

**WATER QUALITY ASSESSMENT OF MAUMELLE  
AND WINONA RESERVOIR SYSTEMS,  
CENTRAL ARKANSAS,  
MAY 1989 - OCTOBER 1992**

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**U.S. GEOLOGICAL SURVEY  
Water-Resources Investigations Report 93-4218**

*Prepared in cooperation with the*  
**LITTLE ROCK MUNICIPAL WATER WORKS**



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*by W. Reed Green*

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**Little Rock, Arkansas  
1994**

**U.S. DEPARTMENT OF THE INTERIOR**  
**BRUCE BABBITT, *Secretary***

**U.S. GEOLOGICAL SURVEY**  
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## CONTENTS

	Page
Abstract .....	1
Introduction .....	2
Purpose and scope .....	2
Description of study area .....	3
Maumelle reservoir .....	4
Winona reservoir .....	4
Study methods and approach .....	6
Hydrologic setting .....	10
Thermal and dissolved oxygen dynamics .....	16
Water quality related to municipal water supply .....	21
Water quality related to other regional streams and reservoirs .....	29
Regional streams .....	29
Regional reservoirs .....	32
Water quality of Maumelle in relation to trophic state and sensitivity to change .....	35
Summary .....	40
Selected references .....	41

## ILLUSTRATIONS

Figures 1-3. Maps showing:

1. Location of study area .....	3
2. Maumelle reservoir system and location of data collection stations .....	7
3. Winona reservoir system and location of data collection stations .....	7
4-7. Graphs showing:	
4. Daily mean discharge for Maumelle River (M11) and Alum Fork Saline River (W5), August 1989 through October 1992 .....	11
5. Flow-duration relations for Maumelle River (M11) and Alum Fork Saline River (W5), water-years 1990-92 .....	12
6. Daily discharge-percentage total discharge relations for Maumelle River (M11) and Alum Fork Saline River (W5), water-years 1990-92 .....	13
7. Daily mean reservoir volume for Maumelle and Winona reservoirs, August 1989 through October 1992 .....	14
8. Map showing Maumelle reservoir bathymetry .....	15
9. Map showing Winona reservoir bathymetry .....	15
10-17. Graphs showing:	
10. Percentage of capacity and depth relation for Maumelle and Winona reservoirs .....	16
11. Distribution of temperature with depth and time in Maumelle reservoir at site M2, January 1991-October 1992 .....	17
12. Temperature-depth profiles during winter, spring, and summer in Winona reservoir at site W2, 1989-92 .....	18
13. Distribution of dissolved oxygen as percentage of saturation with depth and time in Maumelle reservoir at site M2, January 1991-October 1992 .....	19
14. Dissolved oxygen-depth profiles during winter, spring, and summer in Winona reservoir at site W2, 1989-92 .....	20
15. Chloride, nitrite plus nitrate nitrogen, total iron, and total manganese concentrations in water from inflow and reservoir stations from Maumelle and Winona reservoirs .....	23
16. Sodium, sulfate, and total dissolved solid concentrations, and turbidity in water from inflow and reservoir stations from Maumelle and Winona reservoirs .....	26

## ILLUSTRATIONS (Continued)

	Page
Figure 17. Color intensity and organic carbon concentrations in water from inflow and reservoir stations from Maumelle and Winona reservoirs . . . . .	28
18. Map showing regional streams and reservoirs used in water-quality comparisons. . . . .	30
19-21. Graphs showing:	
19. Chloride, sulfate, total ammonia nitrogen, and total phosphorus concentrations in water from selected streams in Arkansas . . . . .	31
20. Total phosphorus and chlorophyll-a concentrations in water from selected reservoirs in Arkansas . . . . .	33
21. Expected maximum chlorophyll-a concentrations for Maumelle reservoir generated by the Reckhow (1988) model. . . . .	38

## TABLES

Table 1. Descriptive data for Maumelle and Winona reservoir systems. . . . .	5
2. Sampling dates for Maumelle and Winona inflow and reservoir stations . . . . .	8
3. Primary standards for selected constituents mandated by the U.S. Environmental Protection Agency and the Arkansas Department of Health, and secondary standards recommended by the Arkansas Department of Health for drinking water . . . . .	22
4. Variables used in the Reckhow (1988) empirical trophic state models for Maumelle reservoir . . . . .	36
5. Observed and calculated values generated from the Reckhow (1988) empirical trophic state models for mean summer phosphorus, nitrogen, and maximum summer chlorophyll-a concentrations in Maumelle reservoir. . . . .	37

## CONVERSION FACTORS AND VERTICAL DATUM

<u>Multiply</u>	<u>By</u>	<u>To obtain</u>
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
acre	0.4047	hectare
square mile (mi <sup>2</sup> )	2.590	square kilometer
gallon	3.785	liter
	0.003785	cubic meter
million gallons (Mgal)	3,785	cubic meter
billion gallons (Ggal)	3,785,000	cubic meter
million gallons per day (Mgal/d)	0.04381	cubic meter per second
acre-foot (acre-ft)	1,233	cubic meter
cubic foot per second (ft <sup>3</sup> /s)	0.02832	cubic meter per second
	28.32	liter per second

Degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) by using the following equation:

$$^{\circ}\text{F} = 9/5(^{\circ}\text{C}) + 32$$

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Water year: In this report "water year" refers to October 1 through September 30, numbered for the calendar year starting January 1. For example, water-year 1991 is defined as October 1, 1990 through September 30, 1991.



# WATER QUALITY ASSESSMENT OF MAUMELLE AND WINONA RESERVOIR SYSTEMS, CENTRAL ARKANSAS, MAY 1989 - OCTOBER 1992

*By W. Reed Green*

## ABSTRACT

Water quality of the Maumelle and Winona water supply reservoir systems in central Arkansas, was assessed on the basis of data collected from May 1989 through October 1992. Water quality was assessed relative to: (1) suitability for municipal water supply; (2) other streams and reservoirs within the region; and for the Maumelle reservoir, (3) the ecological trophic condition and sensitivity to change. The Maumelle reservoir covers 8,900 acres and is relatively shallow (maximum depth is 45 feet). The Winona reservoir covers 1,240 acres and has a maximum depth of 100 feet.

The tributary and reservoir water was analyzed for constituents regulated by the U.S. Environmental Protection Agency and the Arkansas Department of Health. In many cases, the concentration of these constituents was at or below detection limits, which was well below the respective maximum contaminant levels used by the Arkansas Department of Health. Total iron and manganese concentrations often exceeded the maximum contaminant level, especially in the bottom water of Maumelle. Turbidity levels also exceeded the maximum contaminant level, but this would be expected in the raw water.

The water quality of Maumelle and Winona reservoir systems also compared favorably when measured against other regional streams and reservoirs. From these comparisons, it can be considered that the water quality of the major tributaries discharging into the respective reservoirs represents the baseline or pristine condition within the region. Likewise, the water quality of the reservoirs could be considered to represent the baseline condition; Maumelle for a shallow, impounded flood-plain reservoir, and Winona for a deep river valley reservoir.

Data from the Maumelle reservoir system were used to investigate trophic condition using empirical models developed from an 80 lake cross-sectional data set that examined, specified, and parameterized trophic state relations. Observed and predicted values generated from empirical trophic state models compared favorably. The Maumelle reservoir can be considered in a state of oligo-mesotrophic transition. If nutrient inputs can be maintained at current levels, the water quality of the Maumelle reservoir should remain relatively stable. However, increases in phosphorus load may alter the water quality from its present oligo-mesotrophic condition to that of a more eutrophic condition, and this trophic response may be amplified with increases in nitrogen loading.

## INTRODUCTION

Surface-water reservoirs (impounded free-flowing streams) are a major source for domestic, industrial, and agricultural water supply. Maintaining the quality of water in the reservoirs is critical to water supply management and operation. In order for the water to be suitable for consumption, the finished product must meet certain water-quality criteria and standards established by the U.S. Environmental Protection Agency (USEPA) and other State and local governments. In order for water-supply management to establish obtainable objectives, accurate data must be available on the quantity and quality of the raw water resource.

All too often, the quality of a water resource deteriorates to an unacceptable condition before remedial actions are enacted to address the problem or source of the problem. Evidence of this is found throughout the literature and is witnessed in the number of Federal and State agencies regulating water quality and the number of private environmental engineering and consulting firms specializing in water-quality regulation, protection, and restoration. The North American Lake Management Society, a professional organization, also is devoted to lake and reservoir management and restoration. This society has published documents for the USEPA dealing with lake and reservoir restoration (Olem and Flock, 1990; and Wedepohl and others, 1990).

The critical element in reservoir management is water-quality protection. If the resource can be protected from water-quality deterioration then the restoration element is eliminated. Restoration techniques, when available, can be costly and are often only partially successful. The problem in restoration lies in the complexity of the functional interactions between the physical, chemical, and biotic components. Eliminating or reducing the input of one element, for example phosphorus loading, may or may not produce the desired results. Therefore, management should have a water-quality data base that can be used to accurately assess present water-quality conditions, trends, and sensitivity to change.

The physical, chemical, and biological dynamics of reservoirs exist along the gradient between those typical of riverine and lake systems. As a result, reservoirs behave differently than either natural lake or riverine ecosystems (Wetzel, 1990). Reservoirs, as with all dynamic ecosystems, age and are driven to reach equilibrium. Ultimate equilibrium in reservoirs would be to fill up with sediment and return to the free-flowing state. As maturation occurs in reservoirs, the trophic condition evolves from oligotrophy to mesotrophy, mesotrophy to eutrophy, and from eutrophy to hypereutrophy; oligotrophy could be considered the finest water-quality state or the pristine condition, hypereutrophy being the poorest water-quality state or "polluted." In the natural condition, that is, the existence of a reservoir in a watershed with no influence from cultural activities, equilibrium would not be reached for hundreds of years. However, cultural activities within the watershed can accelerate these processes from hundreds of years to a few decades (Kimmel, 1990).

The reservoir systems investigated in this study are commonly called Lake Maumelle and Lake Winona. For consistency, these bodies of water will be referred to as Maumelle and Winona reservoirs. Maumelle and Winona reservoirs are artificial stream impoundments constructed to provide domestic and industrial water for the city of Little Rock and its subscribers in central Arkansas. Little Rock Municipal Water Works (LRMWW) is the utility that owns and operates the two water-supply reservoirs. Basic hydrologic and water-quality data, and assessment of the water-quality condition of the Maumelle and Winona reservoir systems is needed by LRMWW in order to properly manage these systems as water-supply reservoirs. This study was conducted by the U.S. Geological Survey (USGS) in cooperation with LRMWW.

### Purpose and Scope

The purpose of this report is to assess and describe the water-quality condition of the Maumelle and Winona reservoir systems in central Arkansas. Water-quality data were collected within these systems from May 1989 through October 1992 and continued thereafter but at a less intensive scale. The data on which this report is based is presented in Green and Louthian (1993). Water-quality interpretations range from the detailed description of functional processes between specific physical, chemical, and biotic components of the system to simple comparisons of data values with those values of established water-

quality standards. In this report, the water-quality of the Maumelle and Winona reservoir systems is assessed relative to: (1) suitability for municipal supply; (2) other streams and reservoirs within the region; and for the Maumelle reservoir, (3) the ecological trophic condition and sensitivity to change.

### Description of Study Area

The Maumelle and Winona reservoir systems are located in central Arkansas, west of the city of Little Rock (fig. 1). Construction of Lake Winona and Lake Maumelle was completed in 1938 and 1956, respectively.

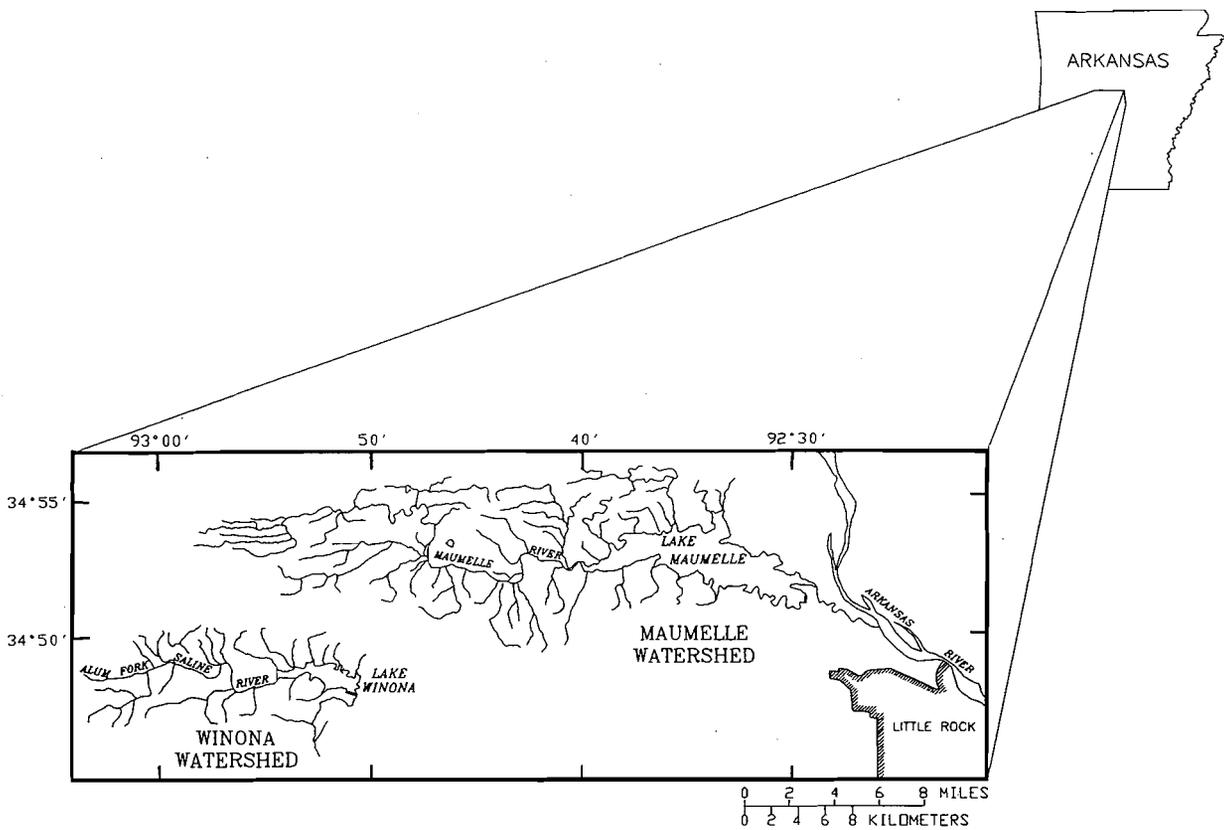


Figure 1.—Location of study area.

### Maumelle Reservoir

The Maumelle River watershed has an area of 137 mi<sup>2</sup> at the Maumelle reservoir dam, and is part of the Arkansas River drainage basin. About 62 percent of the water entering the reservoir enters through the Maumelle River. The normal annual rainfall within the watershed is about 54 in. (Freiwald, 1985).

The general land-use classification for the Maumelle watershed is "forest and woodland grazed" (U.S. Geological Survey, 1970, p. 159). The upper one-third of the watershed is primarily forest land owned and managed by the Ouachita National Forest. The forest land is classified as moderate to low productive land with a full range of site conditions that have been determined to be suitable for timber production (U.S. Department of Agriculture, 1989). The general soil type, defined by the USDA soil surveys of Pulaski and Perry Counties (Haley and others, 1975; Townsend and Williams, 1982; respectively), is Carnasaw-Pirum Clebit: well drained gently sloping to very steep, deep, moderately deep, and shallow, loamy, gravelly and stony soils; on uplands. The remainder of the watershed is also primarily forest with some agriculture existing in the lowland area of the Maumelle River above the reservoir. Turf (sod) farming is the most common agricultural practice in the flood plain.

The Maumelle reservoir contains 219,440 acre-ft (72 Ggal) of water at spillway elevation (290 ft above sea level); and has 187,340 acre-ft (61 Ggal) of usable water. The safe water usage withdrawal yield is 90 Mgal/d. The surface area of the Maumelle reservoir at spillway elevation is 13.9 mi<sup>2</sup> or about 8,900 acres. The maximum length of the reservoir is 12 mi, with a maximum depth of 45 ft, and an average depth of 24.7 ft. Other characteristics of the Maumelle reservoir and its watershed are presented in table 1.

### Winona Reservoir

The Alum Fork of the Saline River watershed has an area of 44.4 mi<sup>2</sup> at the Winona reservoir dam and is part of the Red River drainage basin. About 65 percent of the water entering the reservoir enters through the Alum Fork Saline River. The normal annual rainfall within the watershed is about 52 in. (Freiwald, 1985).

The land-use classification of the Winona watershed, like the Maumelle watershed, is forest and woodland grazed. The entire watershed exists within the boundaries of the Ouachita National Forest, but some of the land is owned by timber companies. The area adjacent to and surrounding the reservoir is owned by Little Rock Municipal Water Works and is protected from timber harvest. The forest land classification is the same as Maumelle; moderate to low productive land with a full range of site conditions that have been determined to be suitable for timber production (U.S. Department of Agriculture, 1989). The general soil type is that of the Carnasaw-Pirum-Clebit described above for the Maumelle watershed.

The Winona reservoir contains 41,730 acre-ft (14 Ggal) of water at spillway elevation (740 ft above sea level) and has 38,000 acre-ft (12.5 Ggal) of usable water. The safe water usage withdrawal yield is 25 Mgal/d. Winona has a surface area at spillway elevation of 1.9 mi<sup>2</sup> or 1,240 acres. The maximum length of the reservoir is 4.5 mi, with a maximum depth of 100 ft and an average depth of 34.7 ft. Other characteristics of the Winona reservoir and its watershed are presented in table 1.

