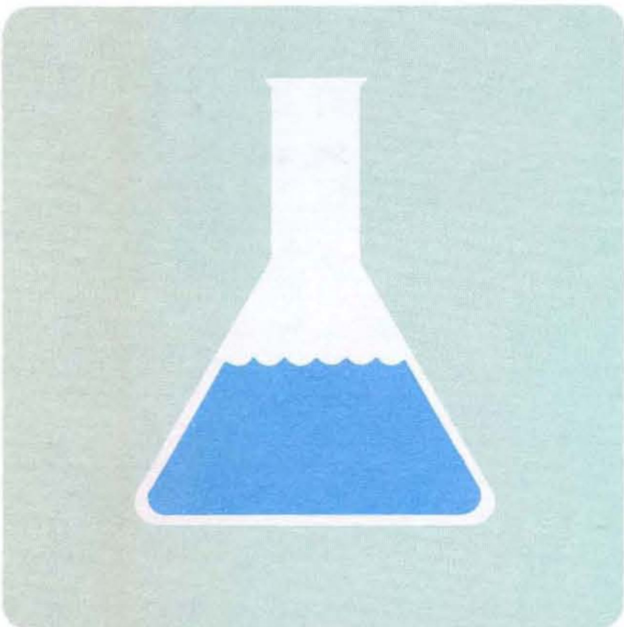
WATER RESOURCES REPORT NUMBER 33



water-quality characteristics of six small lakes in missouri

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BY JAMES H. BARKS, HYDROLOGIST

WATER RESOURCES DIVISION
U.S. GEOLOGICAL SURVEY

Prepared In Cooperation With:

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WATER-QUALITY CHARACTERISTICS OF SIX SMALL LAKES IN MISSOURI

By James H. Barks*

ABSTRACT

A study of six small lakes, representative of those in the major physiographic regions of Missouri, shows variation in physical, chemical, and biological characteristics related to their location in the State. For example, because of climatic differences, ice cover and winter stratification are more prevalent in northern Missouri. Summer stratification lasts about one month longer in the southern than in the northern part of the State. Because of the difference in geology, lake water in the Plains area is more mineralized than in the Ozarks. Different geology and land use generally account for more sedimentation of Plains lakes. Lakes in the Plains area usually receive enough nutrients to be classified as mesotrophic or eutrophic while those in the Ozarks receive less nutrients from natural sources and are often oligotrophic or mesotrophic. However, as seen from one of the study lakes, an oligotrophic lake can be made quite productive through the application of commercial fertilizers within the lake.

INTRODUCTION

About 3,000 lakes that have a surface area greater than 5 acres (2.0 ha) have already been constructed in Missouri and about 150 new lakes are being built each year. These lakes fulfill a variety of needs such as flood control, sediment retention, water supply, recreation, and real-estate enhancement. Recreation (fishing, boating, swimming, etc.) is an important consideration for most small lakes in the State. For purposes of this report small lakes are defined as those having surface areas of 5 to 1,000 acres (2.0 to 405 ha).

The failure rate of lakes in Missouri is high because of unfavorable geologic and hydrologic conditions and poor design and construction practices. A report which deals with these problems was prepared by Dean and others (1976).

The suitability of lakes for various uses is often less than expected because of undesirable water-quality conditions. The purpose of this report is to present the results of a 1972-73 water-quality study of six small lakes in Missouri and to discuss the environmental factors that determine these characteristics so that lakes can be planned and managed more effectively.

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For convenience of the reader most technical terms are defined as they are used in the text.

English units in this report may be converted to metric units by use of the following table:

Multiply English units	By	To obtain metric units
inches (in)	25.4	millimeters (mm)
inches (in)	2.54	centimeters (cm)
feet (ft)	.3048	meters (m)
miles (mi)	1.609	kilometers (km)
square miles (mi^2)	2.590	square kilometers (km^2)
acres	.4047	hectares (ha)
acre-feet (acre-ft)	1.233×10^{-3}	cubic hectometers (hm^3)

COOPERATION AND ACKNOWLEDGMENTS

This report was prepared in cooperation with the Missouri Department of Natural Resources, Geological Survey, Dr. Wallace B. Howe, State Geologist. The work was performed in the Missouri district of the U.S. Geological Survey.

Chemical analyses of lake water were made by the Missouri Geological Survey in accordance with "Standard Methods for the Examination of Water and Wastewater."

We thank the Missouri Department of Conservation for supplying descriptive information and aerial photographs of the Department of Conservation community lakes used in this study.

We also thank the cities of Springfield and Harrisonville for granting permission to study their water-supply lakes and for furnishing descriptive information about the lakes.

FACTORS THAT INFLUENCE WATER QUALITY

Climate, geology, and land use are the principal factors that determine water-quality characteristics of a watershed. These factors vary considerably with geographic location in Missouri.

CLIMATE

The greatest difference in climate is between the northwestern and southeastern parts of the State. The average annual air temperature ranges from 12.2°C (Celsius) in the northwest to 15.0°C in the southeast. Air temperature is 0°C and below about 130 days per year in the northwest and 70 days per year in the southeast. The total number of days when air temperature is 32.2°C and above ranges from 35 days in the northwest to 70 days in the southeast.

Prevailing winds average 2 mi/h (3.2 km/h) from the northwest in January; 2 mi/h (3.2 km/h) from the southwest in April; 2.5 mi/h (4.0 km/h) from the south in July; and 1.5 mi/h (2.5 km/h) from the southwest in October. Relatively high winds occur about March, particularly on the Plains.

Mean annual precipitation ranges from about 34 inches (860 mm) in northern Missouri to more than 46 inches (1170 mm) in the Southeastern Lowlands. The largest amount of precipitation usually occurs from April to June and the smallest amount occurs from November to January. Average annual lake evaporation ranges from 36 inches (910 mm) in the northeastern part of the State to 44 inches (1120 mm) in the southwestern area. About 75 percent of the annual lake evaporation occurs from May to October. The difference between mean annual precipitation and mean annual lake evaporation ranges from a deficit of 6 inches (150 mm) in the northwest to an excess of 8 inches (200 mm) in the southeast (fig. 1).

GEOLOGY

The four physiographic divisions of Missouri, as shown in figure 2, are the Osage Plains, Dissected Till Plains, Ozarks, and Southeastern Lowlands. The bedrock geology is distinctly different for each of these areas (fig. 3). Likewise, the surficial materials, composed of all the fragmental, unconsolidated, and semi-consolidated materials that overlie the bedrock, vary in composition and thickness with physiographic location (fig. 4).

OSAGE PLAINS – The Osage Plains are rolling plains of low relief along the western border of the State south of the Dissected Till Plains (fig. 2). These plains are formed on sedimentary rocks of Pennsylvanian age that dip gently westward. Thin-bedded layers of shale, limestone, sandstone, and coal are covered by a thin surficial material composed of a mixture of sandy-clay residuum derived from weathering of the bedrock and loess (windblown silt). Because of the low relief, lakes usually are wide and shallow.

DISSECTED TILL PLAINS – The Dissected Till Plains cover the part of the State north of the Missouri River valley. Repeated glaciation during the Pleistocene Epoch left the area covered with thick deposits of till (bouldery clay), sand, gravel, and loess. Thickness of the glacial deposits is generally greatest in the filled preglacial valleys and least over the preglacial uplands. In general the thickness decreases southward toward the Missouri River. Beneath the glacial material the bedrock is similar to that of the Osage Plains. Most of the bedrock is shale; however, limestone dominates in the eastern part of the area along the Mississippi River. Bedrock is exposed in a few places where the till has been eroded. Postglacial erosion has carved new valleys which in general are unrelated to the preglacial stream network, but in some cases the older valleys have been reoccupied. Erosion contributes significantly to lake sedimentation in the Dissected Till Plains.

OZARKS – The Ozarks form an elongated uplift that comprises about half the State from the Mississippi River to northern Arkansas and northeastern Oklahoma. The topography is characterized by rugged hills, plateaus, and deep valleys. Limestone and dolomitic rocks are common and their dissolution by water has resulted in numerous springs, caves, and sinkholes that are characteristic of karst regions. Because of the karst topography, thickness of surficial materials is highly variable.

The Salem Plateau, which includes most of the Ozarks in Missouri, is a maturely dissected, rolling surface preserved largely on Ordovician rocks. Streams with a more or less radial drainage pattern have cut valleys hundreds of feet deep. Cherty dolomite and sandstone beds of Ordovician age are at or near the surface over much of the area. Varying thicknesses of clay and sand, and nodules of chert have accumulated at the bedrock surface as residuum. The presence of large fragments of chert has resulted in an irregular surface that retards erosion.

Rugged hills of Precambrian igneous rocks in the eastern part of the Ozarks are referred to as the St. Francois Mountains. These igneous rocks are chiefly red and gray granites and volcanic rocks that are relatively resistant to physical disaggregation and chemical breakdown. Accordingly, the residuum formed from weathering of these rocks consists largely of a thin accumulation of boulders within a matrix of fine-grained material. Dolomite, shale, sandstone, and limestone rocks of Cambrian age cover the igneous rocks in lower slopes and valleys and surrounding areas. Streambeds in igneous areas typically have numerous boulders and relatively little fine-grained material. However, as streams leave the igneous areas and flow across sedimentary rocks their alluvium becomes a heterogeneous mixture of materials.

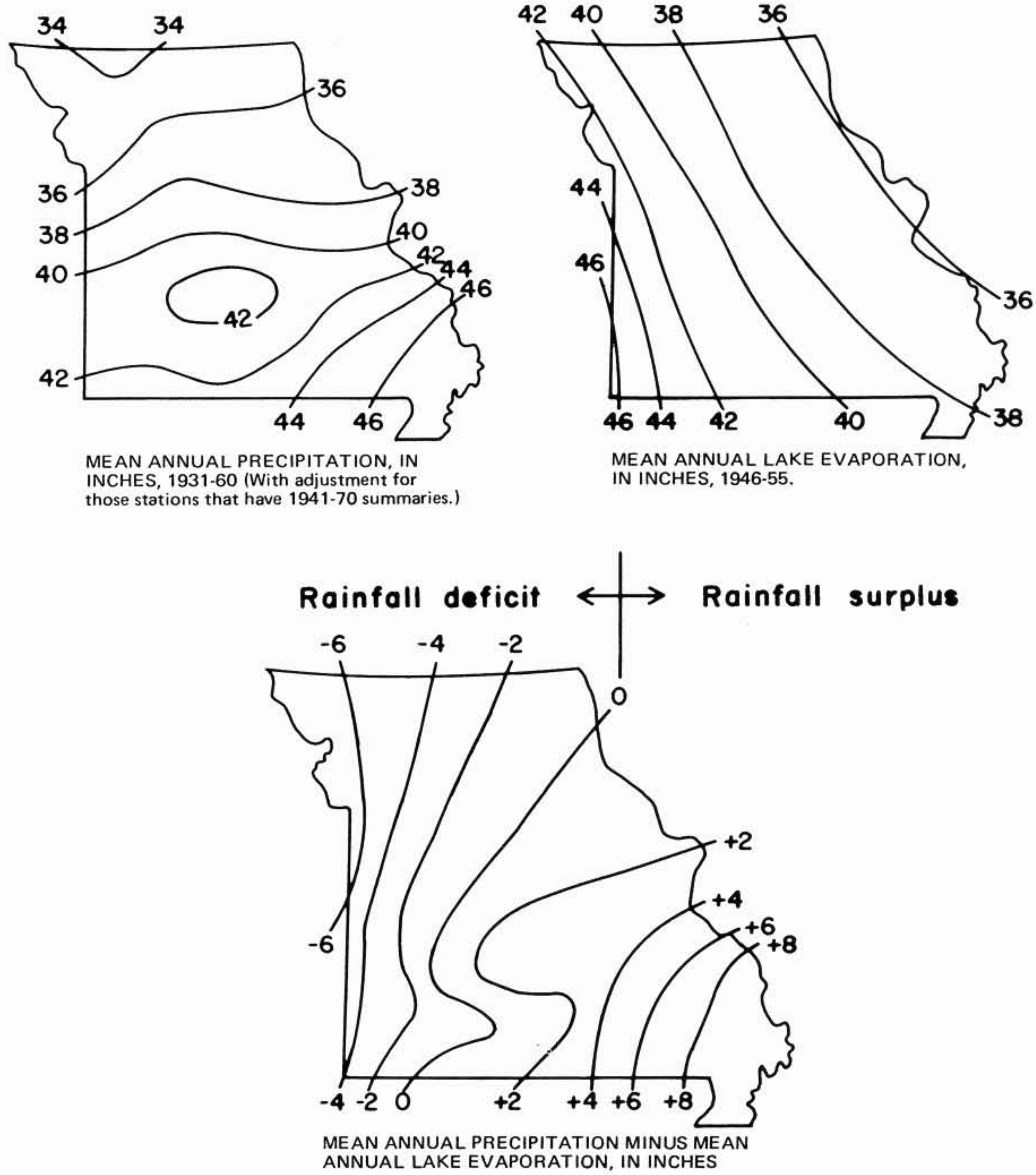


Figure 1

Precipitation and lake evaporation in Missouri.

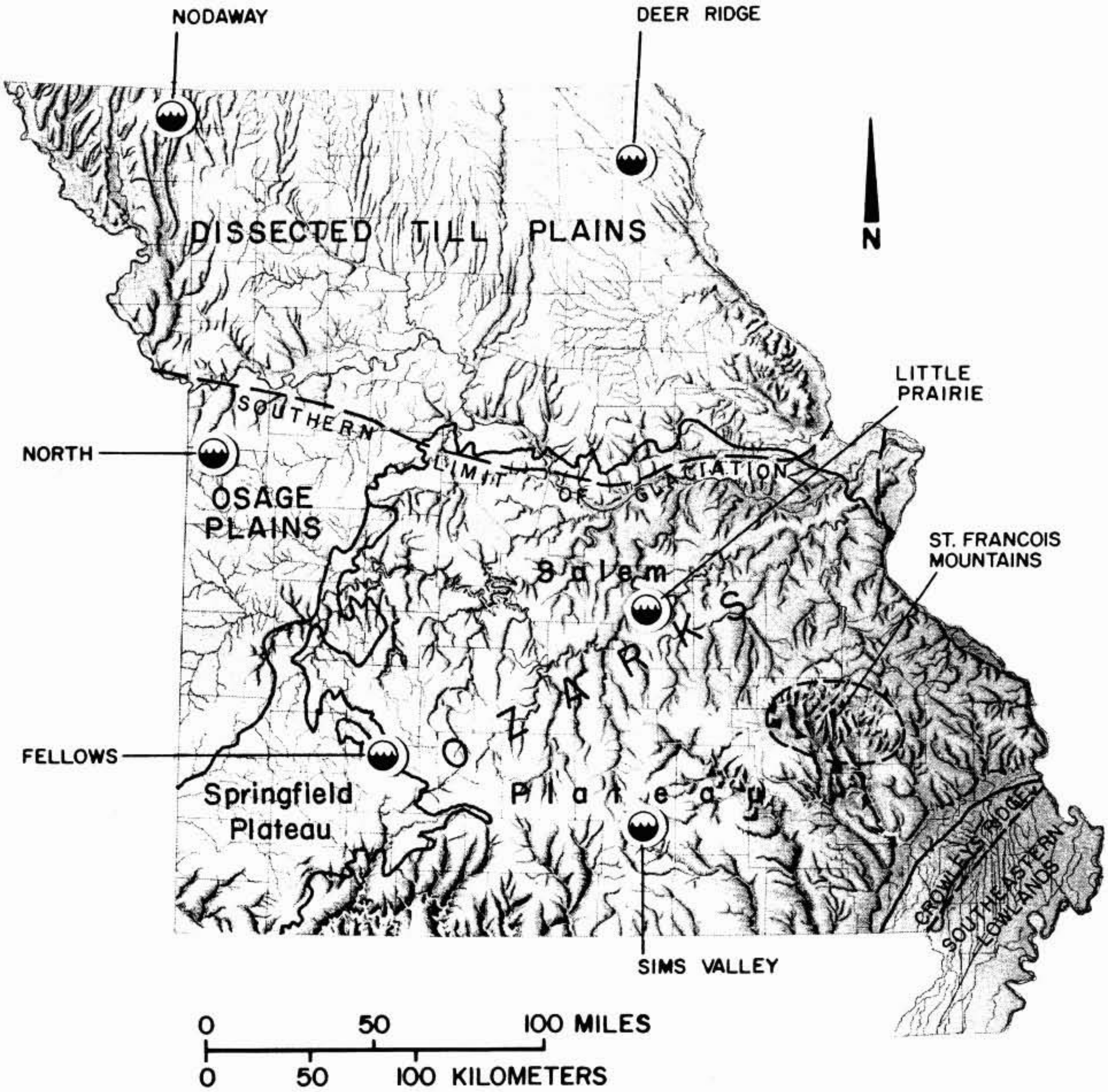


Figure 2

Map showing the major physiographic divisions of Missouri and the locations of the study lakes.

