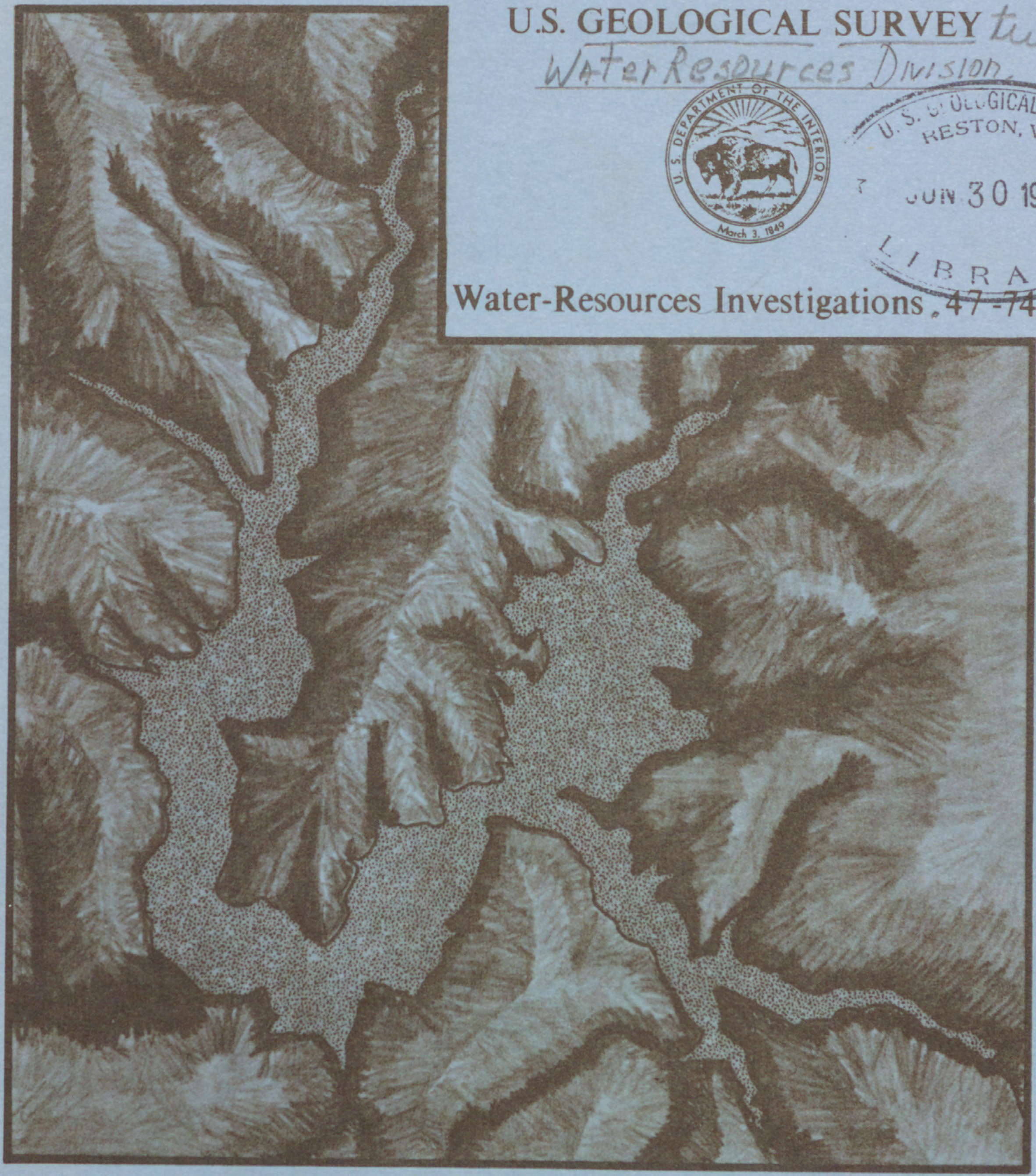
PROBLEMS RELATED TO WATER QUALITY AND ALGAL CONTROL IN LOPEZ RESERVOIR, SAN LUIS OBISPO COUNTY, CALIFORNIA

U.S. GEOLOGICAL SURVEY
Water Resources Division

Water-Resources Investigations 47-74



Prepared in cooperation with the
SAN LUIS OBISPO COUNTY
FLOOD CONTROL AND WATER CONSERVATION DISTRICT

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16. Abstracts

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Lopez Reservoir is thermally stratified from April until November. Dissolved-oxygen stratification closely parallels the thermal stratification. Anoxic conditions begin to develop in mid-May, and by early July all water below a depth of 40 feet (12 metres) is oxygen deficient.

The application of copper sulfate ($CuSO_4$) to reduce algal production has not been completely successful. Possible application rates and methods of determining application rates based upon water chemistry are presented.

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February 1975

UNITED STATES DEPARTMENT OF THE INTERIOR

Rogers C. B. Morton, Secretary

GEOLOGICAL SURVEY

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CONVERSION FACTORS

Factors for converting English units to metric units are given below to four significant figures. However, in the text the metric equivalents are shown only to the number of significant figures consistent with the values for the English units.

Multiply English units	*By*	*To obtain metric units*
acres	4.047×10^{-1}	hm^2 (square hectometres)
	4.047×10^{3}	m^2 (square metres)
acre-ft (acre-feet)	1.233×10^{3}	m^3 (cubic metres)
	1.233×10^{-3}	hm^3 (cubic hectometres)
ft (feet)	3.048×10^{-1}	m (metres)
gal (gallons)	3.785×10^{-3}	m^3 (cubic metres)
in (inches)	2.54×10	mm (millimetres)
mi (miles)	1.609	km (kilometres)
lb (pounds)	4.536×10^{2}	g (grams)
mi^2 (square miles)	2.590	km^2 (square kilometres)
tons (short)	9.072×10^{-1}	t (tonnes)

PROBLEMS RELATED TO WATER QUALITY AND ALGAL CONTROL IN LOPEZ RESERVOIR,

SAN LUIS OBISPO COUNTY, CALIFORNIA

By Richard H. Fuller, Robert C. Averett, and W. G. Hines

ABSTRACT

Lopez Reservoir is a multipurpose impoundment that was filled during a 30-week period following a series of intense storms during the winter 1968-69. The reservoir is used for flood control, water supply, and recreation, including swimming, fishing, and boating. At full pool Lopez Reservoir has a surface area of 974 acres (394 square hectometres), a maximum depth of 145 feet (44.2 metres), and a shoreline of 22 miles (35.4 kilometres).

Nuisance algal blooms have been a frequent occurrence in the reservoir since the first summer after filling (1969). The dominant bloom species was the blue-green alga *Anabaena unispora*. Cospecies were the diatoms *Stephanodiscus astraea* and *Cyclotella operculata* and the green algae *Pediastrum duplex* and *Sphaerocystis schroeteri*. During a bloom of *A. unispora* in May 1972, the total cell count at the lake surface was almost 100,000 cells per millilitre of water.

Lopez Reservoir is thermally stratified from April until November. Dissolved-oxygen stratification closely parallels the thermal stratification. Anoxic conditions begin to develop in mid-May, and by early July all water below a depth of 40 feet (12 metres) is oxygen deficient.

The application of copper sulfate ($CuSO_4$) to reduce algal production has met with little success. Possible application rates and methods of determining application rates based upon water chemistry are presented.

INTRODUCTION

The maintenance of high-quality water in lakes and reservoirs has become an acute environmental problem. The task is particularly difficult in reservoirs used for both water supply and recreation. Man's use of lakes and reservoirs and their drainage basins may result in the addition of excessive plant nutrients to the water. Nutrients may enter a reservoir directly as wastewater, indirectly through runoff from fertilizers applied in the drainage basin or decaying organic matter in the drainage basin, or sorbed on sediments that are transported by streams.

The addition of plant nutrients to lakes and reservoirs increases the production of algae (microscopic green plants), as well as rooted shoreline vegetation. Algal production in water enriched by nutrients may become so excessive that the water is unfit for human consumption. In addition, there are other attendant problems, such as the depletion of oxygen concentrations in hypolimnetic (deep, cool, relatively undisturbed) water, fishkills, the clogging of filters, and decreased recreational use.

Reservoirs that are rich in plant nutrients are termed eutrophic (rich in food), and the process of enrichment is called eutrophication. While eutrophication is an ultimate event in all lakes, it can be greatly accelerated by the activities of man. Accelerated eutrophication is a present day environmental concern.

Unfortunately, the effects of eutrophication are much better understood than the causes. Some reservoirs do not display enrichment until many years after they are filled. Others become eutrophic almost immediately after filling. Lopez Reservoir, in the central coastal region of California, is an example of a reservoir that became eutrophic almost immediately after filling. A massive storm in the area resulted in the reservoir reaching full-pool capacity within a 30-week period after completion of the dam in November 1968. The extensive rain caused erosion in the drainage basin which resulted in heavy sediment and nutrient loads entering the reservoir.

Excessive algal production was noted in Lopez Reservoir during the summer 1969, and large blooms have occurred each subsequent summer. The San Luis Obispo County Flood Control and Water Conservation District is responsible for management of the reservoir. The District has collected periodic water samples for algal identification and counts and treated the reservoir with copper sulfate ($CuSO_4$) in an attempt to control algal growth. Despite the copper sulfate applications, excessive algal production is still evident. In 1970, the District requested the U.S. Geological Survey make a study of the algal problems in Lopez Reservoir. This report presents the results of the study and perhaps will aid in developing a better understanding of the causes of some of the problems in the reservoir and in making future water-quality management decisions.

Purpose and Scope

The purpose of the project was to determine the present enrichment status of Lopez Reservoir and evaluate the effect of copper sulfate treatment on the control of algal growth.

The scope of the study was limited to the collection of water samples for chemical analysis to determine concentrations of dissolved oxygen, major anions, cations, nitrogen, phosphorus, and carbon and for algal-cell counts and species identification. Water temperature, specific conductance, pH, and alkalinity were measured periodically. Dredged samples of the reservoir bottom sediments were analyzed for concentrations of nitrogen and phosphorus and for the percentage of organic material.

Samples were collected from 1970 through 1972 at several sites and at various depths in the reservoir. Water-quality sampling and algal-cell counts and identifications were done by Percy Garcia and other personnel of the San Luis Obispo County Flood Control and Water Conservation District. Supplemental counts and identifications were made by Geological Survey personnel.

Physical Description and Geology

Lopez Reservoir is in San Luis Obispo County, Calif., approximately 11 mi (17.7 km) southeast of the city of San Luis Obispo and 7 mi (11.3 km) northeast of the city of Arroyo Grande (fig. 1). The area is rural, with ranching and farming the predominant industry. The reservoir shoreline is surrounded by mixed oak and other deciduous trees and, except for boat-launching facilities and camp areas, is undeveloped.

The reservoir was formed in 1969 following the construction of an earth-fill dam across Arroyo Grande Creek. The dam has a height of 160 ft (48.8 m) and a crest length of 520 ft (158.5 m). Lopez Reservoir provides flood control and water for the municipalities of Oceano, Grover City, and Arroyo Grande and is heavily used for recreation. San Luis Obispo County maintains 218 campsites, 140 trailer sites, 156 family picnic sites, and a large boat-launching ramp and dock (fig. 2).

Presently, rainbow trout, *Salmo gairdneri*, are stocked at the rate of about 20,000 per year. Other game fish include bluegill, *Lepomis macrochirus*, largemouth bass, *Micropterus salmoides*, and green sunfish, *Lepomis cyanellus*.

The reservoir has a drainage area of 67.4 mi^2 (174.6 km^2) and at full pool has a surface area of 974 acres (394 hm^2) and 22 mi (35.4 km) of shoreline. Its maximum depth is 145 ft (44.2 m). Major tributaries are Lopez Canyon and Arroyo Grande Creek (fig. 2).

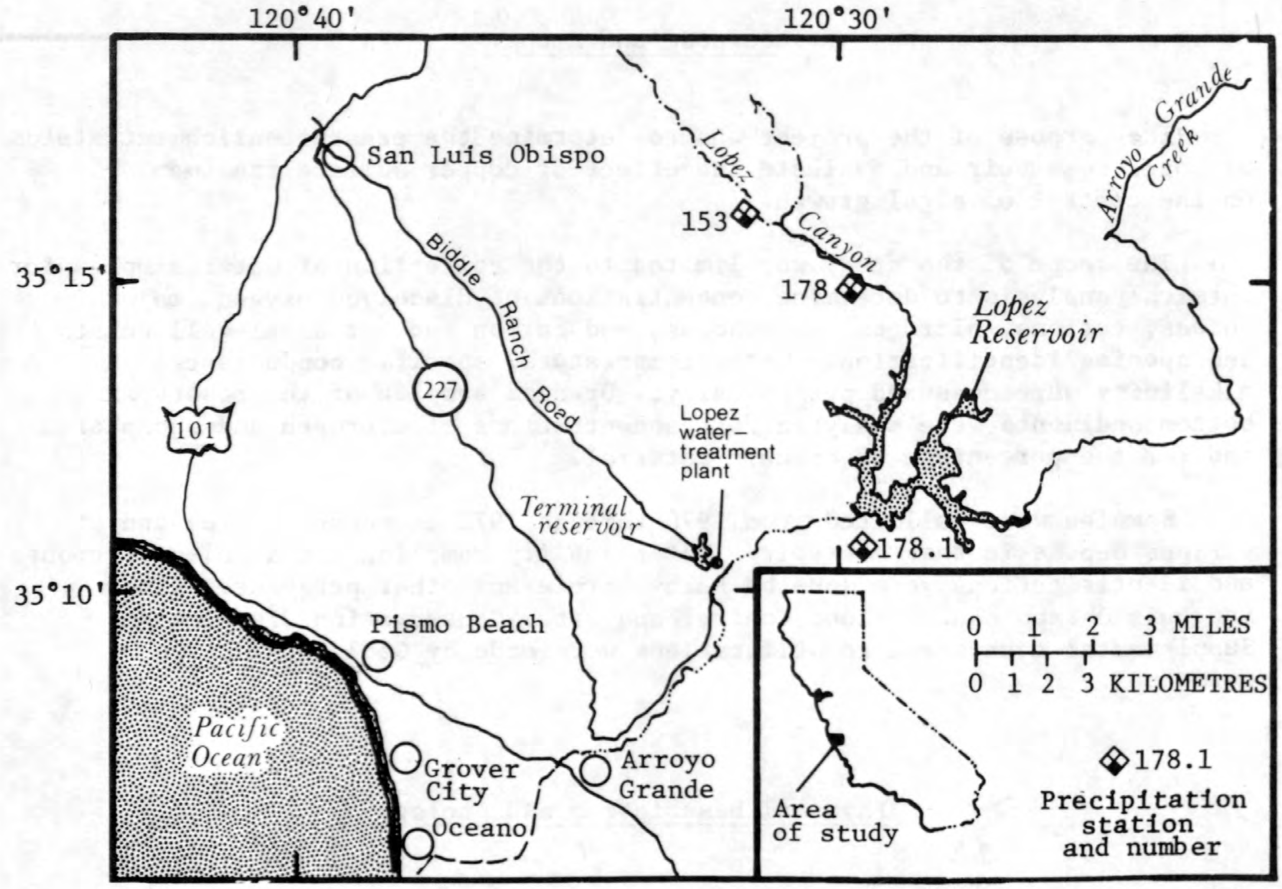


FIGURE 1.--Index map showing the location of Lopez Reservoir. (Adapted from Lawrance and others, 1971, fig. 2, p. 717)

Lopez Dam is a multiple-outlet structure having seven release orifices 15 vertical ft (4.6 m) apart. Water leaving the reservoir may be diverted either into Arroyo Grande Creek for downstream use, or into a terminal reservoir of the water-treatment plant for distribution to customers.

