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Limnological Study of Lake Shastina Siskiyou County California

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·CUMULATIVE DEPARTURE CURVE···ANALOG MODEL···PHOTOSYNTHES

U.S. DEPARTMENT OF THE INTERIOR
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16. Abstracts
Surface water constituted more than 90 percent of the approximately 50,000 acre-foot inflow to Lake Shastina in the 1972 water year. Annual changes in the quantity of water in storage in the lake are related mainly to variations in annual inflow. The lake is thermally stratified from spring through autumn. Water near the surface was supersaturated with oxygen while an acute dissolved-oxygen deficiency existed at depth. Nitrogen and phosphorus in solution are partly stratified during thermal stratification. Algal types consisted mainly of green algae and diatoms. Blue-green algae were absent most of the year. Benthic organisms were primarily Oligochaete, Chironomidae, and Chaoborus, all of which are adapted to a low dissolved-oxygen environment. Nitrogen and phosphorus concentrations in the lake are sufficient to support large algal blooms. Recent development of shoreline properties may accelerate the eutrophication of the lake.

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LIMNOLOGICAL STUDY OF LAKE SHASTINA

SISKIYOU COUNTY, CALIFORNIA

LAKE SHASTINA

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SISKIYOU COUNTY, CALIFORNIA

By Alex E. Dong, Kenneth W. Beatty, and Robert C. Averett

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 19-74

Prepared in cooperation with
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and Water Conservation District

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MARCH 3, 1849

November 1974

UNITED STATES DEPARTMENT OF THE INTERIOR

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CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

Factors for converting English units to the International System of Units (SI) 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.

English	*Multiply by*	*Metric (SI)*
acre-ft (acre-feet)	1.233 x 10^{-3}	hm^3 (cubic hectometres)
ft (feet)	3.048 x 10^{-1}	m (metres)
ft^2/s (cubic feet per second)	2.832 x 10^{-2}	m^2/s (cubic metres per second)
in (inches)	2.540	cm (centimetres)
	2.540 x 10^{-1}	mm (millimetres)
in^2 (square inches)	6.452	cm^2 (square centimetres)
lb (pounds)	4.535 x 10^{-1}	kg (kilograms)
mi (miles)	1.609	km (kilometres)
mi^2 (square miles)	2.590	km^2 (square kilometres)
°F (degrees Fahrenheit)	(°F-32)/1.8	°C (degrees Celsius)

LIMNOLOGICAL STUDY OF LAKE SHASTINA, SISKIYOU COUNTY, CALIFORNIA

By Alex E. Dong, Kenneth W. Beatty, and Robert C. Averett

ABSTRACT

Lake Shastina provides water for irrigation in Shasta Valley, as well as recreation. Presently, its shoreline is being developed for summer homes. Surface water constituted more than 90 percent of the approximately 50,000 acre-foot (62-cubic hectometre) inflow to Lake Shastina in the 1972 water year. Controlled outflow is via the Montague Main Canal; however, leakage from the lake through volcanic rocks to the northwest was estimated to be greater than the measured outflow. Appreciable annual changes in the quantity of water in storage in the lake are related mainly to variations in annual inflow.

From June through August the lake was thermally stratified. In the spring and summer the epilimnion was often supersaturated with oxygen, while at the same time the hypolimnion was undersaturated and often devoid of dissolved oxygen. Vertical stratification of carbon dioxide, carbonate, bicarbonate, hydrogen ion, nitrogen, and phosphorus was also recorded during the spring and summer. Orthophosphate, total phosphorus, and total nitrogen concentrations (organic, ammonium, and nitrate) were highest in the hypolimnion during the period of thermal stratification.

Ten-inch (25-centimetre) core samples from the reservoir bottom were chemically analyzed at 0.8-inch (2-centimetre) intervals. The concentrations ranged from 6.3 to 28.9 milligrams per gram of iron, 0.07 to 0.43 milligrams per gram of manganese, 0.4 to 2.7 milligrams per gram of organic nitrogen plus ammonium, and 0.06 to 1.3 milligrams per gram of total phosphorus. Organic matter in the cores ranged from 4 to 14 percent.