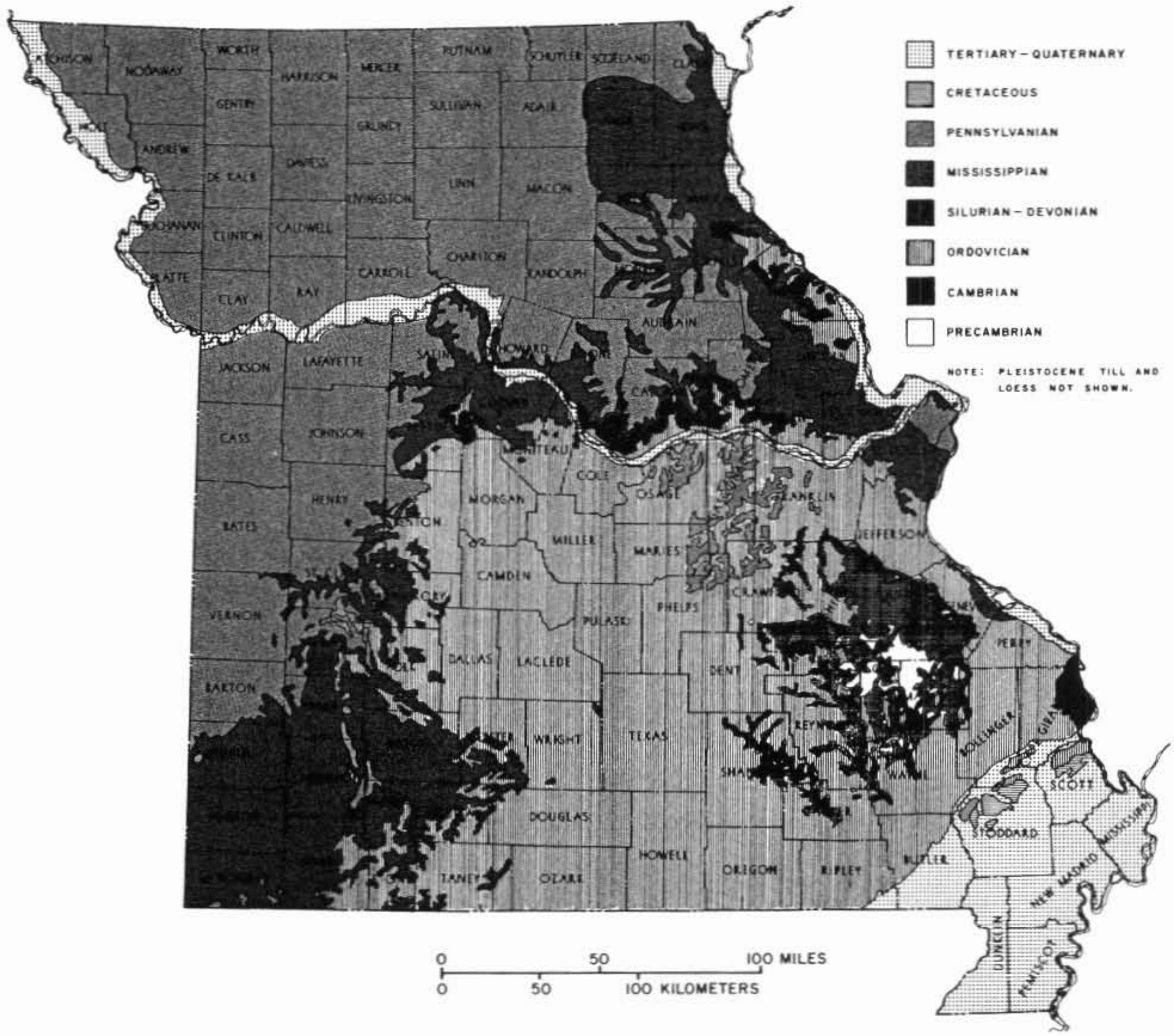


Figure 3

Generalized bedrock geology map of Missouri.

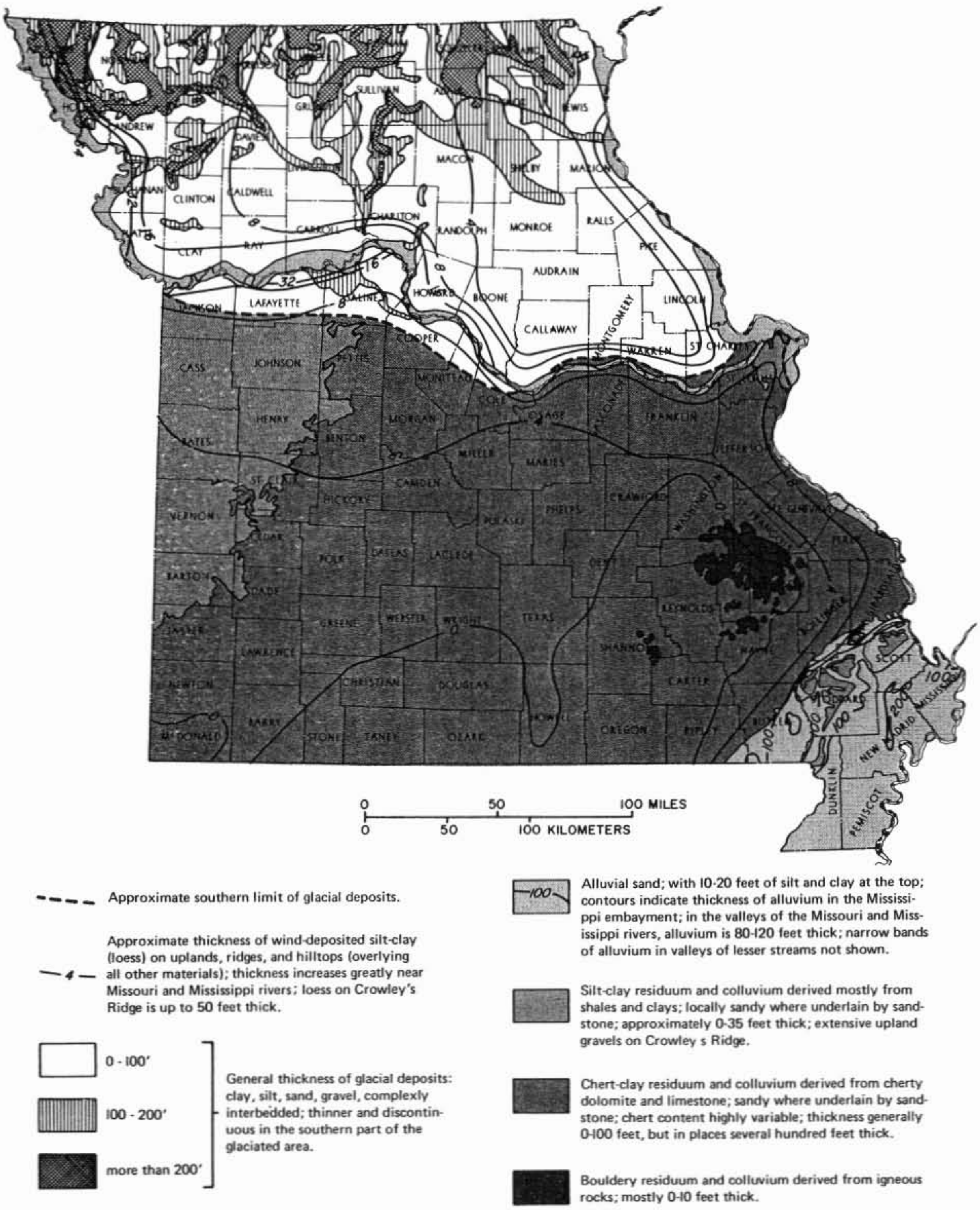


Figure 4

Generalized surficial materials map of Missouri.

The Springfield Plateau resembles the Osage Plains in many ways, but has traditionally been regarded as a part of the Ozarks. The hills are less rugged and the valleys are wider than in most other areas in the Ozarks. Bedrock outcrops of cherty limestone of Mississippian age are common, as are karst features such as caves and sinkholes. Clay, sand, and chert derived from the bedrock compose the surficial materials, which vary in thickness because of the uneven bedrock surface and erosion.

SOUTHEASTERN LOWLANDS – The Southeastern Lowlands, part of the Mississippi embayment, consist largely of alluvial deposits of sand, silt, and clay. Paleozoic, Cretaceous, and Tertiary rocks are exposed on Crowleys Ridge, a line of low hills that rise above the floodplain and lie diagonally across the northern part of the Southeastern Lowlands. Bedrock in the Crowleys Ridge area is principally soft shale and sandstone. Surficial materials on Crowleys Ridge consist of a silt-clay residuum and extensive upland gravels.

Most of the Lowlands area is too flat for conventional construction of dams, and lakes are formed by excavation with dragline into the alluvial plain. Typically, the water table is within 5 to 15 ft (2 to 5 m) of the land surface. Mean annual precipitation exceeds average annual lake evaporation by about 8 inches (20 mm) and helps sustain the water level in the lakes.

LAND USE

About 90 percent of the land in most counties in the State is used for crops, pasture, and forest. About 1 to 9 percent of the land is occupied by urban and suburban development except St. Louis County (75 percent) and Jackson County (25 percent) where St. Louis and Kansas City are located, and other counties near enough to be influenced by these large cities. The remaining 1 to 9 percent of land is used for other purposes such as rural residences, farm roads, feedlots, and small lakes.

Land uses in the Osage Plains and Dissected Till Plains are similar. A little more than 50 percent of the land in most counties in these areas is used for crops. About 20 to 30 percent of the land is in pasture and 10 to 20 percent is forested. Much of the forest in the Plains is confined to the dissected land along streams and to small farm woodlots.

In the Southeastern Lowlands 70 to 90 percent of the land is in cultivation. In most of the Lowlands counties less than 5 percent is in pasture and less than 10 percent is covered by forests.

The Ozark region is heavily forested, especially these counties in the interior or central part of the Ozarks. Most of the interior counties are over 60 percent forested while Reynolds, Shannon, Carter, and Wayne Counties are more than 80 percent forested. The amount of pasture land in the interior counties ranges from 10 to 30 percent. Pasture land has been increasing and forest land decreasing in many Ozark counties because of aerial spraying to kill timber and subsequent seeding to create more pasture. In most interior counties less than 10 percent of the land is used for crop cultivation. Ozark counties that border the Osage Plains, Dissected Till Plains, or Southeastern Lowlands generally have more crop and pasture land than the interior counties.

The effects of land use on lake water-quality, although a factor, were not evaluated in this study.

LOCATION AND DESCRIPTION OF STUDY LAKES

The locations of the study lakes are shown on the physiographic map in figure 2. Two lakes are in the Dissected Till Plains, one in the Osage Plains, one in the Springfield Plateau, and two in the Salem Plateau. North and Fellows Lakes are used primarily as water supplies for the cities of Harrisonville and Springfield, respectively. The remaining four lakes are community lakes used primarily for fishing. The lakes range in size from 41 to 820 acres (17 to 332 ha) and in maximum depth from 22 to 88 feet (6.7 to 26.8 m). A detailed description of each lake is given in figures 5 through 10.

LOCATION OF DAM: T. 65 N., R. 35 W., sec. 20, on tributary to Canal Branch, 0.7 mi (1.1 km) upstream from mouth, about 5.5 mi (8.8 km) north of Maryville, Nodaway County.

DATE CONSTRUCTION WAS COMPLETED: 1966.

DATE WATER LEVEL FIRST REACHED DESIGN POOL ELEVATION: October 1970

USE: Recreation

LAND USE: Cropland and pasture with less than 2 percent woodland.

GEOLOGIC SETTING: The lake setting is typical of northwestern Missouri. Glacial deposits of silt loam and silty clay loam 100 to 200 ft (30 to 61 m) thick cover bedrock that is predominantly shale and has some interbedded limestone and sandstone. The glacial drift is a little thicker than in some areas in northwestern Missouri, but the texture and composition of the deposits are representative of the region. The surficial material is highly susceptible to erosion; thus, sediment accumulation in ponds, lakes, and flood plains is a serious problem.

DRAINAGE BASIN: Platte River.

DESIGN POOL ELEVATION: 1,083 ft (330 m) above mean sea level.

DRAINAGE AREA: 730 acres (300 ha).

SURFACE AREA AT DESIGN POOL ELEVATION: 72 acres (29 ha).

RATIO OF DRAINAGE AREA TO SURFACE AREA OF LAKE: 10.1.

MAXIMUM DEPTH AT DESIGN POOL ELEVATION: 34 ft (10.4 m).

VOLUME AT DESIGN POOL ELEVATION: 631 acre-feet (0.778 hm^3).

INFLOW: Primarily one intermittent stream.

OUTFLOW: Concrete drop-inlet spillway, through the dam and into intermittent stream.

Figure 5

Description and photograph of Deer Ridge Lake near Lewistown, Mo.

LOCATION OF DAM: T. 26 N., R. 8 W., sec. 7, 18, on tributary to North Fabius River, 1.9 mi (3.1 km) upstream from mouth, about 6.5 mi (10.5 km) north of Lewistown, Lewis County.

DATE CONSTRUCTION WAS COMPLETED: January 1960.

DATE WATER LEVEL FIRST REACHED DESIGN POOL ELEVATION: March 1966.

USE: Recreation.

LAND USE: Sixty-eight percent forested, remainder in unused grass fields and light agriculture.

GEOLOGIC SETTING: The lake site and watershed are underlain by relatively impermeable clay-rich deposits which contain some sand and gravel pockets. The lake setting is typical of northeastern Missouri except that a rather large amount of sand was encountered during construction of the core trench. Rapid runoff occurs following rainfall and runoff subsides quickly after rainfall because of the lack of storage capacity within the subsoil materials. The surficial material is susceptible to severe erosion.

DRAINAGE BASIN: Fabius River.

DESIGN POOL ELEVATION: Approximately 673 ft (205 m) above sea level.

DRAINAGE AREA: 577 acres (230 ha).

SURFACE AREA AT DESIGN POOL ELEVATION: 48 acres (19 ha).

RATIO OF DRAINAGE AREA TO SURFACE AREA OF LAKE: 12.0.

MAXIMUM DEPTH AT DESIGN POOL ELEVATION: 28 ft (8.5 m).

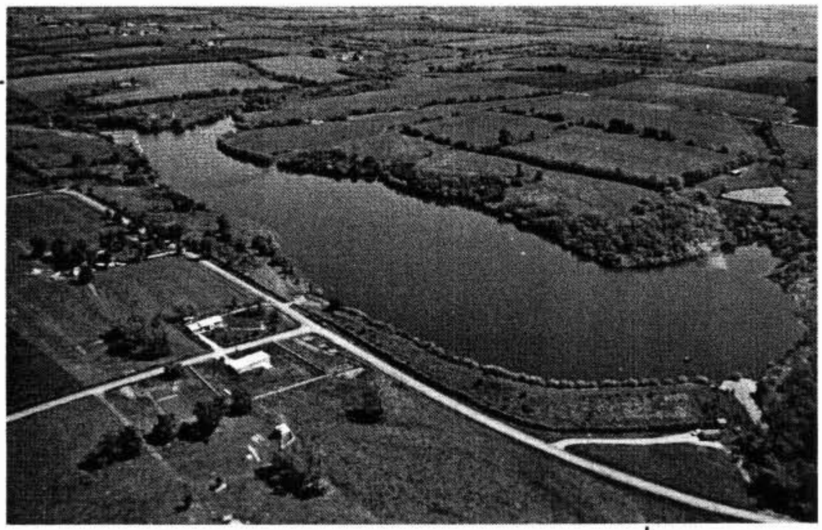
VOLUME AT DESIGN POOL ELEVATION: 514 acre-feet (0.634 hm^3).

INFLOW: Three intermittent streams give the lake a three-fingered configuration.

OUTFLOW: Corrugated metal pipe-drop inlet spillway, through the dam and into intermittent stream.

Figure 6

Description and photograph of Nodaway Lake near Pickering, Mo.



LOCATION OF DAM: T. 45 N., R. 31 W., sec. 28, on Polecat Creek, 3.0 mi (4.8 km) upstream from mouth, about 2.4 mi (3.9 km) north of Harrisonville, Cass County.

DATE CONSTRUCTION WAS COMPLETED: 1957

DATE WATER LEVEL FIRST REACHED DESIGN POOL ELEVATION: 1957

USE: Water supply for the city of Harrisonville and recreation.

LAND USE: 2 percent forested, remainder in pasture.

GEOLOGIC SETTING: The dam site and lower part of the lake are underlain with silty shale and some zones of sandstone. The upper part of the watershed is underlain by interbedded layers of shale and limestone. Relatively impermeable silty clay covers the bedrock from a depth of a few feet on steep slopes to 15 to 20 ft (5 to 6 m) on the upper part of the watershed. Stones occur in the surficial material in the upper part of the watershed where the limestone bedrock has been weathered. Runoff is rapid following rainfall and stops soon after rainfall because of limited storage in the relatively impermeable and moderately thin surficial material. Erosion and subsequent filling of the lake with sediment is a problem.

DRAINAGE BASIN: Osage River.

DESIGN POOL ELEVATION: Approximately 930 ft (283 m) above mean sea level.

DRAINAGE AREA: 1230 acres (500 ha).

SURFACE AREA AT DESIGN POOL ELEVATION: 51 acres (21 ha).

RATIO OF DRAINAGE AREA TO SURFACE AREA OF LAKE: 24.1.

MAXIMUM DEPTH AT DESIGN POOL ELEVATION: 22 ft (6.7 m).

VOLUME AT DESIGN POOL ELEVATION: 365 acre-feet (0.450 hm^3).

INFLOW: Polecat Creek and a tributary join in the headwaters of the lake.

OUTFLOW: Over concrete spillway into Polecat Creek. Water is also pumped from the lake as needed for water supply.

Figure 7

Description and photograph of North Lake near Harrisonville, Mo.

LOCATION OF DAM: T. 30 N., R. 21 W., sec. 15, 21 on Little Sac River, 2.0 mi (3.2 km) upstream from U.S. Highway 65, about 5 mi (8.0 km) northeast of Springfield, Greene County.

DATE CONSTRUCTION WAS COMPLETED: 1955

DATE WATER LEVEL FIRST REACHED DESIGN POOL ELEVATION: 1958.

USE: Water supply for the city of Springfield and recreation.

LAND USE: Approximately 40 percent forested, remainder in pasture and residential.

GEOLOGIC SETTING: The setting of Fellows Lake is representative of gaining river valleys and larger streams in southwestern Missouri. It is not typical of small tributary valleys that are present in the karst or sinkhole setting that is widespread in this region. Several bedrock formations occur in the Sac River valley and adjoining watershed slopes in and near Fellows Lake. Bedrock in the valley is massively bedded siltstone and shale of the Northview Formation which is relatively impermeable and stable except for areas where the shale has been severely weathered. Bedrock on the valley slopes is a cherty limestone, Elsey Formation, which weathers to a rubbly material made up of more than 50 percent angular chert fragments. Fine silt and silty clay are intermixed with the chert. The upper part of the watershed is underlain by massively bedded Burlington Limestone with some chert present. Surficial material derived from weathering of the Burlington Limestone is a moderately to highly permeable red clay and has a minor amount of admixed stones.

DRAINAGE BASIN: Osage River.

