediment loads estimated for the Maumelle River at Williams Junction, Arkansas, 1991 through 2003.

Table 2. Estimated annual loads and yields for the Maumelle River at Williams Junction, Arkansas, 1991 through 2003.

[kg/yr, kilograms per year; SD, standard deviation; kg/yr/km^2, kilograms per year per square kilometer; N, nitrogen; P, phosphorus; C, carbon]

Year	Total ammonia plus organic nitrogen as N		Nitrite plus nitrate as N		Total nitrogen as N		Orthophosphorus as P		Total phosphorus as P		Dissolved organic carbon as C		Suspended sediment	
	Load (kg/yr) (+/-SD)	Yield (kg/yr/km^2)	Load (kg/yr) (+/-SD)	Yield (kg/yr/km^2)	Load (kg/yr) (+/-SD)	Yield (kg/yr/km^2)	Load (kg/yr) (+/-SD)	Yield (kg/yr/km^2)	Load (kg/yr) (+/-SD)	Yield (kg/yr/km^2)	Load (kg/yr) (+/-SD)	Yield (kg/yr/km^2)	Load (kg/yr) (+/-SD)	Yield (kg/yr/km^2)
1991	39,600+/-140	332	2,280+/-20	19	46,500+/-185	389	352+/-4.0	2.9	1,960+/-14	16	431,000+/-2,093	3,610	2,870,000+/-26,020	24,000
1992	16,500+/-59	138	1,020+/-9	9	18,900+/-75	158	146+/-1.6	1.2	822+/-5.0	7	174,000+/-738	1,460	1,090,000+/-9,906	9,150
1993	31,600+/-112	265	1,880+/-17	16	36,600+/-145	307	280+/-3.1	2.3	1,570+/-10	13	338,000+/-1,529	2,830	2,180,000+/-19,799	18,200
1994	29,700+/-106	249	1,790+/-16	15	34,200+/-136	287	263+/-2.9	2.2	1,480+/-9.4	12	315,000+/-1,307	2,640	1,980,000+/-18,031	16,600
1995	16,600+/-60	139	1,040+/-9	7	19,000+/-77	159	147+/-1.6	1.2	832+/-4.9	7	173,000+/-702	1,450	1,050,000+/-9,548	8,780
1996	24,000+/-85	201	1,460+/-13	12	27,600+/-109	231	213+/-2.3	1.8	1,200+/-7.5	10	254,000+/-1,088	2,130	1,590,000+/-14,456	13,400
1997	24,700+/-88	207	1,480+/-13	12	28,600+/-113	239	219+/-2.4	1.8	1,230+/-8.0	10	263,000+/-1,169	2,210	1,680,000+/-15,238	14,000
1998	29,900+/-106	251	1,760+/-16	15	34,900+/-138	292	265+/-3.0	2.2	1,480+/-10	12	323,000+/-1,507	2,700	2,110,000+/-19,158	17,700
1999	21,200+/-75	178	1,280+/-11	11	25,500+/-97	205	188+/-2.1	1.6	1,050+/-6.8	9	226,000+/-996	1,890	1,440,000+/-13,066	12,000
2000	16,400+/-60	138	834+/-9	7	18,600+/-76	156	145+/-1.6	1.2	822+/-4.7	7	170,000+/-673	1,420	1,020,000+/-9,237	8,520
2001	24,400+/-87	205	1,040+/-13	12	28,700+/-115	241	217+/-2.4	1.8	1,210+/-8.6	10	267,000+/-1,330	2,240	1,810,000+/-16,439	15,200
2002	24,100+/-85	202	1,430+/-13	12	28,000+/-111	234	214+/-2.4	1.8	1,200+/-7.9	10	258,000+/-1,165	2,160	1,650,000+/-15,040	13,800
2003	28,300+/-100	237	1,650+/-15	14	33,100+/-131	277	251+/-2.8	2.1	1,400+/-9.7	12	306,000+/-1,455	2,570	2,020,000+/-18,319	16,900
Mean	**25,166**	**211**	**1,503**	**13**	**29,170**	**244**	**223**	**1.9**	**1,249**	**10**	**269,175**	**2,254**	**1,729,591**	**14,486**
Median	**24,458**	**205**	**1,465**	**12**	**28,572**	**239**	**217**	**1.8**	**1,208**	**10**	**263,370**	**2,260**	**1,676,253**	**14,039**



EXPLANATION

a DISTRIBUTIONS ASSOCIATED WITH THE SAME LETTER ARE NOT SIGNIFICANTLY (p<0.05) DIFFERENT

Figure 41. Seasonal nutrient, dissolved organic carbon, and suspended-sediment loads estimated for the Maumelle River at Williams Junction, Arkansas, 1991 through 2003.