Table 1.--Descriptive data for Maumelle and Winona reservoir systems  
 [mi, mile; mi<sup>2</sup>, square mile; Ggal, billion gallons; acre-ft, acre-feet; ft, feet]

	Maumelle	Winona
WATERSHED		
Maximum length	28.0 mi	12.3 mi
Maximum width	4.6 mi	3.6 mi
Area	137.0 mi <sup>2</sup>	44.4 mi <sup>2</sup>
Diameter	28.1 mi	17.5 mi
Perimeter	70.5 mi	35.6 mi
Shape <sup>1</sup>	5.7	3.4
Compactness ratio <sup>2</sup>	1.7	1.5
Slope index (percentage)	1.3	3.9
Main channel length to dam	43.9 mi	17.0 mi
Main channel length to mouth	27.5 mi	11.9 mi
Main channel slope to dam (percentage)	0.27	0.59
Main channel slope to mouth (percentage)	0.31	0.57
Sinuosity ratio <sup>3</sup>	1.57	1.38
RESERVOIR		
Maximum length	12.0 mi	4.5 mi
Maximum width	3.2 mi	0.66 mi
Mean width	1.23 mi	0.42 mi
Shoreline	70.0 mi	25.0 mi
Shoreline development ratio <sup>4</sup>	5.3	5.1
Area	13.9 mi <sup>2</sup>	1.9 mi <sup>2</sup>
Volume	72.0 Ggal	14.0 Ggal
	219,440 acre-ft	41,730 acre-ft
Maximum depth	45.0 ft	100.0 ft
Average depth	24.7 ft	34.7 ft
Watershed area/reservoir area ratio	9.9	23.4

<sup>1</sup> Shape - The shape of the basin computed as the ratio of the length of the basin to its width.

<sup>2</sup> Compactness ratio - The ratio of the perimeter of the watershed to the circumference of a circle of equal area.

<sup>3</sup> Sinuosity ratio - The ratio of main channel length to watershed length.

<sup>4</sup> Shoreline development ratio - The ratio of the length of the shoreline to the length of the circumference of a circle whose area is equal to that of the reservoir.

## STUDY METHODS AND APPROACH

The following is a summary of the methods and approach of the study related to this report. A detailed description of the methods used for measuring discharge and reservoir elevation, water quality sample collection, and sample analysis are given in Green and Louthian (1993). Data collection and analyses were conducted following methods prescribed and accepted by the USGS. All sample collection and analyses were conducted by personnel of the USGS. Chemical analyses were conducted by the USGS National Water Quality Laboratory, Arvada, Colorado.

Continuous reservoir elevation and tributary discharge gaging stations were established within each reservoir system. These stations are designated as M1 and M11 for the Maumelle system, and W1 and W5 for the Winona system (figs. 2-3). The drainage area above the discharge station on the Maumelle River (M11) accounts for 37 percent of the Maumelle watershed, and the drainage area above the discharge station on the Alum Fork Saline River (W5) accounts for 61 percent of the Winona watershed. Rating curves were established for each station based on instantaneous discharge measurements (Buchanan and Somers, 1965; Carter and Davidian, 1965; and Kennedy, 1983) and continue to be updated. High flow on the Alum Fork of the Saline River was computed using indirect methods because conditions would not allow direct instantaneous measurements. The reservoir elevation stations gage the surface elevation and account for capacity based on established elevation-capacity curves provided by LRMWW. Theoretical rating curves for discharge flowing over the respective spillways were established and verified with periodic instantaneous discharge measurements within the streams just below the dams.

Fixed sample stations were established along the downstream gradient in both reservoirs for the collection of water-quality data; M2, M4, and M8 on the Maumelle reservoir; and W2, W3, and W4 on the Winona reservoir (figs. 2-3). Sample stations in the reservoir were located along the original stream channel, the deepest location within the cross section.

The Maumelle and Winona reservoir systems project objectives were modified in the fall of 1990. As a result, sampling protocols were changed. Modifications in the project included water-quality data collection for the purpose of constructing, calibrating, and verifying a numerical model of hydrodynamics and water quality in the Maumelle reservoir. The new protocol included more sampling locations for physicochemical (temperature, pH, dissolved oxygen, and specific conductance) water column profile sampling and more frequent chemical sampling. For the purpose of this report, only data collected at the Maumelle stream inflow station M11 and the reservoir stations M2, M4, and M8; and the Winona stream inflow station W5, and the Winona reservoir stations W2, W3, and W4 will be presented.

During water-years 1989-90, Maumelle and Winona reservoirs were sampled three times annually: once during the winter (January or February), once during the spring (April or May), and once during the late summer (August or September) (table 2). The reservoir inflow stations also were sampled at the same time and three additional samples were collected during separate high-flow storm events when conditions permitted. Only one sample was collected during the rise and fall of the high-flow event.

After project modifications were implemented (water-years 1991-92), sampling was intensified in the Maumelle reservoir system and scaled back in the Winona reservoir system (table 2). Physicochemical water column profiles in Maumelle reservoir were sampled 11 times during water year 1991 and 13 times during 1992, more frequently during periods of thermal stratification. Chemical water-quality components in Maumelle reservoir were sampled six times during water year 1991 and seven times during water year 1992, again, more frequently during periods of thermal stratification. The two upper reservoir stations on Winona reservoir (W3 and W4) were dropped from the sampling protocol after water year 1990, and only Winona reservoir station W2 was sampled during water years 1991-92.

Water-quality samples were collected in the streams (M11 and W5) following equal transit-rate methods using depth integrated samplers described by Guy and Norman (1970). Physicochemical measurements were made using a four-parameter submersible data sonde unit calibrated daily before sampling.

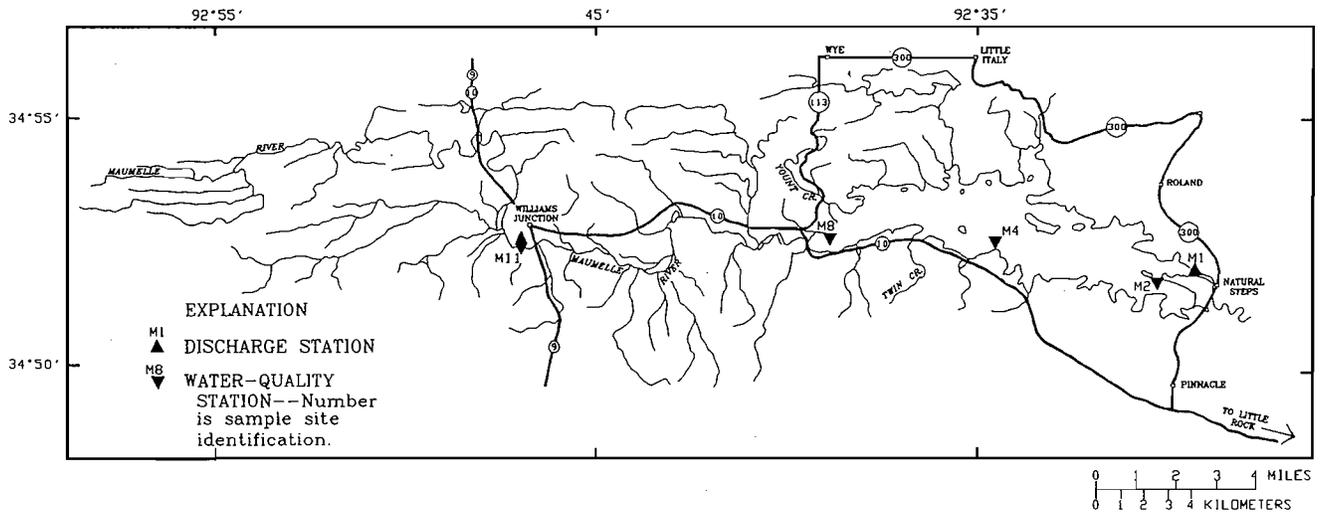


Figure 2.--Maumelle reservoir system and location of data collection stations.

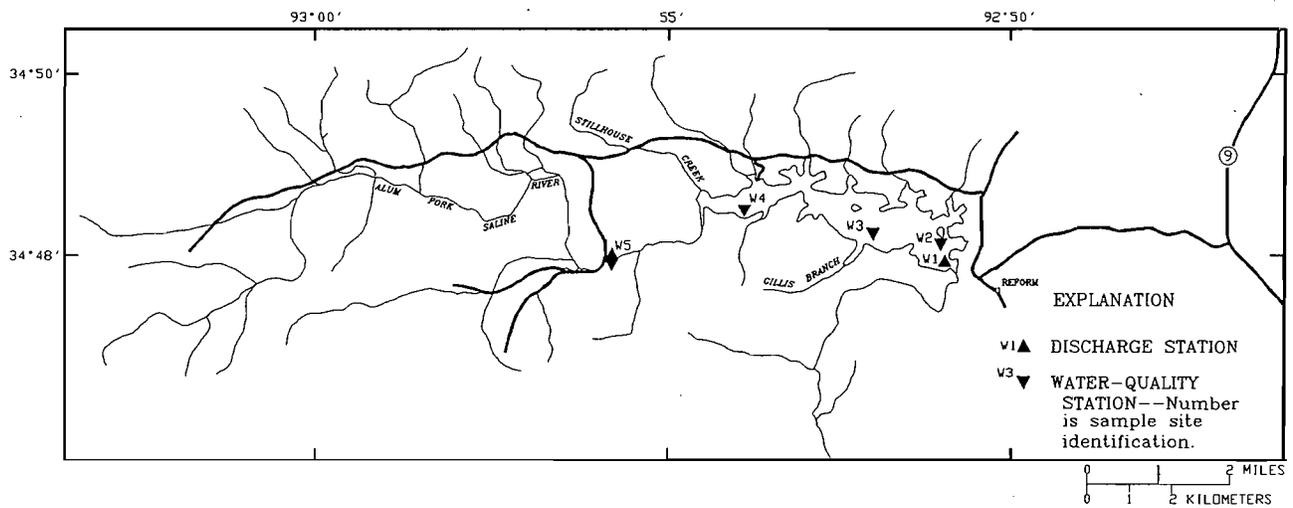


Figure 3.--Winona reservoir system and location of data collection stations.

Table 2.--*Sampling dates for Maumelle and Winona inflow and reservoir stations*

Maumelle stations			
M11	M8	M4	M2
05-22-89	05-25-89	05-26-89	05-26-89
08-28-89	08-30-89	08-30-89	08-30-89
01-19-90	01-31-90	01-31-90	01-31-90
01-29-90	04-04-90	04-04-90	04-04-90
03-08-90	08-30-90	08-31-90	08-31-90
04-02-90	02-06-91	02-08-91	02-08-91
08-28-90	04-24-91	04-25-91	04-23-91
02-06-91	06-05-91	06-05-91	06-07-91
04-23-91	07-08-91	07-09-91	07-10-91
04-27-91	08-06-91	08-07-91	08-08-91
06-04-91	08-27-91	08-28-91	08-28-91
10-29-91	11-06-91	11-07-91	11-07-91
11-06-91	02-05-92	02-05-92	02-06-92
02-03-92	03-24-92	03-25-92	03-23-92
03-23-92	06-01-92	06-02-92	06-02-92
05-22-92	07-08-92	07-09-92	07-10-92
07-01-92	07-28-92	07-29-92	07-30-92
07-27-92	08-31-92	09-01-92	09-03-92
08-25-92	10-19-92	10-20-92	10-21-92
Winona stations			
W2	W3	W4	W5
05-24-89	05-24-89	05-23-89	05-22-89
08-29-89	08-29-89	08-29-89	08-28-89
01-30-90	01-30-90	01-30-90	10-02-89
04-03-90	04-03-90	04-03-90	01-19-90
08-29-90	08-27-90	08-27-90	01-29-90
02-05-91			03-30-90
06-03-91			04-02-90
09-06-91			08-28-90
02-04-92			02-05-91
06-15-92			06-04-91
09-09-92			10-29-91
			02-03-92
			05-21-92
			08-24-92

Secchi disc transparency and physicochemical profile data measurements were conducted at each reservoir station. Measurements were made at various depths within the water column. When thermal stratification was present, measurements were taken at depth intervals where the change in temperature was no more than 1 °C or at 1-ft intervals, whichever was greater. For example, if there was only a 1°C difference between the surface water temperature and the water temperature 5 ft deep, then no measurements were taken in between. However, in the thermocline, temperatures will vary greatly over a small depth range. If the temperatures differed greater than 1 °C between 18 and 20 ft then a measurement was taken at 19 ft, as well.

Water-quality samples were collected at Maumelle reservoir stations using two different methods during the study period, as a result of the project modifications. During water years 1989-90, chemical constituents were sampled at discrete depths within the water column using a cylindrical sampling bottle (Van Dorn type). Discrete points were determined by multiplying the total depth of the water column by 0.2 and 0.8, and sampling at those depths. For example, if the water column was 40 ft, then the sample bottle was lowered to 8 ft for the upper level sample, and lowered to 32 ft for the lower level sample.

Depth integrated samples were collected in the water column during water year 1991-92. Integrated samples were collected using a 3 ft, open-ended bailer. The bailer was lowered at 3 ft intervals within the depth integrated range and the contents of each were placed in a container (churn splitter) and mixed thoroughly prior to dispensing. The integrated depth range was determined based on temperature profiles. When conditions were isothermal, an integrated sample was collected which represented the upper half of the water column, and another integrated sample was collected which represented the bottom half of the water column. For example, if the water column was 40 ft deep, then the first sample integrated the water from 0 to 18 ft below the surface, and the second sample integrated the water from 22 to 40 ft below the surface. When thermal stratification existed, the first integrated sample was collected representing the epilimnion or mixing layer, and the second collected representing the hypolimnion or bottom water layer. For example, if the water column was 40 ft deep and the thermocline existed between 18 and 25 ft below surface, then the first integrated sample would be collected between 0 and 18 ft below the surface, and the second integrated sample would be collected between 25 and 40 ft below the surface. When the bottom layer was absent at M8, only the surface sample was collected.

Discrete water samples were collected at the Winona reservoir stations throughout the study. The vertical locations were determined as described above for the discrete sampling at the Maumelle reservoir stations. However, vertical locations were changed at W2 later in the study because the 0.2 times depth placed the sample location in the metalimnion. The vertical locations at W2 were changed to 10 and 50 ft below the surface instead of the 20 and 80 ft depths.

Depth integrated composites of the epilimnion using the 3-ft bailer were used for collecting chlorophyll samples in both reservoirs for water years 1991-92. Prior to that, discrete chlorophyll samples were collected 3 ft below the surface using the cylindrical sampling bottle. Bacteria samples were collected with the chemical samples, and analysis was conducted at the District laboratory. Chlorophyll and bacteria were analyzed following methods described by Britton and Greeson (1987).

All samples that required chilling were immediately placed on ice at the time of collection. Sample filtering and fixation were conducted immediately upon return to the District laboratory. Chilled and frozen samples were stored in the District laboratory and shipped in coolers packed with ice overnight to the USGS National Water Quality Laboratory for analysis.

## HYDROLOGIC SETTING

Discharge at the tributary inflow stations, Maumelle River at Williams Junction (M11) and Alum Fork Saline River (W5), exhibited typical seasonal variability during August 1989 through October 1992 (fig. 4). Periods of no flow occurred in both rivers during the late summer. High-flow events occurred frequently throughout the fall, winter, and spring. The maximum daily mean flow at M11 and W5 occurred on March 8, 1990 (2,210 ft<sup>3</sup>/s) and December 21, 1990 (5,800 ft<sup>3</sup>/s), respectively.

Daily mean no flow during water years 1990-92 occurred at M11 and W5, 13 and 6.6 percent of the time, respectively (fig. 5). Daily mean flow at M11 exceeded 100 and 1,000 ft<sup>3</sup>/s about 12 and 0.8 percent of the time, respectively. At M11, daily mean flow of 100 ft<sup>3</sup>/s or less accounted for only 20 percent of the total discharge for water-years 1990-92 (fig. 6). Another 20 percent of the total discharge was accounted for at daily mean flows of 1,000 ft<sup>3</sup>/s and greater, which occurred in only 13 days out of the 3-year period (1,095 days). Fifty percent of the total discharge was accounted for at daily mean flows of 331 ft<sup>3</sup>/s and greater, which occurred less than 5.3 percent of the time.

At W5, mean daily mean flow of 100 ft<sup>3</sup>/s or less accounted for 21 percent of the total discharge during water years 1990-92. About 27 percent of the total discharge was accounted for at daily mean flows of 1,000 ft<sup>3</sup>/s or greater, which occurred less than 1 percent of the time (9 days out of 1,095). Fifty percent of the total discharge was accounted for at daily mean flows of 400 ft<sup>3</sup>/s and greater, which occurred less than 3.2 percent of the time (35 out of 1,095 days).

The water level (stage-volume) of Maumelle and Winona reservoirs exhibited seasonal fluctuations during the study period resulting from seasonal inflows and water supply withdrawal (fig. 7). Maximum volumes occurred in late winter and early spring, while minimum volumes occurred during late summer and early fall. Volumes in Maumelle ranged from about 197,000 to 239,000 acre-ft during August 1989 through October 1992, a 42,000 acre-ft difference. The minimum volume in Maumelle was about 10 percent less than the volume when the water level is at spillway elevation. Volumes in Winona ranged from about 31,000 to 44,000 acre-ft. The minimum volume in Winona was about 28 percent less than the volume when the water level is at spillway elevation.

As described earlier, the size, shape, and bathymetry of the Maumelle and Winona reservoirs are considerably different (table 1, figs. 8 and 9). When the reservoirs are at full capacity, about 50 percent of the volume in Maumelle and Winona reservoirs exists within the upper 14 and 21 ft, respectively (fig. 10). During periods of thermal stratification, the thermocline in Maumelle reservoir exists around 18 to 24 ft below water surface. About 64 percent of the water mass exists above the thermocline in the epilimnion, with only about 20 percent of the volume existing below the thermocline in the hypolimnion. The thermocline in Winona reservoir sets up at about 14 to 15 ft below water surface and extends to about 25 ft. About 35 percent of the volume of the Winona reservoir exists in the epilimnion, and 44 percent of the water mass exists in hypolimnion.