DESIGN POOL ELEVATION: 1,260 ft (384 m) above mean sea level.

DRAINAGE AREA: 14,100 acres (5,710 ha).

SURFACE AREA AT DESIGN POOL ELEVATION: 820 acres (332 ha).

RATIO OF DRAINAGE AREA TO SURFACE AREA OF LAKE: 17.2

MAXIMUM DEPTH AT DESIGN POOL ELEVATION: 88 ft (26.8 m).

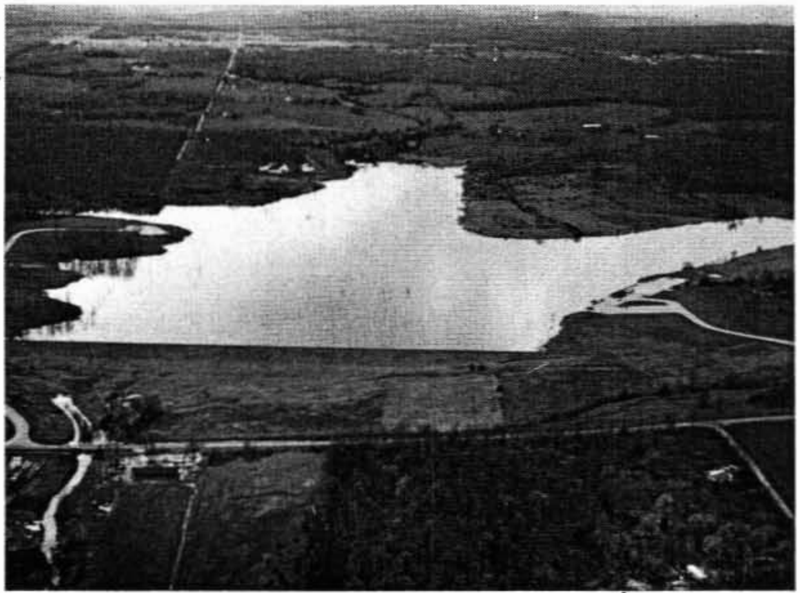
VOLUME AT DESIGN POOL ELEVATION: 27,800 acre-feet (34.3 hm^3).

INFLOW: Little Sac River and a large tributary give lake a two-fingered configuration.

OUTFLOW: Over concrete spillway into Little Sac River. Water is also released through the dam as needed for water supply.

Figure 8

Description and photograph of Fellows Lake near Springfield, Mo.



LOCATION OF DAM: T. 38 N., R. 7 W., sec. 21, on tributary to Bourbeuse River, 0.7 mi (1.1 km) northeast of Rolla, Phelps County.

DATE CONSTRUCTION WAS COMPLETED: 1965

DATE WATER LEVEL FIRST REACHED DESIGN POOL ELEVATION: 1966

USE: Recreation.

LAND USE: 44 percent forested, remainder pasture.

GEOLOGIC SETTING: The geologic setting is rather typical for this part of the Salem Plateau Uplands. The lake site and watershed are underlain by Ordovician age Jefferson City Dolomite. Pennsylvanian deposits which cap the Jefferson City Dolomite consists of medium to massive beds of dolomite which is relatively watertight. Overlying material is silt loam on the flood plain and silt loam underlain by silty clay on the weathered slopes.

DRAINAGE BASIN: Meramec River.

DESIGN POOL ELEVATION: 1,032 ft (314 m) above mean sea level.

DRAINAGE AREA: 1,540 acres (620 ha).

SURFACE AREA AT DESIGN POOL ELEVATION: 100 acres (40 ha).

RATIO OF DRAINAGE AREA TO SURFACE AREA OF LAKE: 15.4.

MAXIMUM DEPTH AT DESIGN POOL ELEVATION: 34 ft (10.4 m).

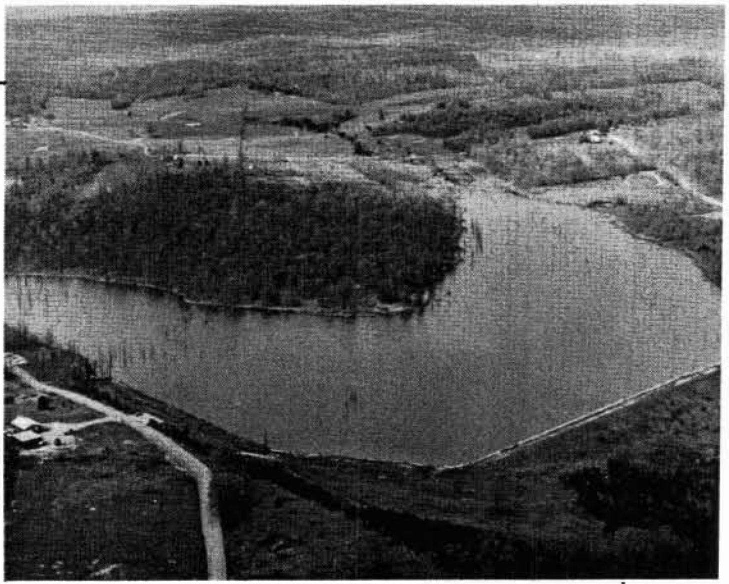
VOLUME AT DESIGN POOL ELEVATION: 1,400 acre-feet (1.72 hm^3).

INFLOW: Two intermittent streams give the lake a two-fingered configuration.

OUTFLOW: Concrete drop-inlet spillway, through the dam and into intermittent stream.

Figure 9

Description and photograph of Little Prairie Lake near Rolla, Mo.



LOCATION OF DAM: T. 27 N., R. 8 W., sec. 20, on tributary to Sims Valley 0.5 mi (0.8 km) upstream from mouth, about 5.5 mi (8.8 km) east of Willow Springs, Howell County.

DATE CONSTRUCTION WAS COMPLETED: December 1963.

DATE WATER LEVEL FIRST REACHED DESIGN POOL ELEVATION: May 1965.

USE: Recreation.

LAND USE: 66 percent forested, remainder in pasture.

GEOLOGIC SETTING: This area is underlain by the Roubidoux Formation which consists of interbedded sandstone, dolomite, and chert. The weathered surficial material is a well-graded clay which ranges from 15 to 100 ft (5 to 30 m) in thickness. It has about 15 to 35 percent silt and sand, but is mostly coarse material, predominantly angular chert fragments that are residual from the chert in the bedrock.

DRAINAGE BASIN: Spring River.

DESIGN POOL ELEVATION: Approximately 1,215 ft (370 km) above mean sea level.

DRAINAGE AREA: 560 acres (230 ha).

SURFACE AREA AT DESIGN POOL ELEVATION: 41 acres (17 ha).

RATIO OF DRAINAGE AREA TO SURFACE AREA OF LAKE: 13.7

MAXIMUM DEPTH AT DESIGN POOL ELEVATION: 25 ft (7.6 m).

VOLUME AT DESIGN POOL ELEVATION: 146 acre-feet (0.181 hm^3).

INFLOW: Two intermittent streams give the lake a two-fingered configuration.

OUTFLOW: Concrete drop-inlet spillway, through the dam and into intermittent stream.

Figure 10

Description and photograph of Sims Valley Lake near Willow Springs, Mo.

WATER-QUALITY CHARACTERISTICS

Water-quality data were collected at Deer Ridge, Nodaway, North, Fellows, Little Prairie, and Sims Valley Lakes from September 1972 through November 1973. All measurements and observations, except plant growth, were made in verticals at the deepest point in each lake.

Vertical temperature and dissolved-oxygen profiles were made approximately once each month. At the same time pH and specific conductance were measured 2 ft (0.6 m) below the water surface and 2 ft (0.6 m) above the bottom. Light penetration and ice thickness were measured, and plant growth was observed. Approximately once each 3 months samples were collected from 2 ft (0.6 m) below the water surface and 2 ft (0.6 m) above the bottom for laboratory analyses. Laboratory analyses are also available for a sample collected from near the surface of Deer Ridge, Nodaway, and Sims Valley Lakes during the summer of 1967. Once during the study minor-element analyses were made on water collected from 2 ft (0.6 m) below the surface and 2 ft (0.6 m) above the bottom of North Lake and Fellows Lake and on bottom mud samples from all six lakes.

PHYSICAL PROPERTIES

THERMAL STRATIFICATION – Water temperature is often a very important factor in determining the effectiveness with which an impoundment serves a particular purpose. It obviously has a direct influence on the usefulness of lake water for cooling. Because of its effects on most aspects of water quality, temperature has an important indirect influence on the suitability of lake water for other uses such as water supply and recreation. Variations in water temperature affect most physical properties, as well as the rates at which chemical, biochemical, and biological processes take place.

The interaction of temperature, density, and wind during the different seasons of the year produces a characteristic seasonal thermal stratification of lakes in Missouri. A good explanation of the mechanics of thermal stratification is given by Peirce (1964, p. 36). Because thermal stratification reflects the movement of water in the vertical direction, it results in vertical gradients of water quality. Thus an understanding of the way water stratifies in small lakes in Missouri is important in determining the suitability of impounded water for different uses.

The characteristic seasonal pattern for thermal stratification of lakes is illustrated in figure 11. In the spring, water temperature and density are uniform throughout. Daily fluctuations in water temperature near the surface, aided by wind disturbance, cause an unstable condition and vertical currents are readily induced. Summer stratification occurs as continued surface warming causes three layers of water having different thermal properties and densities to develop. These are the epilimnion, or warm upper layer of relatively uniform temperature and density in which vertical and horizontal mixing continues; the metalimnion or thermocline, a middle layer having a steep vertical temperature gradient (at least $1^{o}C$ for each 3.28 ft [1.0 m] in depth); and the hypolimnion, or cold lower layer of stagnant water. In the fall the lake "turns over", which means the water surface cools down until the temperature and density are uniform again and vertical and horizontal mixing take place throughout the depth of the water body. Winter stratification occurs when a lake is completely frozen over for a period of time. The ice cover prevents disturbance by the wind and an inverse thermal stratification develops with colder (less than $4^{o}C$), lighter water near the surface.

The isotherm diagrams (figs. 12 to 17) show the seasonal changes in water temperature in each of the six study lakes for the period September 1972 to November 1973. The vertical isotherms represent unstratified conditions, while the slanted and horizontal isotherms represent stratified conditions.

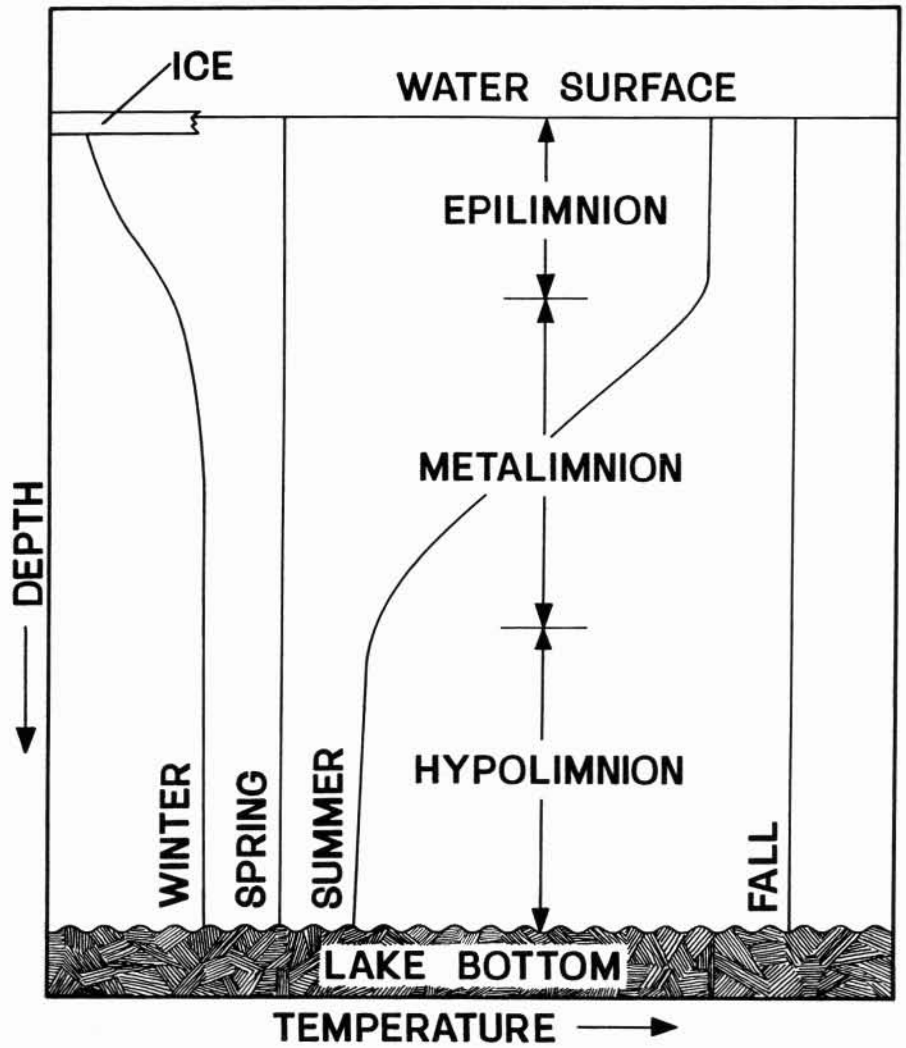


Figure 11

Idealized diagram showing annual cycle of thermal stratification.

Summer stratification occurred from May to November in all six lakes. The three most northern lakes (Deer Ridge, Nodaway, and North Lakes) became stratified about two weeks later in the summer and "turned over" about two weeks earlier in the fall than Fellows, Little Prairie, and Sims Valley, the southernmost lakes. The epilimnions were about 6 ft (2 m) thick in June and became progressively thicker, reaching a thickness of about 20 ft (6 m) in October, except the deeper Fellows Lake, which had an epilimnion thickness of about 35 ft (11 m) in October. The water temperature in Nodaway Lake was about $2^{o}C$ colder than the other lakes throughout the sampling period.

Winter stratification occurred only in the three northern lakes. This is probably typical of winter stratification in Missouri because there is total ice cover for long periods of time on lakes in northern Missouri every winter, and total ice cover for short periods of time on lakes in southern Missouri during severe winters only. During winter stratification

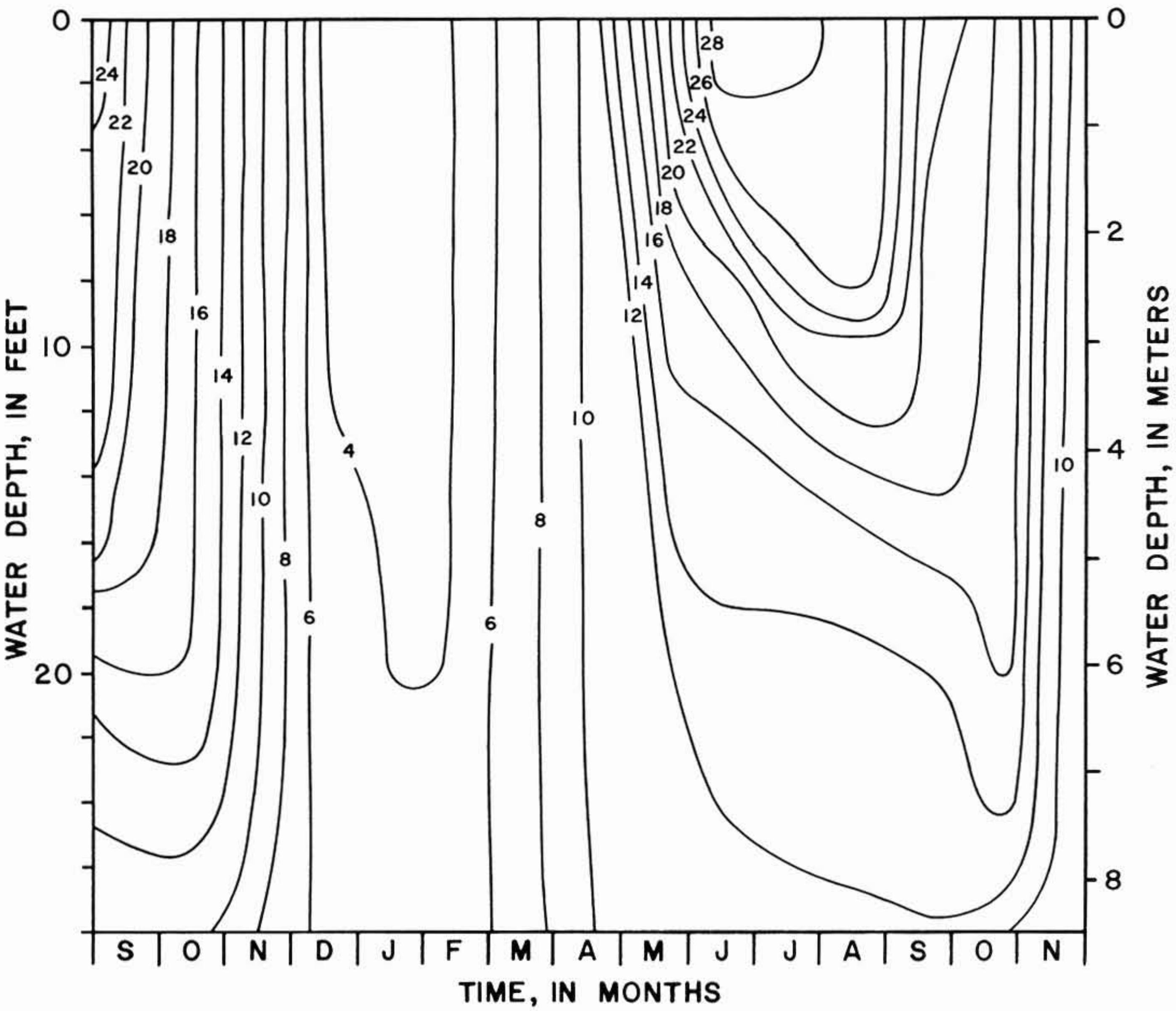


Figure 12

Seasonal changes in water temperature (°C) in Deer Ridge Lake from September 1972 to November 1973.

temperature differences between the epilimnion and hypolimnion are small, thus winter stratification appears less pronounced on the isotherm diagrams. However, the vertical gradients of water quality are present, as illustrated by the seasonal changes in dissolved oxygen.