The Lopez Reservoir drainage area is underlain predominantly by marine sedimentary rocks, mainly sandstone and shale (fig. 3). The major stratigraphic units are the Santa Margarita and Monterey Formations. The drainage areas of the two major tributaries, Arroyo Grande Creek and Lopez Canyon, are underlain by different geologic units. Arroyo Grande Creek drains an area underlain mainly by the Santa Margarita Formation, and the Lopez Canyon drainage area is almost entirely underlain by the Monterey Formation. The Monterey Formation consists of fractured porcelaneous and cherty siltstone and shale. The Santa Margarita Formation in the area surrounding Lopez Reservoir is poorly consolidated, readily weathered, coarse-grained sandstone and siltstone.

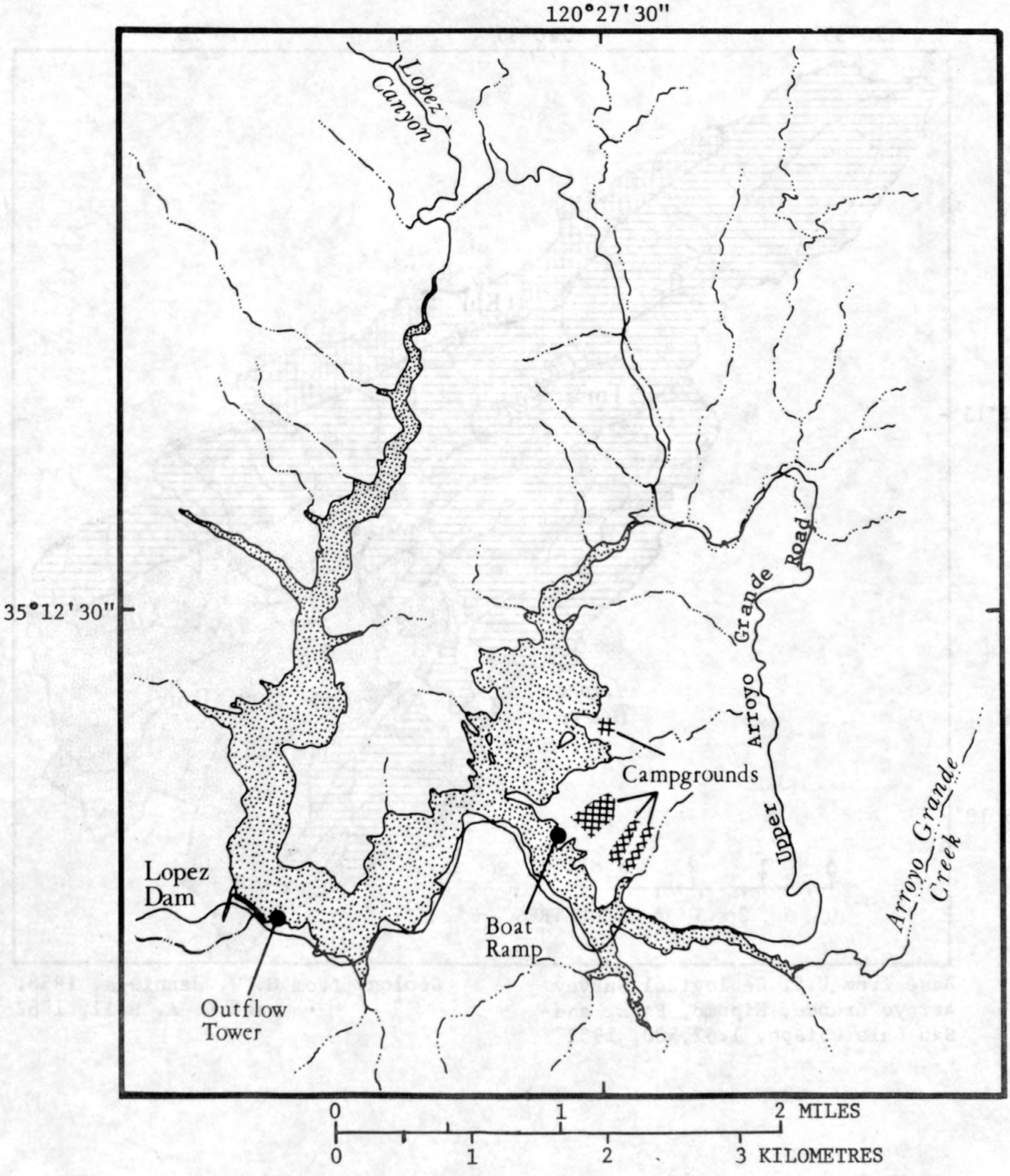
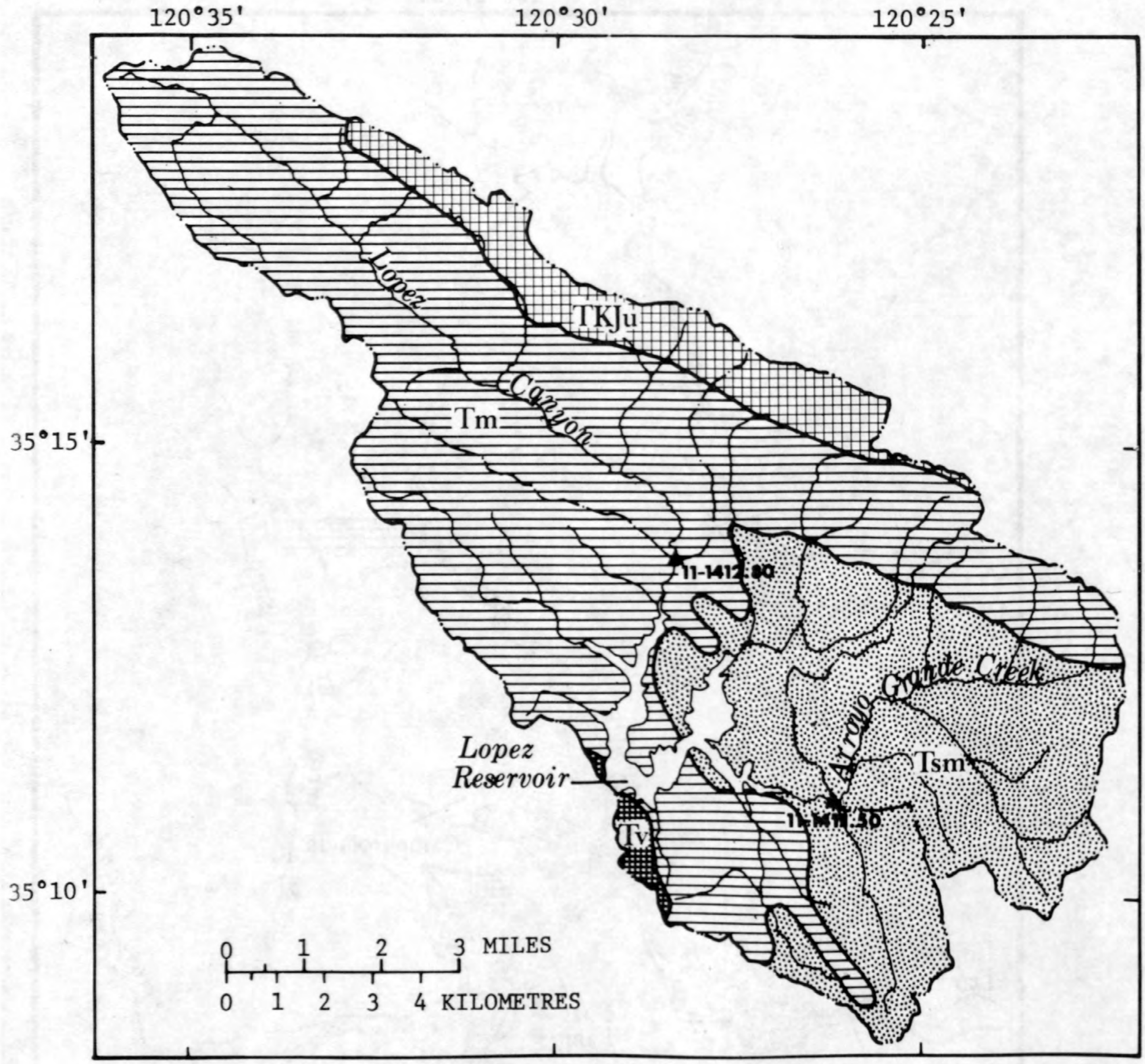


FIGURE 2.--Location of the dam, major tributaries, boat ramp, and campgrounds.



Base from U.S. Geological Survey Arroyo Grande, Nipomo, Poza, and San Luis Obispo, 1:62,500, 1952

Geology from C. W. Jennings, 1958, and C. A. Hall, 1962

FIGURE 3.--Geology of

CORRELATION OF MAP UNITS

Tsm	Pliocene and Miocene	TERTIARY
Tm	Miocene	TERTIARY
Tv	Miocene	TERTIARY
TKJu		TERTIARY, CRETACEOUS, AND JURASSIC

DESCRIPTION OF MAP UNITS

Tsm SANTA MARGARITA FORMATION OF HALL (1962) - Predominantly white-weathering, coarse-grained arkosic sandstone and siltstone, with some yellowish or tan siliceous mudstone

Tm MONTEREY FORMATION - Well bedded resistant opaline, porcelaneous, or siliceous siltstone, cherty shale, and soft siltstone

Tv VOLCANIC ROCKS, UNDIVIDED

TKJu SEDIMENTARY ROCKS, UNDIVIDED Includes nonmarine sandstone and conglomerate; marine sandstone, shale, and siltstone; and sedimentary and metamorphic rocks of the Franciscan Formation

Lithologic contact

Drainage-basin divide

Subbasin drainage divide

▲ 11-1412.80 U.S. Geological Survey gaging station and identification number

drainage basin.

HYDROLOGY

Precipitation

The distribution of precipitation in the vicinity of Lopez Reservoir is extremely variable. For example, 90 percent of the yearly rainfall may occur during 2 months of the year, and 3 to 5 months of the year may have no measurable rainfall. Differences in annual precipitation greater than 400 percent have occurred from year to year.

Lopez Dam was completed in mid-November 1968. By mid-January 1969 only about 1,000 acre-ft (1.23 hm^3) of water was stored behind the dam (Lawrance and others, 1971). Between January 19 and January 28, 1969, however, a massive storm occurred in the central and southern coastal areas of California. The San Luis Obispo area, including the Lopez Reservoir drainage basin, received extensive rain. Another heavy storm occurred in the latter part of February 1969. Table 1 shows rainfall data from three precipitation stations (locations shown in fig. 1) in the Lopez Reservoir drainage area. The data indicate that during January and February 1969 rainfall at precipitation stations 153, 178, and 178.1, in the Lopez Reservoir drainage area, exceeded 49 in (1,240 mm), 37 in (940 mm), and 28 in (710 mm). This rainfall was considerably greater than the average annual amount. Under normal rainfall conditions 4 to 6 years would have been required to fill Lopez Reservoir. However, because of the heavy precipitation in 1969, the reservoir reached full pool in less than 30 weeks (Lawrance and others, 1971, p. 716).

Streamflow in Major Tributaries

The two major streams in the reservoir drainage basin are Lopez Canyon and Arroyo Grande Creek. Lopez Canyon has a drainage area of 21.6 mi^2 (55.9 km^2), and Arroyo Grande Creek has a drainage area of 13.5 mi^2 (34.9 km^2) (Jorgensen and others, 1971). The 4-year average annual rainfall in the Lopez Canyon drainage basin for 1967-71 is 32.2 in (818 mm), and the average in the Arroyo Grande Creek drainage basin is 23.3 in (592 mm) (table 1). Discharge from Lopez Canyon represents 76 percent of the total discharge of the two streams during 1968-71 (table 2). During this same 4-year period, more than 68 percent of the total discharge in both streams occurred during the 1969 water year.[1]

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[1]Water year begins October 1 and ends September 30 of the year given. All water- and sediment-discharge data in the report are for the water year given, unless otherwise stated.

TABLE 1.--*Selected rainfall data from precipitation stations in the Lopez Reservoir area, January 1967 through December 1971*

[Rainfall, in inches. Data from San Luis Obispo County Flood Control and Water Conservation District, 1972. Location of precipitation stations shown in fig. 1]

Month	Station 153					Station 178			Station 178.1			
	1967	1968	1969	1970	1971	1968	1969	1970	1968	1969	1970	1971
January	9.72	3.43	37.15	9.94	3.74	2.92	25.39	7.57		18.39	5.97	1.80
February	1.20	1.19	12.00	6.85	.08	1.77	11.62	1.62		9.93	1.91	.13
March	10.69	5.39	2.26	.11	2.12	4.08	.89	4.02		1.10	3.01	1.13
April	10.54	2.24	1.60	.15	2.04	1.54	2.82	.04		2.57	.00	1.10
May	.42	.22	.00	.00	1.90	.28	.00	.00		.00	.00	.82
June	.20	.00	.00	.00	.00	.00	.03	.10		.08	.00	.00
July	.00	.00	.00	.00	.00	.00	.05	.00	0.00	.00	.00	.00
August	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
September	1.35	.00	.16	.00	.13	.00	.06	.00	.00	.10	.00	.05
October	-	3.79	1.08	.51	.35	2.75	.89	.26	2.85	.83	.25	.18
November	4.05	3.52	1.48	11.37	2.93	[1]2.50	1.09	7.06	1.92	.75	5.89	1.42
December	3.83	6.43	2.37	9.35	.03	4.85	1.90	6.85	3.41	1.27	5.49	5.72
Total	42.00	26.21	58.10	38.28	13.32	20.69	44.74	27.52		35.02	22.52	12.35
Average for years shown				33.44			30.98				[2]23.29	

[1]Estimated from precipitation at stations 153 and 178.1.
[2]Average for years 1969 through 1971.

TABLE 2.--*Annual water and sediment discharge of Lopez Canyon and Arroyo Grande Creek*

Water year	Lopez Canyon near Arroyo Grande, station 11-1412.80		Arroyo Grande Creek above Phoenix Creek near Arroyo Grande, station 11-1411.50	
	Water discharge (acre-ft)	Sediment discharge (tons)[1]	Water discharge (acre-ft)	Sediment discharge (tons)
1968	3,110	50	984	120
1969	25,000	100,879	7,820	238,170
1970	4,620	657	1,480	2,096
1971	3,890	208	1,110	323
Total	36,620	101,794	11,394	240,709
Percentage of total discharge in 1969	68	99	68	99

Total water discharge of Lopez Canyon and Arroyo Grande Creek, 1968-71	48,014 acre-feet
Percent contributed by Lopez Canyon	76 percent
Percent contributed by Arroyo Grande Creek	24 percent
Total sediment discharge of Lopez Canyon and Arroyo Grande Creek, 1968-71	342,502 tons
Percent contributed by Lopez Canyon	30 percent
Percent contributed by Arroyo Grande Creek	70 percent

[1]Sediment load for Lopez Canyon was computed by adding 20 percent to the suspended-sediment load.