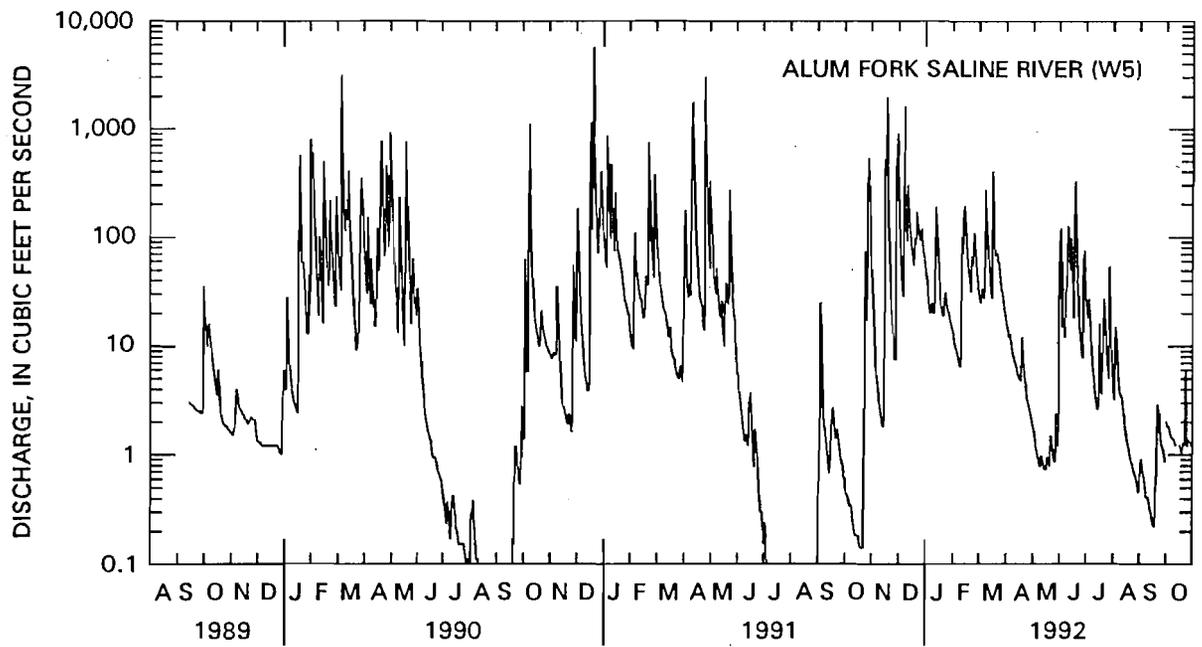
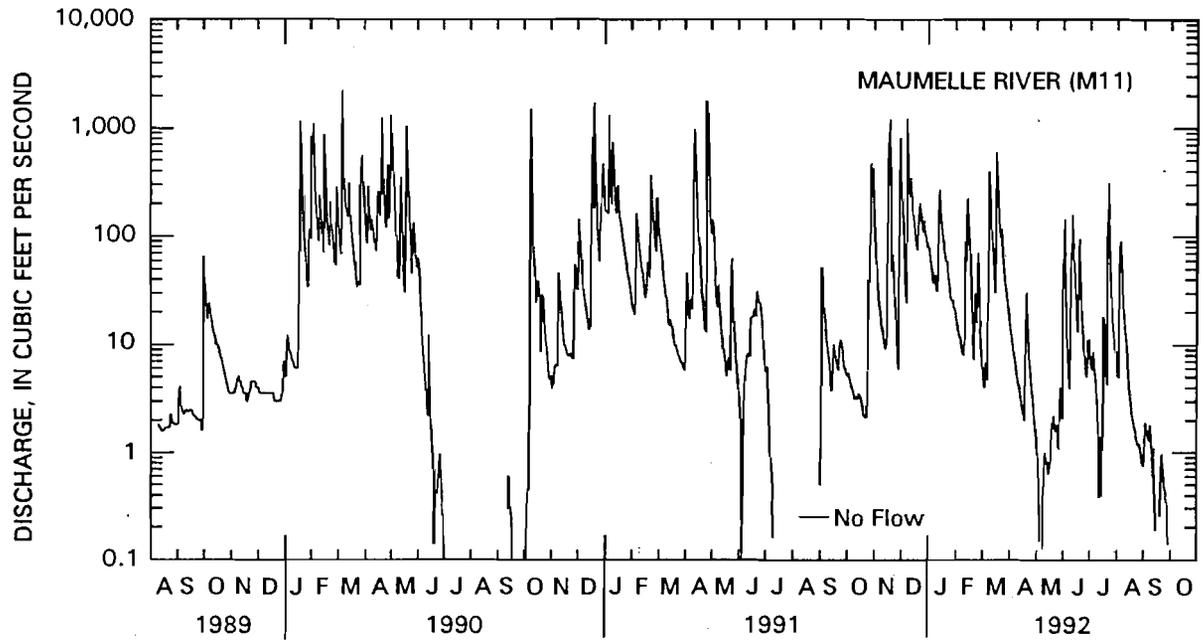


Figure 4.--Daily mean discharge for Maumelle River (M11) and Alum Fork Saline River (W5), August 1989 through October 1992.

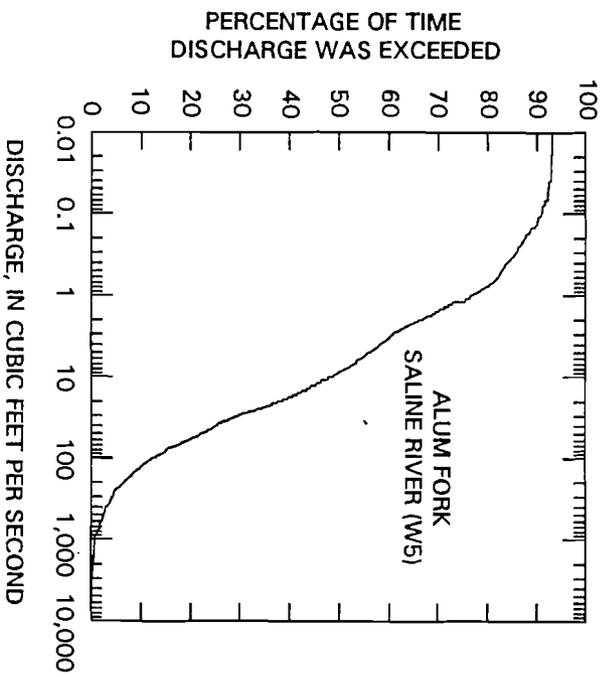
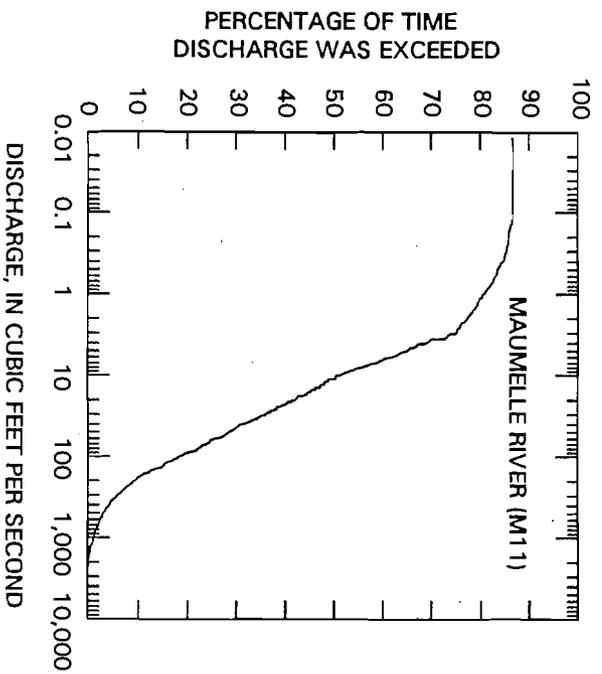


Figure 5.--Flow-duration relations for Maumelle River (M11) and Alum Fork Saline River (W5), water-years 1990-92.

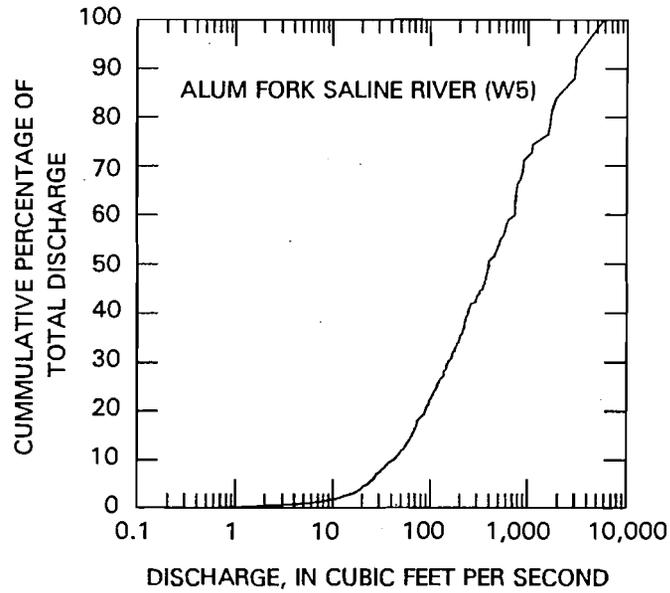
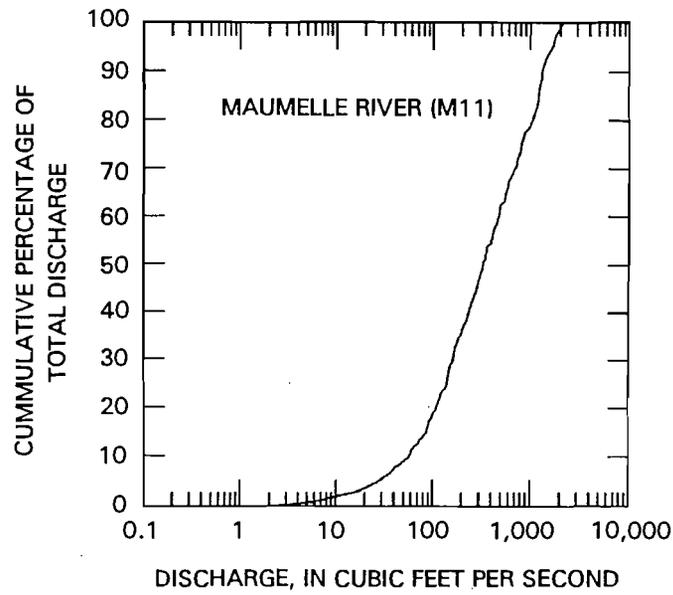


Figure 6.—Daily discharge-percentage total discharge relations for Maumelle River (M11) and Alum Fork Saline River (W5), water-years 1990-92.

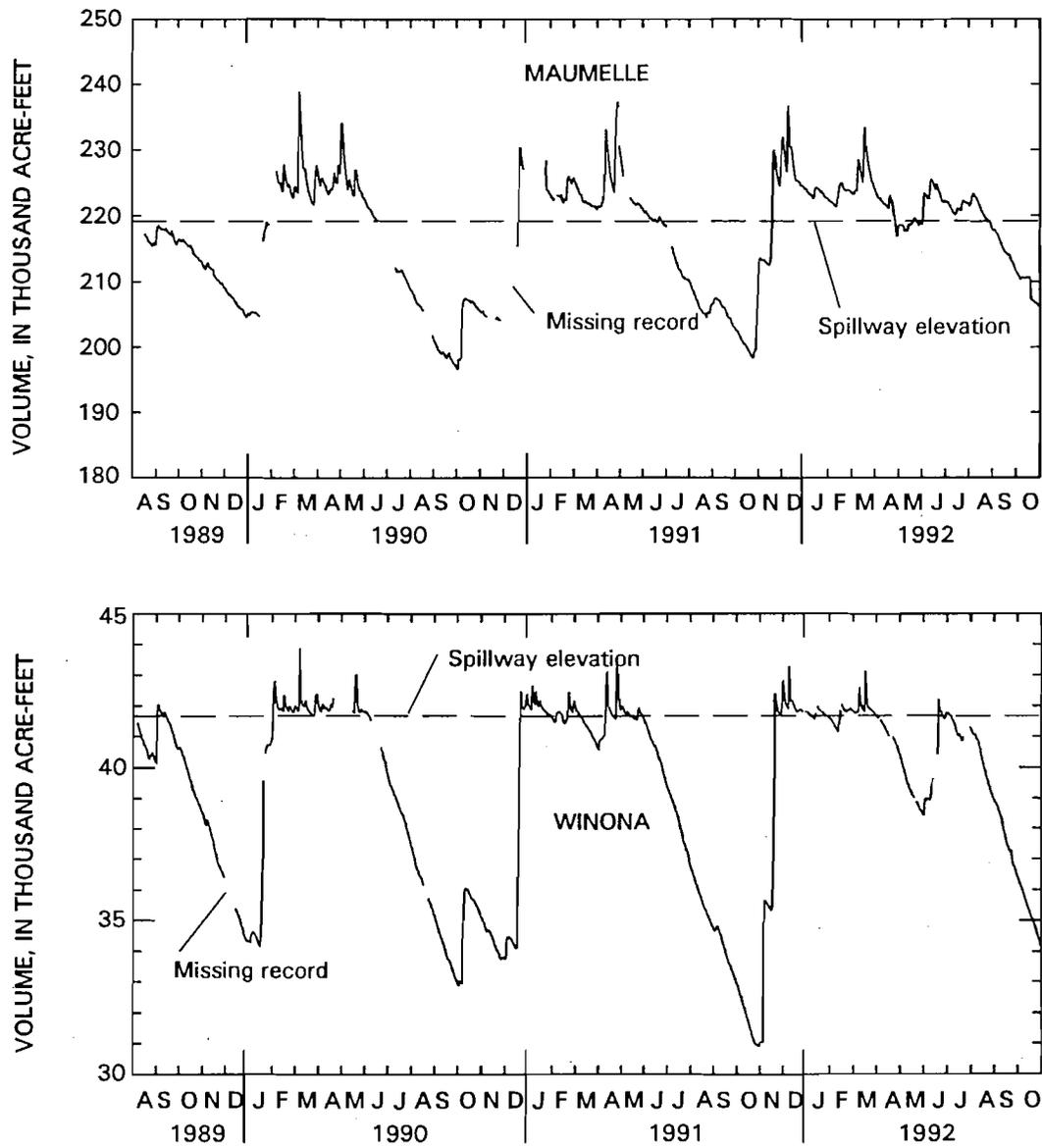


Figure 7.--Daily mean reservoir volume for Maumelle and Winona reservoirs, August 1989 through October 1992.

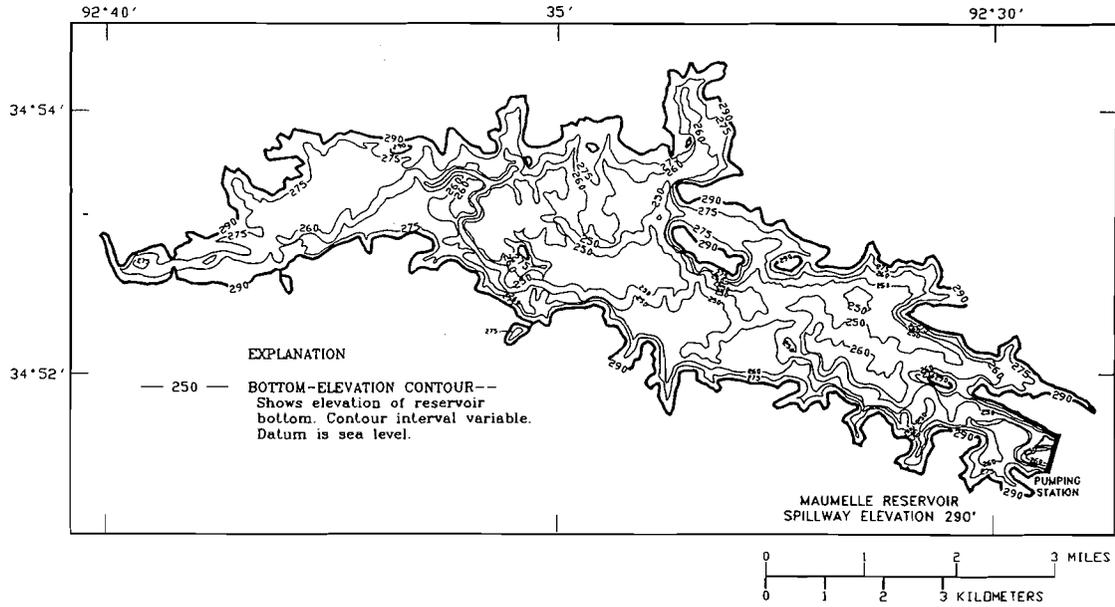


Figure 8.—Maumelle reservoir bathymetry.

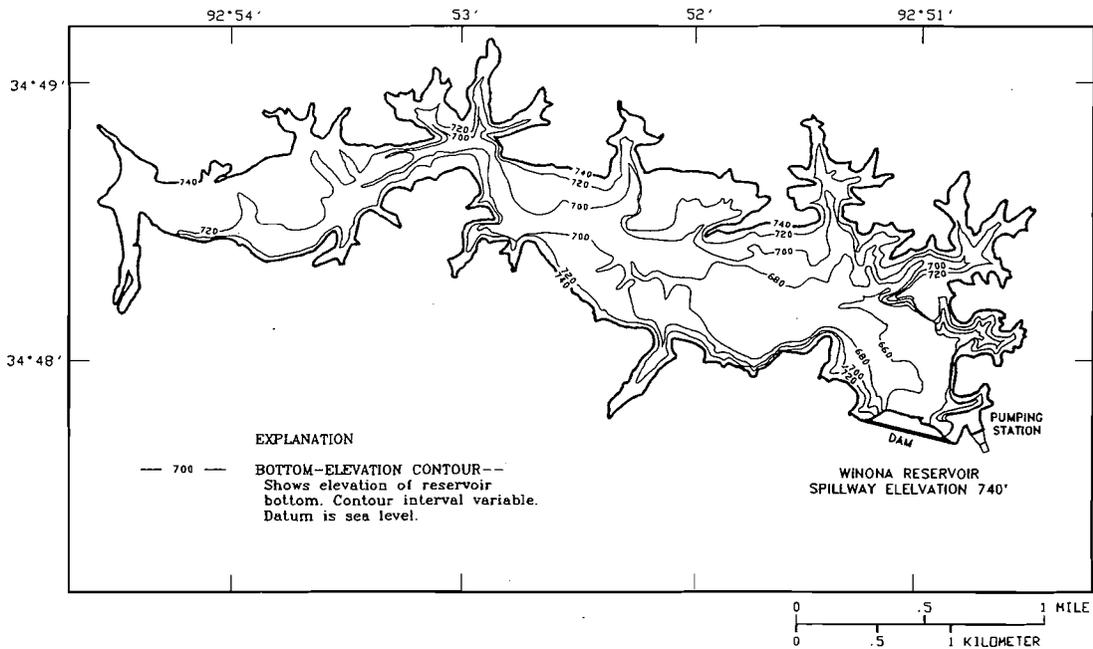


Figure 9.—Winona reservoir bathymetry.