ICE COVER – The extent and thickness of ice cover observed at the six study lakes during the winter of 1972-73 is shown in table 1. As would be expected from the air temperature pattern for Missouri, the three northern lakes had considerably more ice cover than the three southern lakes. Local residents reported that Nodaway Lake had as much as 18 inches (457 mm)

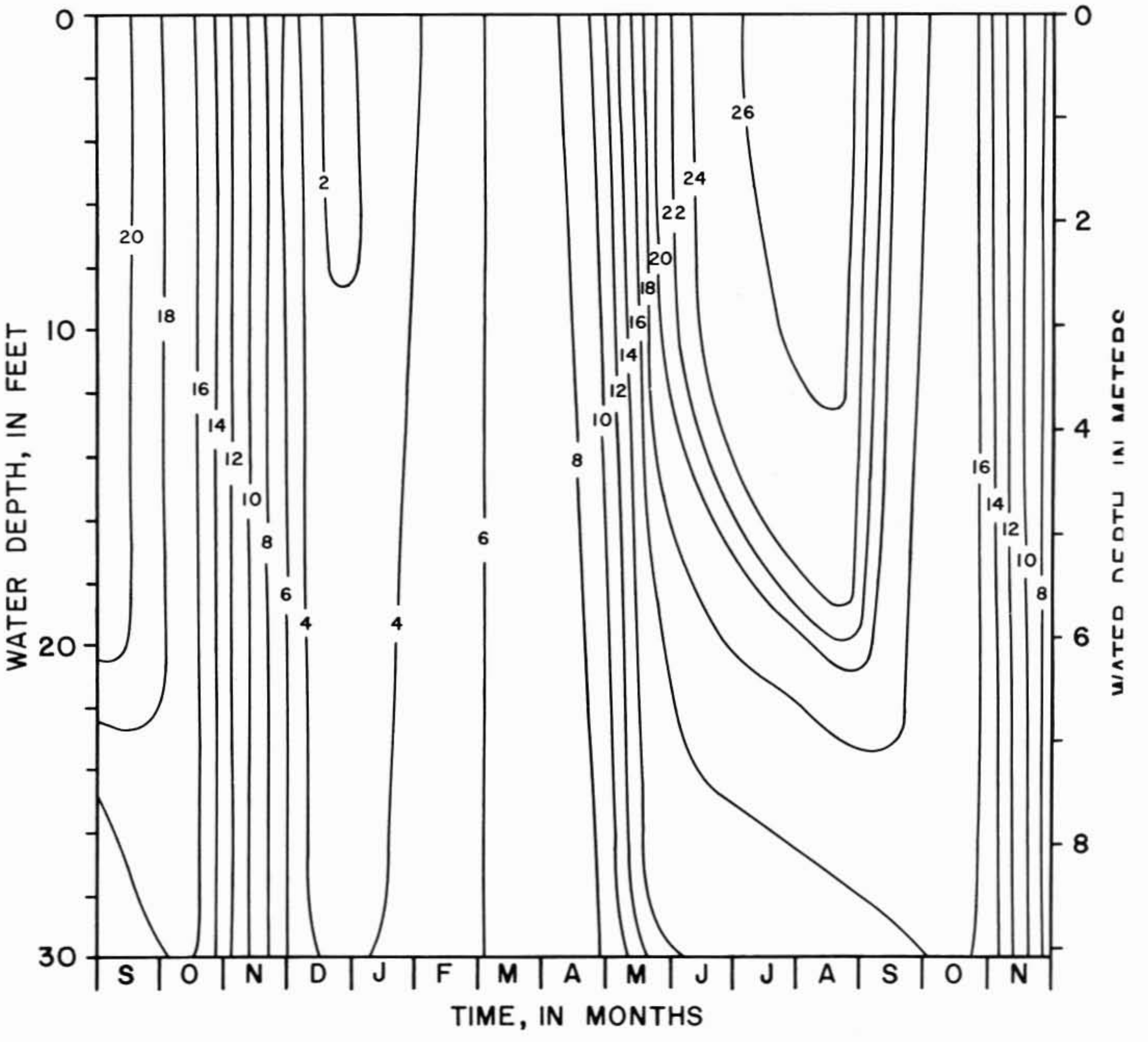


Figure 13

Seasonal changes in water temperature (°C) in Nodaway Lake from September 1972 to November 1973.

TABLE 1

ICE COVER, IN INCHES, ON SIX MISSOURI LAKES DURING THE WINTER OF 1972-73.

Lake	mid-December	mid-January	mid-February
Deer Ridge	5	6	1
Nodaway	5	12	2
North	3	3	0
Fellows	<1 (partial)	<1 (partial)	0
Little Prairie	<1 (partial)	0	<1 (partial)
Sims Valley	1	0	1

ice cover in January 1972. Monthly inspection trips for the past eight years to eight gaged small lakes located throughout the State verify extensive ice cover on lakes in northern Missouri every year and limited ice cover on lakes in the southern part of the State about every other year.

TRANSPARENCY – Lake transparency is the ability of the water to transmit light. This property is particularly important to the biological productivity of a lake.

Transparency is reduced by color and turbidity, because light is absorbed by color which is caused by dissolved inorganic and organic substances, and scattered by turbidity which is caused by suspended material consisting of mineral and organic particles and plant and animal organisms. Thus, transparency is closely related to the chemical and biological properties of the water.

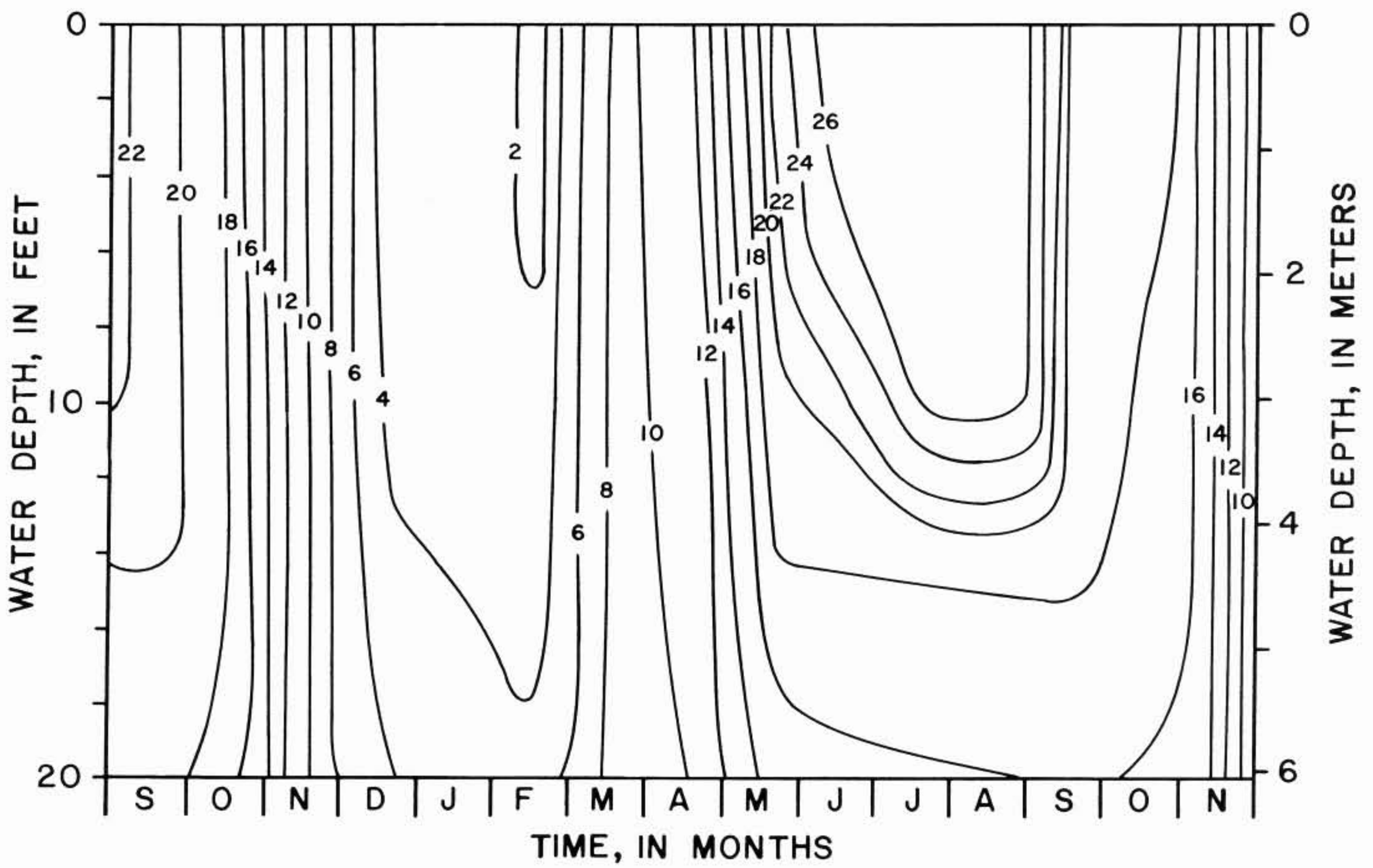


Figure 14

Seasonal changes in water temperature (°C) in North Lake from September 1972 to November 1973.

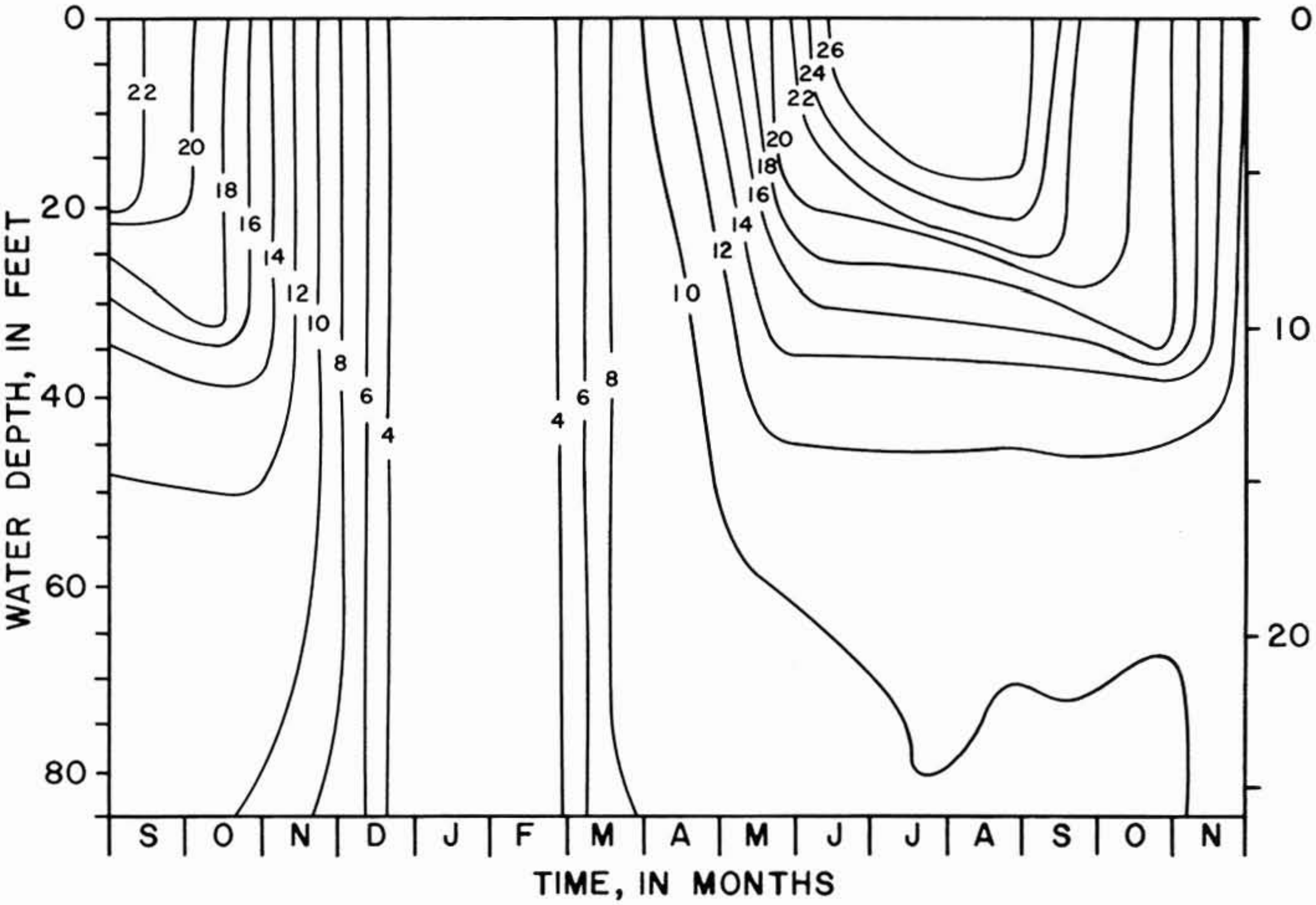


Figure 15

Seasonal changes in water temperature (°C) in Fellows Lake from September 1972 to November 1973.

A simple method of measuring transparency is with a Secchi disc, which is a 20-cm-diameter plastic plate with alternating black and white quadrants. It is lowered into the water with a calibrated line to the point where it is no longer visible, which is the depth at which less than 5 percent of the sunlight is transmitted.

Differences in transparency in different lakes are considerable. Secchi discs are normally visible at depths of 150 ft (46 m) or more in crater lakes, 30 to 100 ft (9 to 30 m) in mountain lakes, and from less than 1 ft (0 m) to 30 ft (9 m) in lowland lakes (Ruttner, 1953). Lakes in Missouri are in the latter category because they receive storm runoff and are biologically productive, making them subject to moderate to high turbidity and coloraton.

Monthly Secchi disc readings for the period September 1972 to November 1973 are summarized for the six study lakes in table 2. The graphs in figure 18 show the seasonal changes in Secchi-disc visibility for North, Fellows, and Sims Valley Lakes. Secchi-disc visibility in Deer Ridge and Nodaway Lakes was similar to that in North Lake, and visibility in Little Prairie Lake was usually similar to that in Sims Valley Lake. Maximum transparency was always observed in the larger and deeper Fellows Lake. Transparency was usually greatest during the winter when storm runoff and aquatic plant production were at a minimum. However, Fellows Lake was very clear in May and June. The least amount of transparency generally occurred after major storm events in the spring. The three Plains lakes became

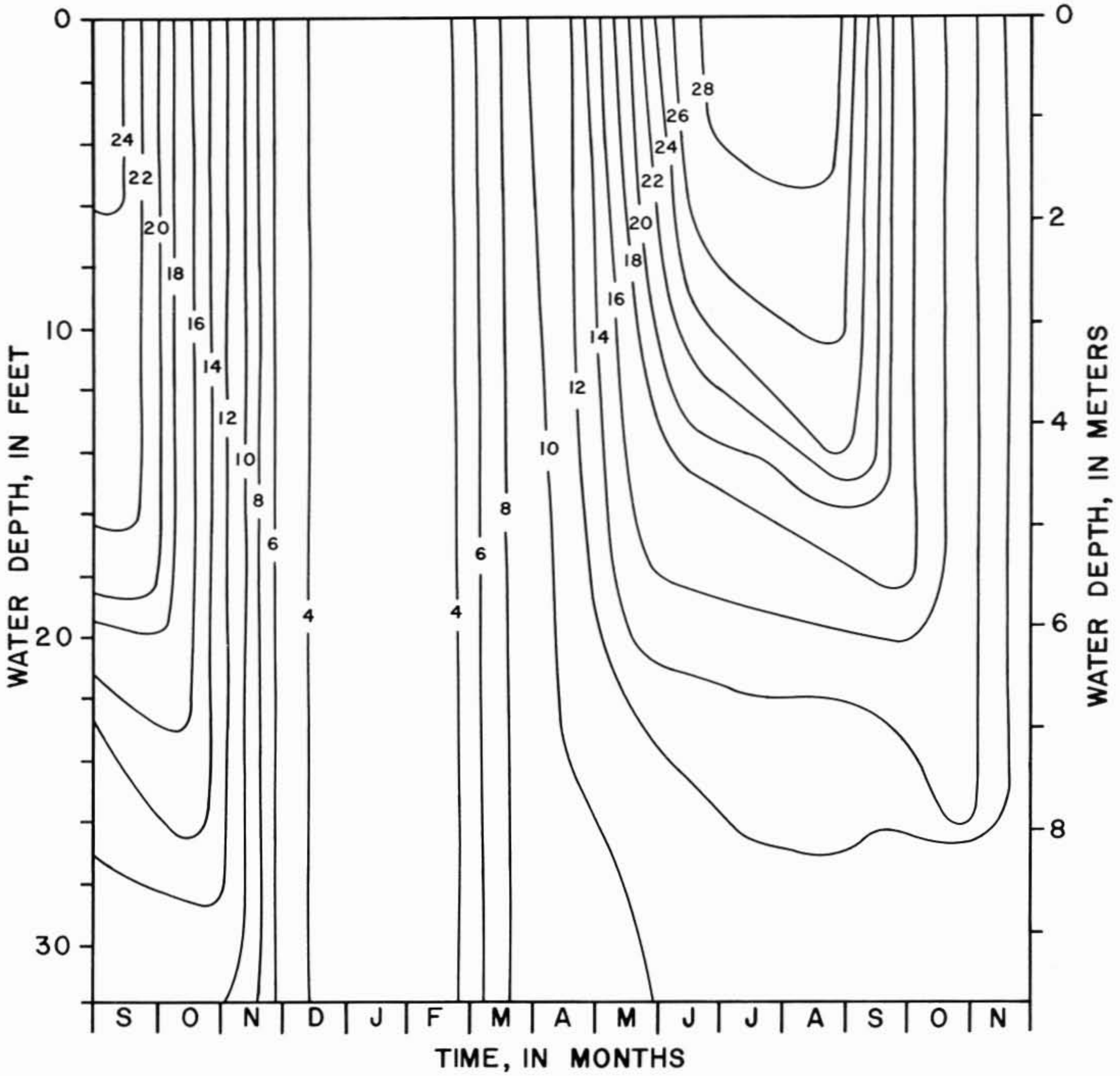


Figure 16

Seasonal changes in water temperature (°C) in Little Prairie Lake from September 1972 to November 1973.