Green algae and diatoms were the dominant algal types, reaching maximum concentrations of about 7 and 30 million cells per litre, respectively. These phytoplankton occurred near the surface during thermally stratified periods, but were distributed at greater depths during nonthermally stratified periods. Blue-green algae were present only in the spring samples, and reached a maximum concentration of about 5 million cells per litre.

Zooplankton numbers were greatest in March, July, and September, with lesser concentrations in June. Three major zooplankton groups, Cladocera, Copepoda, and Rotifera, were present. The major groups of benthic organisms were Oligochaeta, Chironomidae, and Chaoborus, with numbers ranging from 3350, 890, and 8450 per square metre, respectively.

A discussion on algal control is included.

INTRODUCTION

Increased use of lakes and reservoirs for recreation, as well as for urban shoreline development, has emphasized the need for intensive water-quality studies and management. Although all lakes and reservoirs ultimately undergo enrichment (eutrophication), the process is hastened by man's activities. Accelerated eutrophication frequently results in excessive algal production, with attendant problems of taste and odor, anaerobic conditions in the bottom waters, and impairment of the esthetic value of the lake or reservoir.

Lake Shastina in Siskiyou County, Calif., is used to store water for irrigation and as a recreational lake. In recent years, the recreational use of the reservoir has increased, and shoreline development in the form of summer homes and cabins has taken place. Because of frequent algal blooms during summer and subsequent decomposition of algae, the recreational attractiveness of Lake Shastina is impaired. To maintain or improve recreational values, an assessment of the lake's present water quality and enrichment status is needed.

Recognizing the need for a water-quality study, the Siskiyou County Flood Control and Water Conservation District requested in 1971 that the U.S. Geological Survey conduct a limnological reconnaissance of the lake. The purposes of the study include determination of: (1) The general physical, chemical, and biological characteristics of Lake Shastina, (2) the present enrichment condition of the lake, (3) the annual amount of water entering or leaving the lake, and (4) an assessment of the available algal control methods applicable to Lake Shastina.

To meet the requirements of the study, selected physical, chemical, and biological measurements were made at two and sometimes three sampling stations in the lake, two stations in major inlets, and at the lake outlet. Field-data collection began in August 1971 and ended in September 1972.

DESCRIPTION OF LAKE SHASTINA AND DRAINAGE BASIN

Lake Shastina (formerly known as Dwinnell Reservoir) was formed in 1928 by the construction of Dwinnell Dam on the Shasta River. The lake lies in the southeastern part of Shasta Valley about 6 mi (10 km) north of the town of Weed (fig. 1). The lake has a full-pool operating altitude of 2,800 ft (853 m) and an unregulated spillway at 2,805 ft (855 m) above mean sea level. The major inlets are Shasta River and Garrick Creek. The main outlet is Montague Main Canal.

Table 1.--*Selected morphometric features*

[Dimensions are referenced to a full-pool altitude of 2,800 feet]

Dimensions	Value
Area	
Drainage area	117 mi^2
Surface area	2.85 mi^2
Main axis (extends from south-southwest to north-northeast)	3.8 mi
Width	
Maximum width	1.5 mi
Mean width	.8 mi
Depth	
Maximum depth	65 ft
Mean depth	22 ft
Volume	41,300 acre-ft
Length of shoreline	13.5 mi