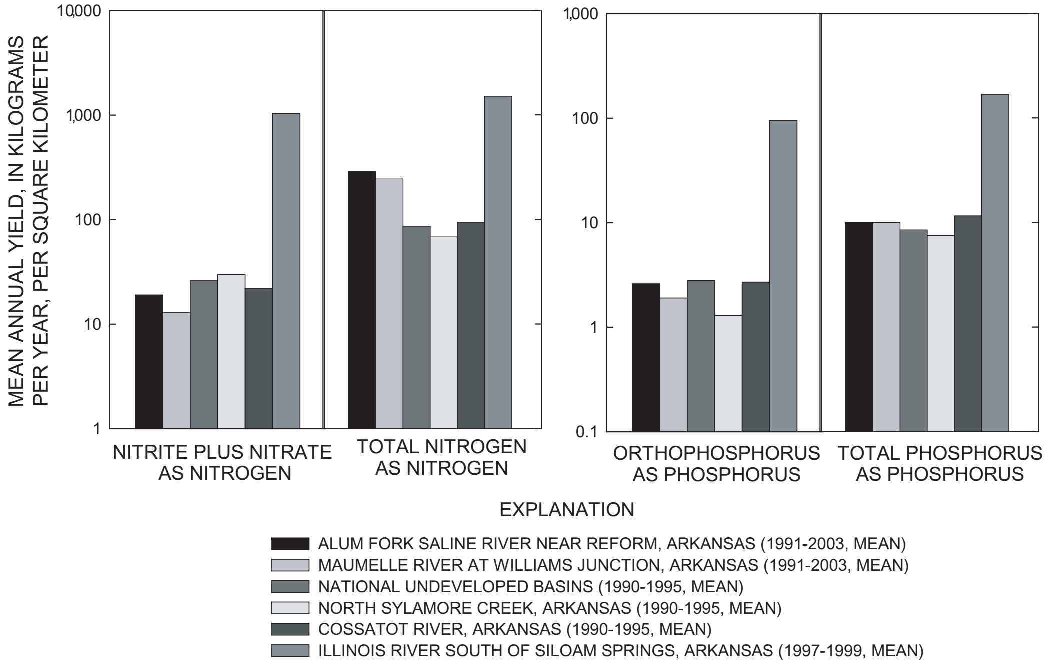


Figure 42. Annual nutrient yields for the Maumelle River at Williams Junction, Arkansas, Alum Fork Saline River near Reform, Arkansas, and selected other stream basins.

Flow-Weighted Concentrations of Nutrients, Dissolved Organic Carbon, and Suspended Sediment

Flow-weighted concentrations computed for the Maumelle River did not vary substantially on an annual basis (table 3). Total ammonia plus organic nitrogen flow-weighted concentrations ranged from 0.46 to 0.50 mg/L as nitrogen, nitrite plus nitrate flow-weighted concentrations were consistently 0.029 mg/L as nitrogen, and total nitrogen flow-weighted concentrations ranged from 0.52 to 0.59 mg/L as nitrogen. Orthophosphorus flow-weighted concentrations were consistently 0.004 mg/L as phosphorus, and total phosphorus concentrations ranged from 0.023 to 0.025 mg/L as phosphorus. Dissolved organic carbon flow-weighted concentrations ranged from 4.74 to 5.48 mg/L as carbon with a mean of 5.15 mg/L as carbon. Suspended-sediment flow-weighted concentrations ranged from 28.4 to 37.2 mg/L with a mean of 32.9 mg/L.

The flow-weighted concentrations computed for the Maumelle River also were compared to 82 undeveloped sites identified across the Nation including 2 sites in Arkansas (Clark and others, 2000) and to the Illinois River south of Siloam Springs, Arkansas, which is representative of a developed basin (Green and Haggard, 2001) (fig. 43). The mean nitrite plus nitrate flow-weighted concentration for undeveloped sites was more than 5 times greater than mean flow-weighted concentration computed for the Maumelle River. However, the mean total nitrogen flow-weighted concentration for the Maumelle River was similar to the mean concentration for the undeveloped basins. The mean orthophosphorus flow-weighted concentration for undeveloped basins was 3.8 times greater than for the Maumelle River, and the mean total phosphorus flow-weighted concentrations for the undeveloped basins was slightly more than the flow-weighted concentrations for the Maumelle River. The mean nitrite plus nitrate flow-weighted concentration for the Illinois River was 83 times the mean concentration for the Maumelle River. The mean total nitrogen flow-weighted concentration for the Illinois River was more than 6 times greater than the concentrations for the Maumelle River. The mean orthophosphorus and total phosphorus flow-weighted concentrations were 55 times and 17 times greater, respectively, than the mean flow-weighted concentrations for the Maumelle River.

Lake Winona

Samples were collected at the main inflow to Lake Winona, the Alum Fork Saline River, from 1991 through 2003 (excluding 2001). This section summarizes the constituent concentrations and presents the estimated annual and seasonal loads, and computed yields and flow-weighted concentrations for the Alum Fork Saline River for the period.

Table 3. Annual flow-weighted concentrations computed for the Maumelle River at Williams Junction, Arkansas, 1991 through 2003.

[Concentrations are in milligrams per liter; N, nitrogen; P, phosphorus; C, carbon]

Year	Total ammonia plus organic nitrogen as N	Nitrite plus nitrate as N	Total nitrogen as N	Ortho-phosphorus as P	Total phosphorus as P	Dissolved organic carbon as C	Suspended sediment
1991	0.50	0.029	0.59	0.004	0.025	5.45	36.2
1992	0.47	0.029	0.54	0.004	0.023	4.96	31.2
1993	0.49	0.029	0.56	0.004	0.024	5.21	33.5
1994	0.48	0.029	0.55	0.004	0.024	5.10	32.1
1995	0.46	0.029	0.53	0.004	0.023	4.82	29.2
1996	0.48	0.029	0.55	0.004	0.024	5.03	31.6
1997	0.48	0.029	0.56	0.004	0.024	5.16	32.8
1998	0.49	0.029	0.58	0.004	0.024	5.32	34.8
1999	0.48	0.029	0.56	0.004	0.024	5.12	32.6
2000	0.46	0.029	0.52	0.004	0.023	4.74	28.4
2001	0.50	0.029	0.59	0.004	0.025	5.48	37.2
2002	0.49	0.029	0.57	0.004	0.024	5.22	33.5
2003	0.50	0.029	0.58	0.004	0.025	5.38	35.4
Mean	**0.48**	**0.029**	**0.56**	**0.004**	**0.024**	**5.15**	**32.9**
Median	**0.48**	**0.029**	**0.56**	**0.004**	**0.024**	**5.16**	**32.8**