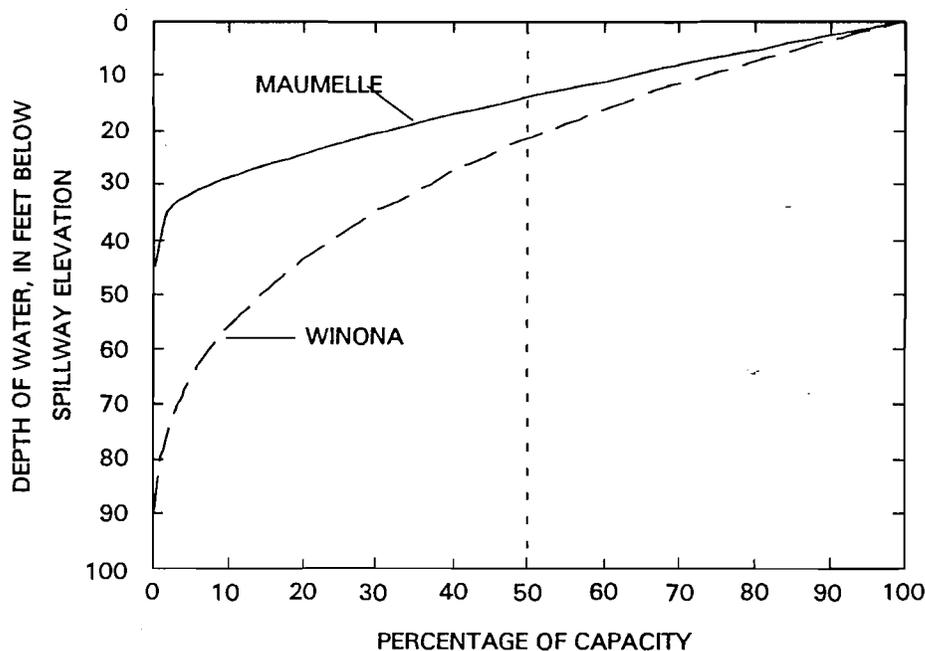


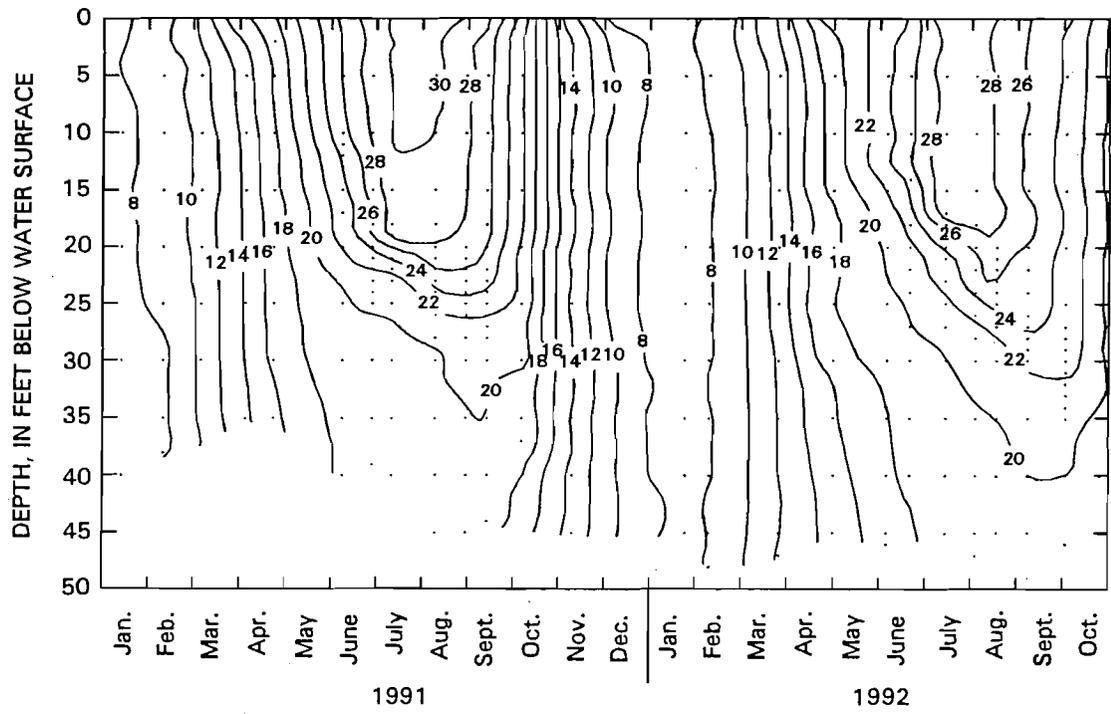
Figure 10.—Percentage of capacity and depth relation for Maumelle and Winona reservoirs.

### THERMAL AND DISSOLVED OXYGEN DYNAMICS

The thermal dynamics in Maumelle and Winona reservoirs exhibit the typical seasonal cycles of lakes and reservoirs (Wetzel, 1983) located within similar latitudes. Maumelle and Winona reservoirs are monomictic systems, in which thermal stratification becomes established annually during the summer season and complete mixing occurs during fall turnover. Isothermal conditions (uniform temperature) exist in both reservoirs during winter (figs. 11-12). Very little wind energy is needed to mix the water column under these conditions. As the layer of water near the surface heats up during the spring, more rapidly than the heat is distributed throughout the water column, temperature or density gradients begin 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 (Wetzel, 1983).

Thermal stratification begins at the Maumelle damsite (M2) during May and June, and becomes fully established by July (fig. 11). Stratified conditions continue until October when climatic conditions force thermal breakdown. Vertical temperature profiles at the Winona damsite (W2) show that isothermal conditions exist during winter, and thermal stratification becomes established during the spring (fig. 12). By late summer, thermal stratification is fully established. The temperature of water below a depth of about 40 ft at the Winona damsite ranges between 6.5 and 12.0 °C throughout the year. Whereas, the temperature of water near the bottom of Maumelle ranges from about 8 to 20 °C.

The temperature and volume of the hypolimnetic water is critical to the dissolved oxygen dynamics and chemical kinetics of the reservoir (Wetzel, 1983). The equilibrium concentration of dissolved oxygen in water in contact with air is a function of temperature and pressure (Hem, 1989). Colder water can hold more dissolved oxygen than warmer water. For example, dissolved-oxygen equilibrium levels in water at 10 and 30 °C and at a total pressure of 760 millimeter (mm) of mercury are about 11.3 and 7.6 milligrams per liter (mg/L), respectively (American Public Health Association and others, 1989). Because the hypolimnion is physically isolated from the surface during periods of thermal stratification (summer and early fall), reaeration from surface mixing is eliminated and very little if any oxygen input from photosynthetic activity occurs below the thermocline (Wetzel, 1983). Consequently, once oxygen is



EXPLANATION

- 20 — LINES OF EQUAL TEMPERATURE, IN DEGREES CELSIUS
- SAMPLE POINT

Figure 11.—Distribution of temperature with depth and time in Maumelle reservoir at site M2, January 1991 - October 1992.

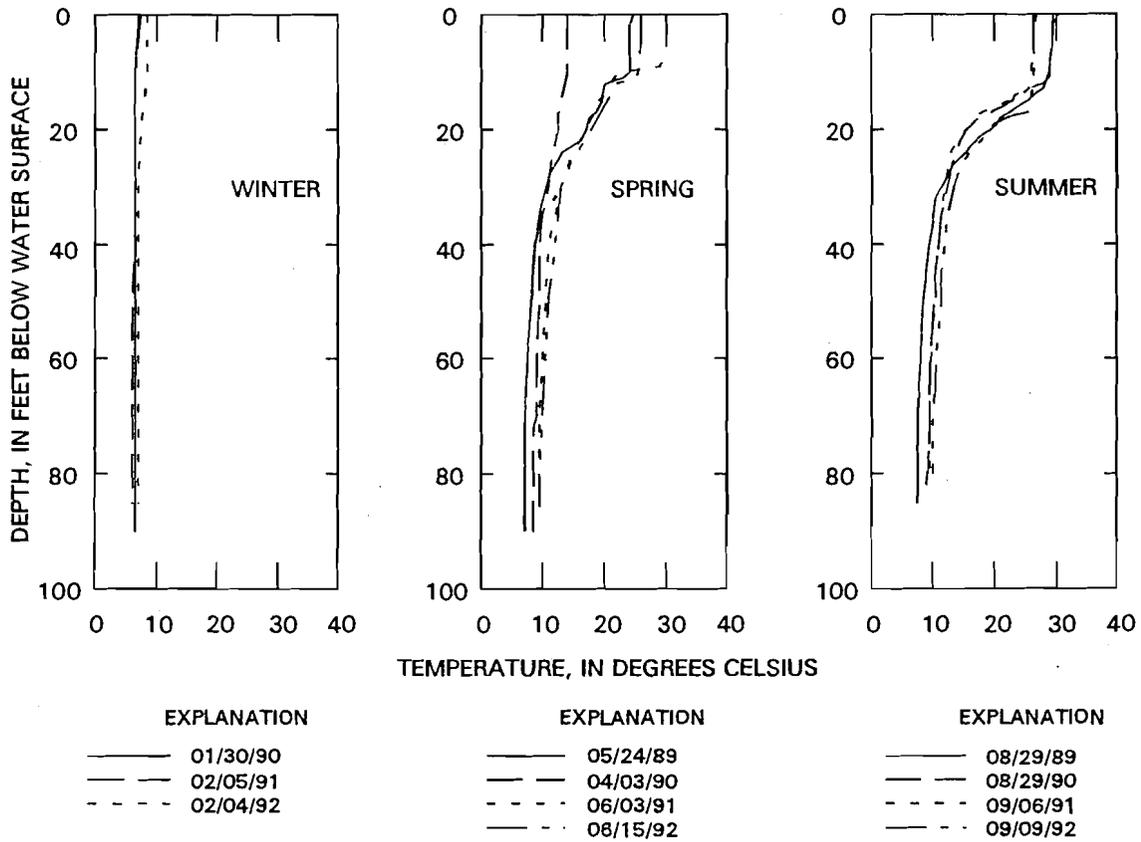


Figure 12.--Temperature-depth profiles during winter, spring, and summer in Winona reservoir at site W2, 1989-92.

removed from the hypolimnion, it cannot be replenished until fall, when thermal gradients break down as a result of climatic events. The sediment and biochemical-oxygen demand within the hypolimnion can consume oxygen quickly once the system becomes thermally stratified. If all the dissolved oxygen is removed, the chemical environment transforms from an oxidizing environment to a reducing one. Constituents that occur in the combined form in the oxidizing epilimnetic water become reduced (dissolved) in the hypolimnion when oxygen is low or absent. Under these conditions dissolved constituents increase in concentration with depth (Hem, 1989; Wetzel, 1983).

Oxygen concentrations during winter remained near saturation levels because of the isothermal conditions in Maumelle reservoir (fig. 13). As thermal stratification becomes established in Maumelle reservoir, oxygen concentrations in the hypolimnion began to diminish, and by summer, conditions in the hypolimnion are anoxic (void of dissolved oxygen). The reduction of oxygen in the hypolimnion in Maumelle reservoir is presumably the result of four phenomenon in addition to the sediment oxygen demand. First, the volume of water existing in the hypolimnion, as mentioned earlier, is relatively small and as a result, the total mass of oxygen is limited. Second, the temperature of the hypolimnetic water is relatively warm, further reducing the amount of oxygen that can be contained within. Third, as phytoplankton and other particulate matter settles out of the water, decay and chemical reduction consumes the oxygen within the hypolimnion. And fourth, once the surface water begins to heat up in spring, the cooler inflow from the Maumelle River and surrounding tributaries would tend to sink below the surface water because of the density (temperature) differences. This phenomenon is described as underflow by Wetzel (1983). As a result, the organic and chemical load, which can be associated with underflows, is displaced into the hypolimnion and adds to the consumption of oxygen.

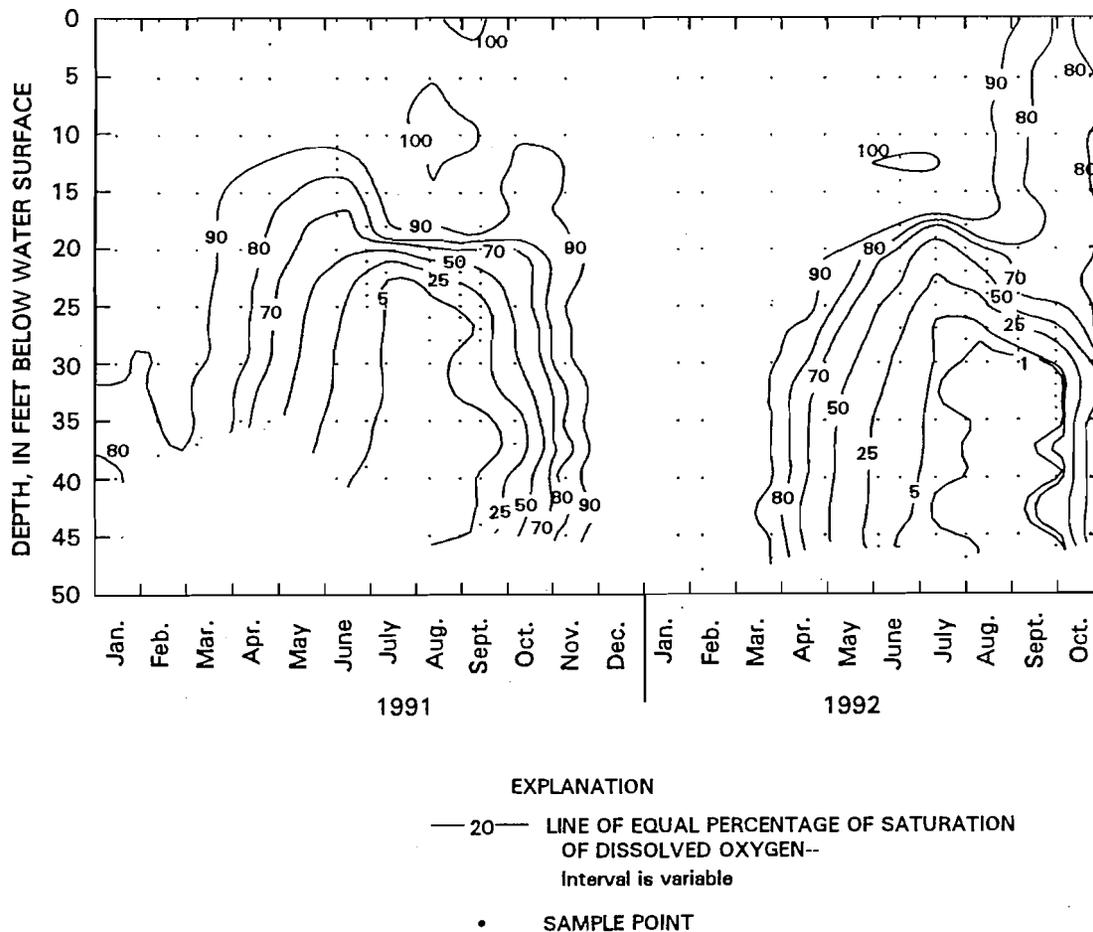


Figure 13.--Distribution of dissolved oxygen as percentage of saturation with depth and time in Maumelle reservoir at site M2, January 1991 - October 1992.

Winona reservoir exhibits different seasonal oxygen dynamics than Maumelle reservoir (fig. 14). First, the volume of the hypolimnion in relation to total volume is greater in Winona than Maumelle reservoir, allowing for a relatively greater mass of oxygen. Second, the temperature of the bottom water remains relatively cool allowing for greater concentrations of oxygen. Third, because of the seasonally cooler temperatures of the hypolimnion (fig. 12), the inflow from the Alum Fork Saline River and surrounding tributaries would tend to move through the middle layers (metalimnion) of the reservoir as interflow (Wetzel, 1983). As a result, the organic and chemical load associated with the interflow would consume oxygen within the metalimnion. The interflow process is further established because of the placement of the water-supply withdrawal penstock, 22 to 26 ft below spillway elevation. And fourth, the phytoplankton and other particulate matter, settling out of the epilimnion would decay and consume oxygen within this layer as well. Dissolved oxygen levels in Winona reservoir during winter exhibit homogenous concentrations from top to bottom (fig. 14). By spring, dissolved oxygen levels begin to diminish in the metalimnion, and by summer the dissolved oxygen levels in the metalimnion exhibit anoxia. Oxygen concentrations near the bottom also become depleted during the summer, presumably the result of the sediment oxygen demand.

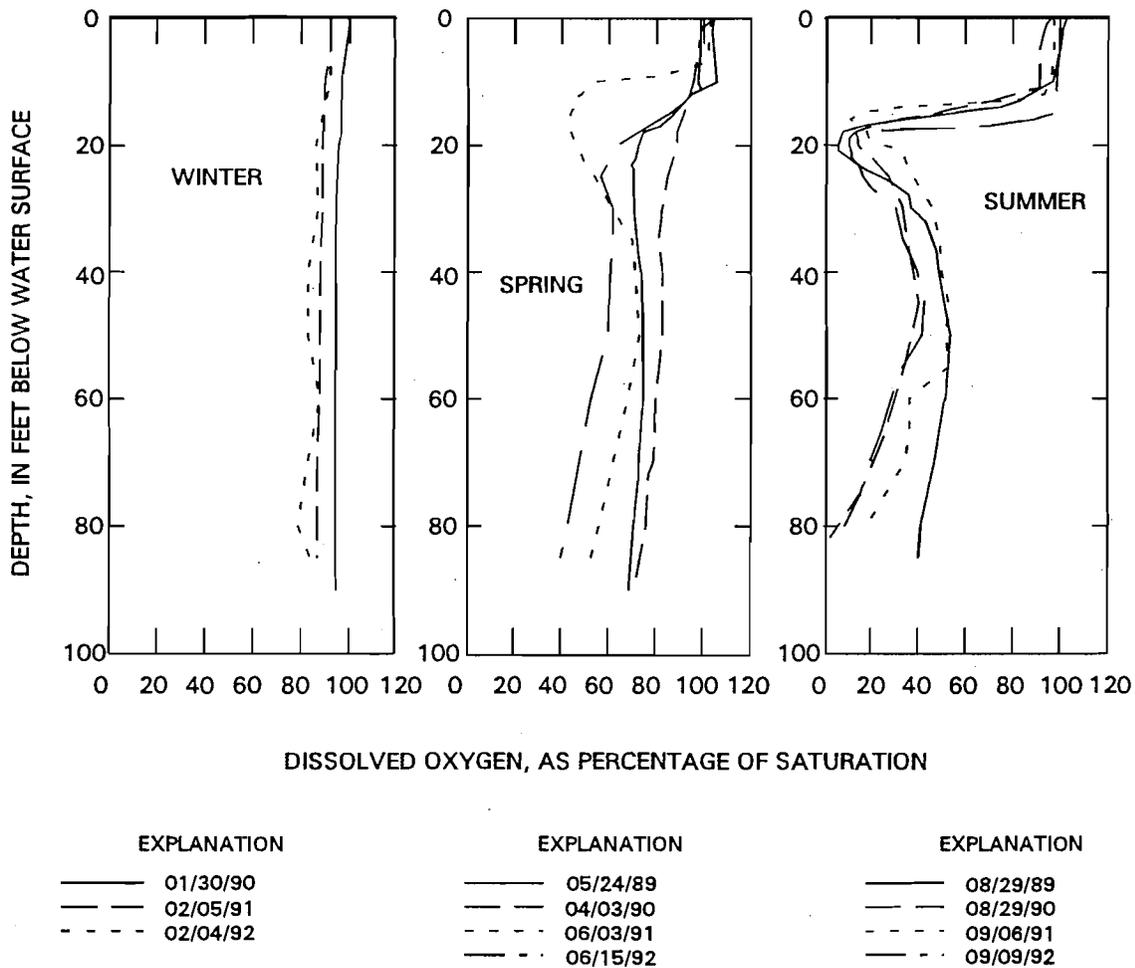


Figure 14.—Dissolved oxygen—depth profiles during winter, spring, and summer in Winona reservoir at site W2, 1989-92.