The flow response to the early 1969 storms in the two major tributaries[2] of Lopez Reservoir was dramatic. The streamflow hydrographs for Lopez Canyon (11-1412.80) and Arroyo Grande Creek above Phoenix Creek (11-1411.50) are shown in figures 4 and 5. The hydrographs are plotted on a logarithmic scale which tends to subdue the relative magnitude of flood peaks. However, the 1969 water year runoff is striking when compared to that of other years of record in that it is 5 to 10 times greater than that in any of the other years studied between 1968 and 1971.

[2]Gaging stations were established in late summer 1967 to obtain continuous water-discharge records. Sediment-discharge records begin October 1, 1967.

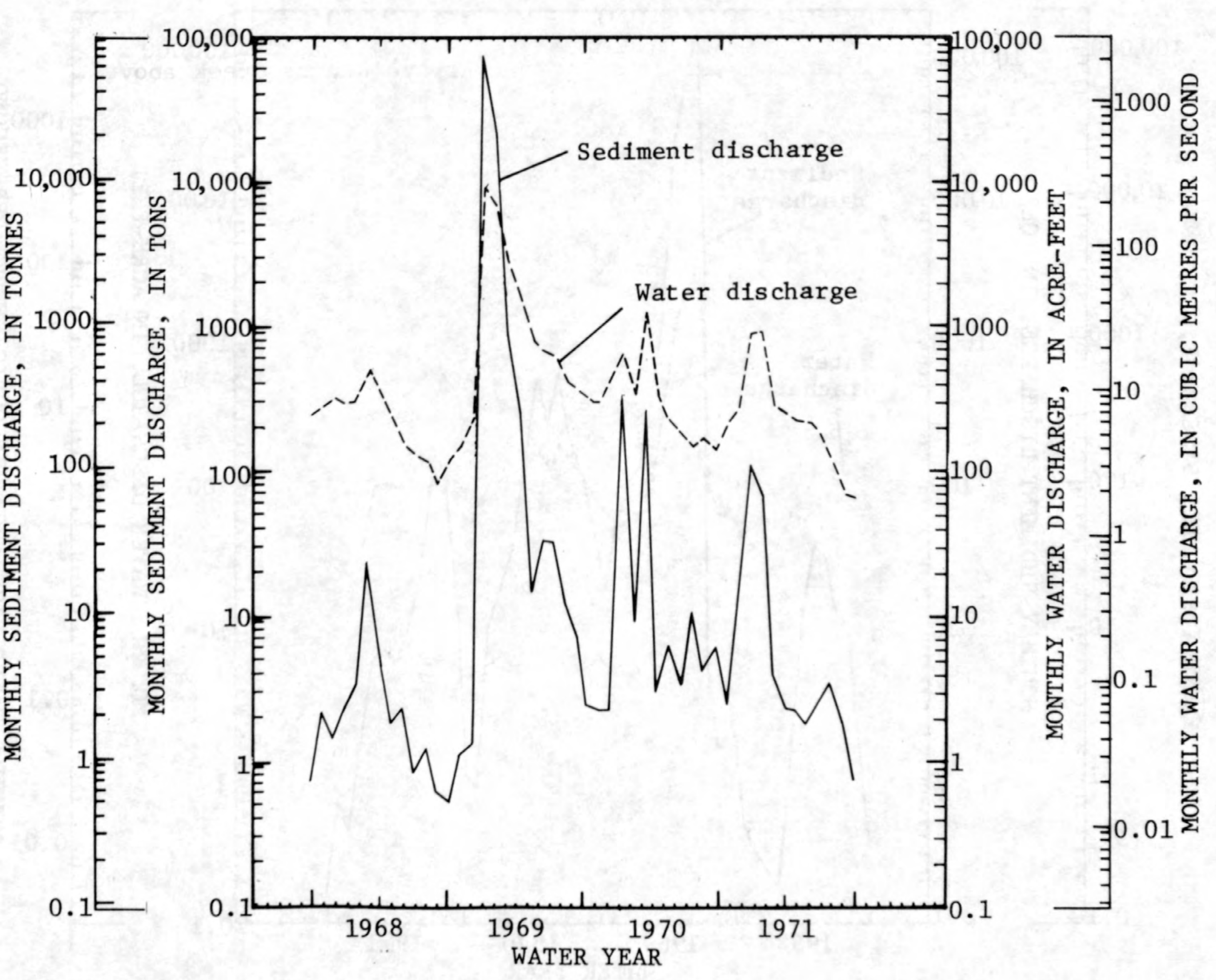

FIGURE 4.--Sediment discharge and water discharge at Lopez Canyon near Arroyo Grande, water years 1968-71. (U.S. Geological Survey gaging station 11-1412.80.)

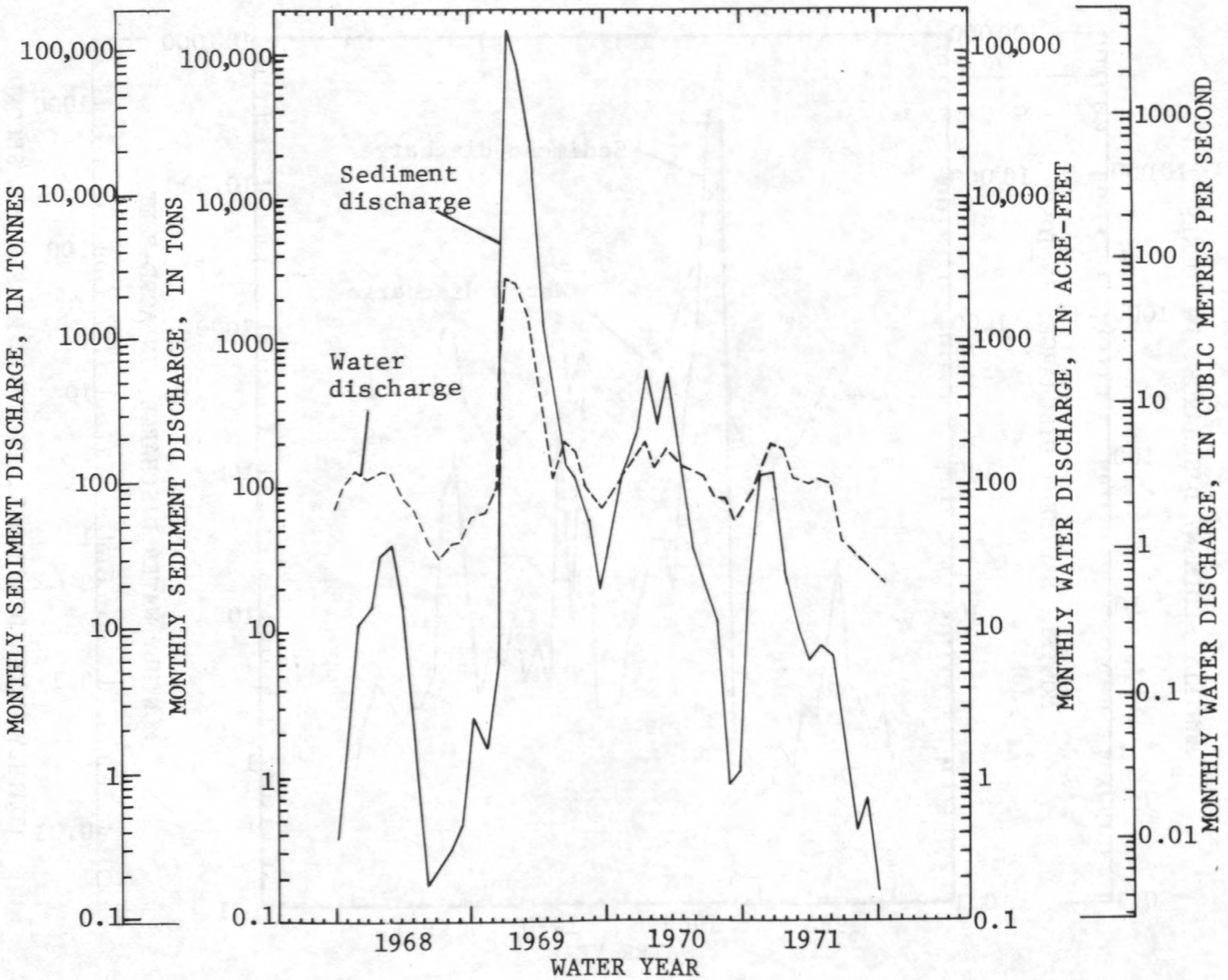

FIGURE 5.--Sediment discharge and water discharge at Arroyo Grande Creek above Phoenix Creek, near Arroyo Grande, water years 1968-71. (U.S. Geological Survey gaging station 11-1411.50.)

Sediment Transport

Sediment transport in the Lopez Reservoir drainage basin was extremely large during the January 1969 storm (figs. 4 and 5). Based on data from Lopez Canyon and Arroyo Grande Creek, the sediment load of streams in the Lopez Reservoir drainage basin during the 1969 storms was more than 100 times the total for the years 1968, 1970, and 1971. Note that the 1969 water year (table 2) accounted for more than 99 percent of the total sediment discharge for the 1968-71 period. Moreover, nearly all of this discharge occurred during January and February 1969.

Lopez Canyon accounted for more than three-fourths of the combined water discharge but only 30 percent of the combined sediment discharge of the two streams (table 2). The remaining 70 percent of the sediment discharge was from Arroyo Grande Creek. The great difference in the quantity of sediment transported by the two streams results in large part from differences in the geology of the two stream basins (fig. 3).

The Santa Margarita Formation, which underlies most of the drainage area of Arroyo Grande Creek, is poorly consolidated and easily eroded. The predominant formation in the Lopez Canyon drainage basin is the Monterey Formation, which is much less erodible than the Santa Margarita and therefore yields less sediment to the creek.

For the period of record, the 1969 water year was the most significant for sediment as well as water discharge. The storm of January 1969, a 35-year storm[3] (Lawrance and others, 1971, p. 716) is responsible for almost all of the sediment and by inference for most of the total nitrogen and phosphorus transported into Lopez Reservoir since November 1968. Figure 6 shows a comparison of sediment transport in 1969, a high runoff year, and 1970, a more normal runoff year.

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[3]A 35-year storm is one of such intensity that it occurs, on the average, once every 35 years.

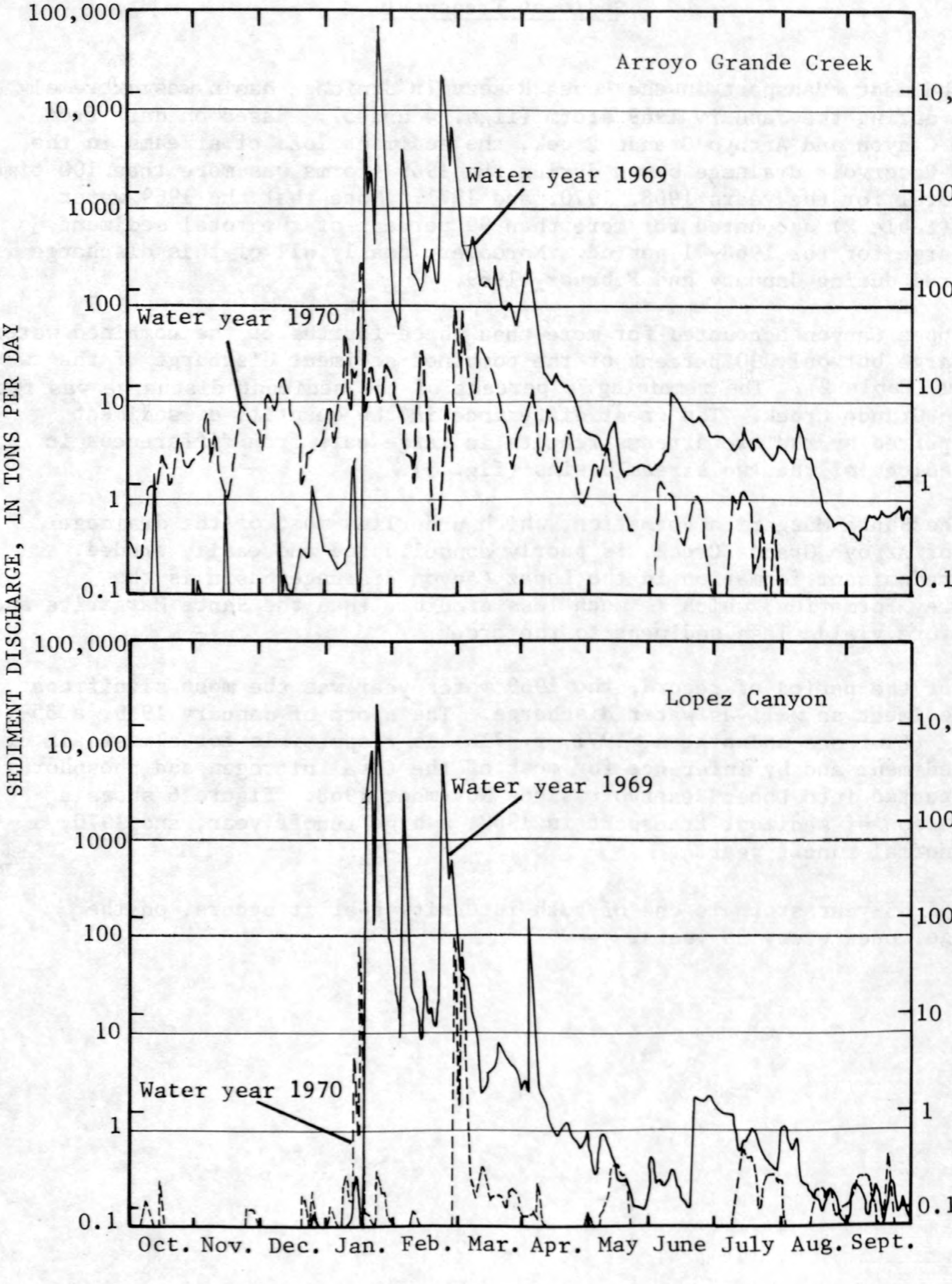


FIGURE 6.--Sediment discharge from Arroyo Grande Creek and Lopez Canyon in years of high (1969) and more typical (1970) runoff.

METHODS

To facilitate water-quality sampling, the reservoir was divided into 11 areas with letter designations A through K (fig. 7). Physical and chemical measurements made weekly in the reservoir included temperature profile, pH, conductivity, and Secchi disk transparency. Conductivity, pH, and Secchi disk measurements were made in areas A through J, and the temperature profile was determined in area F. All the above measurements were made by San Luis Obispo County personnel. Alkalinity, dissolved oxygen, major dissolved ions including silica, and nitrogen and phosphorus were determined once in 1971 and three times in 1972 in areas A, C, F, and I by Geological Survey personnel. No measurements were made in area K.