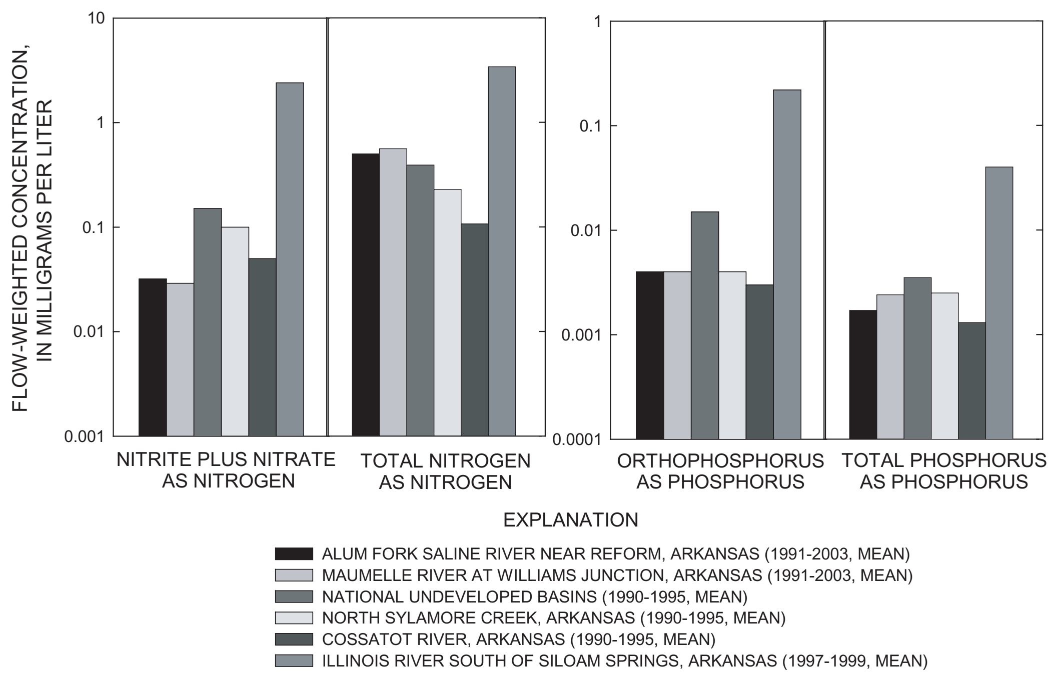


Figure 43. Annual flow-weighted nutrient concentrations for the Maumelle River at Williams Junction, Arkansas, Alum Fork Saline River near Reform, Arkansas, and selected other stream basins.

Constituent Concentrations

Nutrient and dissolved organic carbon concentrations measured on the Alum Fork Saline River (fig. 44) generally were less than concentrations measured at the Maumelle River (fig. 37). Total ammonia plus organic nitrogen, nitrite plus nitrate, and total nitrogen had median concentrations of 0.100, 0.012, and 0.204 mg/L as nitrogen, respectively, for 1991 through 2003. Total phosphorus had a median concentration of 0.008 mg/L as phosphorus, and orthophosphorus was usually near or below laboratory detection limits from 1991 through 2003. Dissolved organic carbon concentrations had a median concentration of 2.4 mg/L as carbon, which was slightly less than the median concentration measured at the Maumelle River. The greatest concentrations of nutrients and dissolved organic carbon for the Alum Fork Saline River generally were measured in 1995 and 1996, but no noticeable trend in concentration was observed over the entire period of 1991 through 2003 (fig. 45).

Similar to the nutrient concentrations, suspended-sediment concentrations measured at the Alum Fork Saline River were less than suspended-sediment concentrations measured at the Maumelle River. The median suspended-sediment concentration at the Alum Fork was 9.00 mg/L, which is approximately 28 percent less than the median concentration measured at the Maumelle River (12.5 mg/L) for 1991 through 2003 (figs. 37 and 44). The greatest concentrations of suspended sediment were measured in 1995 and 1996, and the lowest concentrations were measured in 1991 and 1992 (fig. 45). No noticeable trend in concentration was observed over the entire period of 1991 through 2003.

Concentrations of fecal streptococci bacteria measured at the Alum Fork Saline River were similar to concentrations measured at the Maumelle River and concentrations of fecal coliform were less. Concentrations of fecal streptococci bacteria had a median concentration of 230 colonies per 100 mL (fig. 44), compared to a median concentration of 265 colonies per 100 mL at the Maumelle River. Fecal coliform bacteria concentrations had a median of 50 colonies per 100 mL, which was approximately half the median concentration measured at the Maumelle River (110 colonies per 100 mL) (fig. 39).

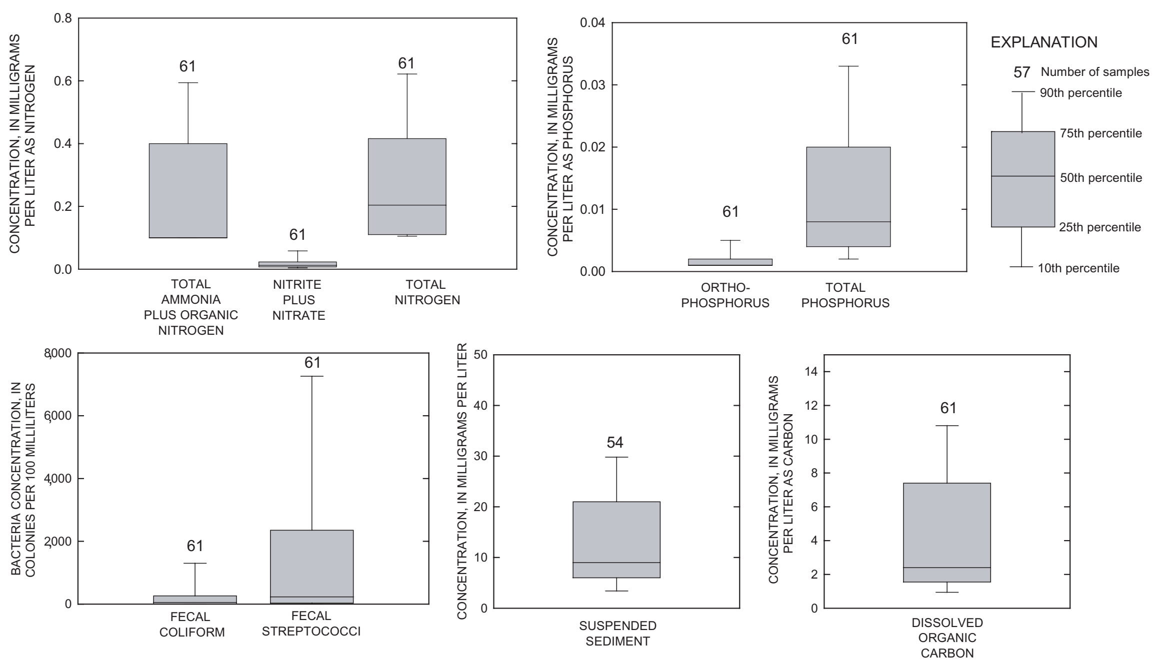


Figure 44. Distribution of nutrient, dissolved organic carbon, suspended-sediment, and fecal indicator bacteria concentrations for the Alum Fork Saline River near Reform, Arkansas, 1991 through 2003.