TABLE 2

SUMMARY OF MONTHLY SECCHI-DISC MEASUREMENTS FOR SIX MISSOURI LAKES DURING THE PERIOD SEPTEMBER 1972 to NOVEMBER 1973.

	Secchi-disc visibility, in feet		
Lake	Maximum	Minimum	Mean
Deer Ridge	4.8	1.1	2.8
Nodaway	5.8	1.0	3.3
North	5.1	0.4	2.5
Fellows	12.6	5.2	8.1
Little Prairie	6.5	2.0	3.8
Sims Valley	5.6	2.4	4.0

quite turbid after spring storms, primarily because of suspended silt and clay particles, and remained turbid from about March through June. Light penetration in the Ozark lakes was less affected by storm runoff because of less erosion in the Ozarks. During September and October 1972 and 1973, decaying aquatic plants appeared to reduce light penetration in Deer Ridge Lake by imparting a brownish color to the water. A heavy algal bloom in Sims Valley Lake during May and June reduced light penetration considerably. Decay of the algae during July and August resulted in the water having a light-brownish color.

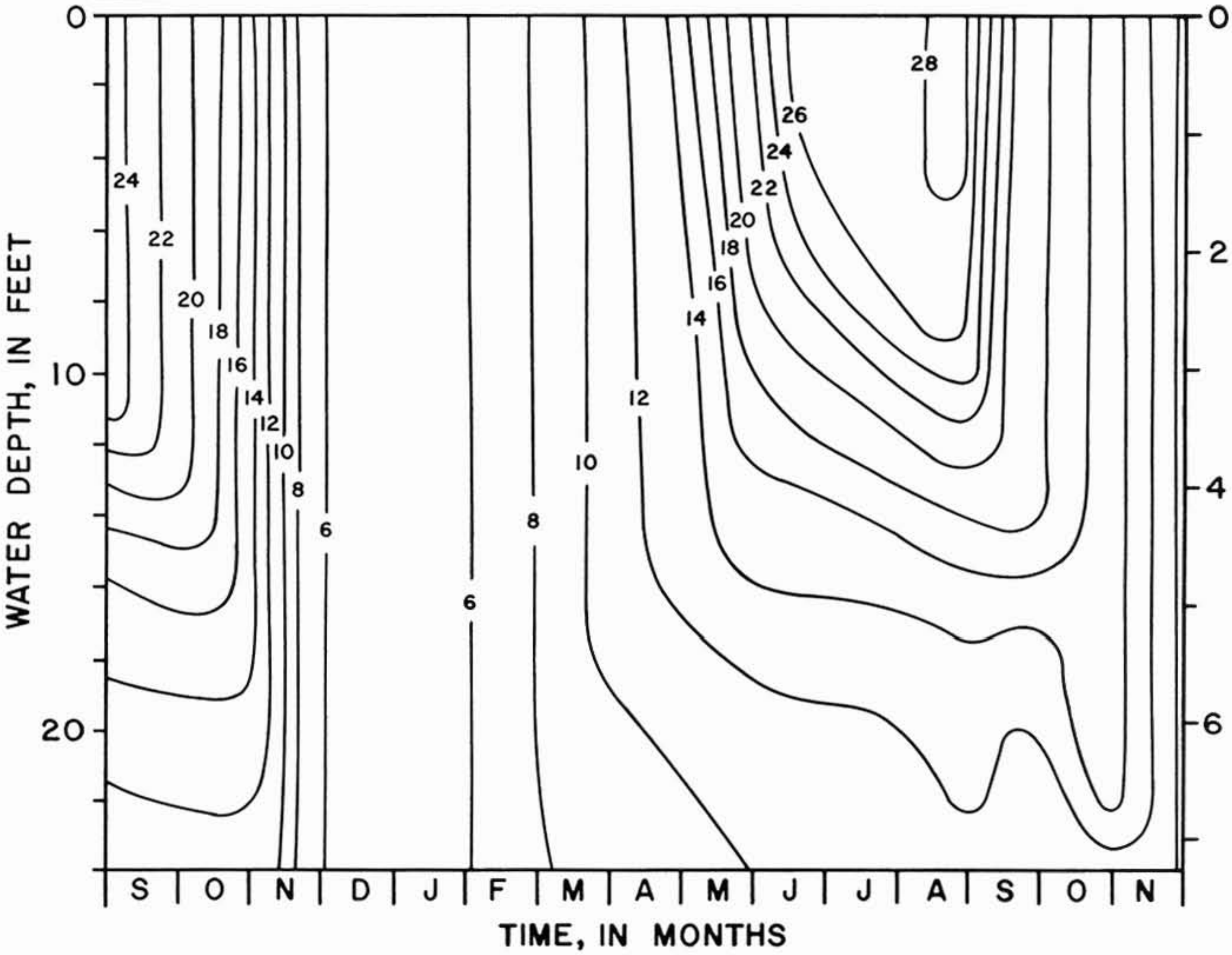


Figure 17

Seasonal changes in water temperature (°C) in Sims Valley Lake from September 1972 to November 1973.

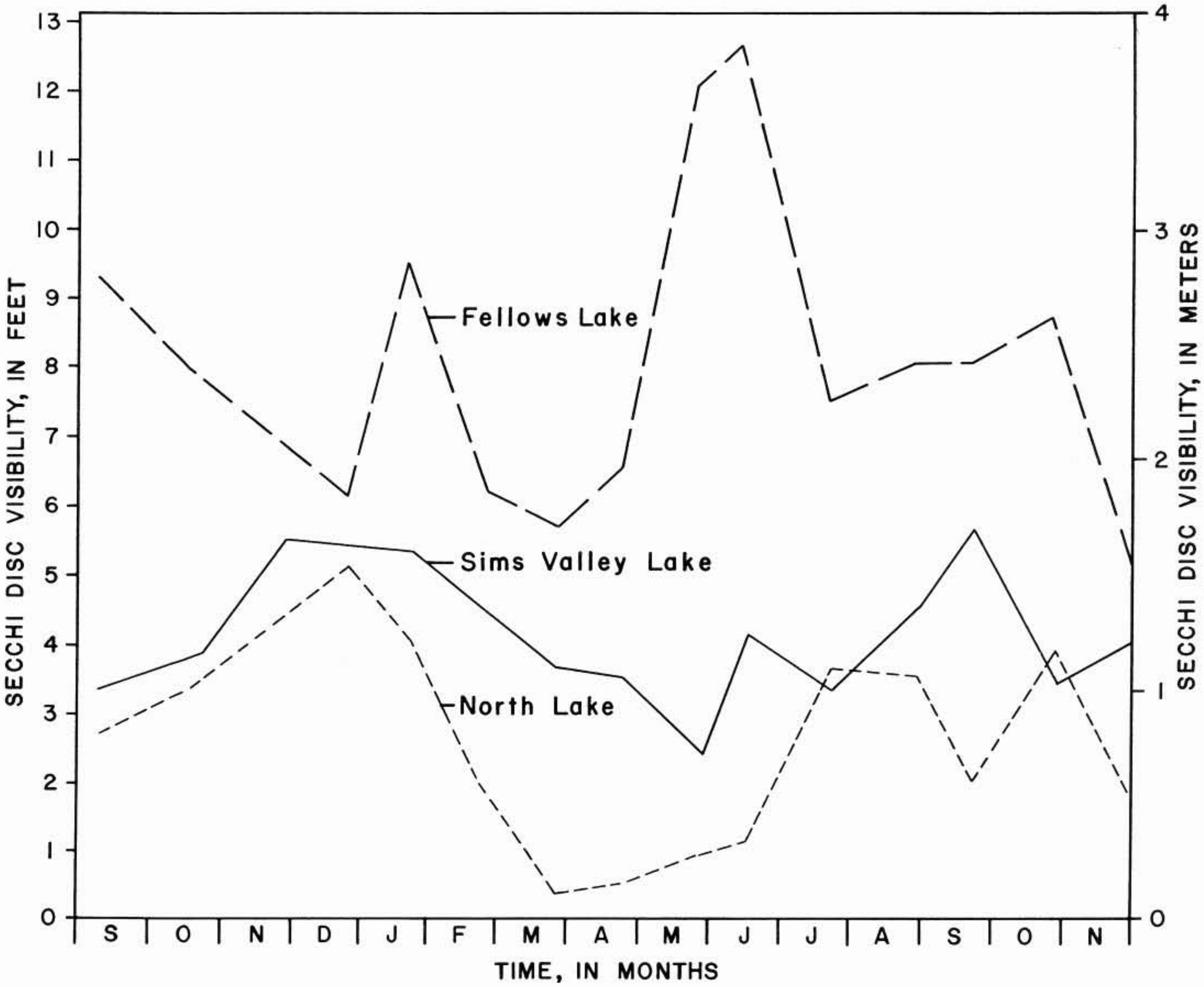


Figure 18

Graph showing seasonal changes in Secchi disc visibility in North, Fellows, and Sims Valley Lakes from September 1972 to November 1973.

SEDIMENTATION – Sedimentation is an important part of the interrelated physical, chemical, and biological properties of lakes. It also has a direct relation to the useful life of a lake.

Because of the limited scope of this study no sediment data were collected. However, it appears from Secchi-disc measurements and visual observations made by the author that lakes in the Plains receive considerably more sediment than lakes in the Ozarks. The three Plains lakes had significantly reduced Secchi-disc visibility and a "muddy" appearance from March to June. Storm runoff was considerably more in 1973 than 1972 at Deer Ridge Lake,which resulted in more suspended sediment and less light penetration during the spring and early summer of 1973. This is believed to be the cause of an estimated 67-percent reduction in aquatic-plant production in Deer Ridge Lake during 1973 as compared to 1972.

CHEMICAL QUALITY

DISSOLVED OXYGEN – Oxygen dissolved in water is derived from the air and from oxygen given off in the process of photosynthesis by aquatic plants. The solubility of oxygen in water is dependent upon the partial pressure of oxygen in air, the temperature of the water, and the mineral content of the water (Brown and others, 1970).

As previously mentioned, the development of thermal stratification in a lake is important to the distribution and concentrations of dissolved gases and solids. During stratification, water in the hypolimnion does not mix with water in the epilimnion, and in Missouri lakes photosynthesis does not occur in the hypolimnion because light penetration generally does not reach deeper than the epilimnion. As a result oxygen in the hypolimnion is depleted by bacterial decomposition of organic matter soon after stratification and remains depleted until the lake "turns over." The magnitude and rate of oxygen depletion in the hypolimnion is directly dependent upon the amount of organic matter requiring oxidation, generally large amounts in the six study lakes.

Seasonal changes in dissolved oxygen in each of the study lakes are illustrated by isoline diagrams (figs. 19 to 24). As shown by the shaded areas, dissolved oxygen in the hypolimnion was deficient (with respect to the 5.0 mg/l criterion described below) during summer stratification. From June to September about 70 percent of each lake volume had dissolved-oxygen concentrations of 5.0 mg/l or less and about 60 percent of each lake volume had concentrations of 1.0 mg/l or less. A much smaller percent of the lake volume for Deer Ridge and North Lakes was deficient in dissolved oxygen during winter stratification. Nodaway Lake was also stratified during the winter, but dissolved oxygen did not fall below 5.0 mg/l. According to specific water-quality criteria for Missouri, with few exceptions, dissolved oxygen in classified streams shall not be less than 5 mg/l at any time due to effluents (Missouri Clean Water Commission, 1973). Water released from the hypolimnion of Missouri lakes could cause dissolved-oxygen concentrations in receiving streams to be below the 5 mg/l criterion.

Water in each of the study lakes was usually 80 to 100 percent saturated with oxygen (with respect to air-water equilibrium) throughout the total depth when the lakes were unstratified and throughout the epilimnion during stratification. On a few occasions during the winter when there was clear ice cover and during early summer, water near the surface was supersaturated (greater than 100 percent) because of photosynthetic activity of algae and higher plants. Saturation near the surface was lowest (60 to 80 percent) from September to November when plants were dying and the lakes were turning over.

IONIC PROPERTIES – Dissolved solids, hardness, and alkalinity are properties that reflect the mineralization of water. They are widely used in evaluating water quality and comparing waters with one another and may be important in determining the suitability of the water for particular uses. They are also indicative of the fertility, and thus the productivity of the water.

Ionic composition of lake water is mainly a consequence of the mineralogy of the rocks and soils in the drainage basin. The ionic properties of water in the six study lakes, except Deer Ridge Lake, are considered to be fairly representative of the physiographic areas in which the lakes are located. Compared

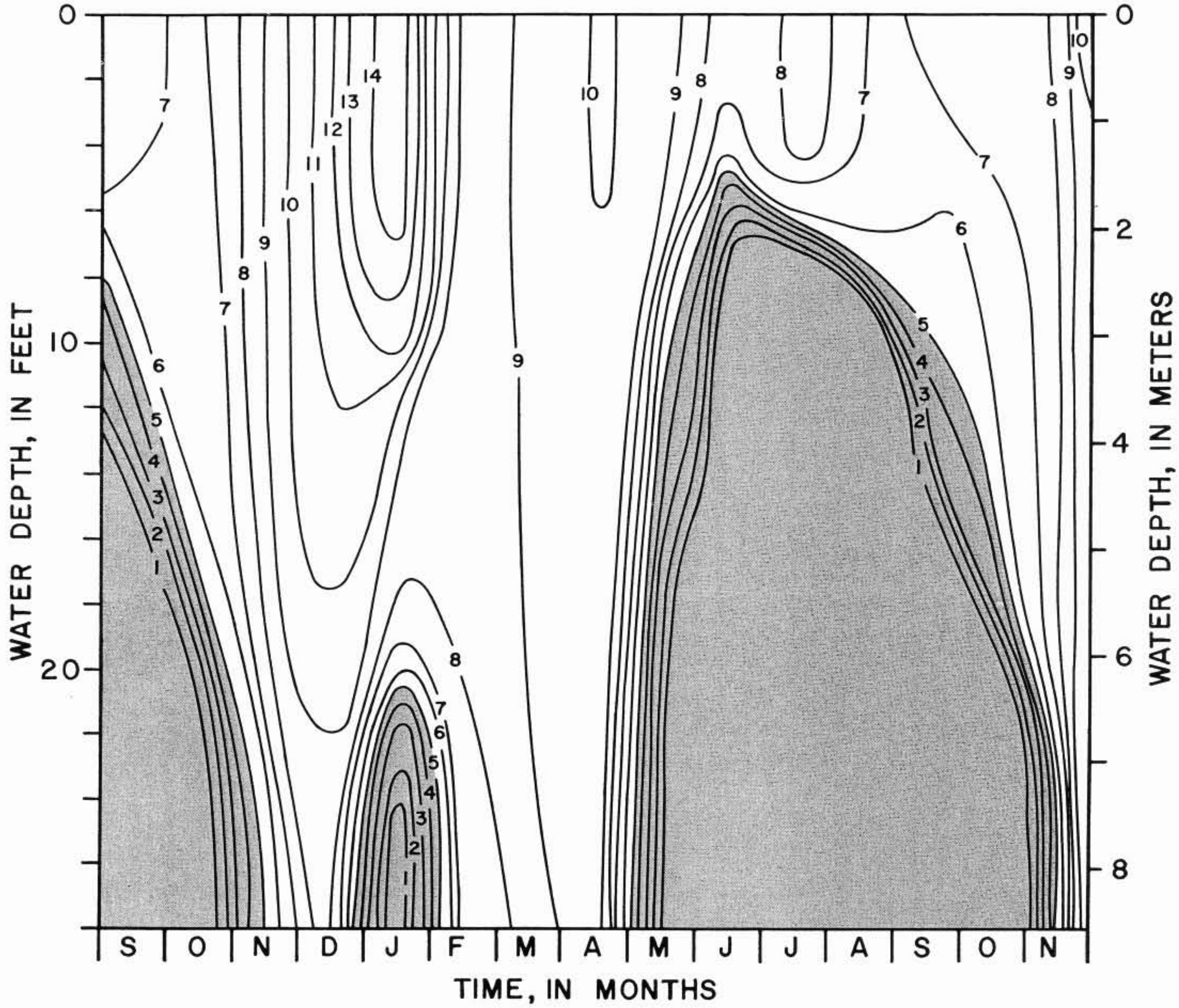


Figure 19

Seasonal changes in dissolved oxygen (mg/1) in Deer Ridge Lake from September 1972 to November 1973. Shaded areas represent water with dissolved oxygen concentrations less than the 5.0 mg/1 criterion established for classified streams by the Missouri Clean Water Commission in 1973.