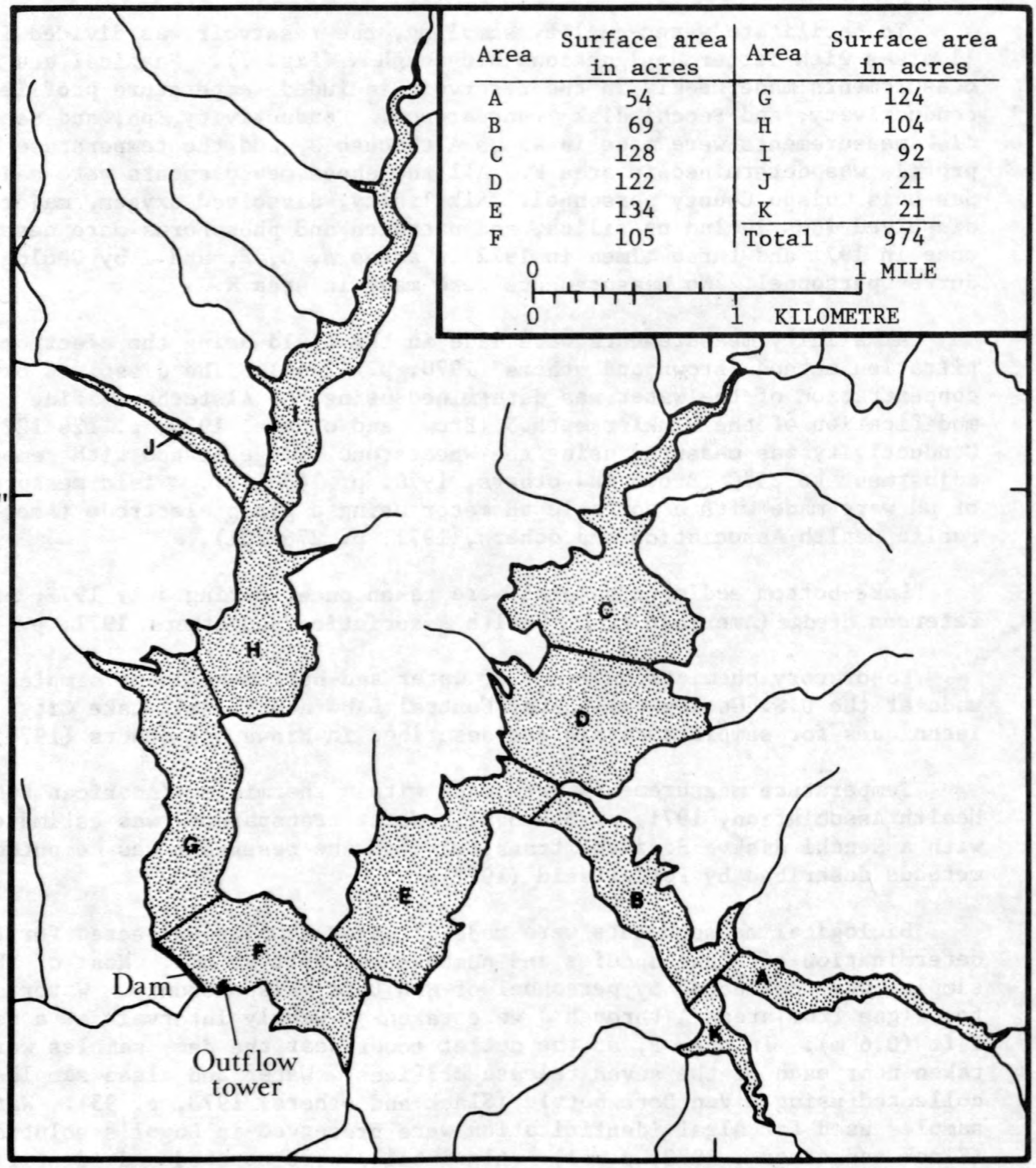
Alkalinity measurements were made in the field using the electrometric titration method (Brown and others, 1970, p. 42-44). The dissolved oxygen concentration of the water was determined using the Alsterberg azide modification of the Winkler method (Brown and others, 1970, p. 126-127). Conductivity was measured using the Wheatstone bridge method with temperature adjustment to 25°C (Brown and others, 1970, p. 148-150). Field measurements of pH were made with a portable pH meter using a glass electrode (American Public Health Association and others, 1971, p. 276-281).

Lake-bottom sediment samples were taken once, during July 1972, using a Petersen dredge (American Public Health Association and others, 1971, p. 761-762).

Laboratory chemical analysis of water and bottom-sediment samples were made at the U.S. Geological Survey Central Laboratory, Salt Lake City, Utah. Techniques for sample analysis are described in Brown and others (1970).

Temperature measurements were made with a thermister (American Public Health Association, 1971, p. 348-349). Water transparency was estimated with a Secchi disk. Sediment transport into the reservoir was computed using methods described by Porterfield (1972).

Biological measurements were made of water samples collected for the determination of algal species and numbers per unit volume. Most of the samples were collected by personnel of San Luis Obispo County. Water samples for algae from areas A through J were taken at weekly intervals at a depth of 2 ft (0.6 m). In area F, at the outlet tower near the dam, samples were also taken near each of the seven release orifices. Water and algae samples were collected using a Van Dorn bottle (Slack and others, 1973, p. 95). Water samples used for algal identification were preserved in Lugol's solution (Slack and others, 1973, p. 71). Algal cells were counted and identified by Lopez Water Treatment Plant personnel using the Sedgwick-Rafter method (Slack and others, 1973, p. 70-72). As a quality control measure, Geological Survey personnel recounted algae in approximately 35 samples using the inverted microscope method (Slack and others, 1973, p. 72-75). Algal counts and species composition data were used to evaluate the effectiveness of copper sulfate which was used in the reservoir as an algicide. In addition, the data were used to determine algal growth rates at specific times.



Area	Surface area in acres	Area	Surface area in acres
A	54	G	124
B	69	H	104
C	128	I	92
D	122	J	21
E	134	K	21
F	105	Total	974

FIGURE 7.--Areas for sampling and algicide treatment.

RESULTS

Thermal Profiles

Lopez Reservoir becomes thermally stratified by April, and stratification continues through the summer and into November. Thermal stratification is common in other temperate-zone reservoirs (Hutchinson, 1957) and is one of the more influential processes controlling lake water chemistry during the warm late-spring, summer, and autumn months of the year.

A thermally stratified lake has two distinct water masses separated by temperature-density differences. The upper water mass or epilimnion is homothermous and warm. The lower water mass or hypolimnion is homothermous and cold. Between is the metalimnion, a water mass having a rapidly decreasing temperature with depth.

Figure 8 shows the thermal regimen during January, April, August, and November. The January period shows a lack of thermal stratification with temperature changes of only 1.2°C between points near the surface and near the bottom at a depth of more than 100 ft (30.5 m). The April profile shows the development of thermal stratification with a hypolimnion below 65 ft (19.8 m) and a thick metalimnion from 33 to 65 ft (10.1 to 19.8 m). The midsummer profile taken in August shows a well-stratified profile, with the hypolimnion below 52 ft (15.8 m) and the metalimnion between depths of 32 and 52 ft (9.8 and 15.8 m). The November profile shows less stratification and a temperature difference of only 3.6°C between the top and bottom of the reservoir.

Overall the thermal stratification pattern reveals the development in early spring of a deep-water hypolimnion that thickens during the warm summer months and reaches a maximum in mid-August to encompass two-thirds of the water column. By November, stratification is less evident, and in January there is no noticeable stratification.

Dissolved-Oxygen Profiles

As the water becomes thermally stratified in Lopez Reservoir, oxygen stratification also takes place. Oxygen stratification results from bacterial oxidation in the decomposition of organic matter such as algae. The result of this oxidation is the development of a hypolimnion that is anaerobic, or devoid of oxygen. Anaerobic conditions favor chemical reduction and breakdown of organic matter so that plant nutrients are released into solution (Hasler, 1947; Mortimer, 1941). These nutrients may then be recycled as overturn takes place in the spring and autumn of the year. After an initial period of nutrient enrichment, recycling of nutrients may be sufficient to maintain high levels for a number of years (Fruh, 1967).

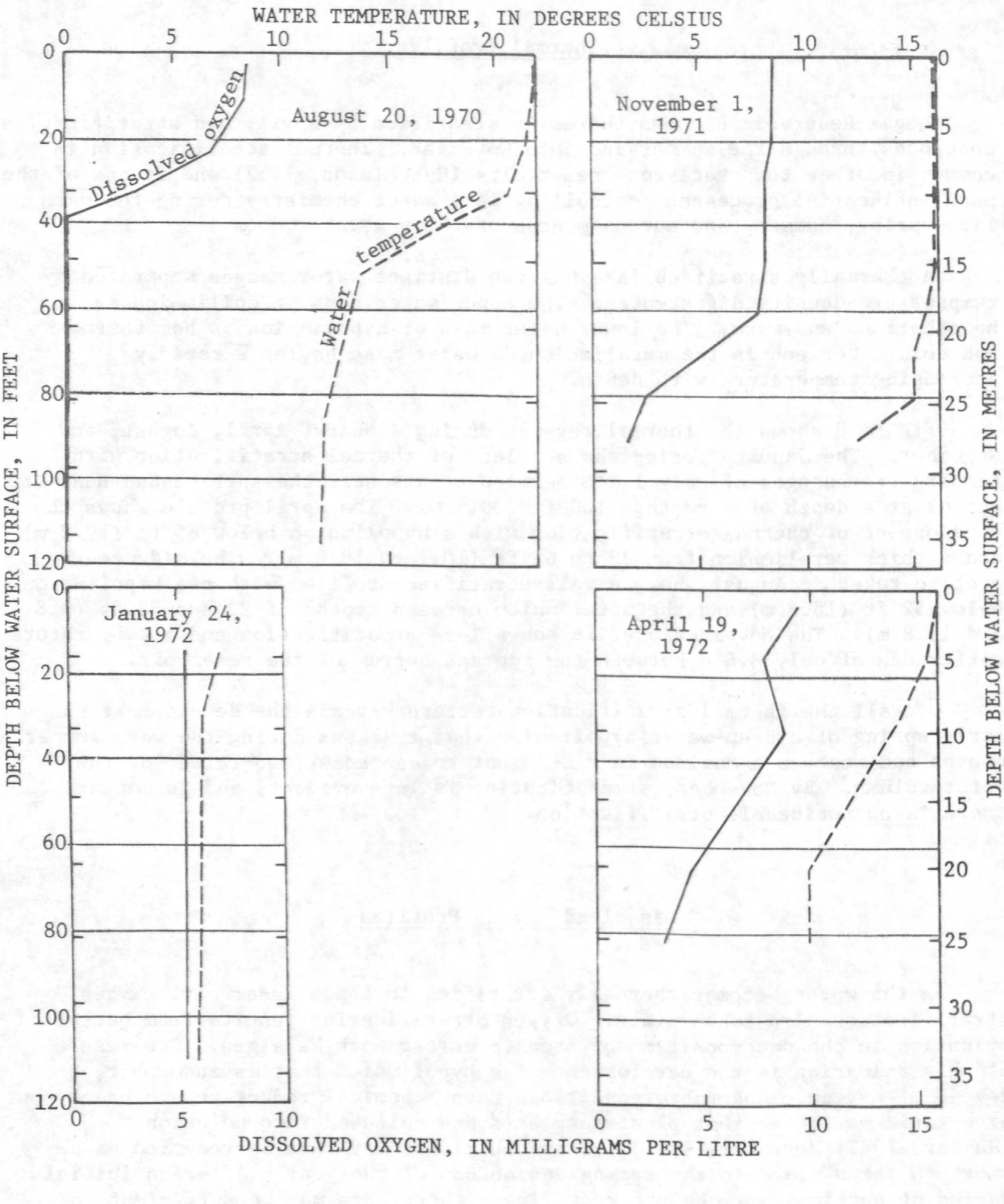


FIGURE 8.--Thermal and oxygen profiles in area F.

Figure 8 shows oxygen profiles in January and April 1972, August 1970, and November 1971. The January profile shows complete mixing with no stratification. Oxygen levels were the same at the surface and at a depth of 100 ft (30.5 m). The April profile shows the beginning of oxygen stratification. Dissolved-oxygen concentration decreases from almost 10 mg/l (milligrams per litre) at the surface to less than 2 mg/l at a depth of 80 ft (24.3 m). The August profile represents the period of maximum oxygen stratification. Surface water has a dissolved-oxygen concentration of about 8 mg/l. This concentration drops to 0 mg/l at a depth of 38 ft (11.6 m). This stratification continues until November when mixing begins.

Figure 9 shows the period of time and depth at which near-anaerobic conditions occur in area F of the reservoir. For this report, any oxygen concentration of less than 1 mg/l is considered to be near anaerobic. Near-anaerobic conditions exist from mid-May through November. Anaerobic conditions are greatest from June through September.

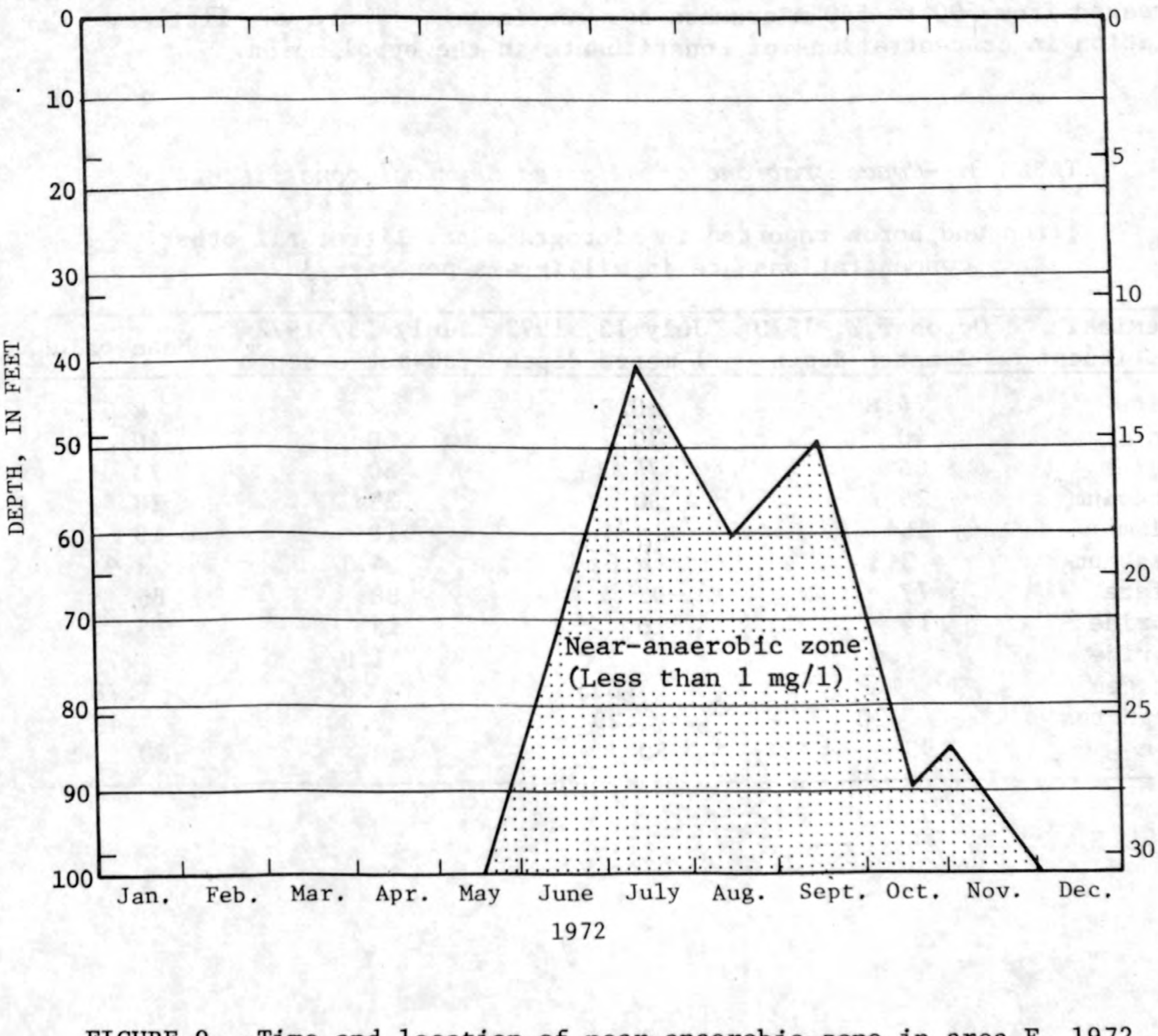


FIGURE 9.--Time and location of near-anaerobic zone in area F, 1972.