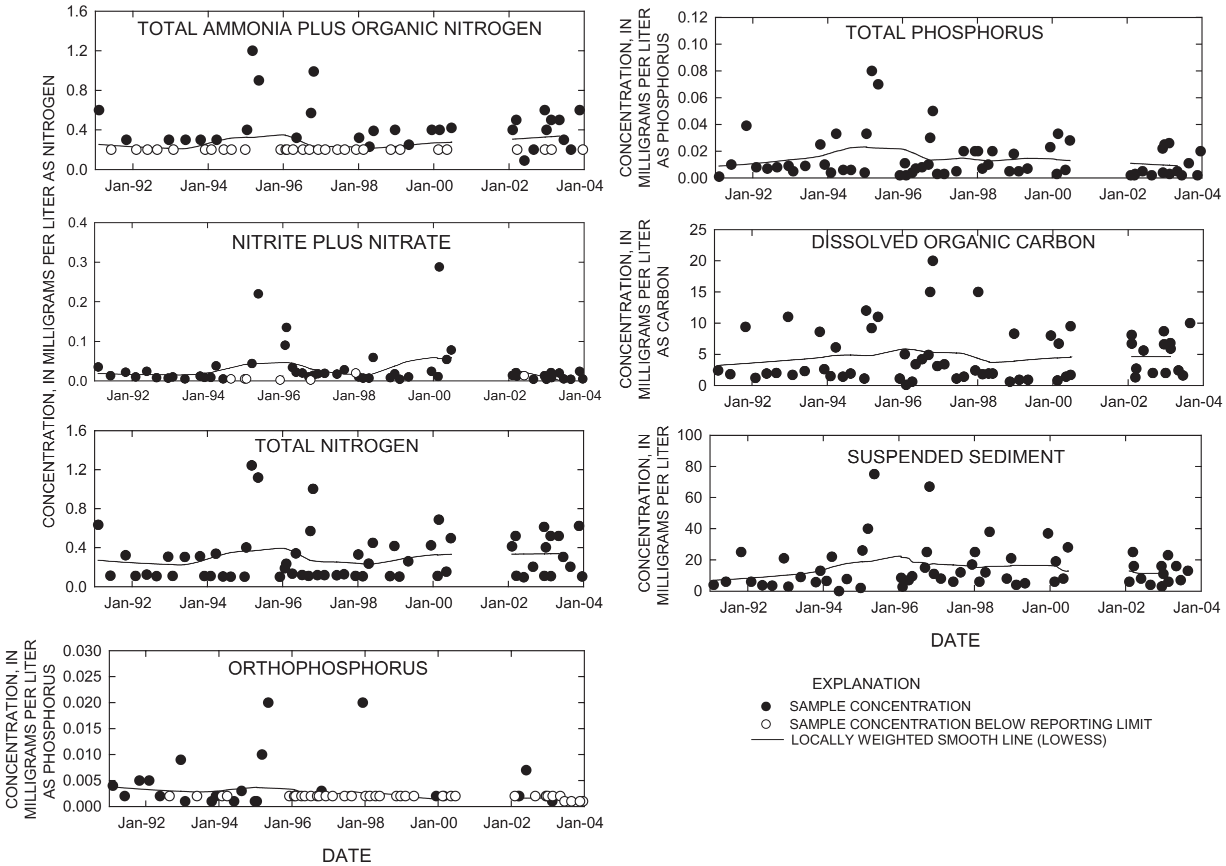


Figure 45. Time series of nitrogen, phosphorus, dissolved organic carbon, and suspended-sediment concentrations for the Alum Fork Saline River near Reform, Arkansas, 1991 through 2003.

Loads and Yields of Nutrients, Dissolved Organic Carbon, and Suspended Sediment

Annual loads estimated for the Alum Fork Saline River (fig. 46 and table 4) varied with time and were similar to loads estimated for the Maumelle River (fig. 40 and table 2). Nutrients, dissolved organic carbon, and suspended sediment at the Alum Fork Saline River had the greatest annual loads in 1991 and the least loads in 1995. Estimated annual total nitrogen loads ranged from 13,700 in 1995 to 41,400 kg/yr in 1991 with a mean load of 20,243 kg/yr for the period of 1991 through 2003. The mean annual total nitrogen load for the Alum Fork Saline River was approximately 30 percent less than the loads for the Maumelle River. Total ammonia plus organic nitrogen accounted for most of the annual nitrogen load with a mean of 18,072 kg/yr. The annual mean nitrite plus nitrate load was only 1,307 kg/yr. The annual total phosphorus load for the Alum Fork Saline River ranged from 468 kg/yr in 1995 to 1,380 kg/yr in 1991 with a mean load of 685 kg/yr. The ratios of annual total nitrogen load to total phosphorus load for the Alum Fork River ranged from 29 to 30, indicating that the nutrient loads entering Lake Winona are phosphorus limited (Redfield, 1958; Wetzel, 2001). The mean annual load of orthophosphorus was 181 kg/yr. Total phosphorus loads computed for the Alum Fork Saline River were half the phosphorus loads for the Maumelle River. The mean annual dissolved organic carbon load estimated for the Alum Fork Saline River was 257,895 kg/yr, which was slightly less than the mean dissolved organic carbon load estimated for the Maumelle River. The mean estimated suspended-sediment load was 705,729 kg/yr, which was approximately 60 percent less than the suspended-sediment load estimated for the Maumelle River (figs. 40 and 46 and tables 2 and 4).