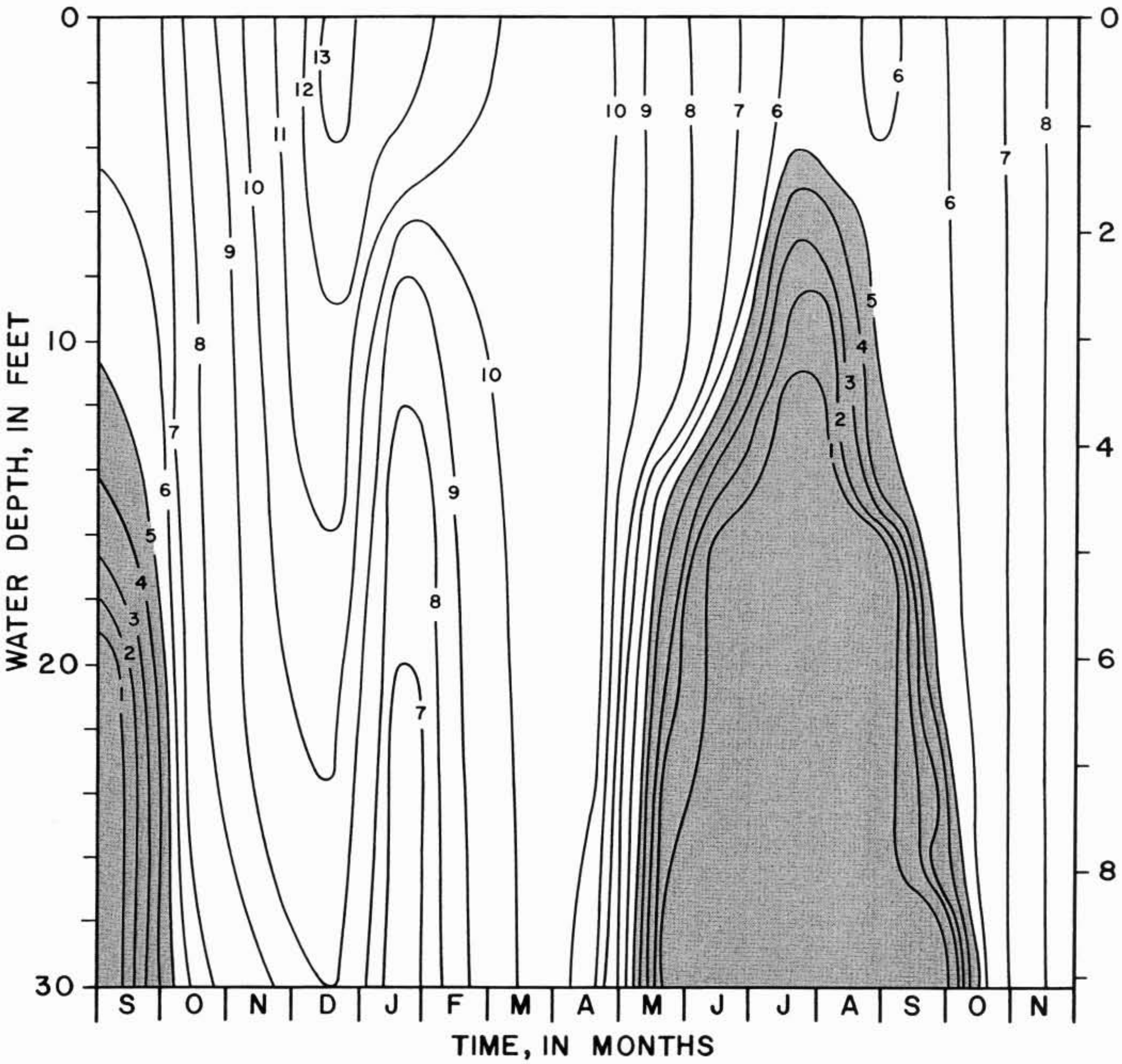


Figure 20

Seasonal changes in dissolved oxygen (mg/1) in Nodaway Lake from September 1972 to November 1973. Shaded areas represent water with dissolved oxygen concentrations less than the 5.0 mg/1 criterion established for classified streams by the Missouri Clean Water Commission in 1973.

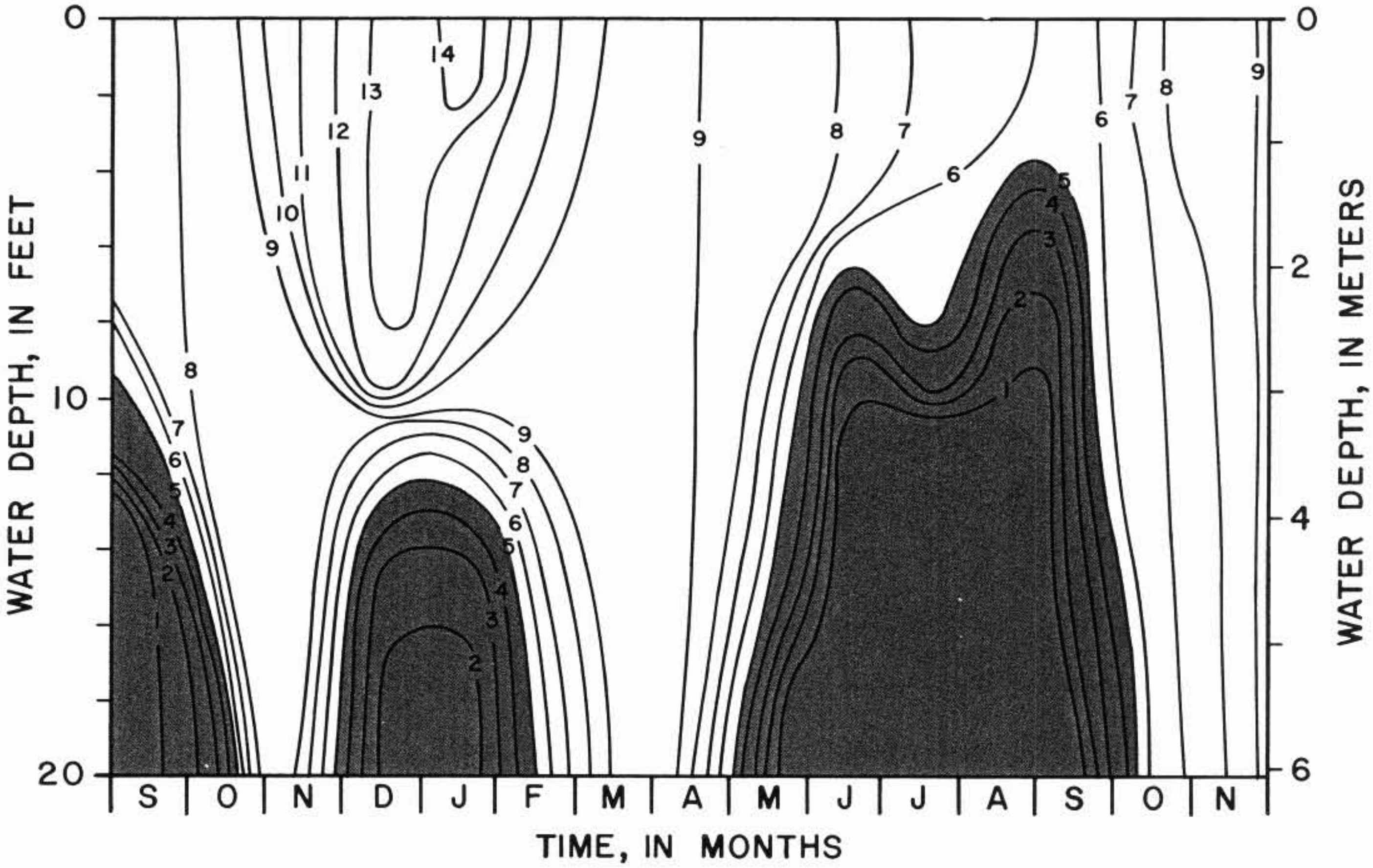


Figure 21

Seasonal changes in dissolved oxygen (mg/1) in North Lake from September 1972 to November 1973. Shaded areas represent water with dissolved oxygen concentrations less than the 5.0 mg/1 criterion established for classified streams by the Missouri Clean Water Commission in 1973.

to the rest of the Dissected Till Plains the eastern edge, where Deer Ridge is located, is more dissected, has thinner surficial material, and is underlain by limestone bedrock. Thus, water in Deer Ridge Lake is chemically similar to that in the Salem Plateau of the Ozarks and is representative of only the eastern edge of the Dissected Till Plains.

Average dissolved-solids concentrations for five samples collected near the surface and five collected near the bottom of each study lake during 1972-73 are included in table 3. These values represent the combined mineralization of the water and do not indicate the concentrations of particular ions. However, table 4 on pages 30-35, includes the specific ions that compose the dissolved solids. Water in Deer Ridge, Nodaway, North, and Fellows Lakes is a calcium-bicarbonate type while water in Little Prairie and Sims Valley Lakes is a calcium-magnesium-bicarbonate type. The increased magnesium in the Ozarks is thought to be due to dolomitic rocks.

Streams in Missouri have a pattern of decreasing dissolved-solids concentrations from the Plains to the Springfield Plateau of the Ozarks to the Salem Plateau of the Ozarks. The same general trend is evident for the six study lakes. Higher mineralization of water in the Plains is attributed to slower movement of the water through relatively impervious surficial material of large particulate surface area.

TABLE 3

AVERAGE CONCENTRATIONS OF SELECTED PROPERTIES FOR 10 SAMPLES COLLECTED DURING 1972-73.
[concentration in mg/l]

Lake	Dissolved solids	Hardness ($CaCO_3$)	Alkalinity ($CaCO_3$)
Deer Ridge	118	56	67
Nodaway	169	103	113
North	190	122	117
Fellows	126	87	87
Little Prairie	92	38	46
Sims Valley	57	16	27

During summer stratification dissolved-solids concentrations near the lake bottoms were as much as double those near the surface. This is caused by the reducing conditions during anaerobic decomposition which result in the solution of minerals from the bottom sediment as well as from release of ions from decaying organisms settling from the epilimnion.

Hardness is caused primarily by calcium and magnesium, which are the two most prevalent cations in Missouri waters. Hardness of water is

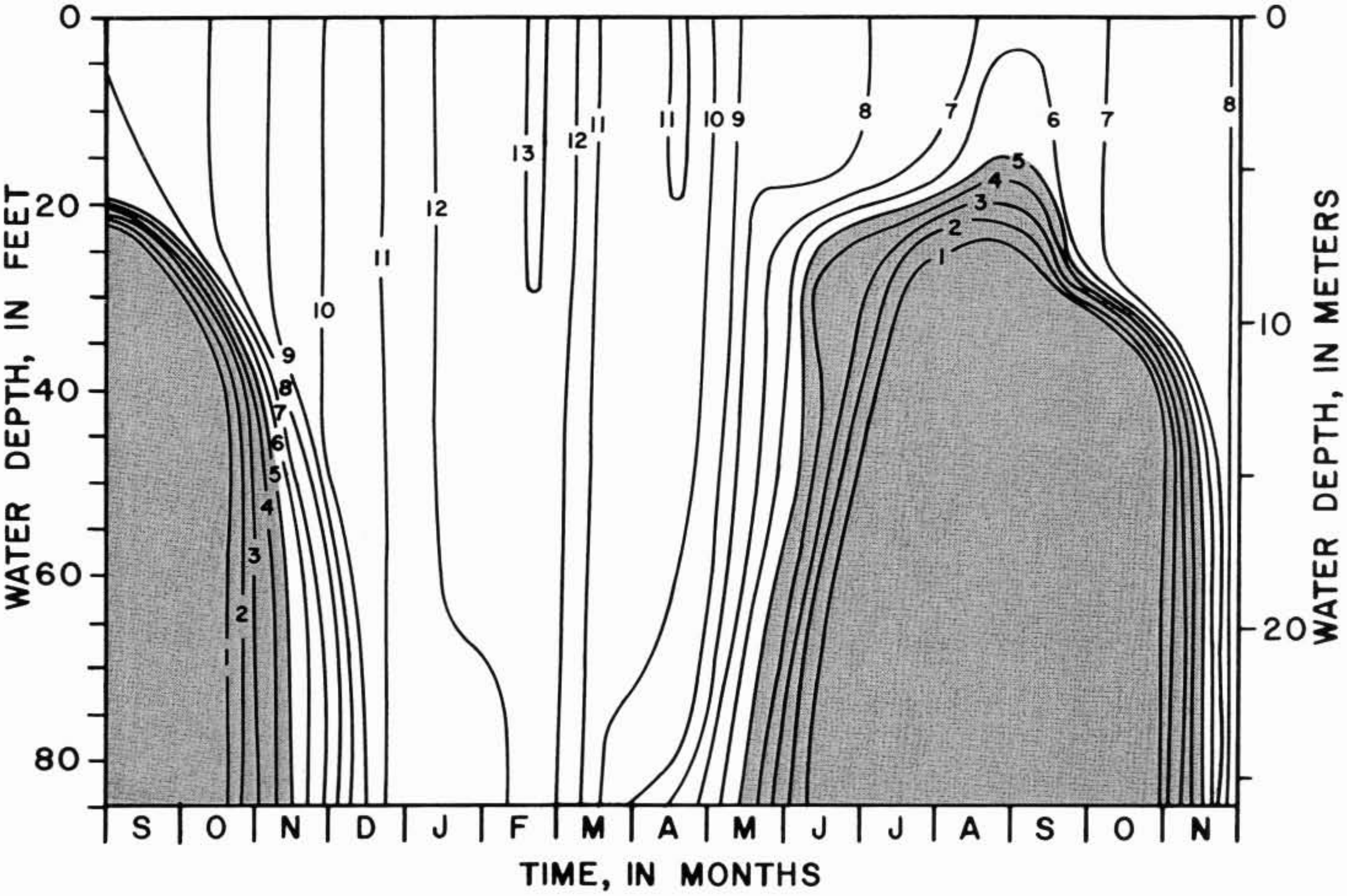


Figure 22

Seasonal changes in dissolved oxygen (mg/1) in Fellows Lake from September 1972 to November 1973. Shaded areas represent water with dissolved oxygen concentrations less than the 5.0 mg/1 criterion established for classified streams by the Missouri Clean Water Commission in 1973.

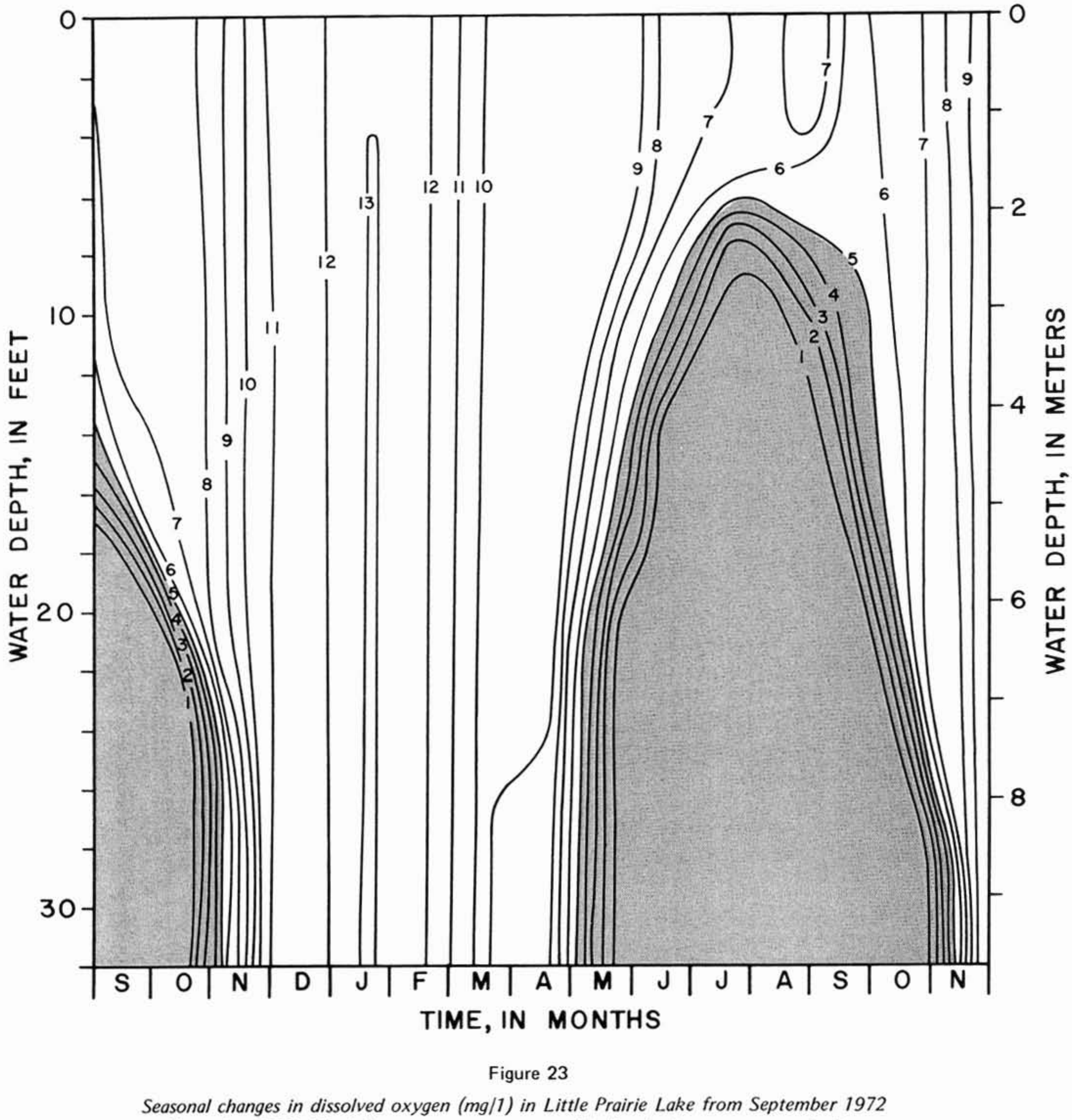


Figure 23

Seasonal changes in dissolved oxygen (mg/1) in Little Prairie Lake from September 1972 to November 1973. Shaded areas represent water with dissolved oxygen concentrations less than the 5.0 mg/1 criterion established for classified streams by the Missouri Clean Water Commission in 1973.