Chemical Profiles Other Than Dissolved Oxygen

Three water samples were collected to determine the concentrations of major dissolved constituents in the reservoir water (table 3). The concentrations of constituents in the samples taken over a 2-year period show little variation. This may indicate that the reservoir reaches an equilibrium state during the summer months with regard to the concentrations of major chemical constitutents.

Figures 10 and 11 show profiles of temperature, conductivity, pH, and alkalinity in August 1970 and October 1971. Both samples were taken in area F, the deepest part of the lake. The August sample represents a period when the lake was thermally stratified. Three basic zones are differentiated in figure 10. In the epilimnion, the values for pH, conductivity, alkalinity, and temperature showed little variation. In the metalimnion, the temperature dropped from about 21° to 14°C, the pH dropped from 8.5 to 7.6, and the alkalinity increased from 220 to more than 270 mg/1. The specific conductance increased from 500 to 540 micromhos per centimetre. There was little variation in concentrations of constituents in the hypolimnion.

TABLE 3.--*Concentrations of selected chemical constituents*

[Iron and boron reported in micrograms per litre; all other concentrations are in milligrams per litre]

Chemical constituent	October 2, 1970 2-metre depth	July 13, 1972 1-metre depth	July 13, 1972 20-metre depth	Mean values
Silica	4.8	0.3	2.5	2.5
Iron	40	20	60	40
Calcium	66	74	80	73
Magnesium	25	30	29	28
Sodium	16	19	18	18
Potassium	3.5	4.0	4.1	3.9
Sulfate	77	92	88	86
Chloride	14	16	15	15
Fluoride	.4	.7	1.0	.7
Nitrogen	–	.69	.86	.78
Phosphorus	.20	.29	.80	.43
Boron	90	50	50	60

The October 1971 (fig. 11) profile shows both similarities and differences from the August 1970 profile (fig. 10). Well-stratified conditions are indicative of little or no vertical mixing in the reservoir. This is exemplified by the August profile. The October profile shows some mixing, less developed thermal stratification, and greater variations in measured parameters within each zone of the reservoir. These conditions occur at the beginning of the autumn overturn in the reservoir. The pH values are lower in October than in August. This may be due to a decrease in biological activity. There was a slow but steady decrease in pH values with increasing depth in the epilimnion and a more rapid decrease in the metalimnion. Specific conductance is generally greater in the October profile than in the August profile at all depths and is more variable with depth. Alkalinity values are similar in both profiles, but there was more variability with depth in the October profile in the epilimnion than in the August profile.

Secchi Disk Transparency

Figure 12 shows the trends in Secchi disk transparency, measured in areas C, F, and I, using mean monthly values for 1972. Mean values range from 4.3 ft (1.3 m) in August and September to 28 ft (8.5 m) in October. The reduced light penetration in the spring and summer was a result of increased algal production.

In a study of Lake Oneida, Greeson (1971) found Secchi disk transparency to have a mean value of 5.86 ft (1.79 m). This lake is comparable to Lopez Reservoir not only in Secchi disk transparency, but also in algal counts. Rawson (1942) reported that Secchi disk transparencies ranged from 24 to 40 ft (7.3 to 12.2 m) in large unsilted alpine lakes of the Canadian Rockies.

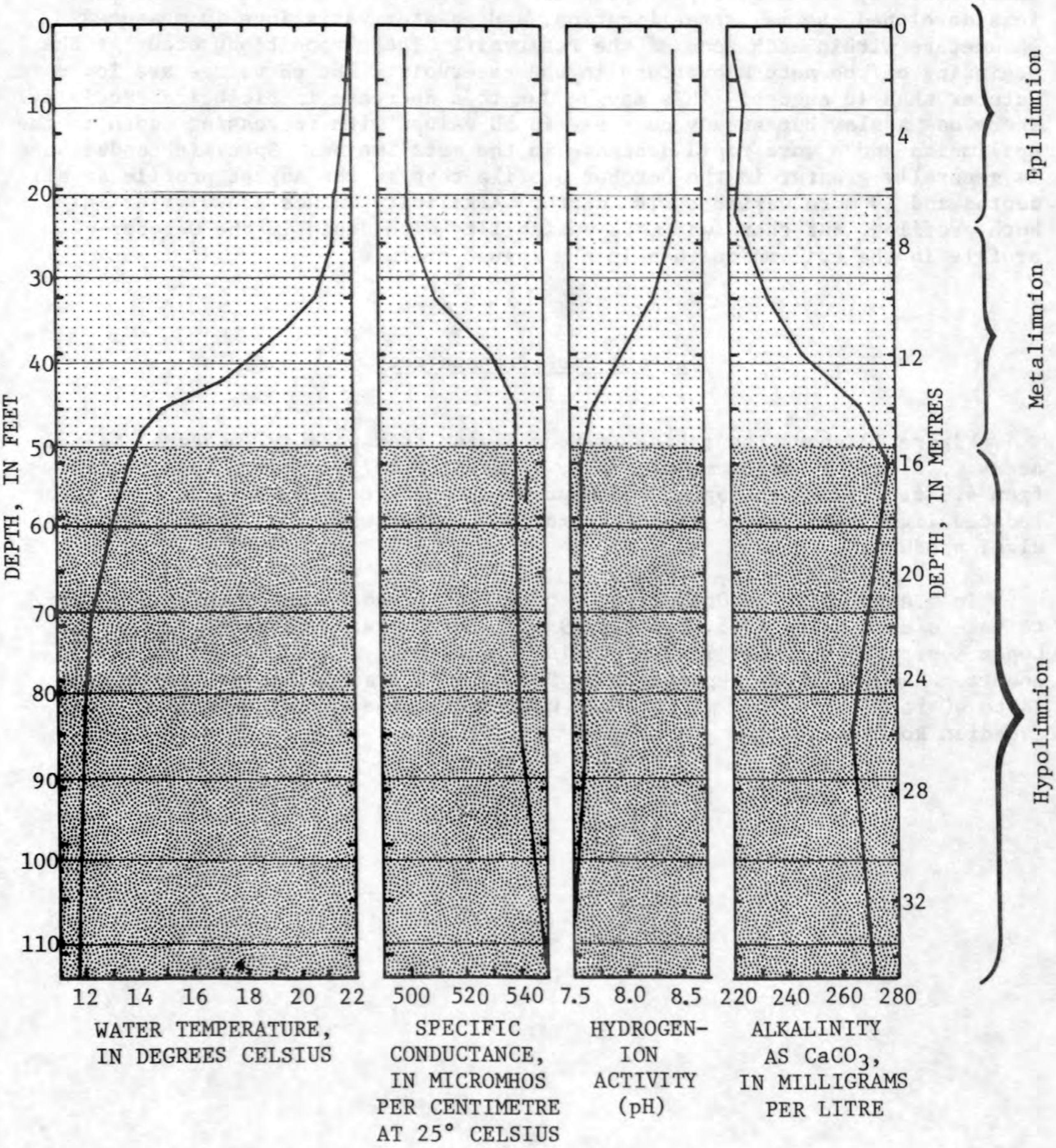


FIGURE 10.--Reservoir profile in area F, August 20, 1970.

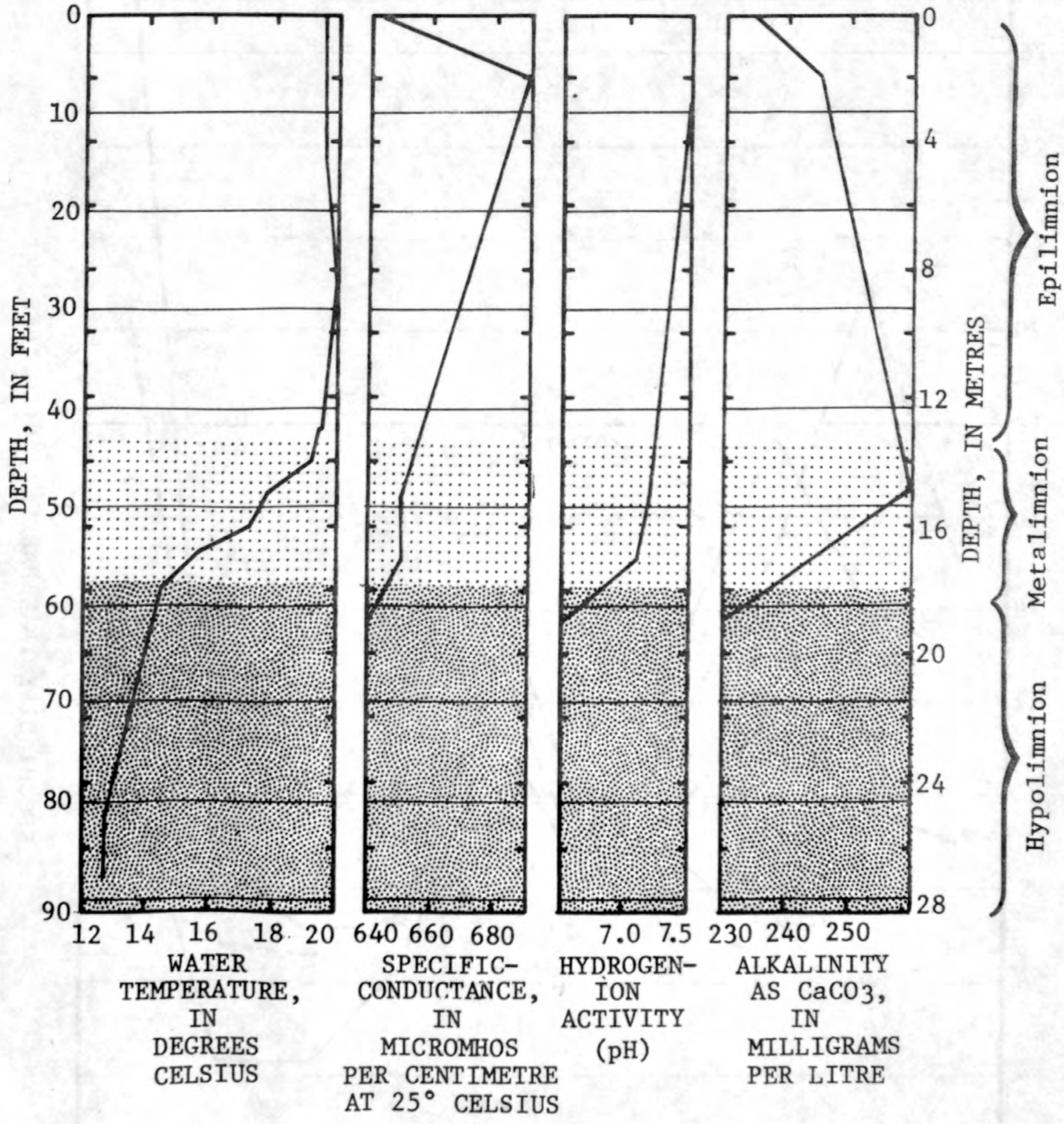


FIGURE 11.--Reservoir profile in area F, October 13, 1971.

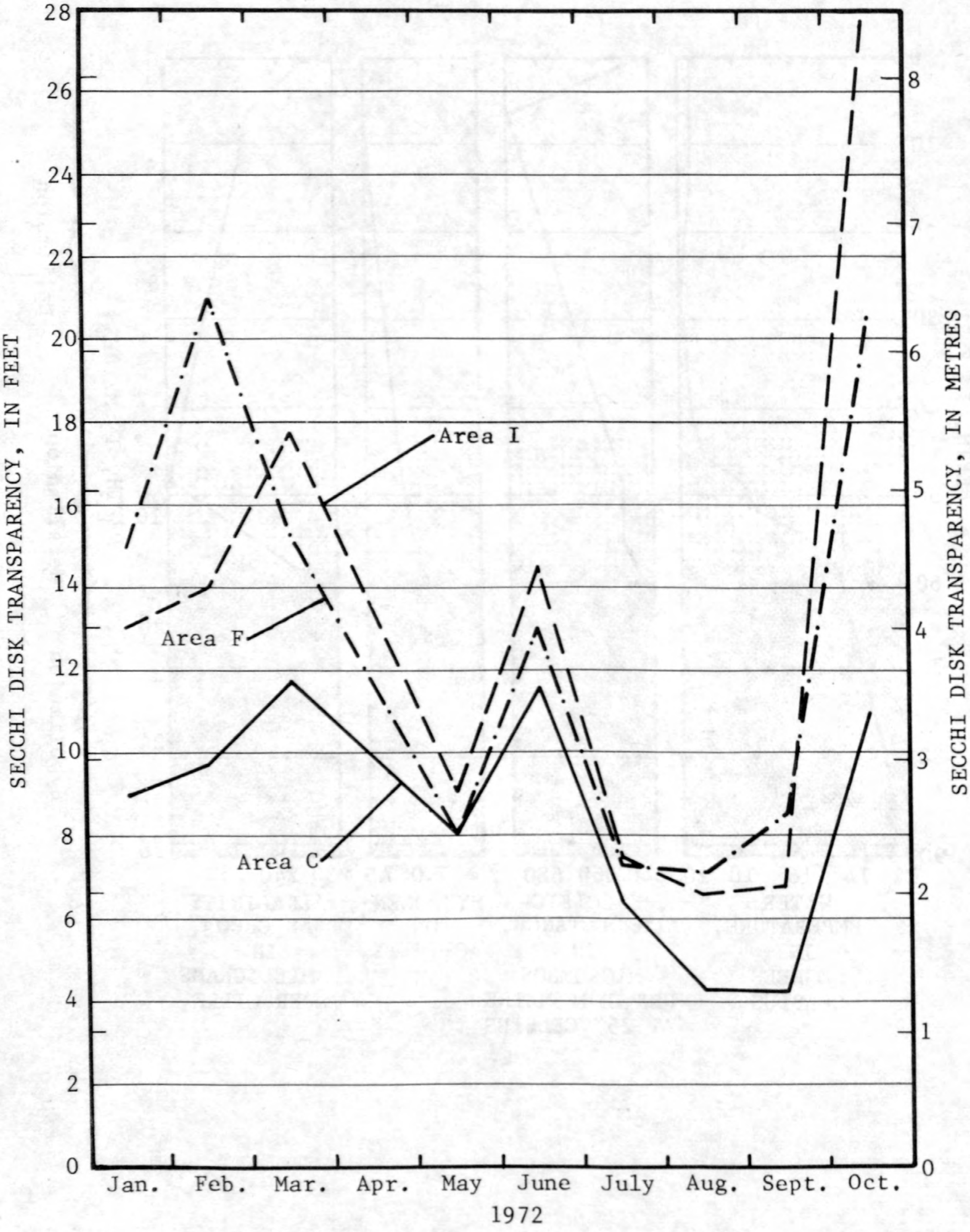


FIGURE 12.--Secchi disk transparency in areas C, F, and I, 1972.