## WATER QUALITY RELATED TO MUNICIPAL WATER SUPPLY

The following discussion concerns selected water-quality standards (table 3) mandated by the USEPA and Arkansas Department of Health (ADH), and the concentration of these constituents from water samples collected in the Maumelle and Winona reservoir systems from May 1989 through October 1992 (Green and Louthian, 1993). Discussion of these standards will follow LRMWW terminology where all standards are referred to as maximum contaminant levels (MCLs); maximum level/concentration allowed by USEPA.

Arsenic can occur in water in various forms. Which form is found in water is dependent upon variables such as redox potential, pH, organic content, suspended solids, and sediment (U.S. Environmental Protection Agency, 1986). Arsenic can be toxic even in small amounts to humans, as well as aquatic life, and is considered a highly undesirable contaminant in water supply (Hem, 1989). The different forms of arsenic vary in toxicity from species to species (U.S. Environmental Protection Agency, 1986). Arsenic was used as a component of pesticides and can enter streams through waste disposal or agricultural drainage (Hem, 1989). The MCL for arsenic is 50  $\mu\text{g}/\text{L}$  (microgram per liter). The concentration of arsenic in water samples from Maumelle and Winona (inflow and reservoir sites) ranged from less than 1 to 10  $\mu\text{g}/\text{L}$ , most of which were less than the detection limit of 1  $\mu\text{g}/\text{L}$ .

Barium naturally occurs in the minerals barite and witherite, which are highly insoluble (U.S. Environmental Protection Agency, 1986). In natural waters, the concentrations of barium are controlled by the solubility of barite (Hem, 1989). Barium compounds are used for a variety of industrial and medicinal purposes (U.S. Environmental Protection Agency, 1986). The MCL for barium is 1,000  $\mu\text{g}/\text{L}$ . The concentration of barium in water samples from Maumelle and Winona (inflow and reservoir sites) was 100  $\mu\text{g}/\text{L}$  or less.

Cadmium is a toxic metal that is present in zinc ore minerals and recovered from some copper ores during smelting and refining (Hem, 1989). Cadmium may be liberated into the environment from metallurgical processes and in the combustion of fossil fuels. Cadmium bioaccumulates in the food chain and bioconcentration factors can range from 3 to 2,213 for freshwater fishes (U.S. Environmental Protection Agency, 1986). The MCL for cadmium is 10  $\mu\text{g}/\text{L}$ . The concentration of cadmium in water samples from Maumelle and Winona (inflow and reservoir sites) was 1  $\mu\text{g}/\text{L}$  or less.

The chloride ion is present in all natural waters, but concentrations generally are low. In most streams, chloride concentrations are lower than those of sulfate or bicarbonate except in streams that receive inflows of high-chloride ground water or industrial waste (Hem, 1989). The MCL for chloride is 250  $\text{mg}/\text{L}$ . The concentration of chloride in water samples from Maumelle and Winona (inflow and reservoir sites) ranged from 0.2 to 2.5  $\text{mg}/\text{L}$  (fig. 15).

Chromium is present in rock minerals, and dissolved chromium may be present as trivalent cations or as anions (Hem, 1989). Industrial applications of chromium can produce waste solutions containing chromate anions (Hem, 1989). Chromium toxicity is closely associated with the hardness of water, and chromium is more toxic in soft water than in hard water (U.S. Environmental Protection Agency, 1986). The MCL for chromium is 50  $\mu\text{g}/\text{L}$ . The concentration of chromium in water samples from Maumelle and Winona (inflow and reservoir sites) ranged from less than 1 to 6  $\mu\text{g}/\text{L}$ , most of which were less than 1  $\mu\text{g}/\text{L}$ .

The fluoride ion is almost all tied up in rock minerals (Hem, 1989). This element sometimes is added to drinking water to aid in the structure of bones and teeth. The MCL for fluoride is 2.0  $\text{mg}/\text{L}$ . The concentration of fluoride in samples from Maumelle and Winona (inflow and reservoir sites) ranged from less than 0.1 to 0.3  $\text{mg}/\text{L}$ , most of which were 0.1  $\text{mg}/\text{L}$  or less.

Iron is one of the most abundant elements in the Earth's crust and is an essential trace element in plants and animals. It is common in many rocks and is a component of many soils. If present in water in excessive amounts, iron forms a red oxyhydroxide precipitate that stains laundry and plumbing fixtures and, therefore, is an objectionable impurity in water supplies (Hem, 1989). The MCL for iron is 300  $\mu\text{g}/\text{L}$ .

Table 3.--Primary standards for selected constituents mandated by the U.S. Environmental Protection Agency and the Arkansas Department of Health, and secondary standards recommended by the Arkansas Department of Health for drinking water (finished product)

[NTU, Nephelometric Turbidity Unit; CFU, Colony Forming Unit; mg/L, milligrams per liter (parts per million); µg/L, microgram per liter (parts per billion); 2,4-D, 2,4-dichlorophenoxyacetic acid; 2,4,5-TP, Silvex, 2,4,5-trichlorophenoxypropionic acid; PCU, Platinum-Cobalt Unit]

Property or constituent	PRIMARY STANDARDS	
	Unit	Maximum contaminant level <sup>1</sup>
<b>CLARITY</b>		
Turbidity	NTU	1.0
<b>MICROBIOLOGICAL</b>		
Total coliform bacteria	CFU	4
<b>INORGANIC CHEMICALS</b>		
<b>HEAVY METALS</b>		
Arsenic	µg/L	50
Barium	µg/L	1,000
Cadmium	µg/L	10
Chromium	µg/L	50
Lead	µg/L	50
Mercury	µg/L	2
Selenium	µg/L	10
Silver	µg/L	50
<b>NONMETALS</b>		
Fluoride	mg/L	2.0
Nitrate	mg/L	10.0
<b>ORGANIC CHEMICALS</b>		
Picloram	µg/L	no established regulation
2,4-D	µg/L	100
2,4,5-TP, Silvex	µg/L	10
<b>SECONDARY STANDARDS</b>		
<b>PHYSICAL PROPERTIES</b>		
Color	PCU	15
<b>INORGANIC CHEMICALS</b>		
Chloride	mg/L	250
Iron	µg/L	300
Manganese	µg/L	50
Sodium	mg/L	no established regulation
Sulfate	mg/L	250
Total dissolved solids	mg/L	500

<sup>1</sup> Maximum contaminant level - maximum level/concentration allowed by U.S. Environmental Protection Agency.

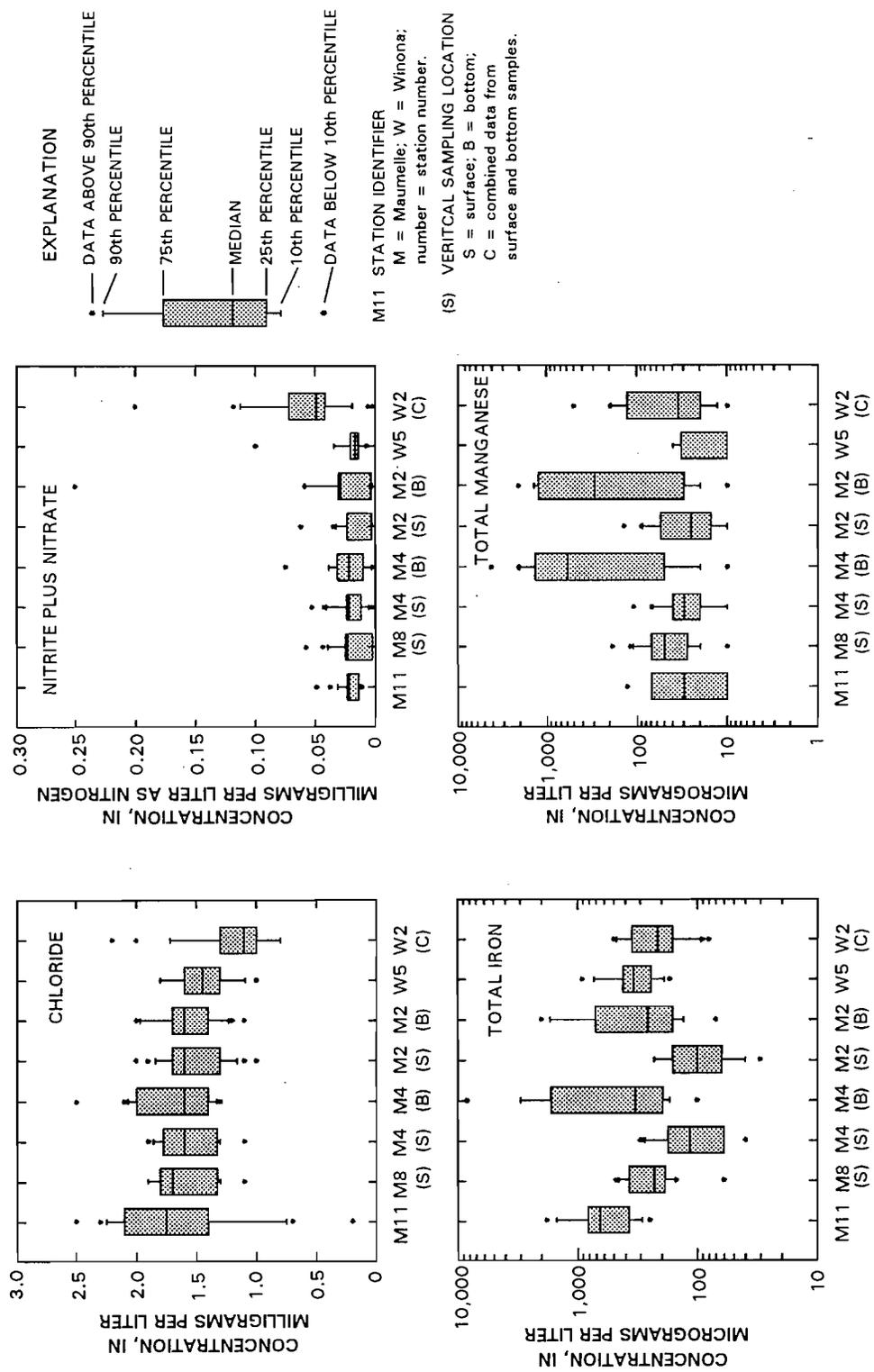


Figure 15.—Chloride, nitrite plus nitrate nitrogen, total iron, and total manganese concentrations in water from inflow and reservoir stations from Maumelle and Winona reservoirs.

The concentration of iron in water samples from Maumelle and Winona (inflow and reservoir sites) ranged from 30 to 8,400  $\mu\text{g/L}$  (fig. 15). Iron concentrations were highest in the bottom water of Maumelle during periods of thermal stratification when the hypolimnion was anoxic.

The solubility of lead in water is low and the maintenance of low concentrations in surface water is attributed to adsorption on organic and inorganic sediment surfaces and coprecipitation with manganese oxides (Hem, 1989). The occurrence of lead in the aquatic environment is low, but the combustion of "leaded" gasoline has contributed substantially to the amount of lead introduced into the environment. The MCL for lead is 50  $\mu\text{g/L}$ . The concentration of lead in water samples from Maumelle and Winona (inflow and reservoir sites) ranged from less than 1 to 15  $\mu\text{g/L}$ , most of which were 1  $\mu\text{g/L}$  or less.

Manganese does not occur naturally as a metal, but is a constituent of various oxides and minerals and is frequently associated with iron compounds (U.S. Environmental Protection Agency, 1986). Manganese is an essential trace element required by plants and animals, but is an undesirable impurity in water supplies because of its tendency to deposit black oxide stains (Hem, 1989). The MCL for manganese is 50  $\mu\text{g/L}$ . The concentrations of manganese in water samples from Maumelle and Winona (inflow and reservoir sites) ranged from less than 10 to 4,200  $\mu\text{g/L}$  (fig. 15). As with iron, manganese levels were highest in the bottom water of Maumelle during periods of thermal stratification when the hypolimnion was anoxic.

Elemental mercury is a liquid at normal temperatures, and it has a relatively low presence in water because of its volatility (Hem, 1989). Various cultural uses of mercury and its release to the atmosphere in smelting and fossil-fuel combustion probably have raised the general background level. Its natural tendency to volatilize tends to disperse it widely (Hem, 1989). Mercury can form chloride or hydroxide complexes, depending on pH and chloride concentrations. Organic complexes (methylmercury) can be produced by methane-generating bacteria in contact with metallic mercury in lake or stream sediments (Wood and others, 1968; Hem, 1989). Methylmercury bioaccumulates in the food chain, and fish that live in mildly contaminated environments could contain mercury levels greater than levels safe for human consumption (Hem, 1989). The bioconcentration factor for methylmercury in the fathead minnow has been reported to be 81,700 (Olson and others, 1975). Available bioassay data indicate that methylmercury is the most chronically toxic of the tested mercury compounds (U.S. Environmental Protection Agency, 1986). The MCL for mercury is 2  $\mu\text{g/L}$ . The concentration of mercury in all water samples from Maumelle and Winona (inflow and reservoir sites) was less than 0.1  $\mu\text{g/L}$ .

Nitrogen gas makes up most of the Earth's atmosphere and the nitrogen cycle has been the subject of many scientific investigations. Nitrogen in the aquatic environment is in the inorganic and organic forms, and a significant amount of nitrogen can be introduced by the application of synthetic fertilizers, municipal and industrial waste loads, septic tank discharge, and confined animal waste runoff. Nitrogen in the organic form is converted microbially into ammonia and then into nitrite and nitrate. Nitrogen is a major nutrient in plants and animals and is used in the production of amino acids and proteins. Nitrates become toxic only under conditions in which they are, or can be, reduced to nitrites (U.S. Environmental Protection Agency, 1986). This condition can occur in the digestive tract in warm-blooded animals and once excessive levels of nitrite enter the bloodstream, it reacts directly with hemoglobin to produce methemoglobin. This reaction can be hazardous in infants under 3 months of age (U.S. Environmental Protection Agency, 1986). The MCL for nitrate is 10 mg/L as nitrogen. The concentration of nitrite plus nitrate in water sampled from Maumelle and Winona (inflow and reservoir sites) ranged from less than 0.005 to 0.250 mg/L as nitrogen (fig. 15). The concentrations of nitrite levels ranged from less than 0.001 to 0.018 mg/L as nitrogen (N).

Selenium is a relatively rare element, closely associated with uranium ore deposits, and in the presence of iron, it can coprecipitate with pyrite or form the mineral ferroselite (Hem, 1989). It is relatively insoluble in elemental form. The MCL for selenium is 10  $\mu\text{g/L}$ . The concentration of selenium in all water samples from Maumelle and Winona (inflow and reservoir sites) was less than 1  $\mu\text{g/L}$ .

Silver is a rare element within the Earth's crust and has a relatively low solubility in natural water (Hem, 1989). It is extensively used in the photography and electronic industries and is a common minor constituent of industrial wastes (Hem 1989). The MCL for silver is 50 µg/L. The concentration of silver in samples collected from Maumelle and Winona was less than 1 µg/L.

Sodium is the most abundant member of the alkali metal group. When sodium is brought into solution, it tends to remain in that status (Hem, 1989). The disposal of brine pumped or flowing from oil wells and the use of salt for deicing highways in winter has significantly increased sodium concentrations in surface and ground water (Hem, 1989). Sodium is listed as a contaminant under the Clean Water Act of 1986, but has no established regulation (MCL). The concentration of sodium in water samples from Maumelle and Winona (inflow and reservoir sites) ranged from 0.7 to 2.3 mg/L (fig. 16).

Sulfur emissions from combustion of fuel and other industrial processes such as smelting or sulfide ores is believed to be a major factor in producing acid precipitation (Hem, 1989). Rock weathering and volcanism also contributes sulfur to the environment. In many places, sulfate is a predominant anion in surface water (Hem, 1989). The MCL for sulfate is 250 mg/L. The concentration of sulfate in water samples from Maumelle and Winona (inflow and reservoir sites) ranged from less than 1.0 to 8.5 mg/L (fig. 16).

Filterable residue such as inorganic salts, small amounts of organic matter, and dissolved materials are the principal components of dissolved solids in freshwater systems (U.S. Environmental Protection Agency, 1986). The principal inorganic anions dissolved in water include the carbonates, chlorides, sulfates, and nitrates, and the principal cations are sodium, potassium, calcium, and magnesium. Excess dissolved solids normally are associated with unpalatable mineral tastes in water and can affect human health (U.S. Environmental Protection Agency, 1986). The MCL for total dissolved solids is 500 mg/L. The concentration of total dissolved solids in water samples from Maumelle and Winona (inflow and reservoir sites) ranged from less than 1 to 40 mg/L (fig. 16).