TABLE 4
WATER-QUALITY DATA FOR SIX SMALL LAKES IN MISSOURI
(units are milligrams per liter, except as indicated)

Date of Collection	Depth below surface (ft)	Maximum depth (ft)	Temperature (°C)	Silica (SiO_2)	Total Iron (Fe)	Total Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)
DEER RIDGE LAKE NEAR LEWISTOWN, MO.												
7-10-67	2	----	28.5	----	0.83	----	17	3.0	3.0	2.3	70	0
9-5-72	2	28.5	25.5	4.6	.25	0.12	16	3.0	4.1	2.2	78	0
	26.5	28.5	11.5	---	26	13	30	4.2	4.1	2.8	224	0
12-18-72	2	27	3.5	3.0	.30	.16	21	3.3	4.1	2.7	83	0
	25	27	5.0	2.3	.52	.52	23	3.3	3.8	2.7	83	0
4-16-73	2	28	10.5	8.5	2.7	.09	13	2.3	3.1	2.3	49	0
	26	28	10.0	8.5	2.9	.01	13	2.3	3.3	2.3	46	0
7-16-73	2	28	28.0	.4	.36	.34	12	1.9	2.6	2.1	42	2
	26	28	12.0	9.8	9.1	2.8	17	2.2	2.8	2.2	83	0
10-24-73	2	24.5	17.0	4.2	1.1	.96	14	1.9	2.2	2.2	51	0
	22.5	24.5	14.0	9.9	19	6.7	20	2.4	2.6	2.5	68	0
NODAWAY LAKE NEAR PICKERING, MO.												
6-8-67	2	----	23.5	----	0.59	----	39	9.5	7.1	3.1	168	0
9-6-72	2	30	22.0	4.5	.40	0.22	30	7.6	6.5	3.2	154	0
	28	30	15.0	----	8.4	6.3	46	9.0	6.5	3.3	234	0
12-19-72	2	35	3.0	4.6	.10	.04	39	9.1	6.4	4.9	163	0
	33	35	4.0	4.7	2.0	.19	40	8.4	6.2	4.8	158	0
4-17-73	2	30.5	8.5	8.7	2.4	.06	28	6.0	6.1	3.5	123	0
	28.5	30.5	7.0	11	9.5	.13	20	4.7	4.5	3.8	89	0
7-17-73	2	30	26.5	2.7	.24	.20	24	5.2	5.6	3.5	110	0
	28	30	15.0	4.6	2.8	3.2	33	5.7	5.8	4.1	144	0
10-25-73	2	30	16.0	5.3	1.5	.38	22	4.5	4.2	4.2	102	0
	28	30	16.0	8.2	2.1	.28	22	4.6	4.7	4.3	102	0

Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue at 180°C)	Hardness as $CaCO_3$: Calcium–Magnesium	Hardness as $CaCO_3$: Noncarbonate	Alkalinity	Specific conductance (micromhos per centimeter at 25°C)	pH	Dissolved oxygen	Percent oxygen saturation	Secchi disc visibility (ft)
10	1.5	0.2	0.1	86	55	0	57	----	---	---	---	---
12	2.7	.2	.0	121	54	0	64	150	7.7	7.4	90	4.8
33	4.7	.4	.0	262	94	0	192	460	6.8	0	0	4.1
11	3.2	.3	.5	113	67	0	68	175	8.0	12.8	96	4.1
11	3.7	.3	.8	108	72	4	68	175	7.4	7.4	66	---
8.6	1.7	.2	1.3	110	43	3	40	130	7.6	10.0	89	1.1
9.8	1.7	.2	1.2	111	42	4	38	135	7.5	9.7	86	---
9.5	.2	.3	.1	69	38	0	38	115	8.4	8.6	109	2.7
7	.2	.3	.2	100	51	0	68	200	6.9	.1	1	---
11	.2	.3	1.7	81	43	1	42	120	7.9	7.5	77	2.5
1.8	.2	.3	17	103	60	4	56	125	7.5	.3	3	---
18	2.0	0.4	0.0	172	136	0	138	----	---	---	---	---
9.6	4.7	.3	0	173	108	0	126	255	7.7	6.1	69	4.5
4.8	6.7	.5	0	240	151	0	192	420	7.3	0.0	0	---
11	6.2	.4	.3	174	135	1	134	275	8.3	13.0	96	5.8
11	6.2	.4	1.0	185	136	6	130	280	7.9	8.7	66	---
12	4.2	.3	2.1	154	94	0	101	240	8.2	10.2	87	1.0
5.6	2.5	.3	3.4	190	70	0	73	185	7.9	9.4	78	---
9.1	3.7	.3	0.0	149	80	0	90	230	8.0	5.5	68	2.9
1.6	4.2	.3	8.7	182	106	0	118	----	7.3	0	0	---
8.3	3.2	.3	1.9	121	75	0	84	200	7.6	7.2	73	2.0
8.7	3.2	.3	1.9	121	75	0	84	200	7.0	6.9	70	---

TABLE 4 *(continued)* . . . . .
WATER-QUALITY DATA FOR SIX SMALL LAKES IN MISSOURI
(units are milligrams per liter, except as indicated)

Date of Collection	Depth below surface (ft)	Maximum depth (ft)	Temperature (°C)	Silica (SiO_2)	Total Iron (Fe)	Total Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)
NORTH LAKE NEAR HARRISONVILLE, MO.												
9-7-72	2	15.5	22.0	3.0	0.51	0.44	43	4.5	6.1	3.2	156	0
	13.5	15.5	21.0	5.7	1.2	2.9	49	4.6	6.2	3.2	183	0
12-20-72	2	16	2.5	1.9	.14	.08	57	5.1	5.8	4.8	178	0
	14	16	4.0	4.8	1.0	1.1	57	5.1	5.7	4.8	185	0
4-18-73	2	20	12.0	14	4.9	.09	37	2.9	3.5	3.0	100	0
	18	20	10.0	14	6.1	.18	37	3.0	3.4	3.0	102	0
7-17-73	2	19	28.0	1.8	.22	.11	32	2.8	4.2	2.9	112	0
	17	19	17.0	12	4.1	2.6	41	2.9	3.6	2.9	149	0
10-25-73	2	17	18.0	2.8	1.2	.38	40	3.5	4.0	3.3	129	0
	15	17	17.0	5.0	2.4	.35	38	3.1	3.7	3.3	129	0
FELLOWS LAKE NEAR SPRINGFIELD, MO.												
9-7-72	2	83	23.0	2.8	0.25	0.07	27	5.8	3.6	2.1	115	0
	80	83	10.0	6.0	2.1	2.5	29	5.9	3.5	2.2	136	0
12-20-72	2	88	4.0	5.1	.20	.09	27	5.4	2.9	2.3	104	0
	80	88	4.0	4.5	.22	.09	28	5.5	2.9	2.3	105	0
4-18-73	2	88	13.5	1.7	.26	.02	28	4.6	2.9	2.1	93	2
	80	88	9.0	1.9	.48	.13	30	4.6	2.9	2.1	98	0
7-18-73	2	83	27.0	2.3	.15	.10	20	4.3	3.0	1.9	78	5
	80	83	10.0	5.2	.32	2.2	25	4.7	3.1	2.1	98	0
10-26-73	2	78	18.5	2.9	.11	.06	24	4.4	2.7	2.0	102	0
	75	78	10.0	6.5	6.2	3.2	27	4.5	2.8	2.2	115	0

Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue at 180°C)	Hardness as $CaCO_3$		Alkalinity	Specific conductance (micromhos per centimeter at 25°C)	pH	Dissolved oxygen	Percent oxygen saturation	Secchi disc visibility (ft)
					Calcium–Magnesium	Noncarbonate						
17	7.7	0.2	0.1	205	125	0	128	295	7.9	7.4	84	2.7
14	8.2	.3	0.0	216	141	0	150	320	7.1	.4	4	---
19	9.2	.3	.2	200	162	16	146	335	8.3	13.5	99	5.1
18	9.2	.4	3.1	213	162	10	152	350	7.6	3.2	24	---
10	4.2	.3	5.7	200	104	22	82	220	7.8	9.0	83	.5
9.6	3.2	.3	5.5	195	105	21	84	235	7.8	8.1	72	---
11	3.7	.2	.0	158	90	0	92	240	8.3	6.7	85	3.6
5.3	3.2	.3	12	213	115	0	122	320	7.2	.0	0	---
12	4.7	.3	1.9	151	113	7	106	260	8.1	8.6	90	3.9
12	4.7	.3	2.1	148	108	2	106	240	7.9	7.3	75	---
6.5	9.7	0.1	0	141	91	0	94	215	8.1	7.2	83	9.3
4.8	9.2	.1	.1	147	97	0	112	280	7.3	.0	0	---
7.7	9.2	.2	.8	121	90	5	85	210	7.9	11.0	84	6.1
7.2	9.2	.2	.5	122	93	7	86	210	8.1	10.8	82	---
7.6	8.2	.1	1.5	109	90	10	80	200	8.7	11.1	106	6.5
7.2	8.2	.1	1.2	111	94	14	80	205	8.3	9.3	80	---
6.1	7.7	.1	0	122	68	0	72	195	8.7	7.6	95	7.5
5.7	6.7	.1	3.9	147	82	2	80	225	7.4	.2	2	---
5.8	7.7	.2	.2	117	78	0	84	205	7.9	7.6	80	8.7
8.4	7.7	.2	.7	125	86	0	94	260	7.9	.1	1	---

TABLE 4 *(continued)* . . . . .
WATER-QUALITY DATA FOR SIX SMALL LAKES IN MISSOURI
(units are milligrams per litre, except as indicated)

Date of Collection	Depth below surface (ft)	Maximum depth (ft)	Temperature (°C)	Silica (SiO_2)	Total Iron (Fe)	Total Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)
LITTLE PRAIRIE LAKE NEAR ROLLA, MO.												
9-11-72	2	32	24.5	2.0	0.25	0.07	8.2	5.2	3.0	1.5	51	0
	30	32	11.5	---	8.7	13	12	6.1	3.0	2.1	134	0
12-27-72	2	34	2.5	3.5	.35	.06	5.6	4.2	3.0	1.6	39	0
	32	34	2.5	4.2	.60	.12	5.6	4.3	2.7	1.6	39	0
4-20-73	2	33	12.0	2.4	.56	.04	7.1	4.7	2.3	1.2	29	0
	31	33	9.5	2.7	3.1	.32	7.6	4.7	2.3	1.3	32	0
7-19-73	2	32.5	29.5	1.2	.32	.37	6.2	2.9	2.4	1.5	32	0
	30.5	32.5	11.5	7.0	5.5	8.6	7.5	4.0	2.8	1.7	42	0
10-29-73	2	32.5	15.0	2.4	.52	.88	7.2	3.9	2.5	1.7	39	0
	30.5	32.5	11.0	9.8	26	11	12	4.4	2.3	2.0	120	0
SIMS VALLEY LAKE NEAR WILLOW SPRINGS, MO.												
6-7-67	2	----	25.0	----	0.27	----	9.2	3.1	0.8	1.7	30	0
9-8-72	2	23	24.0	3.5	.20	0.25	3.4	1.3	1.1	1.4	22	0
	21	23	12.5	8.3	19	14	6.0	1.8	1.3	2.1	102	0
11-22-72	2	23.5	6.0	3.2	.40	.23	3.0	1.3	1.1	1.4	22	0
	21.5	23.5	6.0	3.3	.70	.34	3.0	1.2	1.0	1.4	20	0
4-19-73	2	23.5	14.0	3.7	.72	.19	2.4	1.2	.8	1.0	12	0
	21.5	23.5	9.5	3.2	1.4	.48	3.6	1.2	1.2	1.0	15	0
7-19-73	2	22	27.5	3.6	.24	.23	3.3	1.3	2.9	1.2	24	0
	20	22	12.0	4.8	4.5	9.5	5.0	1.5	1.7	1.6	20	0
10-24-73	2	22	15.0	3.1	.63	1.3	2.0	1.3	1.3	1.3	17	0
	20	22	14.5	9.6	28	32	7.2	1.6	1.4	2.2	73	0

Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue at 180°C)	Hardness as $CaCO_3$ Calcium–Magnesium	Hardness as $CaCO_3$ Noncarbonate	Alkalinity	Specific conductance (micromhos per centimeter at 25°C)	pH	Dissolved oxygen	Percent oxygen saturation	Secchi disc visibility (ft)
15	2.7	0.1	0.0	88	43	1	42	125	7.6	7.6	90	6.5
6.0	3.2	.2	0	134	55	0	110	280	7.4	.1	1	---
13	2.7	.2	.5	83	31	0	32	120	7.5	12.1	89	5.8
12	3.0	.2	.8	85	32	0	32	120	7.4	11.8	87	---
14	2.2	.2	.2	62	37	13	24	105	7.4	9.8	91	3.8
14	2.2	.2	.3	62	38	12	26	110	7.5	8.1	70	---
12	2.2	.2	1.6	98	27	1	26	100	7.8	7.0	91	3.0
2.3	1.7	.2	14	117	35	1	34	185	7.1	.0	0	---
9.8	3.2	.3	3.3	71	34	2	32	<50	7.2	7.2	71	2.9
6.3	1.7	.3	.3	115	47	0	98	<50	---	.2	2	---
4.0	1.0	0.1	0.0	33	36	11	25	---	---	----	--	---
1.1	1.7	.1	.1	46	17	0	18	<50	7.1	7.3	86	3.3
2.4	1.7	.1	0	94	23	0	84	265	7.3	.0	0	---
2.4	1.2	.2	.2	30	13	0	18	<50	6.5	10.0	81	5.5
2.4	1.2	.2	.9	29	12	0	16	<50	6.5	10.0	81	---
4.0	1.7	.2	.1	28	11	1	10	<50	7.2	9.4	90	3.5
3.5	1.7	.2	.1	24	14	2	12	<50	6.7	5.6	49	---
2.3	.2	.2	0	67	14	0	20	<50	8.1	7.2	90	3.3
1.1	.2	.2	.1	80	19	3	16	160	7.5	.1	1	---
1.8	.7	.2	2.6	33	10	0	14	70	7.1	7.2	71	3.4
.5	1.7	.3	32	139	25	0	60	340	7.7	1.2	12	---

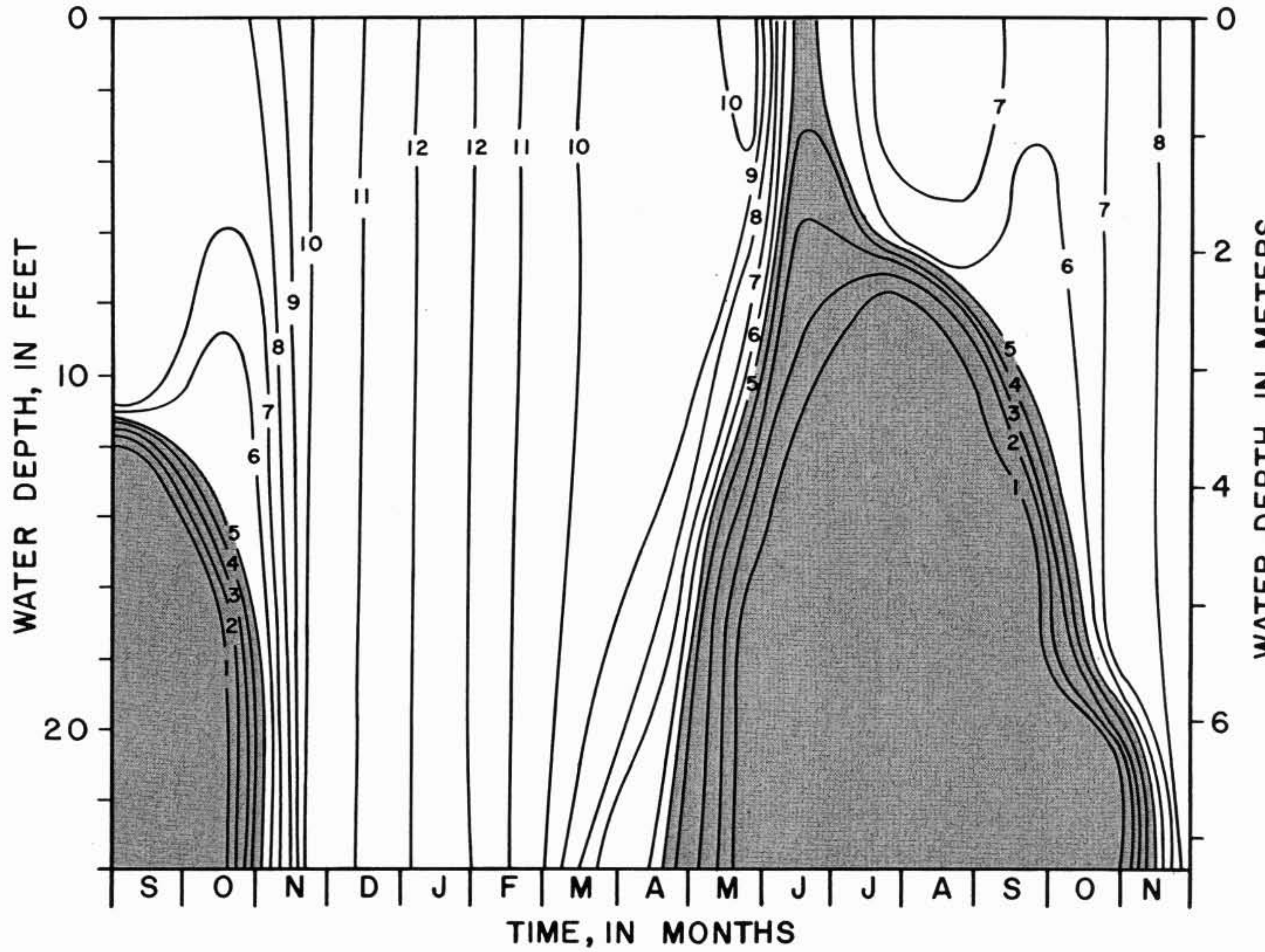


Figure 24

Seasonal changes in dissolved oxygen (mg/1) in Sims Valley Lake from September 1972 to November 1973. Shaded areas represent water with dissolved oxygen concentrations less than the 5.0 mg/1 criterion established for classified streams by the Missouri Clean Water Commission in 1973.

classified with respect to calcium carbonate according to the following:

Hardness (mg/l $CaCO_3$)	**Classification**
0 - 60	Soft
61 - 120	Moderately hard
121 - 180	Hard
> 180	Very hard

From the average hardness values shown in table 3, water in Deer Ridge, Little Prairie, and Sims Valley is soft; water in Nodaway and Fellows is moderately hard; and water in North Lake is hard.

Alkalinity in Missouri waters is primarily bicarbonate, the dominant anion in the study lakes. The alkalinity is relatively low in the lakes and generally decreases from the Plains to the Springfield Plateau to the Salem Plateau.

Data in table 4 show that water in Deer Ridge, Nodaway, and Sims Valley Lakes in June and July 1967 was more mineralized than in July 1973. The lower mineralization in 1973 was probably the result of dilution by excessive rainfall in the spring of 1973. The period of data collection is insufficient to accurately determine any progressive chemical changes with time.