Nitrogen and Phosphorus

Nitrogen and phosphorus are two of the more important nutrients for algal growth. A lack of one of these nutrients may limit algal growth and hence the development of algal blooms (Gerloff and Skogg, 1954; Carrol, 1962; Chu, 1943; Sawyer, 1947; and Rodhe, 1949). Various minimum levels of these nutrients have been suggested below which algal growth will be inhibited (Sawyer, 1947; Greeson, 1971; and Kuentzel, 1969). These range from 0.002 to 0.09 mg/l for phosphorus and from a trace to 5.3 mg/l for nitrogen.

A recent paper by Schindler (1974) reported the recovery of several lakes in Canada to which phosphorus had been added to induce eutrophic conditions. The study showed a rapid recovery of a eutrophic lake to an oligotrophic condition after the addition of phosphorus to the system was terminated. The work indicated that little circulation of phosphorus from the decomposition of organic matter occurred, that phosphorus is used almost immediately upon its addition to a system, and that the recovery of a system, after the phosphorus input is terminated, is extremely rapid.

In order to determine how nitrogen and phosphorus affect the development of algal blooms in Lopez Reservoir, a program of sampling for these nutrients was undertaken. Samples were taken in the reservoir at areas A, C, F, and I in October 1971 and in January, April, and July 1972. The mean values and ranges in concentration for total nitrogen and total phosphorus are shown in table 4.

TABLE 4.--*Concentrations of total nitrogen and phosphorus*

[Concentrations are in milligrams per litre]

Date	Total nitrogen as N			Total phosphorus as P		
	Number of samples	Mean	Range	Number of samples	Mean	Range
Oct. 13, 1971	4	0.47	0.29-0.79	4	0.62	0.40-0.85
Jan. 28, 1972	5	.55	.50- .64	5	.43	.40- .47
Apr. 19, 1972	5	.37	.29- .48	5	.39	.32- .47
July 13, 1972	5	.59	.32- .86	4	.47	.29- .80
Total mean		0.50			0.47	

Organic Nitrogen, Phosphorus, and Organic Content in Bottom Sediment

Concentrations of organic nitrogen plus ammonia, total phosphorus, and percentage of organic content (loss on ignition) were determined in bottom sediments in areas A, C, D, F, G, and I. Table 5 shows the results of the sampling. The mean value for organic nitrogen plus ammonia in the bottom sediment, reported as N, was 159 mg/100 g (milligrams per 100 grams) of sediment, and the mean value for phosphorus was 74 mg/100 g. About 11 percent of the bottom sediment was composed of organic material. These bottom sediments may be a source of nutrients required for algal growth.

TABLE 5.--*Concentrations of total nitrogen and phosphorus and percentage of organic content in bottom sediments in areas A, C, D, F, G, and I.*

[Samples taken July 12, 1972. Location of sampling areas shown in fig. 7]

Area	Total organic nitrogen plus ammonia as N (mg/100 g)	Total phosphorus as P (mg/100 g)	Organic content (percent)
A	80	110	14
C	156	53	9.6
D	296	89	15
F	140	71	10
G	128	65	10
I	156	59	9.9
Mean	159.3	74.5	11.4

ALGAL GROWTH AND DISTRIBUTION

Since the reservoir was filled in spring 1969 there have been a number of problems caused by algal blooms. These blooms have resulted in taste and odor problems in the water. Biochemical decomposition of algae in water removes dissolved oxygen. Insufficient oxygen in the water may have been responsible for periodic fishkills in the reservoir (Lawrance and others, 1971, p. 725). In addition, the odor and unsightly nature of the blooms discourage recreational use of the reservoir.

In an attempt to understand the dynamics of algal production in the reservoir, a comprehensive study of algal growth and growth trends was undertaken in lake areas A, C, F, and I during the 1973 water year.

Seasonal Variations in Algal Species Composition

Three distinct groups of algal species were identified during the 1973 water year. Low algae counts averaged approximately 100 cells/ml (cells per millilitre) from October through mid-February. The algal community was dominated by the diatoms *Fragilaria crotonensis* and *Stephanodiscus astraea*. Secondary species included the green alga *Mougeotia sp.* and a small number of the blue-green alga *Aphanizomenon sp.*

From mid-February through mid-June, blue-green algae, primarily *Anabaena unispora*, were dominant. Total cell counts often reached about 100,000 cells/ml.

The final period, from mid-June to October, was characterized by moderate to high algae counts ranging from 100 to 10,000 cells/ml and averaging about 1,000 cells/ml. Dominant species included the blue-green alga *Anabaena unispora*, diatoms *Stephanodiscus astraea* and *Cyclotella operculata*, and the green algae *Pediastrum duplex* and *Sphaerocystis schroeteri*.

Distribution of Algae with Depth

Water samples were collected at various depths at the outflow tower in area F (fig. 7) to define the vertical distribution of algae. In November, the maximum number of algae was found between the water surface and a depth of 60 ft (18.2 m) (fig. 13). Below a depth of 60 ft (18.2 m) algal numbers varied greatly, decreasing near the lake bottom.

In April diatoms and green and blue-green algae were present (fig. 14). A maximum of 82 cells/ml was found at the water surface, and a minimum of 13 cells/ml was found at the lake bottom.

The maximum measured change with depth occurred in May during a bloom period of *Anabaena unispora*, a blue-green alga (fig. 15). The number of cells at the reservoir surface was nearly 100,000 cells/ml. Near the lake bottom (105 ft) (32 m) the count had decreased to slightly more than 1,000 cells/ml.

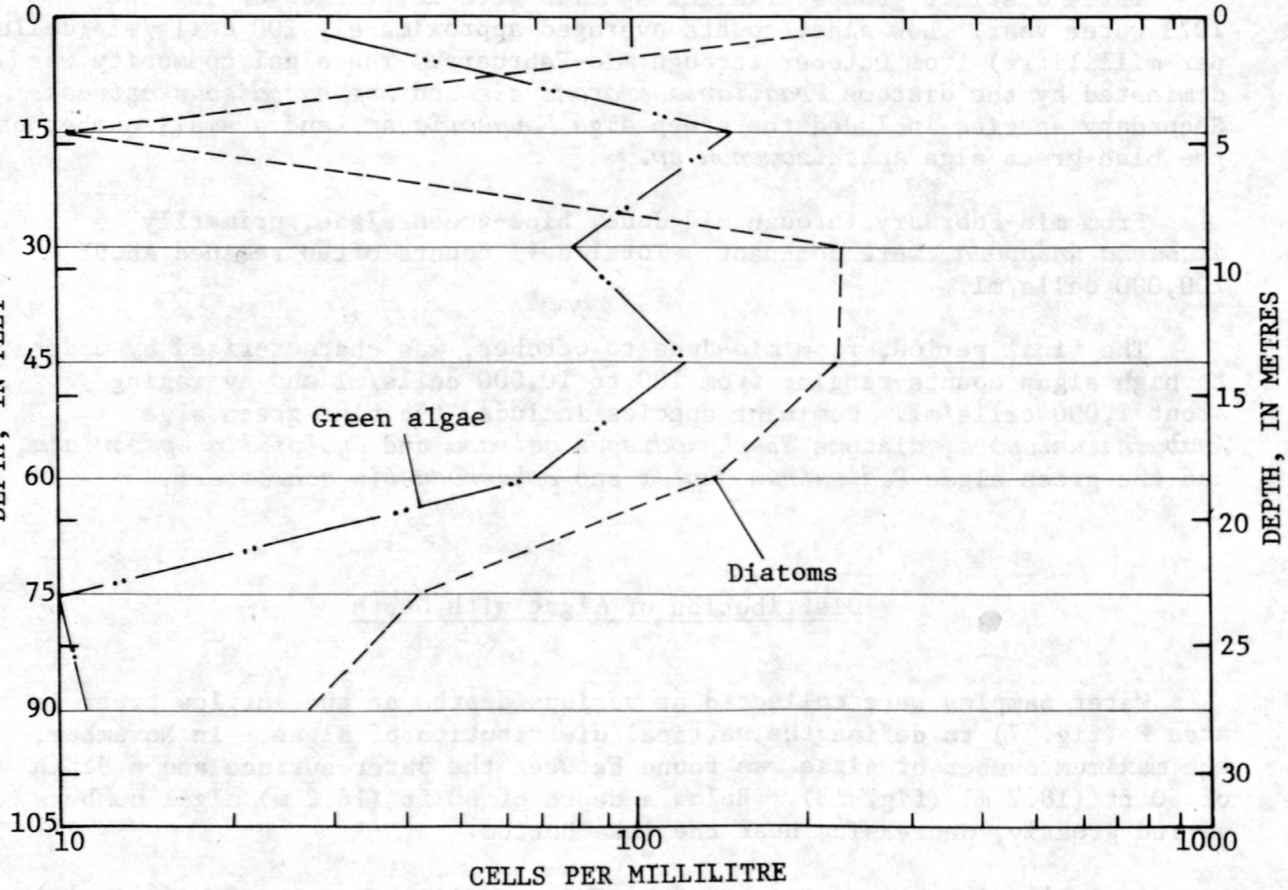


FIGURE 13.--Vertical distribution of algae in area F, November 1, 1971.

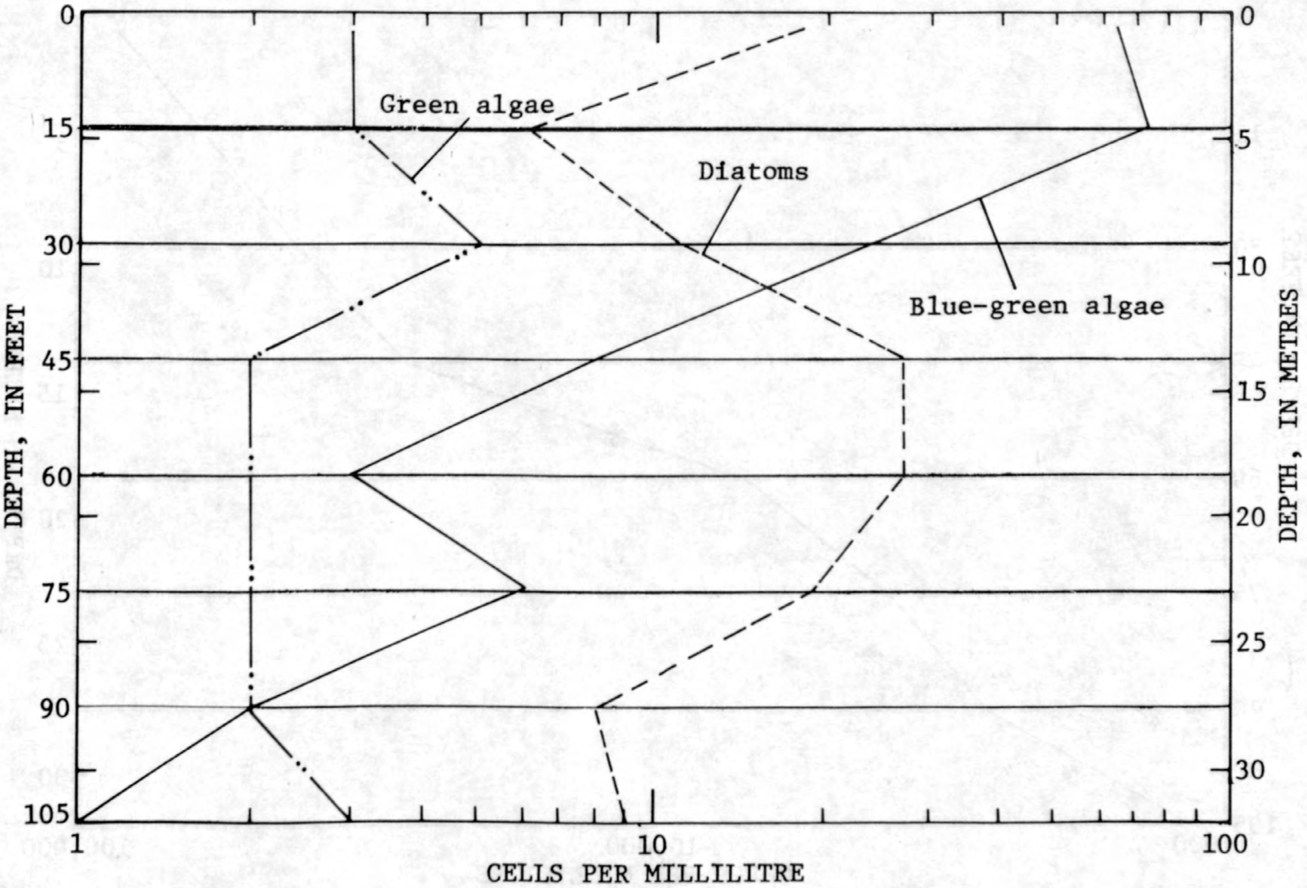


FIGURE 14.--Vertical distribution of algae in area F, April 17, 1972.