Seasonal loads estimated for the Alum Fork Saline River (fig. 47) demonstrated a similar pattern to seasonal loads for the Maumelle River (fig. 41). The greatest loads generally occurred in the winter and the least loads occurred in the summer. Nutrient and suspended-sediment loads generally were more than 33 times greater in the winter than in the summer and dissolved organic carbon loads were 42 times greater in the winter than in the summer.

Annual yields of nutrients and dissolved organic carbon computed for the Alum Fork Saline River (table 4) were slightly greater than yields for the Maumelle River and suspended-sediment yields were less for the period of 1991 through 2003

Table 4. Estimated annual loads and yields for the Alum Fork Saline River near Reform, Arkansas, 1991 through 2003.

[kg/yr, kilograms per year; SD, standard deviation; kg/yr/km^2, kilograms per year per square kilometer; N, nitrogen; P, phosphorus; C, carbon]

Year	Total ammonia plus organic nitrogen as N		Nitrite plus nitrate as N		Total nitrogen as N		Orthophosphorus as P		Total phosphorus as P		Dissolved organic carbon as C		Suspended sediment	
	Load (kg/yr) (+/-SD)	Yield (kg/yr km^2)	Load (kg/yr) (+/-SD)	Yield (kg/yr/ km^2)	Load (kg/yr) (+/-SD)	Yield (kg/yr/ km^2)	Load (kg/yr) (+/-SD)	Yield (kg/yr/ km^2)	Load (kg/yr) (+/-SD)	Yield (kg/yr/ km^2)	Load (kg/yr) (+/-SD)	Yield (kg/yr/ km^2)	Load (kg/yr) (+/-SD)	Yield (kg/yr/ km^2)
1991	35,700+/-184	511	2,510+/-34	36	41,400+/-221	593	349+/-5.1	5	1,380+/-15	20	563,000+/-2,478	8,000	1,450,000+/-9,899	20,700
1992	13,000+/-60	186	954+/-12	14	14,400+/-68	206	132+/-1.7	2	488+/-4.5	7	179,000+/-802	2,560	500,000+/-2,951	7,160
1993	21,500+/-103	307	1,540+/-20	22	24,300+/-121	348	214+/-2.9	3	819+/-8.1	12	316,000+/-1,400	4,520	848,000+/-5,361	12,100
1994	19,800+/-92	283	1,440+/-18	21	21,900+/-105	313	199+/-2.7	3	745+/-6.9	11	273,000+/-1,227	3,900	763,000+/-4,540	10,900
1995	12,400+/-57	178	911+/-11	13	13,700+/-66	197	126+/-1.7	2	468+/-4.3	7	170,000+/-768	2,440	479,000+/-2,825	6,800
1996	19,500+/-90	279	1,420+/-18	20	21,700+/-104	310	196+/-2.6	3	736+/-6.9	11	271,000+/-1,214	3,880	755,000+/-4,506	10,800
1997	17,500+/-82	250	1,270+/-16	18	19,500+/-94	279	176+/-2.4	3	662+/-6.2	9	245,000+/-1,097	3,500	680,000+/-4,094	9,720
1998	18,000+/-84	257	1,310+/-16	19	20,000+/-96	286	181+/-2.4	3	679+/-6.4	10	249,000+/-1,121	3,570	696,000+/-4,157	9,960
1999	14,000+/-65	201	1,030+/-13	15	15,600+/-74	223	142+/-1.9	2	529+/-4.9	8	194,000+/-872	2,780	542,000+/-3,226	7,760
2000	13,200+/-60	190	975+/-12	14	14,500+/-69	208	134+/-1.8	2	496+/-4.5	7	178,000+/-803	2,540	506,000+/-2,924	7,240
2001	19,800+/-96	283	1,420+/-18	20	22,500+/-113	322	196+/-2.7	3	757+/-7.5	11	294,000+/-1,302	4,210	785,000+/-5,023	11,200
2002	14,500+/-67	207	1,060+/-13	15	16,000+/-76	228	147+/-1.9	2	544+/-5.0	8	196,000+/-888	2,800	556,000+/-3,248	7,950
2003	15,800+/-74	226	1,150+/-14	16	17,700+/-85	253	159+/-2.1	2	599+/-5.7	9	224,000+/-999	3,200	616,000+/-3,743	8,800
Mean	**18,072**	**258**	**1,307**	**19**	**20,243**	**289**	**181**	**2.6**	**685**	**10**	**257,895**	**3,688**	**705,729**	**10,092**
Median	**17,505**	**250**	**1,271**	**18**	**19,494**	**279**	**176**	**2.5**	**662**	**9**	**244,646**	**3,498**	**679,550**	**9,718**