IRON AND MANGANESE – During summer stratification, reducing conditions in the oxygen-depleted hypolimnion often result in the solution of considerable amounts of iron and manganese from the bottom sediments. After circulation begins in the fall and oxygen is replenished throughout the depth of the lake, most of the iron and manganese is oxidized and precipitates back to the bottom.

Water containing more than 0.5 mg/l iron or iron and manganese tends to stain laundry, plumbing fixtures, etc., and causes unpleasant taste. Tolerances for iron or manganese in industrial water supplies are usually less than 0.5 mg/l. The U.S. Public Health Service (1962) recommends that the concentration of iron and manganese in drinking and culinary water on carriers subject to Federal quarantine regulations not exceed 0.3 and 0.05 mg/l, respectively.

Iron and manganese data shown in table 4 are total concentrations in unfiltered, unacidified samples. Total iron and total manganese in samples collected 2 ft (0.6 m) below the surface were usually less than 1.00 mg/l. However, samples collected in April and October from the three Plains lakes (Deer Ridge, Nodaway, and North) had relatively high iron concentrations, particularly in April, because of high sediment concentrations. In April the waters in these lakes had a muddy appearance and the Secchi-disc readings were very low; total-iron values for Deer Ridge, Nodaway, and North Lakes were 2.74, 2.40, and 4.90 mg/l, respectively.

Water 2 ft (0.6 m) above the lake bottoms had greatly increased concentrations of iron and manganese, especially during summer stagnation. For example on October 24, 1973, near the end of the stagnation period, iron and manganese concentrations were 27.5 and 32.3 mg/l, respectively, near the bottom of Sims Valley Lake.

MINOR ELEMENTS – Water samples for minor-element analyses were collected from the two water-supply lakes (North and Fellows) in October 1972, toward the end of summer stratification. Arsenic, cadmium, mercury, lead, and selenium were determined from filtered (0.45 m) and unfiltered samples collected from 2 ft (0.6 m) below the surface and 2 ft (0.6 m) above the bottom. The analyses were made by the Environmental Trace Substances Center, University of Missouri at Columbia. Concentrations in micrograms per liter were <10 for arsenic; <,0.5 for cadmium; < 0.10 to 0.38 for mercury; <5 to 38 for lead; and < 5 for selenium. These values are generally well below the U.S. Public Health Service Drinking Water Standards (1962). There was little difference in the concentrations in samples filtered, unfiltered, collected near the top, or collected near the bottom.

Several inches of an almost gelatinous material consisting primarily of organic matter covered each lake bottom at the deepest point. As shown

TABLE 5

Minor-element concentrations in the bottom material of six small lakes in Missouri. [Analyses by the U.S. Geological Survey; concentration in ppm]

Lake	Date collected	Minor elements				
		Arsenic	Cadmium	Mercury	Lead	Selenium
Deer Ridge	12-18-72	25	< 1.0	0.06	56	0.5
Nodaway	12-19-72	30	< 1.0	0.06	47	< 0.5
North	10-12-72	20	1.5	0.07	38	< 0.5
Fellows	10-13-72	25	< 1.0	0.09	51	0.5
Little Prairie	11-27-72	20	< 1.0	0.07	48	0.5
Sims Valley	11-22-72	30	< 1.0	0.06	58	0.5

in table 5, relatively large concentrations of minor elements were present in this material. Concentrations of individual elements were about the same in all six study lakes.

TROPHIC CLASSIFICATION

Eutrophication is the process of nutrient enrichment. Nutrients such as nitrogen and phosphorus are essential to aquatic-plant production. Lakes are often classified according to their trophic state (nutritional status or stage of eutrophication) based on the actual or potential level of plant production. Oligotrophic lakes are nutrient-poor, mesotrophic lakes are moderate in nutrients, and eutrophic lakes are nutrient-rich.

The rate of eutrophication is dependent on a number of interrelated factors which are primarily a consequence of climate, geology, and human influence. All lakes receive nutrients from the surrounding soils; some soils have more to contribute than others. New man-made impoundments are often moderately to highly enriched because of the release of nutrients from inundated soils and decaying vegetation. The influences of man, such as fertilizer application in agriculture and the discharge of sewage, greatly accelerate eutrophication.

Moyle (1945), on the basis of the distribution of aquatic plants, classified lakes in Minnesota that had a total alkalinity ($CaCO_3$) of less than 40 mg/l as soft-water lakes, relatively low in productivity. Lakes of less than 20 mg/l total alkalinity were considered very unproductive; their pH ranged from 6.8 to 7.4. Soft-water lakes are generally found in steep bedrock basins that are relatively infertile. Shallow soft-water lakes are more productive than deep ones because they usually have a larger percentage of littoral area, which is the region along the shoreline that has sufficient light transmission to support rooted vegetation. Moyle classified lakes that had total alkalinities ranging from 40 to 250 mg/l as hard-water lakes. Their summer pH range was 8.0 to 8.8. These lakes receive abundant nutritive materials such as calcium carbonate from the surrounding soils, making them eutrophic.

According to Reid (1961), W. Ohle, a German limnologist, found that lake waters containing 10 to 25 mg/l calcium had moderate biological productivity.

According to Russell-Hunter (1970), the two principal lake types (oligotrophic and eutrophic) can in a majority of cases be distinguished by certain characteristics. Oligotrophic lakes are always low in plant nutrients, usually highly oxygenated, and have relatively small amounts of slowly decaying organic material in their bottom deposits. They are mostly deep with steep rock sides. Lakes termed eutrophic are relatively rich in plant nutrients, usually have much rapidly decaying organic mud on the bottom, and are deficient in dissolved oxygen in the hypolimnion during summer. They are usually relatively shallow and have gently sloping banks and wide littoral zones.

It is beyond the scope of this study to determine quantitatively the rate or degree of eutrophication for the six study lakes. However, based upon the preceding discussion and the data in tables 3 and 4, the study lakes can generally be classified as follows:

Lake	Classification
Deer Ridge	Mesotrophic
Nodaway	Eutrophic
North	Eutrophic
Fellows	Mesotrophic
Little Prairie	Oligotrophic to mesotrophic
Sims Valley	Oligotrophic

It should be emphasized that this classification is qualitative, based primarily upon a few indicators of nutrient enrichment.

AQUATIC PLANTS

Aquatic-plant production is an important part of the successional process by which lakes become shallower because of the deposition of inorganic sediment and organic matter, and smaller due to the encroachment of shoreline vegetation. Aquatic plants benefit a lake by providing food for fish and wildlife, attachment surfaces for other organisms, spawning and nursery areas for fish, temporary storage for nutrients, and by producing dissolved oxygen. However, too many plants can cause fish overpopulation, excessive nutrient recycling, depletion of oxygen through the decomposition of dead plants, and rapid aging of a lake.

The effects of nutrient enrichment on plant production are controlled by several physical and chemical factors, basin morphology and chemistry of the water being particularly significant. Along with nutrients, sunlight is necessary for photosynthesis. Therefore, water depth and transparency may limit plant growth even when there is an abundance of nutrients.

Aquatic-plant production was not measured quantitatively in the study lakes, but visual observations were made of the major types of aquatic macrophytes (higher vascular plants and larger algae like *Chara*) and the approximate extent of their growth. Also, algal blooms and significant growths of algae on rocks and other surfaces near the shoreline were documented.

The chemical analyses in table 4 indicate a sufficient amount of nitrogen in each of the lakes for plant production. Phosphorus was not measured. There was considerable organic mud on the bottom of each lake.

The rather wide littoral zone in Deer Ridge Lake supported a moderate to heavy growth of aquatic vegetation during the summer of 1972. *Chara*, the dominant plant, extended as much as 50 ft (15 m) into the lake in places. A few small patches of *Potamogeton*, *Typha*, *Eleocharis*, *Phalaris*, and *Cephalanthus* grew along the shoreline. In 1973 large amounts of storm runoff significantly increased the suspended sediment, which decreased light penetration during the growing season. As a result, plant growth in the littoral zone in 1973 was light to moderate, being about one-third as heavy as in 1972.

Moderate growths of *Najas* and *Potamogeton* extended as far as 50 ft (15 m) from the bank in many places around Nodaway Lake in 1972. Small amounts of *Typha* were scattered along the shoreline. Like Deer Ridge Lake, aquatic vegetation in Nodaway Lake was considerably less in 1973 due to increased amounts of suspended sediment in the water. Light growths of filamentous green algae were observed on rocks near the shoreline.

Macrophytic vegetation was quite deficient in North Lake in both 1972 and 1973 because of the highly fluctuating waterline and changing littoral zone. The city of Harrisonville withdraws large amounts of water from North Lake as needed for water supply, causing the water depth to change as much as 5 ft (1.5 m) in relatively short periods of time. No algal blooms were observed in North Lake during the study. However, the city of Harrisonville has had taste and odor problems in past years due to algal blooms and has chemically treated the lake waters to kill the algae.

Fellows Lake is considerably larger and deeper than the other study lakes. The littoral zone is very narrow around the main part of the lake because of steep rock sides. However, the water is very clear, permitting photosynthesis at a much greater depth than in the other study lakes. The littoral zone is wider in the coves, and moderate growths of *Chara* occurred in some of the coves and in the south arm of the lake. Small amounts of *Najas* and *Potamogeton* were also observed.

Moderate growths of *Najas* appeared along the south side and in both arms of Little Prairie Lake during the summer months, reaching as far as 50 ft (15 m) from the bank in places. Other rooted plants, such as *Typha*, *Eleocharis*, *Scirpus*, and *Phalaris* appeared in limited amounts along the shoreline. Periodically, there were light growths of filamentous green algae on the rocks near the bank.

Soon after Sims Valley Lake was constructed it was apparent that it was oligotrophic and very low in plant productivity. In order to increase productivity and improve fisheries the Missouri Department of Conservation began applying a high-phosphate fertilizer to the water in 1968. Since then over 10 tons have been applied, with the results shown on figure 25. In the summers of 1972 and 1973 there were prolific growths of a variety of aquatic plants all around the lake, except at the dam. *Chara* covered the entire littoral zone, reaching as far as 100 ft (30 m) from the bank in places. *Potamogeton*, *Scirpus*, *Eleocharis*, *Typha*, *Nymphaea*, and several other kinds of rooted plants were abundant. Filamentous green algae were often visible on rocks near the shore. In May 1973, an algal bloom covered the entire lake. The water had a green coloration and imparted a slightly disagreeable odor. Sims Valley Lake is an example of how an oligotrophic lake can be made productive through the application of fertilizers.

SUMMARY

Climate, geology, and land use are the primary factors that control water-quality characteristics of small lakes in Missouri. These factors vary considerably with geographic and physiographic location in the State.

Temperature profiles in the six study lakes show that they are thermally stratified from about mid-May to mid-November. Lakes in the northern part of the State stratify about two weeks earlier in the fall than lakes in southern Missouri. Thick ice cover for long durations causes winter stratification of lakes in northern Missouri, while considerably less ice cover results in infrequent winter stratification of lakes in southern Missouri.

Dissolved-oxygen profiles show that water in the hypolimnion is very deficient in dissolved oxygen. About 60 percent of the volume of each study lake had dissolved-oxygen concentrations of 1.0 mg/l or less from June to September 1973. Releases of hypolimnetic water could result in dissolved-oxygen problems in receiving streams.

The transparency of water in Missouri lakes is relatively low because of turbidity and coloration. Secchi-disc measurements in the study lakes show that light penetration is less in the Plains lakes than in Ozark lakes because of suspended sediment. During the fall, dead plants imparted a brownish color to the water that reduced light penetration slightly in most of the lakes. On one occasion Secchi-disc visibility was significantly reduced by an algal bloom in Sims Valley Lake.

The ionic properties of lake water are determined mainly by the kinds of rocks and soils in the drainage basin and the extent and time that the water is in contact with them. Dissolved-solids concentrations in the Plains lakes were at least two times those in the Salem Plateau of the Ozarks. During summer stratification dissolved-solids concentrations near the bottom of the lakes were as much as double those near the surface, due mainly to reducing conditions in the hypolimnion. Iron and manganese concentrations were particularly high near the lake bottoms during summer and early fall stagnation. Water collected near the bottom of Sims Valley Lake on October 24, 1973, had total iron and total manganese concentra-

Figure 25

Abundant growth of shoreline vegetation in Sims Valley Lake.

tions of 27.5 and 32.3 mg/l, respectively. The average hardness values obtained for the study lakes show that water in Deer Ridge, Little Prairie, and Sims Valley is soft; water in Nodaway and Fellows is moderately hard; and water in North Lake is hard.

Minor-element concentrations were generally below U.S. Public Health Drinking Water Standards (1962) in water samples collected from the two water-supply lakes (North and Fellows). Relatively large concentrations of arsenic, mercury, lead, and selenium were in the bottom materials of all six lakes.
Based upon indicators of nutrient enrichment, the study lakes could be classified as oligotrophic for Sims Valley Lake, to eutrophic for Nodaway Lake and North Lake, with the others being intermediate. Lakes in the Plains have morphological characteristics and dissolved-constituent properties indicative of eutrophic lakes, while lakes in the Ozarks have morphological characteristics and dissolved-constituent properties more indicative of oligotrophic or mesotrophic lakes.

The amount of shoreline vegetation was very limited in North Lake because of a highly fluctuating water level caused by the withdrawal of large quantities of water by the city of Harrisonville. A moderate growth of emersed and submersed plants was evident in the other five lakes. Sims Valley Lake is naturally oligotrophic and was initially very unproductive. However, application of a high-phosphate fertilizer to the lake by the Missouri Department of Conservation has resulted in a prolific growth of a diversity of both emersed and submersed rooted plants. The only algal bloom observed during the study was at Sims Valley Lake in May 1973.

SELECTED REFERENCES

American Public Health Association, *1965, Standard methods for the examination of water and wastewater, 12th ed: New York, Am. Public Health Assoc., 769 p.*

Brown, Eugene, M.W. Skougstad and M.J. Fishman, *1970, Methods for collection and analysis of water samples for dissolved minerals and gases: U.S. Geol. Survey Techniques of Water Resources Inv., book 5, chap. A1, 160 p.*

Dean, T.J., J.H. Barks and J.H. Williams, *1976, Guide for the geologic and hydrologic evaluation of small lake sites in Missouri: Mo. Dept. of Natural Resources, Geol. Survey, Water Resources Rept. 31, (in press).*

Fassett, N.C., *1972, A manual of aquatic plants: The Univ. of Wisc. Press, 405 p.*

Frey, D.G., et al., *1966, Limnology in North America: The Univ. of Wisc. Press, p. 301-337.*

Greeson, P.E., *1969, Lake eutrophication — a natural process: Water Resources Bull., v. 5, n. 4, p. 16-30.*

Heinemann, H.G., *1961, Sediment distribution in small floodwater-retarding reservoirs: U.S. Dept. Agr., Agr. Research Svc., ARS 41-44, 37 p.*

Hem, J.D., *1970, Study and interpretation of the chemical characteristics of natural water, 2nd ed: U.S. Geol. Survey Water-Supply Paper 1473, 363 p.*

Hotchkiss, Neil, *1972, Common marsh, underwater and floating-leaved plants of the United States and Canada: New York, Dover Publications, Inc., 124 p.*

Kathandaraman, Veerasamy and R.L. Evans, *1970, Annual temperature variations in an impoundment in central Illinois: Am. Water Works Assoc. Jour., v. 62, n. 10, p. 639-642.*

Missouri Clean Water Commission, *1973, Missouri water quality standards: Mo. Clean Water Comm., p. 51-57.*

Moyle, J.B., *1945, Classification of lake waters upon the basis of hardness: Proc. Minn. Acad. Sci., p. 8-12.*

Ott, A.N., J.L. Barker and D.J. Growitz, *1973, Physical, chemical, and biological characteristics of Conewago Lake drainage basin, York County, Pennsylvania: Pa. Dept. of Natural Resources Bull. n. 8, 96 p.*

Peirce, L.B., *1964, Reservoir temperatures in north-central Alabama: Ala. Geol. Survey Bull. 82, 103 p.*

Rausch, D.L. and H.G. Heinemann, *1968, Reservoir sedimentation survey methods: U. Mo. Agr. Expt. Sta., Research Bull. 939, 20 p.*

________________ *1969, Sedimentation and eutrophication research on three small reservoirs: U.S. Dept. Agr., Agr. Research Service, ARS 41-158, 11 p.*

Rawson, Jack and M.W. Lansford, *1971, The water quality of Sam Rayburn Reservoir, eastern Texas: U.S. Geol. Survey Water-Supply Paper 1999-J, 67 p.*

Reid, G.K., *1961, Ecology of inland waters and estuaries: New York, Reinhold Publishing Corp., 375 p.*

Rickert, D.A. and A.M. Spieker, *1971, Real-estate lakes: U.S. Geol. Survey Circ. 601-G, 19 p.*

Russell-Hunter, W.D., *1970, Aquatic productivity: The Macmillan Co., New York, p. 108-136.*

Ruttner, Franz, *1953, Fundamentals of limnology: Univ. of Toronto Press, 242 p.*

Smith, S.A. and D.A. Bella, *1973, Dissolved oxygen and temperature in a stratified lake: Water Pollution Control Federation Jour., v. 45, n. 1, p. 119-133.*

State Soil and Water Conservation Needs Inventory Committee, *1970, Missouri conservation needs inventory: U.S. Dept. of Agr., 196 p.*

Stout, L.N. and David Hoffman, *1973, An introduction to Missouri's geologic environment: Mo. Geol. Survey and Water Resources, Educ. Ser. 3, p. 7-13.*

Taylor, C.T., *1964, Chemical quality of Missouri surface water: Mo. Dept. Public Health and Welfare, Water Pollution Board, 28 p.*

U.S. Geological Survey and Missouri Geological Survey and Water Resources, *1967, Mineral and water resources of Missouri: U.S. 90th Cong., 1st sess., Senate Doc. 19, Washington, U.S. Govt. Printing Office, 399 p.*

U.S. Public Health Service, *1962, Drinking water standards: U.S. Public Health Service, Pub. 956, 61 p.*

Warren, C.E., *1971, Biology and water pollution control: W.B. Saunders Co., Philadelphia, 434 p.*

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