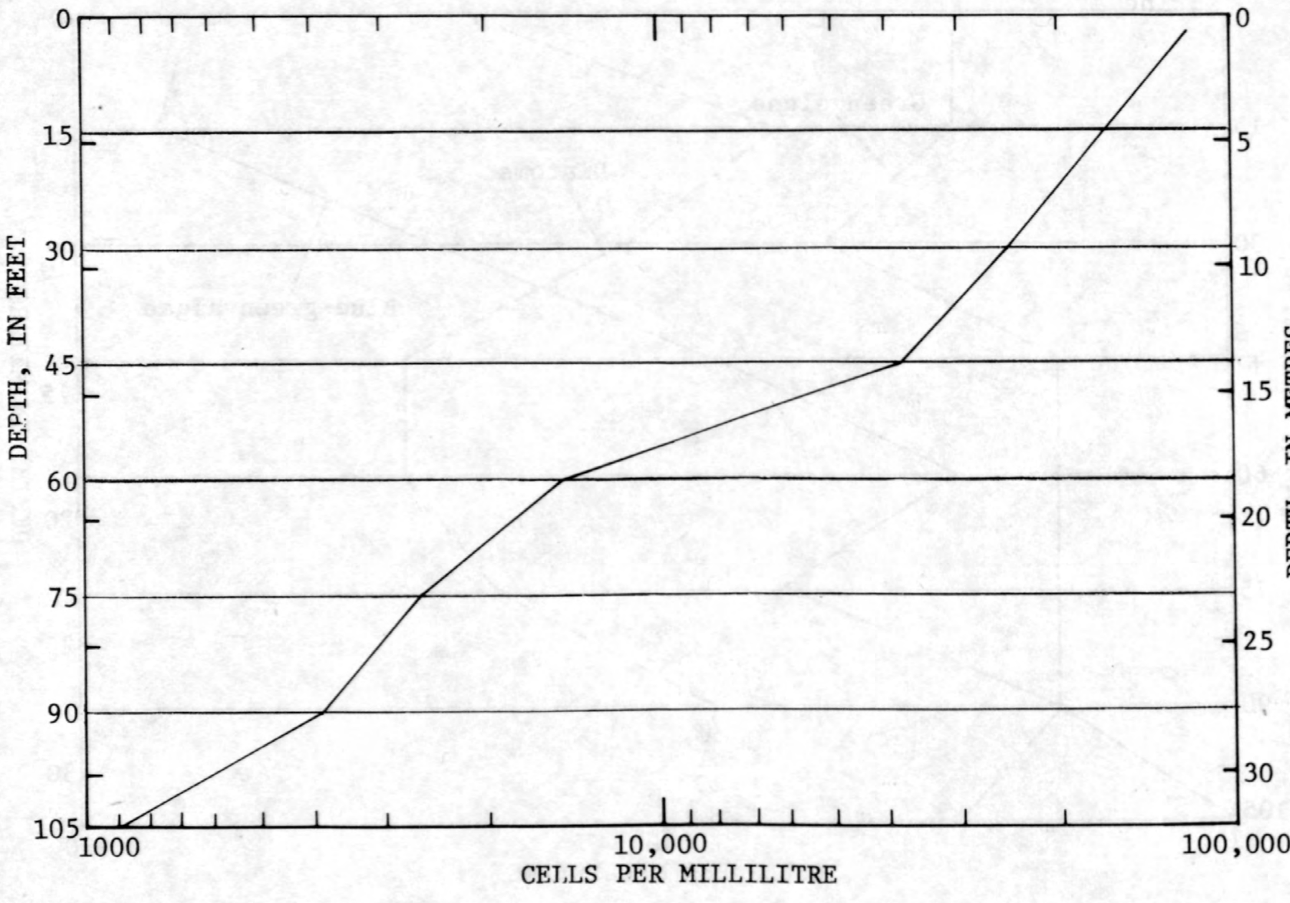


FIGURE 15.--Vertical distribution of the blue-green algae *Anabaena unispora* in area F, May 22, 1972.

Areal Distribution of Algae

The areal distribution of dominant and codominant species of algae throughout the reservoir is somewhat uniform. Table 6 shows that widely separated areas in the reservoir have the same general algal composition, the same dominant species, and generally the same secondary species. Changes in the algal population tend to take place simultaneously over the entire reservoir.

Algal Growth

The control of algal growth in Lopez Reservoir requires a knowledge of the algal growth rate so that an algicide, such as copper sulfate, can be applied at the optimum time. Algal growth follows the growth curve illustrated in figure 16 (Fogg, 1966). For a given algal species the growth pattern consists of an initial, or lag, phase when cell division is rapid, but only a few cells are present. Soon the number of dividing cells increases, and the exponential growth phase begins. This growth phase gives rise to excessive production or so-called algal blooms. The bloom reaches its peak during the stationary, or limiting, growth phase. At this time, the number of cells is large, but cell division has virtually stopped because some factor in the environment, such as nutrients or sunlight, has become limiting. Following the stationary growth phase the algal cells die, and many sink to the reservoir bottom where they are decomposed by bacteria. This bacterial decomposition removes dissolved oxygen from the water.

Ideally, the time to apply an algicide is at the lag-exponential growth junction (fig. 16). Algicide application at this time will lessen the total amount of organic material produced and help control oxygen depletion in the hypolimnion caused by decomposing organic material.

TABLE 6.--*Algal species*

[All samples taken at a depth of 2 ft (0.6 m).

Cell count (cells/ml)	Reservoir area	Primary species	Secondary species
		December 1, 1971	
840	C	*Fragilaria crotonensis* Diatom 87 percent	*Stephanodiscus astraea* Diatom 5 percent
319	F	*Fragilaria crotonensis* Diatom 71 percent	*Stephanodiscus astraea* Diatom 20 percent
633	I	*Fragilaria crotonensis* Diatom 75 percent	*Stephanodiscus astraea* Diatom 22 percent
		January 10, 1972	
494	C	*Fragilaria crotonensis* Diatom 37 percent	*Fragilaria copucina* Diatom 26 percent
571	F	*Fragilaria crotonensis* Diatom 61 percent	*Stephanodiscus astraea* Diatom 21 percent
816	I	*Fragilaria crotonensis* Diatom 75 percent	*Stephanodiscus astraea* Diatom 9 percent
		January 24, 1972	
258	C	*Fragilaria crotonensis* Diatom 60 percent	*Synedra delicatissima* Diatom 12 percent
340	F	*Fragilaria crotonensis* Diatom 60 percent	*Flagellates* 12 percent
845	I	*Fragilaria crotonensis* Diatom 69 percent	*Pandorina morum* Green 11 percent

found in water samples

Location of sampling areas shown in fig. 7]

Tertiary species	Other species
December 1, 1971	
January 10, 1972	
Coleochaeta soluta Green 18 percent	*Pandorina morum* Green 6 percent
Gloeocapsa sp Blue green 10 percent *Synedra delicatissima* Diatom 7 percent	
Gloeocapsa sp Blue green 6 percent *Synedra delicatissima* Diatom 5 percent	
January 24, 1972	
Stephanodiscus astraea Diatom 8 percent	
Synedra delicatissima Diatom 10 percent	*Stephanodiscus astraea* Diatom 8 percent
Stephanodiscus astraea Diatom 8 percent	*Synedra delicatissima* Diatom 6 percent

TABLE 6.--*Algal species found*

Cell count (cells/ml)	Reservoir area	Primary species	Secondary species
		April 17, 1972	
44	C	*Aphanizomenon spp.* Blue green 91 percent	*Fragilaria spp.* Diatom 4.5 percent
85	F	*Aphanizomenon spp.* Blue green 75 percent	*Fragilaria spp.* Diatom 21 percent
171	I	*Anabaena spp.* Blue green 96 percent	*Fragilaria spp.* Diatom 4 percent
		July 31, 1972	
1,537	C	*Polycystis spp.* Blue green 73 percent	*Scenedesmus spp.* Green 12 percent
1,667	F	*Polycystis spp.* Blue green 82 percent	*Aphanizomenon spp.* Blue green 5 percent
3,099	I	*Polycystis spp.* Blue green 96 percent	*Scenedesmus spp.* Green 2 percent
		September 25, 1972	
115	C	*Melosira spp.* Diatom 39 percent	*Polycystis spp.* Blue green 30 percent
215	F	*Melosira spp.* Diatom 67 percent	*Anabaena spp.* Blue green 22 percent
261	I	*Melosira spp.* Diatom 79 percent	*Polycystis spp.* Blue green 13 percent

in water samples--Continued

Tertiary species		Other species	
	April 17, 1972		
Sphaerocystis spp. Green	4.0 percent		
Sphaerocystis spp. Green	4 percent		
	July 31, 1972		
Chlorella spp. Green	8 percent		
Scenedesmus spp. Green	4 percent	*Chlorella spp.* Green	3 percent
Chlorella spp. Green	1 percent		
	September 25, 1972		
Fragilaria spp. Diatom	17 percent	*Anabaena spp.* Blue green	10 percent
Ceratium spp. Flagellate	4 percent		
Fragilaria spp. Diatom	8 percent		

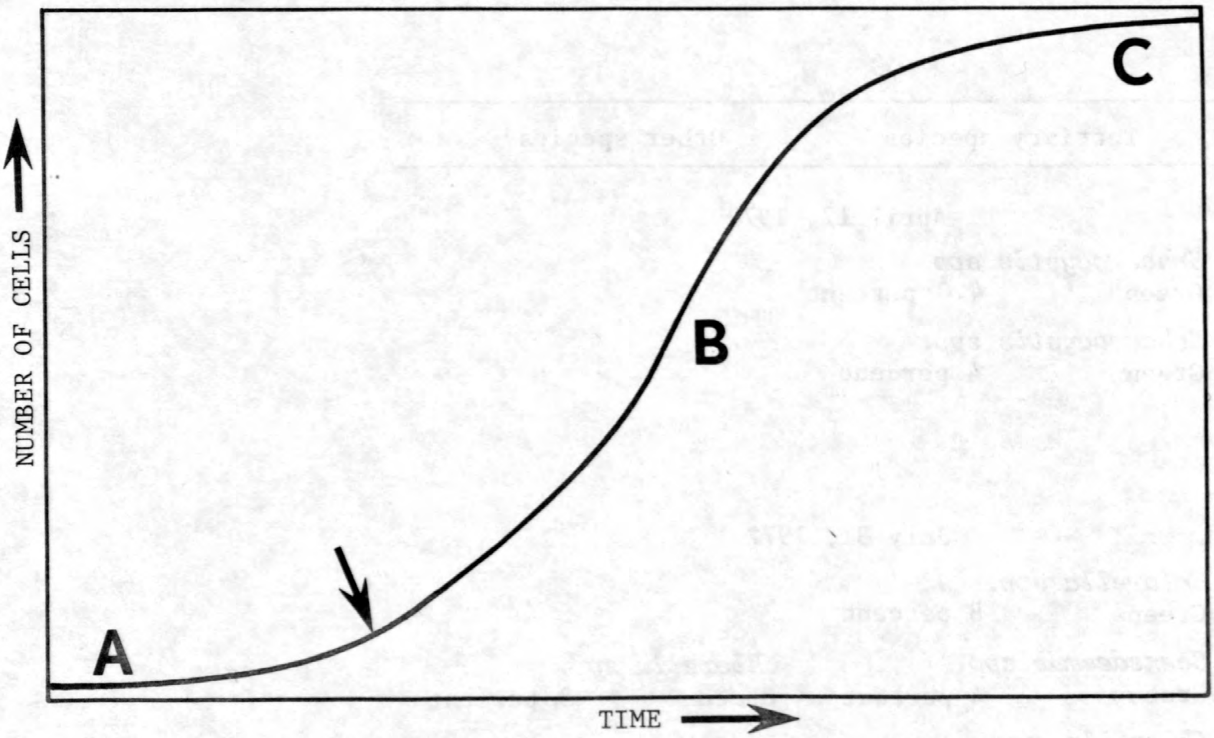


FIGURE 16.--Modified algal growth curve showing the three main growth phases of algal cells. A refers to the initial (lag) phase, B refers to the exponential growth phase, and C refers to the stationary growth phase. Arrow shows lag-exponential growth junction. (Modified from Fogg, 1966)

ALGAL CONTROL

The San Luis Obispo County Flood Control and Water Conservation District is presently attempting to control algal growth with a mixture of copper sulfate and sodium citrate. The mixture is applied uniformly to the water surface from a self-propelled pontoon-supported raft (Lawrance and others, 1971). The raft contains equipment to mix copper sulfate and sodium citrate with water and spray the resulting solution on the water surface.

Water samples are taken weekly from areas A-J for the determination of the number and species of algae present in the reservoir. When high counts of algae are found in an area copper sulfate is applied to the water surface. The rates of application of copper sulfate for areas A and F are given in figures 17 and 18.

The effectiveness of copper sulfate applications, as reflected in algal-growth trends, was plotted for areas A and F. These areas were compared with areas C and I, which were not treated with copper sulfate (figs. 17 and 18). It is evident from the comparison that algal growth in areas that were treated with copper sulfate (areas A and F) shows the same trends as growth in the areas that were untreated (areas C and I). Clearly this indicates that algal growth was not suppressed by the application of copper sulfate. While the results of this study indicate that treatment with copper sulfate is not presently effective in controlling algae in Lopez Reservoir, this does not preclude its future use with some modifications, because many studies have shown that copper sulfate is an effective algicide.

Copper sulfate has been used in the United States to control algae since 1901 (Moore and Kellerman, 1904). It is still one of the more widely used and economical algicides for use in large bodies of water (Moyle, 1949; Sawyer, 1962; and Fair and others, 1968). It is considered to be the most useful algicide for reservoirs (Flentje, 1952, p. 727). There are several advantages to the use of copper sulfate as an algicide. It is relatively inexpensive (McCain, 1970), easy to apply (Whipple, 1914; Goudey, 1936; Nesin, 1954; Monie, 1956; and Makenthum, 1960), and usually effective in concentrations below levels toxic to aquatic animals (Moyle, 1949, p. 79).

The successful control of algae with copper sulfate requires that three important factors be considered (Monie, 1956, p. 392):

1. The correct time to treat the water supply;

2. The correct quantity of copper sulfate to be applied; and

3. Uniform distribution in applying the copper sulfate.

The correct time at which a reservoir should be treated is determined by the concentration of algal cells present in the water. The optimum time for treatment is at the time when the lag-exponential growth junction (fig. 16) is reached. Copper sulfate applications at this time will result in the destruction of the algal population when it still has a small biomass and therefore will contribute only a minimal amount of organic matter to the reservoir bottom. The lag-exponential growth junction may be estimated by plotting algal-cell counts with time as was done in figures 17 and 18. With several such plots, the lag-exponential growth junction can be determined. The cell concentration at this junction may then be used to indicate the correct time for copper sulfate application.

One of the most difficult tasks in controlling algae is the determination of the optimum quantity of copper sulfate to apply. The application of an inadequate quantity is ineffective in controlling algae; any excess from overapplication is wasted. Copper sulfate is not additive in the water column. If an application is inadequate, the next application must be the full amount needed to control the algae.