Agricultural pesticide application in the United States has steadily increased over the past decades. Herbicides are also applied in the aquatic environment to control nuisance aquatic vegetation. In general, herbicides are nonpersistent environmental contaminants and are rapidly biodegraded by microbial populations or are chemically attenuated by photolytic or hydrolytic reactions (Smith and others, 1988). Three of the many agricultural and industrial organic compounds sampled in Maumelle and Winona (Green and Louthian, 1993) are listed as contaminants by the Safe Water Act of 1986: pichloram; 2,4-D (2,4-dichlorophenoxyacetic acid); and 2,4,5-TP (silvex, 2,4,5-trichlorophenoxypropionic acid). Pichloram has no established level of regulation. The MCL for 2,4-D and 2,4,5-TP are 100 and 10 µg/L, respectively. The concentration of 2,4,5-TP and pichloram in water samples from Maumelle and Winona (inflow and reservoir sites) were less than 0.01 µg/L. The concentration of 2,4-D in water ranged from less than 0.01 to 0.10 µg/L; 77 percent of the 53 samples collected had concentrations less than 0.01 µg/L. All but one sample that was reported above 0.01 µg/L was either reported as 0.01 or 0.02 µg/L.

Total coliform bacteria are tested for in the finished water. The MCL for total coliform is 4 colony forming units per 100 mL (milliliters). Fecal coliform usually are used as indicators of the sanitary quality of water (American Public Health Association and others, 1989). Fecal coliform bacteria are generally present in the intestines or feces of warm-blooded animals. Fecal coliform densities in Maumelle and Winona reservoirs were higher at the inflow tributary sites than within the reservoir, and the densities became progressively smaller at the sampling sites toward the dam. Fecal coliform densities at the damsite on Maumelle (M2) ranged from less than 1 to 8 colonies per 100 mL. More than 50 percent of the 33 samples collected at M2 contained less than 1 colony per 100 mL. Fecal coliform densities at the damsite on Winona (W2) ranged from less than 1 to 6 colonies per 100 mL. More than 58 percent of the 17 samples collected at W2 contained less than 1 colony per 100 mL.

Turbidity is a measurement of the amount of light that is scattered or absorbed rather than transmitted through a sample water. Turbidity is caused by the presence of clay, silt, and finely dissolved organic or inorganic matter being suspended in water (American Public Health Association and others, 1989). Suspended solids and turbidity are important properties in municipal and industrial water-supply practices, and the ability of common water-treatment processes to remove suspended matter to achieve acceptable final turbidity values is a function of the composition of the material as well as its concentration

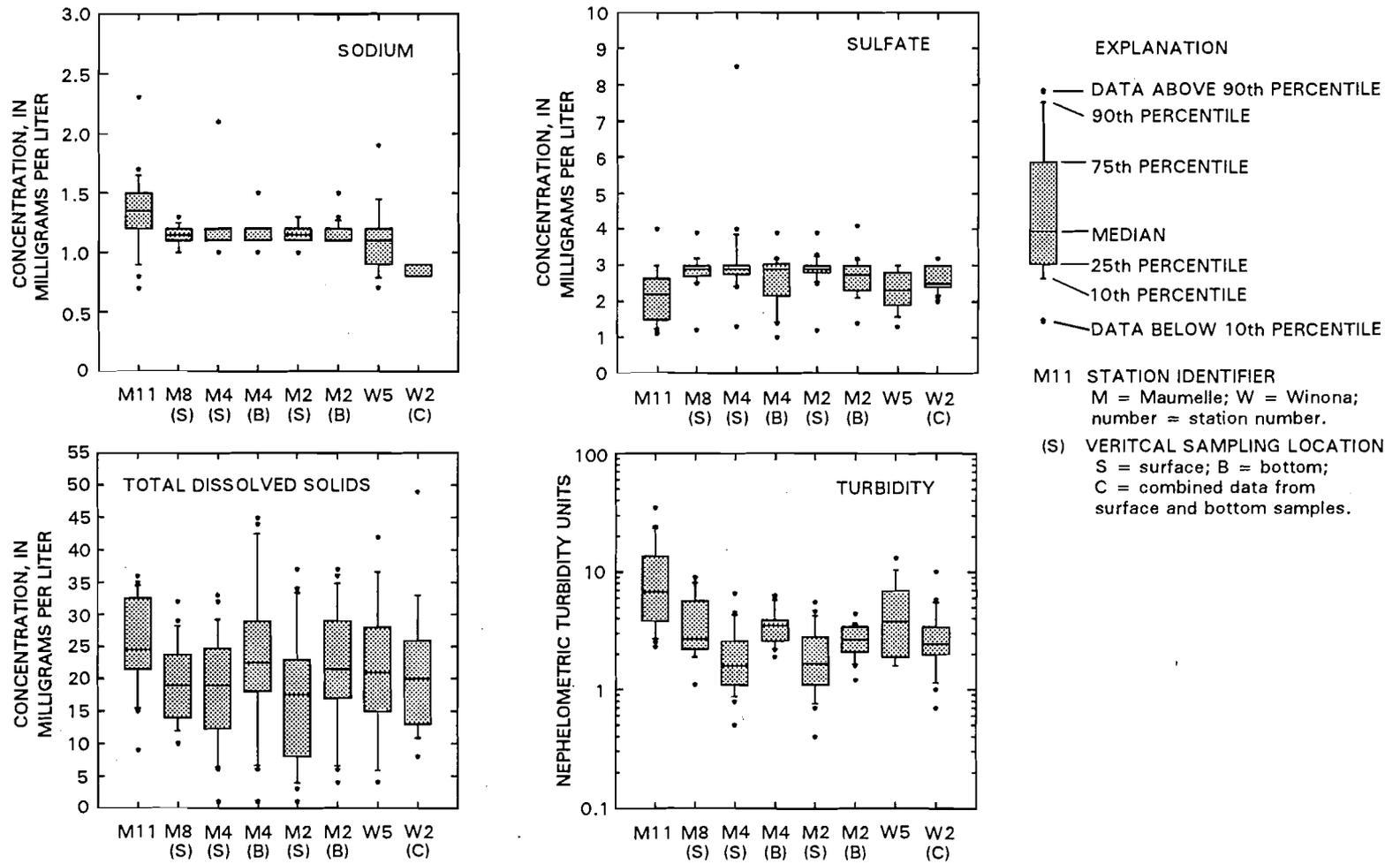


Figure 16.—Sodium, sulfate, and total dissolved solid concentrations, and turbidity in water from inflow and reservoir stations from Maumelle and Winona reservoirs.

(U.S. Environmental Protection Agency, 1986). The MCL for turbidity is 1 NTU (nephelometric turbidity unit). The concentration of turbidity in water collected from Maumelle and Winona (inflow and reservoir sites) ranged from 0.4 to 35 NTU (fig. 16). As expected, the inflow tributary sites (M11 and W5) had higher turbidity levels than the reservoir sites.

Color in water generally results from degradation processes and the leaching of organic debris. Color in water is an important constituent in terms of aesthetic considerations, and to be aesthetically pleasing, water should be free from substances introduced that produce objectionable color (U.S. Environmental Protection Agency, 1986). Increases in color above background levels can originate from human activity, such as discharge of industrial waste from textile and chemical facilities. The MCL for color is 15 platinum-cobalt units (PCU). Color of water from Maumelle and Winona (inflow and reservoir sites) ranged from 1 to 200 PCUs (fig. 17). Color of water collected from the damsite at Winona (W2) generally was more than that from the damsite at Maumelle (M2). This probably is due to the amount of dissolved organic carbon in the water.

Organic carbon in the raw water reacts with chlorine as the result of the chlorination process to produce trihalomethanes (THMs). Trihalomethanes include compounds such as chloroform, bromodichloromethane, chlorodibromomethane, and bromoform. Organic carbon sources originate within the stream and reservoir, and terrestrially from within the watershed (Wetzel, 1983). Sources within the stream or reservoir include active secretion from and decay of macrophytes, attached microflora, and phytoplankton. Sources outside the stream and reservoir include vegetative litter in various stages of decomposition, leachates from the soil, and manmade compounds transported into the watershed.

Detailed investigation of trihalomethane potential and formation in the water of Maumelle and Winona was beyond the scope of this project. Palmstrom and others (1988) provides a detailed investigation involving the potential links between the eutrophication process in lakes and reservoirs and the formation of THMs. Pope and others (1988) demonstrated linear relations between total and dissolved organic carbon and THM formation in water-supply lakes in eastern Kansas. The MCL for THM is 100  $\mu\text{g/L}$ .

The concentrations of total organic carbon (TOC) in water from Maumelle and Winona reservoirs were highest in samples collected from the tributary inflow sites (M11 and W5). Maximum concentrations at these two sites were 11.2 and 11.0 mg/L, respectively (fig. 17). Maximum TOC concentrations within the reservoirs were considerably lower, ranging from 3.9 to 6.8 mg/L at stations M2 and W2, respectively. Generally, water in the streams is expected to have higher TOC levels than water in the reservoirs. The dissolved organic carbon (DOC) levels at the inflow station on Winona (W5) were somewhat lower than at the damsite (W2), suggesting that the source of DOC originates from within the reservoir. The concentration of DOC in water at the damsite on Winona (W2) generally was higher than all the reservoir sites on Maumelle (fig. 17). The slightly higher concentrations of DOC in Winona than those in Maumelle might be attributed to relatively higher annual leaf-litter load, and to the age of the Winona reservoir. The concentration of particulate (suspended) organic carbon in water samples from Maumelle and Winona was relatively low (fig. 17). Particulate organic carbon made up about 3 to 21 percent of the total organic carbon concentration within the samples collected.

The TOC and DOC concentrations in water samples from Maumelle and Winona reservoirs were in the lower range of concentrations reported by Pope and others (1988) in their investigation of THM formation potential in water-supply lakes of eastern Kansas. Pope and others (1988) investigated 15 lakes, and the mean TOC and DOC concentrations ranged from 2.89 to 10.2 and 2.67 to 5.29 mg/L, respectively. The mean total THMs in unfiltered and filtered water ranged from 307 to 921 and 261 to 669  $\mu\text{g/L}$ , respectively. The median DOC concentrations in water samples collected from Maumelle and Winona reservoirs were about 3.2 and 3.7 mg/L, respectively. If the linear relation between DOC and mean THM concentration in filtered water developed by Pope and others (1988) was applied to water from Maumelle and Winona, then total THM formation from filtered water from Maumelle and Winona would average about 372 and 437  $\mu\text{g/L}$ , respectively. However, the test used by Pope and others (1988) was designed to

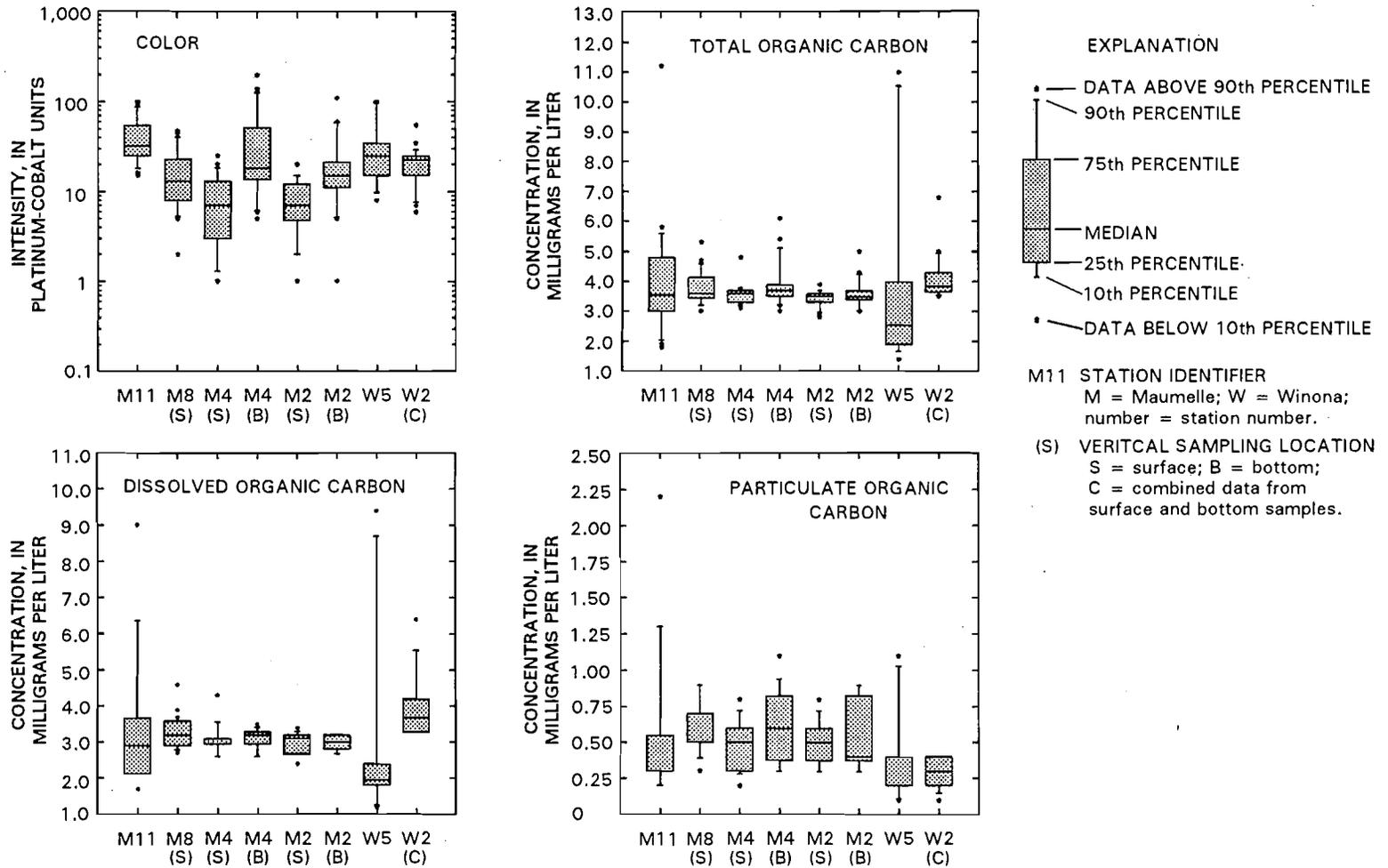


Figure 17.--Color intensity and organic carbon concentrations in water from inflow and reservoir stations from Maumelle and Winona reservoirs.

yield THM concentrations more than those that normally would be present in a water-distribution system. Essentially, the test produces the maximum possible concentration of THMs during a 7-day incubation period after chlorination with a hypochlorite reagent (Pope and others, 1988).

### **WATER QUALITY RELATED TO OTHER REGIONAL STREAMS AND RESERVOIRS**

The data used in the following discussion were retrieved from the USGS National Water Information System data base and were collected during water years 1989-92, which is the period of study on Maumelle and Winona. These data are documented in published reports by Moore and others (1990), Porter and others (1991), Morris and others (1992), Porter and others (1993), and Green and Louthian (1993). All but the latter report are annual Arkansas District USGS data reports that are prepared in cooperation with the Arkansas Department of Pollution Control and Ecology (ADPCE), which conducts some of the sampling and analysis in many of the streams used as reference in this report. Other State and local agencies, including LRMWW, also cooperate in the annual data report project.

The streams selected for water-quality comparison are located within the Arkansas Valley and Ouachita Mountain section of the Ouachita physiographic province (Fenneman, 1938), except the site representing the Arkansas River (fig.18), and are as follows: (1) Petit Jean River near Booneville, USGS station number 07258500; (2) Ouachita River near Mount Ida, USGS station number 07356000; (3) Fourche la Fave near Gravelly, USGS station number 07261500; (4) Arkansas River at David T. Terry Lock and Dam, USGS station number 07263620; (5) Cossatot River near Vandervoort, USGS station number 07340300; (6) Maumelle River at Williams Junction, USGS station number 07263295; and (7) Alum Fork Saline River near Reform, USGS station number 07362587. The last two stations are the inflow stations for Maumelle (M11) and Winona (W5), respectively. The ADPCE collects and analyzes data for the Petit Jean, Ouachita, and Fourche la Fave Rivers. The USGS collects and analyzes data for the Arkansas, Cossatot, Alum Fork Saline, and Maumelle Rivers. The Cossatot River station is part of the USGS Hydrologic Benchmark Network, designed to analyze the water quality of small watersheds throughout the United States that represent the most pristine or least disturbed systems within its region. Data collected from the benchmark streams are expected to resemble background or natural conditions. The Alum Fork Saline and Cossatot Rivers are also water-quality reference streams for the ADPCE's Ouachita Mountain ecoregion, and the Petit Jean River is a water-quality reference stream for the Arkansas Valley ecoregion (Giese and others, 1987).

The regional reservoirs selected for water-quality comparison, are located within the Ouachita physiographic province (fig. 18) and are as follows: (1) Blue Mountain, (2) Nimrod, (3) Gillham, (4) Dierks, (5) DeQueen, (6) Maumelle, and (7) Winona reservoirs. All the water samples from the reservoirs were collected and analyzed by the USGS. The data collection sites for the reservoir water-quality comparisons used in this discussion were located nearest the dam: USGS station number 07259000 for Blue Mountain, USGS station number 07262000 for Nimrod, USGS station number 07340450 for Gillham, USGS station number 07340990 for Dierks, USGS station number 07339450 for DeQueen, USGS station number 07263295 for Maumelle (M2), and USGS station number 07362590 for Winona (W2).

### **Regional Streams**

The concentration of chloride in water samples collected from the Alum Fork Saline River and Maumelle River are similar to those concentrations in water samples collected from the Cossatot River (fig. 19). Chloride concentrations from these three streams were consistently lower than chloride concentrations in the Petit Jean, Ouachita, and Fourche la Fave Rivers. The chloride concentrations from water samples collected from the Arkansas River were at least one order of magnitude greater than the chloride concentrations in the other rivers. These data indicate that chloride concentrations in the Alum Fork Saline River and Maumelle River have chloride concentrations that could be considered background levels.