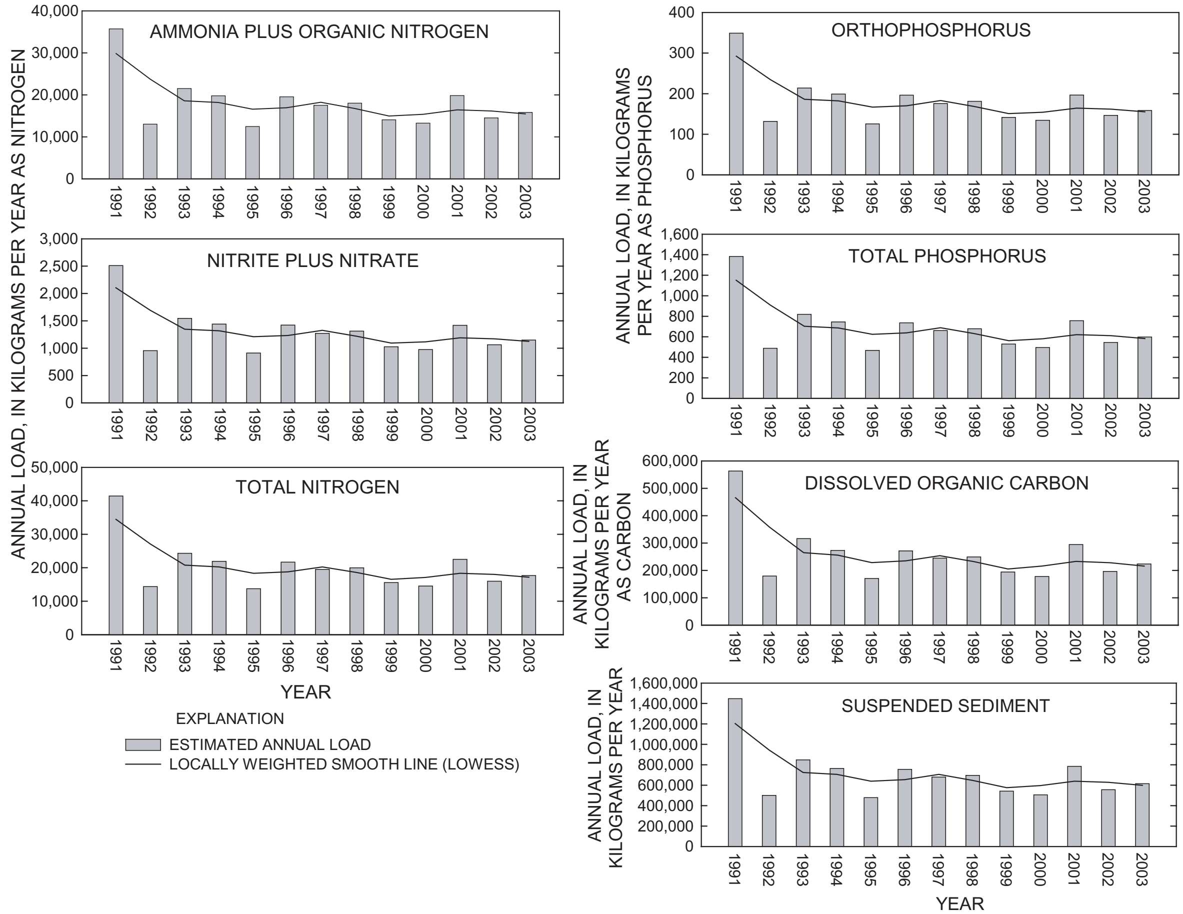


Figure 46. Annual nutrient, dissolved organic carbon, and suspended-sediment loads estimated for the Alum Fork Saline River near Reform, Arkansas, 1991 through 2003.