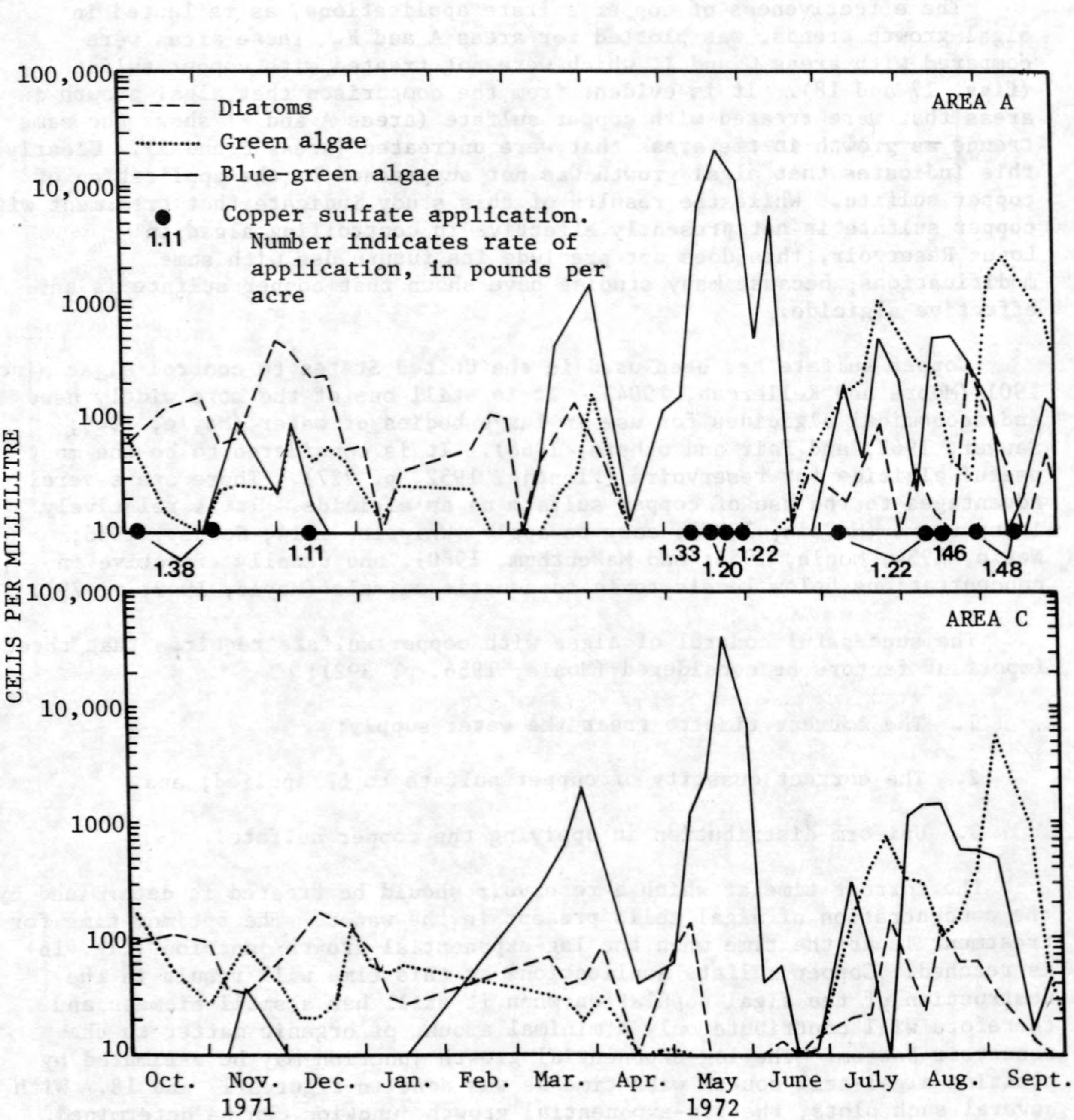


FIGURE 17.--Algal growth in areas A and C and rates of copper sulfate application in area A.

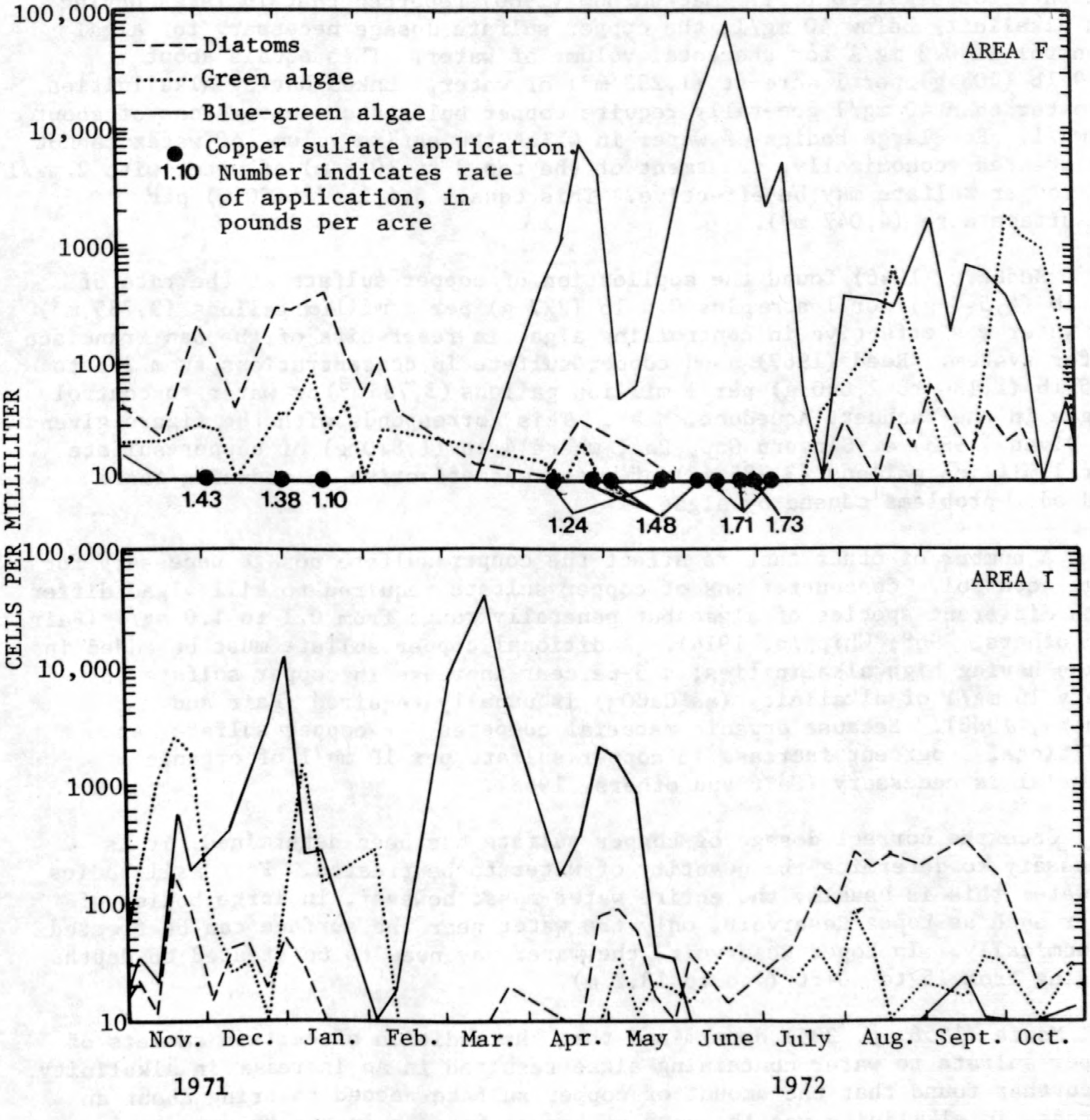


FIGURE 18.--Algal growth in areas F and I and rates of copper sulfate application in area F.

The literature contains numerous guidelines for the application of copper sulfate for algal control. Mackenthum (1960) reported that in lakes having an alkalinity below 40 mg/l, the copper sulfate dosage necessary for algal control is 0.3 mg/l for the total volume of water. This equals about 0.9 lb (408 g) per 1 acre-ft (1,233 m^3) of water. Lakes having alkalinities greater than 40 mg/l generally require copper sulfate concentrations of about 1 mg/l. For large bodies of water in which the entire volume of water cannot be treated economically, treatment of the top 2 ft (0.6 m) of water with 2 mg/l of copper sulfate may be effective. This equals 5.4 lb (2,450 g) per 1 surface acre (4,047 m^2).

Medbery (1946) found the application of copper sulfate at the rate of 10 lb (4,540 g) per 1 acre plus 0.5 lb (227 g) per 1 million gallons (3,785 m^3) of water was effective in controlling algae in reservoirs of the San Francisco water system. Reed (1967) used copper sulfate in concentrations from 2.5 to 4.5 lb (1,130 to 2,040 g) per 1 million gallons (3,785 m^3) of water to control algae in the Wachuett Aqueduct, Mass. This corresponds with the figure given by Diven (1963) at Singers Gap, Pa., where 4 lb (1,810 g) of copper sulfate per 1 million gallons (3,785 m^3) of water was effective in reducing taste and odor problems caused by algae.

A number of other factors affect the copper-sulfate dosage necessary for algal control. Concentrations of copper sulfate required to kill algae differ with different species of algae but generally range from 0.1 to 1.0 mg/l (Fair and others, 1968; Whipple, 1914). Additional copper sulfate must be added in lakes having high alkalinities; a 5-percent increase in copper sulfate for every 10 mg/l of alkalinity (as $CaCO_3$) is usually required (Fair and others, 1968). Because organic material competes for copper sulfate, an additional 2-percent increase in copper sulfate per 10 mg/l of organic material is necessary (Fair and others, 1968).

Once the correct dosage of copper sulfate has been determined, it is necessary to determine the quantity of water to be treated. For small bodies of water this is usually the entire water mass; however, in large bodies of water such as Lopez Reservoir, only the water near the surface can be treated economically. In Lopez Reservoir, the water may need to be treated to depths ranging from 15 to 60 ft (4.6 to 18.2 m).

Monie (1956, p. 395) determined that the addition of certain amounts of copper sulfate to water containing algae resulted in an increase in alkalinity. He further found that the amount of copper sulfate needed to bring about an increase in alkalinity was the correct amount for use in the treatment of algae in lakes and reservoirs. This is the basis for the "Monie Test" for the determination of copper sulfate dosages in the treatment of algae. A detailed description of this test is given in the section "Supplemental Information."

DISCUSSION AND CONCLUSIONS

Stratification of water in Lopez Reservoir influences a number of water-quality parameters during the late spring through autumn months. During this period, thermal stratification separates the reservoir into a surface zone where mixing occurs and a central and bottom zone where virtually no mixing occurs. The predominant result of thermal stratification is the development of an oxygen-deficient zone, caused by bacterial oxidation of organic matter that has settled from the surface or is present in the bottom sediments. When this oxidation occurs, dissolved oxygen is removed from the hypolimnion and the lower section of the metalimnion. Thermal stratification prevents mixing of the oxygenated epilimnion water with the oxygen-deficient hypolimnion and metalimnion.

The lack of oxygen favors the chemical reduction of organic material found in the bottom sediment. As algae die and sink to the lake bottom, they decompose and release nutrients into the hypolimnion. In addition, the bottom sediment in Lopez Reservoir is made up of 10 to 14 percent organic material. This material may decompose and provide a large source of nutrients for algal growth.

Because of thermal stratification, water of the hypolimnion does not mix with water of the epilimnion during the primary algal growing season. The effect of the release of nutrients in the hypolimnion is therefore not immediately expressed in increased algal growth but is delayed until water in the reservoir begins to cool in the autumn and overturn begins. At this time, the water of the hypolimnion mixes with the rest of the water in the reservoir. This results in the enrichment of the overall water body with respect to the nutrients that were released in the hypolimnion during the period of thermal stratification.

The development of reservoir stratification also affects a number of other chemical parameters, such as alkalinity, pH, and conductivity, that change with depth across the thermocline.

The Secchi disk transparency measurements taken during this study show a seasonal variation in the transparency of the reservoir water. A comparison of the Secchi disk transparencies (fig. 12) with the trends in algal growth (figs. 17 and 18) indicates that there is a strong relation between algal population and water transparency. The highest values of Secchi disk transparency, about 28 ft (8.5 m), occur during October when the algal community has the lowest density, about 30 cells/ml of water. Conversely, the lowest Secchi disk values, as low as 4.3 ft (1.3 m), were recorded during the mid-July through mid-September period and the mid-May period when the algal community had densities exceeding 100,000 cells/ml of water. Therefore, the transparency of water in Lopez Reservoir may be largely controlled by the algal population in the reservoir.

The major problem plaguing the operation of Lopez Reservoir is algal production. This production is esthetically displeasing and reduces recreational activities in the reservoir area. The algae, by depleting the dissolved oxygen, may also have been responsible for periodic fishkills that have occurred in the reservoir. During periods of darkness, algal respiration removes dissolved oxygen from the reservoir water. When the algal community is extremely large, as during bloom periods, the use of oxygen during periods of darkness may deplete the epilimnion of oxygen and result in the death of fish. The large algal populations also cause taste and odor problems in water that is used for domestic purposes.

Lopez Reservoir has a large algal population for a number of reasons. These include an abundance of nutrients, especially nitrogen and phosphorus, relatively warm water, and clear skies during the summer months, which result in high light intensities. Nitrogen and phosphorus do not seem to be a limiting factor in algal growth.

Lake bottom sediments may be a large potential source of nutrients in the reservoir. These nutrients could contribute to the development of large algal populations.

From figures 17 and 18 it is evident that algal populations show a periodic growth pattern in which the exponential growth phase is followed by an exponential drop. Applications of copper sulfate, as shown in area A (fig. 17) and in area F (fig. 18) do not significantly affect algal-growth trends. The growth, in many instances, remains exponential even after the application of the copper sulfate. Moreover, similar growth trends occur in treated and nontreated areas. It is evident that present copper sulfate treatments are ineffective in controlling algal growth. Because the present doses of copper sulfate are not controlling algae, the Monie test ("Supplemental Information") may be used to determine the proper doses of copper sulfate.

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SUPPLEMENTAL INFORMATION

The Monie Test for Determining the Correct Amount of Copper Sulfate to Control Algal Growth

(From W. D. Monie, 1956, p. 395)

Explanation of the Monie Test

Equipment and Reagents

"The equipment and chemicals necessary for the test are:

a. Six 50 ml Nessler tubes.

b. A copper sulphate solution of a strength so that 2 ml added to a liter of water equals a copper sulphate treatment of 1.0 lb per mil gal.

c. Phenolphthalein indicator.

d. NaOH solution, 0.01136 N.

"To make the copper sulphate solution mentioned in item b, dissolve 0.6 gram of the commercial copper sulphate used for treatment in 1 liter of distilled water. Dilute 100 ml of this solution to 1 liter with distilled water. Two ml of this final solution per liter equals 1.0 lb of $CuSO_4 \cdot 5H_2O$ per mil gal or 0.1 ml per 50 ml of sample equals one pound of copper sulphate crystals per mil gal.

Test Procedure

"Place 50 ml samples of the water to be treated in each of six 50 ml Nessler tubes A, B, C, D, E, and F. To tube A, add 0.1 ml of copper sulphate solution (b) to equal a treatment of 1.0 lb per mil gal.; to tube B, add 0.2 ml of solution (b); to tube C, add 0.3 mil of solution (b); to tube D, add 0.4 ml of solution (b); to tube E, add 0.5 ml of solution (b). To tube F, no copper sulphate is added. Tubes A, B, C, D, E now contain, respectively, copper sulphate dosages equal to 1.0, 2.0, 3.0, 4.0, and 5.0 lb per mil gal. These samples are then mixed by corking and inverting approximately thirty times simultaneously.

"To the Nessler tube F (the blank sample) phenolphthalein indicator is added. If there is a negative amount of free carbon, enough indicator is added until there is a faint but distinct pink color. Then the same amount of phenolphthalein is added to each of the other samples. The samples are compared and the tube with the deepest color is the tube containing the sample to which has been added the correct amount of copper sulphate to use in treating.

Influence of Carbon Dioxide

"If there is free carbon dioxide present (and there usually is), three drops of phenolphthalein are added to each of the six samples in the Nessler tubes after they have been mixed with the various amounts of solution (b) as described above. Then 0.01136N sodium hydroxide is added to the Nessler tube F (the blank sample) until there is a faint but distinct pink color. The same amount of the sodium hydroxide is then added to the other five samples and the tubes are compared for color. The deepest color will be found to be in the tube containing the sample to which the most effective and economical amount of copper sulphate to use in treating has been added.

"This test is practically the same as a free carbon dioxide titration. However, in the algae test it is simpler to have both the phenolphthalein and the sodium hydroxide in dropper bottles, as the equal amounts can be easily added to the sample tubes by counting drops. The 0.01136N sodium hydroxide concentration is used simply because finer control can be maintained on the color. In waters with considerable carbon dioxide, 0.02272N can be used just as effectively.

"It is important to note that the tube with the deepest color is always darker than the blank sample...."

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