The concentration of sulfate in water samples collected from the Alum Fork Saline River and Maumelle River can also be considered to be at background levels. The sulfate concentrations in water samples from the Alum Fork and Maumelle River are generally lower than sulfate concentrations in water samples collected from the Cossatot River (fig. 19). The concentration of sulfate from water samples

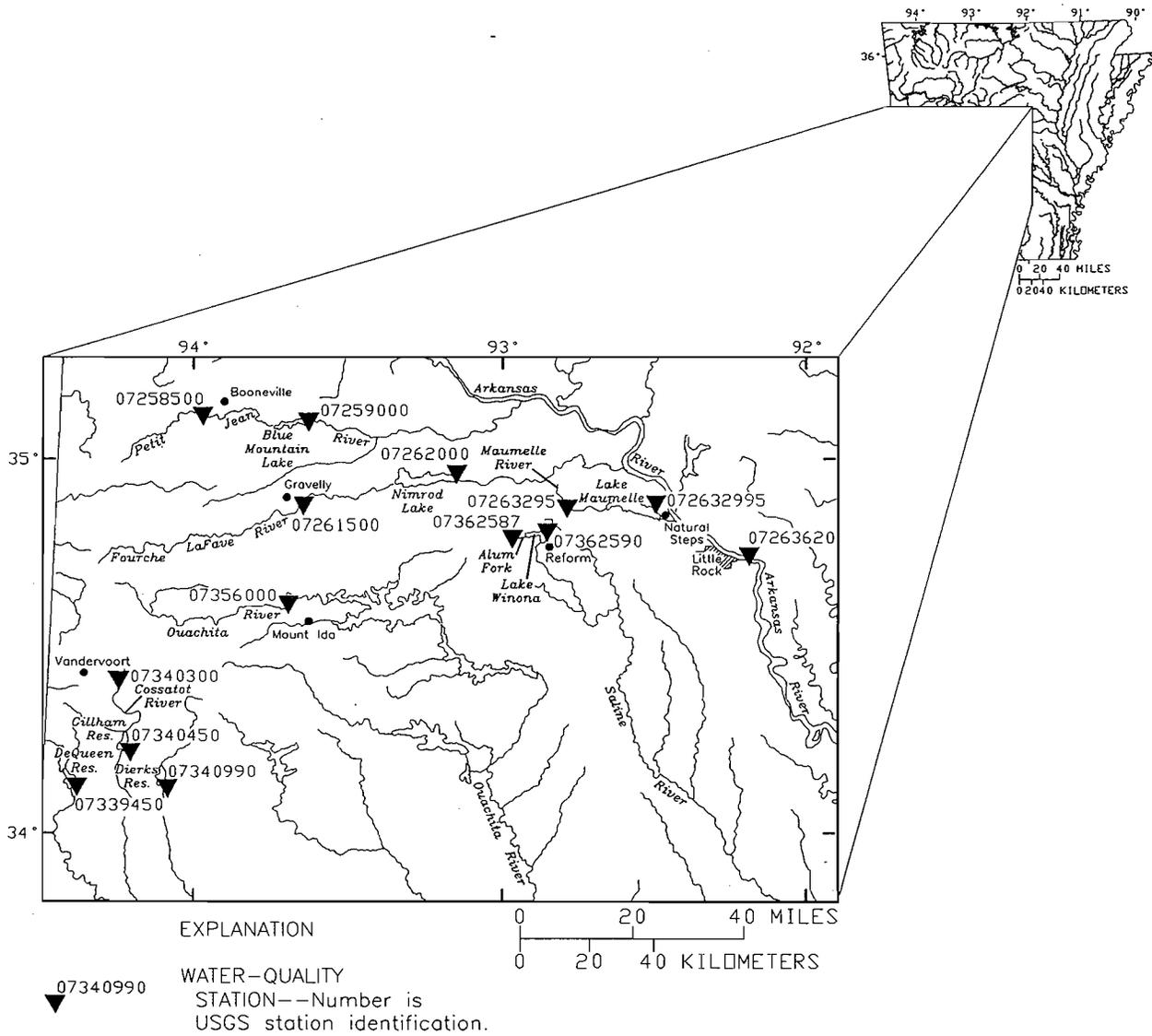
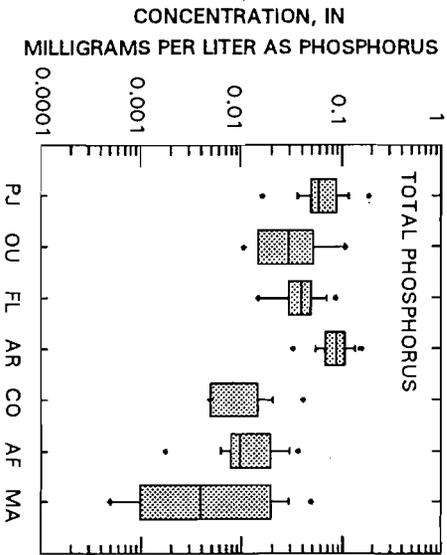
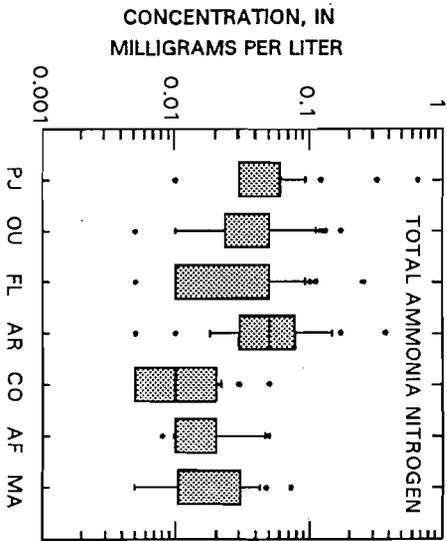
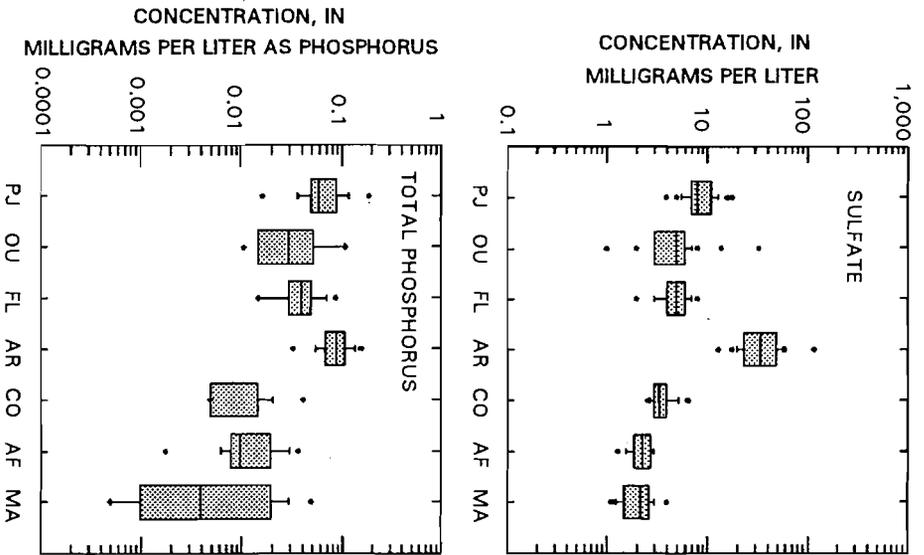
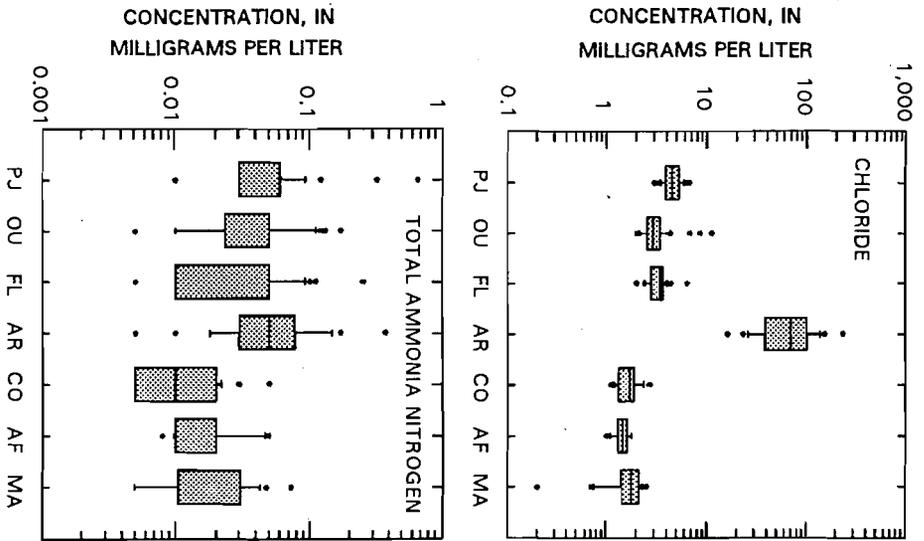


Figure 18.—Regional streams and reservoirs used in water-quality comparisons.



**EXPLANATION**

- DATA ABOVE 90th PERCENTILE
- 90th PERCENTILE
- 75th PERCENTILE
- MEDIAN
- 25th PERCENTILE
- 10th PERCENTILE
- DATA BELOW 10th PERCENTILE

**PJ STREAM IDENTIFICATION**

PJ = Petit Jean; OU = Ouachita;  
 FL = Fourche la Pave;  
 AR = Arkansas; CO = Cossatot;  
 AF = Alum Fork; MA = Maumelle.

Figure 19.—Chloride, sulfate, total ammonia nitrogen, and total phosphorus concentrations in water from selected streams in Arkansas.

collected from these three rivers were lower than the concentration of sulfate in the Petit Jean, Ouachita, and Fourche la Fave Rivers. The Arkansas River water samples contained sulfate concentrations one order of magnitude greater than the sulfate concentrations in the other rivers.

The concentrations of total ammonia nitrogen from water samples collected from the Alum Fork Saline River and Maumelle River were as low as those concentrations of total ammonia nitrogen in the Cossatot River. However, the Cossatot River had more values reported as being below reporting limits (less than 0.01 mg/L as N) than the Alum Fork Saline River or Maumelle River. The total ammonia nitrogen concentrations from water samples collected from the Petit Jean, Ouachita, Fourche la Fave, and Arkansas River were somewhat higher than total ammonia concentrations collected from the Cossatot, Alum Fork Saline River, and Maumelle River (fig. 19).

Relating the nitrite plus nitrate nitrogen concentrations among the selected streams was somewhat difficult because of the differences in media and minimum reporting values. Inconsistencies in detection limits resulting from the different methods used for the determination of nitrite plus nitrate make comparisons impractical.

Total phosphorus concentrations in water samples collected from the Cossatot, Alum Fork Saline, and Maumelle Rivers are considerably lower than total phosphorus concentrations in water collected from the Petit Jean, Ouachita, Fourche la Fave, and Arkansas Rivers (fig. 19). The majority of the total phosphorus concentrations of water samples collected from the Maumelle River were 0.04 mg/L as phosphorus (P) or less, lower than the concentrations in any of the other rivers. Total phosphorus levels in the Alum Fork Saline River and Maumelle River probably are at background levels.

### **Regional Reservoirs**

Total phosphorus concentrations at the damsites in Maumelle and Winona were lower than total phosphorus concentrations at the damsites in other reservoirs (fig. 20). In general, the highest total phosphorus concentrations were in the bottom water within each reservoir. The highest level of total phosphorus (0.22 mg/L as P) among the reservoirs occurred in the bottom water at the damsite of DeQueen, whereas the maximum levels in the bottom water at the damsite of Maumelle (M2) and Winona (W2) were 0.04 and 0.03 mg/L as P, respectively. The highest level of total phosphorus (0.11 mg/L as P) among the reservoirs in the surface water, occurred in Blue Mountain. The surface water at damsites of Maumelle (M2) and Winona (W2) contained maximum concentrations of total phosphorus of 0.02 and 0.01 mg/L as P, respectively. The median values of total phosphorus sampled at the damsite on Winona (W2) in the surface and bottom water were one order of magnitude lower than those sampled in the other reservoirs except Maumelle. Total phosphorus values from Maumelle, although greater than those from Winona, were consistently lower than the values from other reservoirs within the region.

Phytoplankton production can be measured indirectly by analyzing for chlorophyll-a, the primary photosynthetic pigment of all oxygen-evolving photosynthetic organisms (Wetzel, 1983). Phytoplankton require light and nutrients for growth, and rates of growth are affected by temperature. The two nutrients that most likely limit phytoplankton growth are nitrogen and phosphorus. Chlorophyll-a concentrations in a water body reflect, in part, nutrient availability, and therefore reflect the trophic status of the water body.

Many empirical relations have been developed to link nutrient availability, mainly phosphorus, with that of chlorophyll-a production. In general, the greater the nutrient availability, the greater the chlorophyll-a concentrations. Oligotrophic systems with low nutrient concentrations have low chlorophyll-a. Eutrophic systems have higher nutrient and corresponding chlorophyll-a concentrations. The Carlson index (Carlson, 1977) probably is one of the most extensively used measures of trophic status in lakes and reservoirs. According to the Carlson index, the threshold chlorophyll-a concentration along the gradient between oligotrophy and mesotrophy is considered to be about 2.5 µg/L; between mesotrophy and eutrophy, about 10 µg/L; and between eutrophy and hypereutrophy, about 30 µg/L.

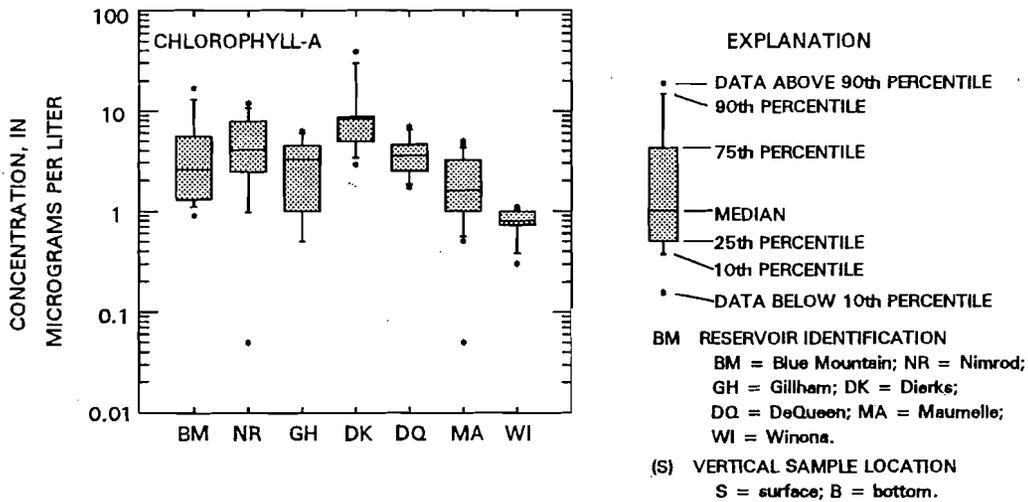
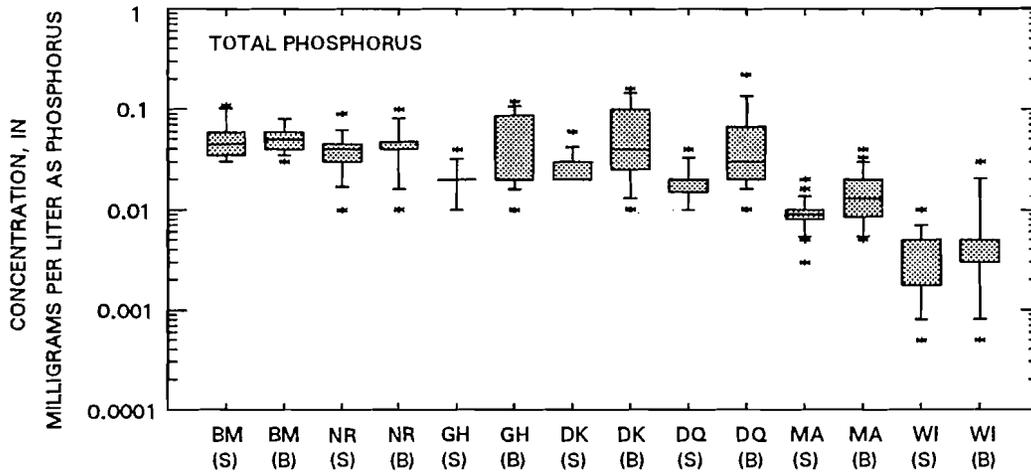


Figure 20.—Total phosphorus and chlorophyll-a concentrations in water from selected reservoirs in Arkansas.

Chlorophyll-a concentrations at the damsites on Maumelle and Winona (M2 and W2) for water years 1989-92 generally were lower than those concentrations reported for Blue Mountain, Nimrod, Gillham, Dierks, and DeQueen reservoirs (fig. 20). The maximum concentrations reported for chlorophyll-a at the damsite on Maumelle (M2) and Winona (W2) were 5.0 and 1.1  $\mu\text{g/L}$ , respectively, and the median values were 1.6 and 0.8  $\mu\text{g/L}$ , respectively. The median values for chlorophyll-a at Blue Mountain, Nimrod, Gillham, Dierks, and DeQueen reservoirs ranged from 2.6 to 8.25  $\mu\text{g/L}$ , while the maximum concentrations ranged from 6.3 to 39  $\mu\text{g/L}$ . Based on the chlorophyll-a data in relation to the empirical trophic state model developed by Carlson (1977), the open water of Maumelle reservoir near the dam, but not necessarily the entire reservoir, can be considered to exist in a transitional state along the gradient between oligotrophy and mesotrophy. However, the open water near the dam of Winona can be considered in a state of oligotrophy.

Based upon phosphorus and chlorophyll-a concentrations, the water quality of Maumelle and Winona reservoirs compares favorably with that of the other selected reservoirs within the Ouachita physiographic province. Investigation as to the reasons why Maumelle and Winona reservoirs differ from the other selected reservoirs is beyond the scope of this study. However, nutrient concentrations (nitrogen and phosphorus) were somewhat lower in Maumelle and Winona reservoirs and these levels were reflected in the chlorophyll-a levels. As with the water quality of their tributaries, the water quality of Maumelle and Winona reservoirs reflects the baseline or pristine condition for reservoirs in this region. The differences in water quality between Maumelle and Winona reservoirs are presumably more the result of watershed and water-body characteristics (including size, shape, slope, and depth) rather than differences in chemical contributions originating within the watershed. Because physical characteristics of these systems are considerably different, as discussed above, nutrient and algal dynamics would be expected to differ as well. The water quality of Winona is considered an example of the baseline condition for a deep river valley reservoir, and Maumelle is considered an example of the baseline condition of an impounded flood-plain reservoir within this region.