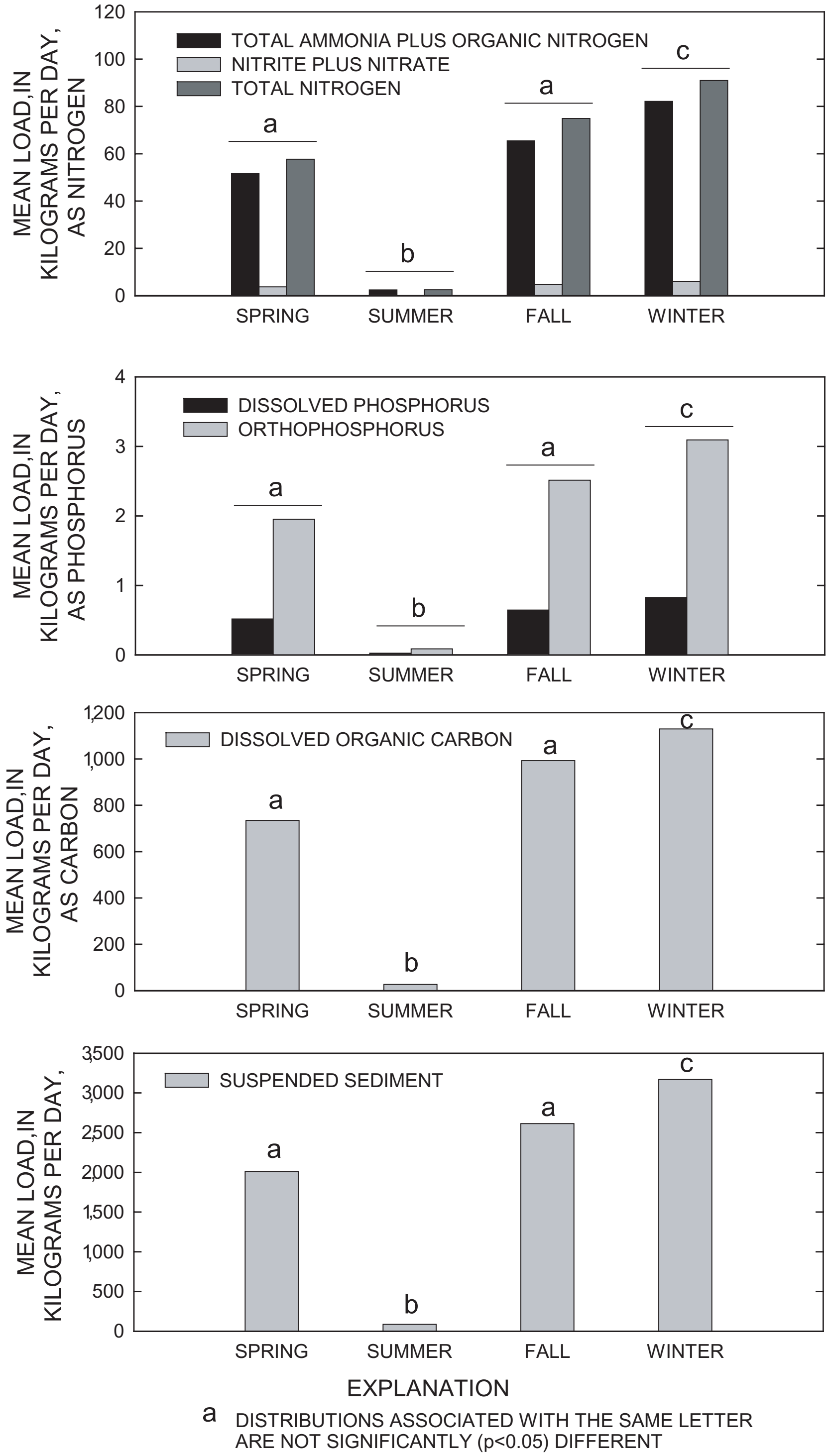


Figure 47. Seasonal nutrient, dissolved organic carbon, and suspended-sediment loads estimated for the Alum Fork Saline River, Arkansas, 1991 through 2003.

(tables 2 and 4). The mean total nitrogen yield was 289 kg/yr/km^2, which was slightly greater than the mean total nitrogen yield for the Maumelle River. The mean total phosphorus was 10 kg/yr/km^2, which was the same as the mean total phosphorus yield for the Maumelle River. The mean dissolved organic carbon yield for the Alum Fork Saline River was 3,688 kg/yr/km^2, approximately 1.6 times greater than the mean yield for the Maumelle River. The Maumelle River had a mean suspended-sediment yield that was 1.4 times the mean suspended-sediment yield for the Alum Fork Saline River.

Annual yields of total nitrogen and phosphorus for the Alum Fork Saline River were greater than yields for 82 sites representative of undeveloped basins identified across the Nation including 2 sites in Arkansas (Clark and others, 2000), and less than yields for the Illinois River south of Siloam Springs, Arkansas, which is representative of a developed basin (Green and Haggard, 2001) (fig. 42). The mean total nitrogen yield for the Alum Fork Saline River was more than three times the mean yield for the undeveloped basins and the total phosphorus was similar to the yields for the undeveloped sites. The Alum Fork Saline River had a mean yield of total phosphorus that was approximately 6 percent of the mean yield for the Illinois River near Siloam Springs. The mean yield of total nitrogen for the Alum Fork Saline River was approximately 16 percent of the total nitrogen yield for the Illinois River.

Flow-Weighted Concentrations of Nutrients, Dissolved Organic Carbon, and Suspended Sediment

Annual flow-weighted concentrations of nutrients and dissolved organic carbon (table 5) generally were the same as those computed for the Maumelle River (table 3). Suspended-sediment flow-weighted concentrations for the Alum Fork Saline River were approximately one-half those computed for the Maumelle River.

The Alum Fork Saline River generally had lower flow-weighted concentrations compared to the mean flow-weighted concentrations for undeveloped sites and substantially lower flow-weighted concentrations than those for the Illinois River south of Siloam Springs, Arkansas, representative of a developed basin (fig. 43). Flow-weighted concentrations of nitrite plus nitrate for the undeveloped sites were 4.7 times greater than the flow-weighted concentration for the Alum Fork Saline River, although the flow-weighted concentration of total nitrogen was slightly greater for the Alum Fork Saline River than for the undeveloped sites. Orthophosphorus flow-weighted concentrations for the Alum Fork Saline River were approximately 26 percent of the flow-weighted concentrations for the undeveloped sites, and total phosphorus flow-weighted concentrations were approximately 50 percent of the flow-weighted concentrations for the undeveloped sites.

Table 5. Annual flow-weighted concentrations computed for the Alum Fork Saline River near Reform, Arkansas, 1991 through 2003.

[Concentrations are in milligrams per liter; N, as nitrogen; P, phosphorus; C, carbon]

Year	Total ammonia plus organic nitrogen as N	Nitrite plus nitrate as N	Total nitrogen as N	Ortho-phosphorus as P	Total phosphorus as P	Dissolved organic carbon as C	Suspended sediment
1991	0.49	0.034	0.57	0.005	0.019	7.70	19.8
1992	0.43	0.031	0.47	0.004	0.016	5.90	16.5
1993	0.46	0.033	0.52	0.005	0.017	6.71	18.0
1994	0.44	0.032	0.49	0.004	0.017	6.05	16.9
1995	0.43	0.032	0.48	0.004	0.016	5.92	16.6
1996	0.44	0.032	0.49	0.004	0.017	6.10	17.0
1997	0.44	0.032	0.49	0.004	0.017	6.12	17.2
1998	0.44	0.032	0.49	0.004	0.017	6.09	17.0
1999	0.44	0.032	0.48	0.004	0.016	6.02	16.8
2000	0.43	0.031	0.47	0.004	0.016	5.72	16.3
2001	0.46	0.033	0.52	0.005	0.018	6.86	18.3
2002	0.43	0.032	0.48	0.004	0.016	5.84	16.6
2003	0.44	0.032	0.50	0.004	0.017	6.27	17.3
Mean	**0.44**	**0.032**	**0.50**	**0.004**	**0.017**	**6.26**	**17.3**
Median	**0.44**	**0.032**	**0.49**	**0.004**	**0.017**	**6.09**	**17.0**

Summary

Lakes Maumelle and Winona are water-supply reservoirs for the Little Rock and North Little Rock metropolitan areas in central Arkansas. In addition to water supply, the reservoirs are used for recreation and fish and wildlife habitat. Monitoring the changes in the hydrology and water quality in the basin as land use changes is critical to managing the resource.

The purpose of this report is to describe the hydrology and water quality of Lakes Maumelle and Winona and their inflows from data collected by the USGS in cooperation with CAW for calendar years 1991 through 2003. Water-quality samples were collected at four locations in Lake Maumelle and at three locations in Lake Winona. Samples also were collected at four inflow sites to Lake Maumelle and one inflow site to Lake Winona. Annual and seasonal loads of nutrients, dissolved organic carbon, and suspended sediment were estimated for the main inflows into Lakes Maumelle and Winona including the Maumelle River at Williams Junction, Arkansas, and the Alum Fork Saline River near Reform, Arkansas. Yields and flow-weighted concentrations were calculated from estimated annual loads for comparison with selected undeveloped basins and one developed basin.

The main inflows into Lakes Maumelle and Winona, the Maumelle River and Alum Fork Saline River, exhibited typical seasonal variability in streamflow with high flows usually occurring in the late fall, winter, and early spring, and low or no flow in the summer and early fall. The mean annual streamflow for 1991 through 2003 for the Maumelle River at Williams Junction was 1.64 m^3/s and for the Alum Fork Saline River near Reform was 1.28 m^3/s. The highest annual mean streamflow for both streams occurred in 1991, and the lowest annual mean streamflow occurred in 1992 for the Maumelle River and 1995 for the Alum Fork Saline River.

Lakes Maumelle and Winona are monomictic systems, in which thermal stratification occurs annually during the summer and complete mixing occurs in the fall. Isothermal conditions exist throughout the winter and early spring. The distribution of dissolved oxygen in Lakes Maumelle and Winona exhibits seasonal changes mainly because of the thermodynamics in the hypolimnion of the reservoir. Dissolved-oxygen concentrations during the winter remain uniform and near saturation levels and as thermal stratification becomes established, concentrations in the hypolimnion decrease until summer when conditions in the hypolimnion are nearly anoxic (devoid of dissolved oxygen).

Water quality measured in Lakes Maumelle and Winona varied spatially and temporally. Although total phosphorus concentrations were significantly less in the lower ends of lakes than concentrations in the upper ends of the lakes, nitrogen and orthophosphorus concentrations did not vary significantly among the sampling sites on each lake. The highest concentrations of nitrogen generally were measured in 1991 and from 1998 through 2003 at all of the sampling sites. The highest total phosphorus concentrations were measured from 1994 to 1996 and from 1998 to 2001 on Lake Maumelle and from 1993 to 1994 on Lake Winona. Total and dissolved organic carbon concentrations were similar among sites on each lake and the greatest concentrations were measured in 1996 and 1997 at all of the sites. The chlorophyll *a* concentrations varied seasonally, with the highest concentrations in October and November, but were relatively uniform spatially and annually in Lakes Maumelle and Winona for 1991 through 2003. Water clarity was greater at the lower ends of the lakes than the upper ends. Secchi depth varied seasonally, with the greatest depth from July to September and the least depth during October through December, although there was no apparent trend in Secchi depth over the entire sampling period.

The TSI calculated from near-surface concentrations of total phosphorus and chlorophyll *a* for Lakes Maumelle and Winona indicated that they generally were oligotrophic although they fluctuated in time between mesotrophic and oligotrophic conditions.

Water-quality concentrations generally were less for the Alum Fork Saline River, the main inflow to Lake Winona, than for the Maumelle River, Bringle, Yount, and Reece Creeks, which flow into Lake Maumelle. Nutrient and dissolved organic carbon concentrations for the Maumelle and Alum Fork Saline Rivers remained fairly uniform from 1991 through 2003. The median suspended-sediment concentration at the Alum Fork Saline River was approximately 28 percent less than the median concentration measured at the Maumelle River. Suspended-sediment concentrations generally were greatest at Bringle Creek. Concentrations of fecal streptococci measured at the Alum Fork Saline River were similar to concentrations measured at the Maumelle River, and fecal coliforms had a median concentration for the Alum Fork Saline River that was approximately half the median concentration measured at the Maumelle River. Bringle and Reece Creeks had greater median concentrations of fecal coliforms and fecal streptococci than the Maumelle River, and Yount Creek had the least median concentration of fecal streptococci among all the sites although Bringle, Yount, and Reece Creeks were sampled only during high-flow events while the Maumelle and Alum Fork Saline Rivers were sampled mainly during base-flow conditions.

Annual loads estimated for the Maumelle River and the Alum Fork Saline River were similar between sites and varied annually and seasonally from 1991 through 2003. Annual loads were greatest in 1991 for the Maumelle and Alum Fork Saline Rivers and were the least in 2000 for the Maumelle River and in 1995 for the Alum Fork Saline River. Estimated annual total nitrogen loads ranged from 18,000 to 46,500 kilograms per year for the Maumelle River and from 13,700 to 41,400 kilograms per year for the Alum Fork Saline River. Total phosphorus loads ranged from 822 to 1,960 kilograms per year for the Maumelle River and 468 to 1,380 kilograms per year for the Alum Fork Saline River. Estimated loads also demonstrated seasonal trends with the highest daily loads in the winter and fall and lowest daily loads in the summer for both sites.

Annual yields of nutrients and dissolved organic carbon computed for the Maumelle River were similar to yields for the Alum Fork Saline River and suspended-sediment yields were

less for the period of 1991 through 2003. The Alum Fork Saline River had a mean total nitrogen yield that was slightly greater than the mean total nitrogen yield for Maumelle River and more than 3 times greater than yields for selected undeveloped sites across the Nation. The mean total phosphorus yield for 1991 through 2003 for both the Maumelle and Alum Fork Saline River was 10 kilograms per year per square kilometer, which was similar to the selected undeveloped sites. The mean dissolved organic carbon yields for the Maumelle and Alum Fork Saline Rivers were 2,254 and 3,688 kilograms per year per square kilometer, respectively. The mean suspended-sediment yields for the Maumelle and Alum Fork Saline Rivers were 14,486 and 10,092 kilograms per year per square kilometer, respectively.

Annual flow-weighted nutrient and dissolved organic carbon concentrations computed for the Maumelle and Alum Fork Saline Rivers were similar and suspended-sediment flow-weighted concentrations for the Maumelle River were approximately twice the suspended-sediment flow-weighted concentrations for the Alum Fork Saline River. Nutrient concentrations for the Maumelle River and Alum Fork Saline River also were similar to selected undeveloped sites across the Nation.

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