## WATER QUALITY OF MAUMELLE IN RELATION TO TROPHIC STATE AND SENSITIVITY TO CHANGE

Reckhow (1988) investigated a data set from 80 lakes and reservoirs with a range of sizes, morphometry, and trophic status in nine Southeastern States to examine, specify, and mathematically express trophic state relations. Trophic state relations were based on measurements of several limnological variables collected over the course of a growing season or year in each of the water bodies. The trophic state models developed by Reckhow (1988) relate phosphorus and nitrogen loading to reservoir phosphorus and nitrogen concentrations, which are related to maximum chlorophyll-a level, Secchi disc depth, dominant algal species, and hypolimnetic dissolved oxygen status. Because of the empirical nature of Reckhow's investigation, cause and effect conclusions are limited, but, the models are useful for prediction of average growing season conditions related to trophic state. Reckhow (1988) adds that these models simply express inter-lake (reservoir) associations among variables, and a more detailed lake-specific study is often necessary for a thorough evaluation of lake management options.

According to Reckhow (1988), the phosphorus model is a function of the variables mean annual influent concentration of phosphorus, hydraulic detention time, and the nutrient trapping parameter,

$$\log P = \log \left( \frac{P_{in}}{1 + kT_w} \right) \quad (1)$$

where P is the predicted mean summer reservoir concentration of phosphorus (mg/L as P),

$P_{in}$  is mean annual influent concentration of phosphorus (mg/L as P),

$T_w$  is hydraulic detention time (year), and

k is the nutrient trapping parameter and is a function of the variables  $P_{in}$ ,  $T_w$  and z where

$$k = 3.0(P_{in})^{0.53}(T_w)^{-0.75}(z)^{0.58}, \text{ and} \quad (2)$$

z is mean depth (m).

The nitrogen model is similar to the phosphorus model:

$$\log N = \log \left( \frac{N_{in}}{1 + kT_w} \right) \quad (3)$$

where N is the predicted mean summer reservoir concentration of nitrogen (mg/L as N), and

$N_{in}$  is mean annual influent concentration of nitrogen (mg/L as N), and

k is the nutrient trapping parameter which is only a function of hydraulic detention time, where:

$$k = 0.67 (T_w)^{-0.75} \quad (4)$$

The maximum chlorophyll-a model is a function of the mean summer phosphorus and nitrogen concentration in the reservoir, the total number of chlorophyll-a samples collected, and hydraulic detention time, where:

$$\log(\text{chlor } a)_{max} = 1.314 + 0.321 \log(P) + 0.384 \log(N) + 0.450 \log(n_{CA}) + 0.136 \log(T_w) \quad (5)$$

where  $(\text{chlor } a)_{max}$  is predicted maximum summer chlorophyll-a concentration,

P is mean summer reservoir phosphorus concentration (mg/L as P),

N is mean summer reservoir nitrogen concentration (mg/L as N), and

$n_{CA}$  is total number of chlorophyll-a samples collected.

The maximum chlorophyll-a model indicates that maximum observed chlorophyll-a increases with increasing nitrogen and phosphorus concentrations, increasing hydraulic detention time, and increasing sample size. This model (equation 5) was chosen by Reckhow (1988) because the data analysis for the 80 lake/reservoir comparisons indicated that a reasonable predictive model could be fitted for maximum chlorophyll-a, and lake management might benefit from the prediction maximum observed chlorophyll-a

concentrations. It should be noted that this model is a sample predictor, not a population predictor, and that the maximum observed chlorophyll-a concentration in the sample increases as sample size increases (Reckhow, 1988).

Influent nutrient concentrations for Maumelle were estimated using computer software developed by Walker (1986) for the U.S. Army Corps of Engineers called "FLUX." Observed nutrient concentrations and instantaneous discharge from data collected at the inflow station (M11) were loaded into the Walker software (FLUX) and nutrient loading models were chosen based on the lowest coefficient of variation produced among the six different models available. The loading model chosen for both nitrogen and phosphorus was method 4 (Walker, 1986), the first order regression described by Walker (1981). Mean influent nutrient concentrations were then determined based on the calculated annual nutrient load and annual discharge. The nutrient loading model used was as follows:

$$W = \text{mean}(w) [\text{mean}(Q)/\text{mean}(q)]^{b+1} \quad (6)$$

where  $W$  is mean estimated nutrient flux over  $N$  day (kg/yr),

$w_i$  is measured nutrient flux during sample  $i = q_i c_i$  (kg/yr),

$Q$  is mean flow (hm<sup>3</sup>/yr),

$q_i$  is measured flow during sample  $i$  (hm<sup>3</sup>/yr),

$c_i$  is measured concentration in sample  $i$  (mg/m<sup>3</sup>), and

$b$  is slope of  $\log(c)/\log(q)$  regression.

The coefficient of variation (square root of the mean squared error divided by the mean observed flux) for the phosphorus loading model (equation 6) developed for water years 1991 and 1992 was 0.245 and 0.244, respectively. The coefficient of variation for the nitrogen loading model (equation 6) developed for water years 1991 and 1992 was 0.146 and 0.145, respectively.

Variables used for Maumelle in the empirical trophic state models developed by Reckhow (1988) include mean annual nutrient loading and influent nutrient concentration (table 4). The mean summer reservoir phosphorus and nitrogen concentrations were determined using data collected from three reservoir sampling stations (M2, M4, and M8), and mean influent nutrient concentrations were determined using the Walker (1986) FLUX program from data collected at the inflow reservoir sampling station (M11). Empirical trophic state model results were determined separately for water years 1991 and 1992.

Table 4.--Variables used in the Reckhow (1988) empirical trophic state models for Maumelle reservoir

[ $T_w$ , hydraulic detention time in years;  $M_p$ , annual phosphorus mass loading in grams per year as P;  $M_n$ , annual nitrogen loading in grams per year as N;  $P_{in}$ , influent phosphorus concentration in mg/L as P;  $N_{in}$ , influent nitrogen concentration in mg/L as N;  $z$ , mean depth in meters;  $n_{CA}$ , number of chlorophyll-a samples collected]

Variable	Water-year 1991	Water-year 1992
$T_w$	1.41	1.95
$M_p$	$6.7530 \times 10^6$	$4.7935 \times 10^6$
$M_n$	$9.6562 \times 10^7$	$6.8628 \times 10^7$
$P_{in}$	0.035	0.034
$N_{in}$	0.504	0.494
$z$	7.53	7.53
$n_{CA}$	9	12

Phosphorus and nitrogen results compared favorably between the observed and calculated values (table 5). Log transformed mean summer phosphorus concentrations differed between observed and calculated values by 3.5 and 8.6 percent for 1991 and 1992, respectively. Much of the nitrogen data collected during the summer months in Maumelle were below detection limits. Total ammonia and organic nitrogen and dissolved nitrate plus nitrite nitrogen were below detection in 5 out of 9 samples collected in the summer of 1991, and 11 out of 12 samples collected in the summer of 1992. For the purpose of this analysis, mean observed nitrogen concentrations were determined using detection limit values for observed values reported below detection limits. Log transformed mean summer nitrogen concentrations differed between observed and calculated values by 8 and 16 percent for 1991 and 1992, respectively.

Table 5.--*Observed and calculated values generated from the Reckhow (1988) empirical trophic state models for mean summer phosphorus, nitrogen, and maximum summer chlorophyll-a concentrations in Maumelle reservoir*

[mg/L, milligram per liter; µg/L, microgram per liter]

Variable	1991		1992	
	Observed	Calculated	Observed	Calculated
Phosphorus (mg/L as P)	0.011	0.013	0.008	0.012
Nitrogen (mg/L as N)	0.318	0.291	0.215	0.276
Maximum chlorophyll-a (µg/L)	3.1	8.8	3.5	8.1

Log transformed summer maximum chlorophyll-a concentrations differed between observed and calculated values by 92 and 67 percent for 1991 and 1992, respectively. It is not known whether the chlorophyll samples used in the development of the Reckhow (1988) model (equation 5) were corrected for the chlorophyll degradation products (phaeopigments) or not. Analytical procedures for determination of chlorophyll in samples collected from Maumelle did not include the phaeopigment concentrations. Phaeopigments can elevate the analytical determined chlorophyll concentrations considerably. Wetzel (1983) notes that phaeopigment concentrations can equal or exceed those of chlorophyll-a many times during the year. This analytical anomaly (phaeopigment inclusion or exclusion) might explain some of the differences between the higher predicted maximum chlorophyll-a concentrations over those measured. Another source of error is in the model itself. Reckhow (1988) reports that the model error for equation 5 was 0.220 (reflecting log-transformed concentration units) and the prediction error was 0.256. Regardless of the error involved, the expected summer maximum chlorophyll-a levels remain a function of nitrogen and phosphorus concentrations, hydraulic detention time, and the number of samples collected.

Nutrient export coefficients were calculated for the Maumelle River above sampling station M11 based on mean annual loads determined by the FLUX model (equation 6) and the drainage area responsible for the load. Phosphorus export coefficients for water years 1991 and 1992 were 0.21 and 0.15 kg/ha/yr (kilograms per hectare per year as P), respectively. Nitrogen export coefficients for water years 1991 and 1992 were 3.0 and 2.2 kg/ha/yr as N, respectively. These values are similar to those typical of forest land and use reported by Beaulac and Reckhow (1982), where their charts show that the median export coefficient values for phosphorus (as P) and nitrogen (as N) were about 0.2 and 2.5 kg/ha/yr, respectively. In contrast, median phosphorus (as P) and nitrogen (as N) export coefficient values for urban land use were reported by Beaulac and Reckhow (1982) to be about 1.0 and 5.0 kg/ha/yr, respectively.

Based on the average annual discharge at sampling station M11 for water years 1991 and 1992 of  $6.19 \times 10^7 \text{ m}^3/\text{yr}$  and the drainage area of 11,940 ha (hectare), the expected mean annual influent concentration of phosphorus resulting from forest and urban land use export coefficients of 0.1 and 1.0 kg/ha/yr would be about 0.02 and 0.20 mg/L as P, respectively. The mean annual influent concentration of nitrogen

resulting from forest and urban land use export coefficients of 2.5 and 5.0 kg/ha/yr would be about 0.5 and 1.0 mg/L as N, respectively. The differences in influent nutrient concentrations are examples of what generally could be expected if the land use of the Maumelle watershed changed from primarily forest to that of urban land use.

Expected changes in maximum summer chlorophyll-a concentrations in Maumelle reservoir resulting from the changes in nutrient export coefficients in the Maumelle watershed from that of forest to urban land use show that chlorophyll-a concentrations will increase as land use changes (fig. 21). The results in figure 21 were developed by converting forest and urban land use nutrient export coefficients into influent concentrations. The influent nutrient concentrations were then loaded into the nutrient models of Reckhow (1988), equations 1 and 3, to predict mean summer reservoir phosphorus and nitrogen concentrations. The reservoir phosphorus and nitrogen concentrations were then loaded into the maximum chlorophyll-a model of Reckhow (1988), equation 5, to predict the maximum chlorophyll-a values for the variable phosphorus and nitrogen levels. For this analysis, the variables  $T_w$ ,  $z$ , and  $n_{CA}$  were held constant at their water year 1991-92 average of 1.64 yr, 7.53 m (meter), and 10 samples, respectively.

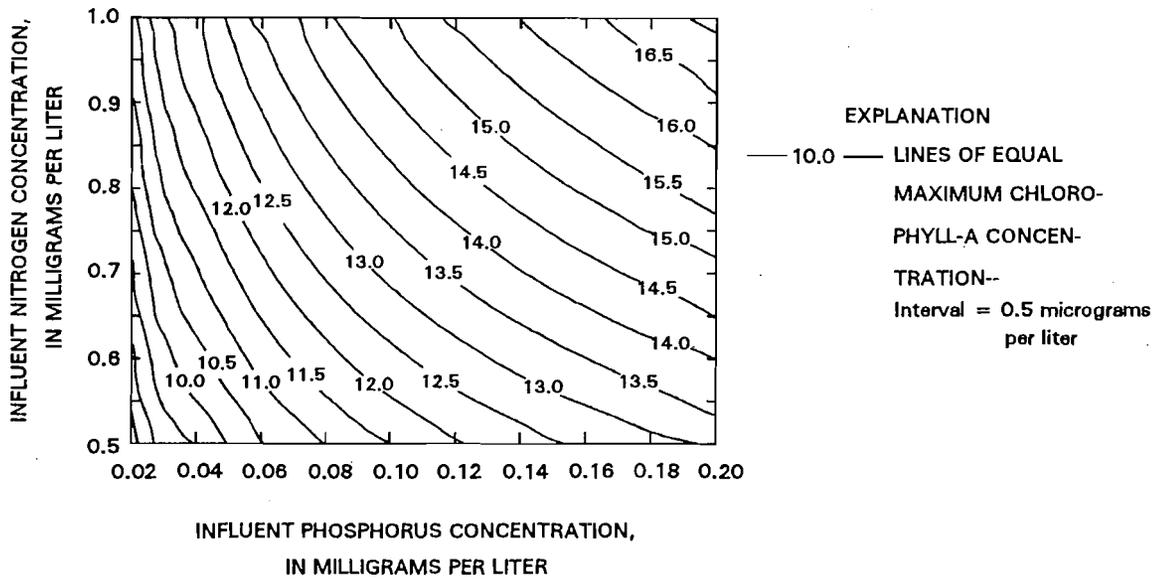


Figure 21.—Expected maximum chlorophyll-a concentrations for Maumelle reservoir generated by the Reckhow (1988) model.

The present influent nutrient and predicted maximum summer chlorophyll-a condition of Maumelle lies within the extreme lower left-hand corner of figure 21. This area of the figure represents the current trophic state condition of Maumelle existing within a forest land-use drainage basin. The upper right-hand corner, represents the expected trophic state condition in Maumelle existing within a urban land-use drainage basin. The significance of this model lies not with the actual quantitative values of chlorophyll-a, but with the magnitude and direction of change in chlorophyll-a (trophic state) imposed by phosphorus and nitrogen loading. The predicted maximum chlorophyll-a values were about 2.5 times greater than the maximum measured. Therefore, the chlorophyll-a values in figure 21 could also be greater than expected under the modeled conditions. However, the isolines of figure 21 should remain about the same, regardless of the magnitude. More detailed sampling and analysis is needed on the Maumelle reservoir to more thoroughly investigate the nutrient/algal relation.

According to the model (fig. 21), changes in influent phosphorus concentrations would increase expectant chlorophyll-a levels greater than relative changes in nitrogen. However, as phosphorus levels increase, the expectant changes in chlorophyll-a levels become more influenced by changes in nitrogen. With influent phosphorus concentrations greater than 0.06 mg/L as P, relative changes in influent nitrogen affect expectant chlorophyll-a levels as much as changes in phosphorus. Increases in both together would be expected to affect chlorophyll levels even greater than increases in only one or the other nutrient. It should be noted that the maximum influent total phosphorus concentration from samples collected at M11 from May 1989 through October 1992 was 0.06 mg/L as P. This sample was collected during a storm event with a flow of 1,930 ft<sup>3</sup>/s, the highest discharge sampled. The maximum influent nitrogen concentration (total ammonia plus organic nitrogen, plus dissolved nitrite plus nitrate nitrogen) from samples collected at M11 was 0.749 mg/L as N. This sample was collected during low flow at a discharge of 2.4 ft<sup>3</sup>/s.

What these data and hypotheses demonstrate (fig. 21), from a management perspective, is that control of phosphorus and nitrogen leading into Maumelle reservoir will be necessary to maintain the present water quality condition of Maumelle. If nutrient inputs can be maintained at present levels, the water quality within Maumelle reservoir should remain relatively stable. However, increases in phosphorus load will alter the water quality from its present oligo-mesotrophic condition to that of a more eutrophic condition, and this trophic response will be amplified with increases in nitrogen loading.

## SUMMARY

Water quality of the Maumelle and Winona water supply reservoir systems was evaluated based on data collected from May 1989 through October 1992. Water quality was assessed relative to: (1) suitability for municipal water supply; (2) other streams and reservoirs within the region; and for Maumelle, (3) the ecological trophic condition and sensitivity to change.

The drainage basin of each reservoir exists within the Ouachita Mountains and consists primarily of forested land. Fifty percent of the total discharge from October 1989 through September 1992 at the inflow tributary gaging station for Maumelle (Maumelle River) occurred at daily mean flows of 331 ft<sup>3</sup>/s and greater, which occurred less than 5.3 percent of the time for the period. Fifty percent of the total discharge over the same period at the inflow tributary gaging station for Winona (Alum Fork Saline River) occurred at daily mean flows of 400 ft<sup>3</sup>/s and greater, which occurred less than 3.2 percent of the time, during the same period as above.

The physical characteristics of Maumelle and Winona reservoirs are considerably different and these differences are reflected in the thermal and dissolved oxygen dynamics. Both reservoirs are monomictic systems. Thermal stratification occurs during the spring and summer months, and mixing occurs in the fall. Isothermal conditions exist during the winter months. The hypolimnion in Maumelle reservoir becomes anoxic during the summer months. However, in Winona, the lowest concentrations of dissolved oxygen occur in the metalimnion, and the hypolimnion remains oxic throughout the summer.

The chemical and physical data collected in the raw water supply for constituents regulated by the U.S. Environmental Protection Agency and the Arkansas Department of Health (ADH) compared favorably against the finished water standards. In many cases, the data collected were at or below detection limits, which was well below the respective maximum contaminant levels (MCLs) used by the ADH. Iron and manganese concentrations often exceeded the MCLs, especially in the bottom water of Maumelle reservoir. Total and dissolved organic carbon concentrations in Maumelle and Winona reservoirs could cause trihalomethane concentrations to exceed the 100 µg/L MCL in the finished product.

The water quality of Maumelle and Winona reservoirs also compared favorably when measured against other regional streams and reservoirs. From these comparisons, it is considered that the water quality of the major tributaries discharging into the Maumelle and Winona reservoirs represent the baseline or pristine condition within the region. The water quality of the reservoirs is also considered to represent the baseline condition; Maumelle for a shallow, impounded flood-plain reservoir, and Winona for a deep river valley reservoir.

Data from Maumelle were used to investigate trophic condition using empirical models developed from an 80 lake data set that examined, specified, and mathematically expressed trophic state relations. Observed and predicted values for nitrogen and phosphorus generated from the empirical trophic state models compared favorably. Maumelle can be considered to exist in a state of oligo-mesotrophic transition. If nutrient inputs can be maintained at present levels, the water quality of Maumelle should remain relatively stable. However, increases in phosphorus load will alter the trophic condition from its present oligo-mesotrophic state to that of a more eutrophic condition. Increases in nitrogen load will also amplify the trophic response.

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