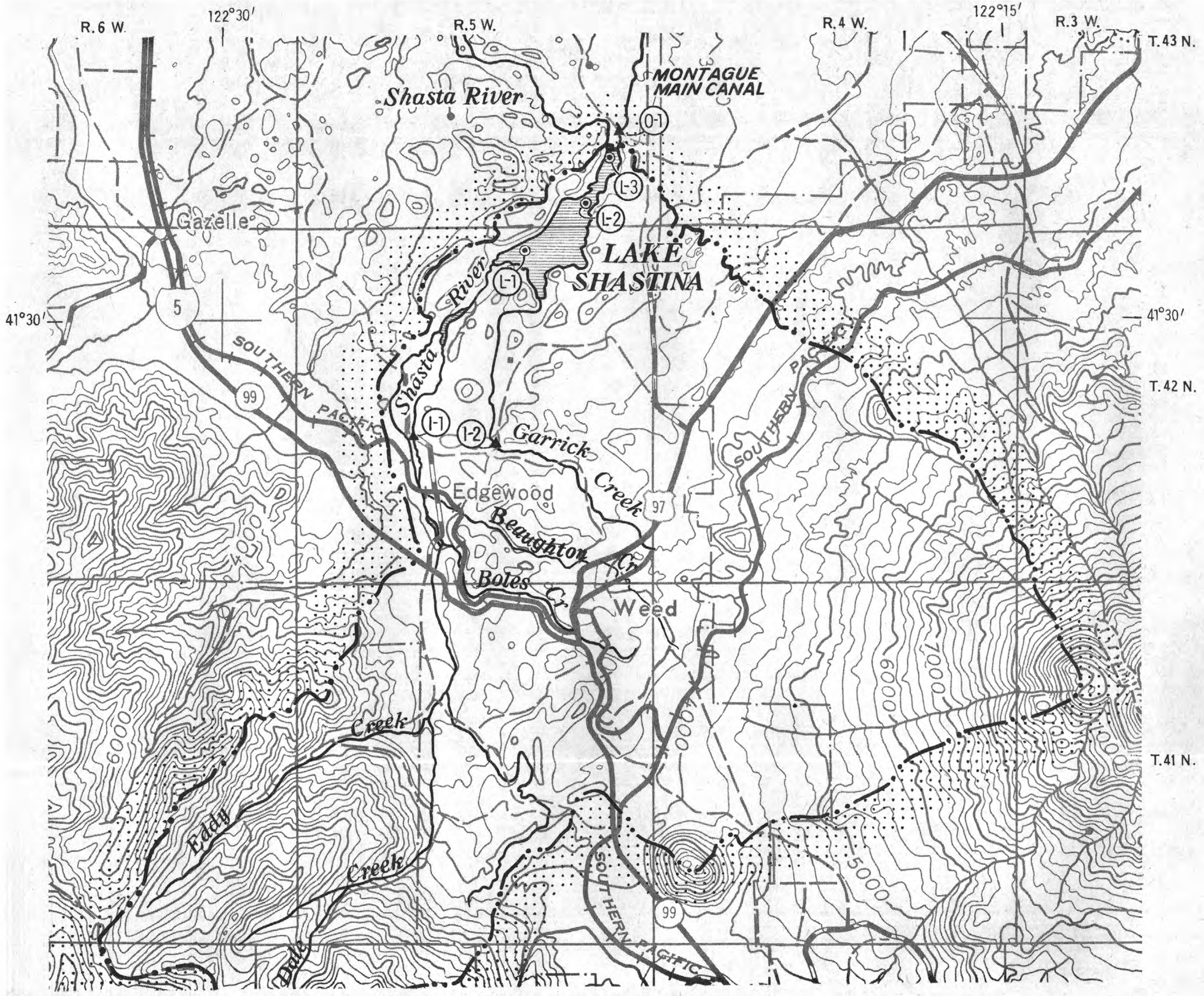
Selected morphometric features of Lake Shastina are listed in table 1. The widest and shallowest part of the lake lies in the southwest where the Shasta River is forming a delta. The lake gradually becomes deeper toward Dwinnell Dam, where it reaches its maximum depth of 65 ft (20 m) (fig. 2). Although a bathymetric map is not available, topographic contours of the lake basin (fig. 2) were prepared before the construction of the dam in 1928. Three profiles of the lake bottom, obtained during the present study by sounding, closely agree with contours shown in figure 2.

The 117-mi^2 (303 km^2) drainage area tributary to the outlet of Lake Shastina is at the southern end of Shasta Valley. The geology of Shasta Valley was described by Mack (1960) and California Department of Water Resources (1961, p. 11). The east and southeast shore of the reservoir consists mainly of morainal and fluvioglacial deposits; along the northwest side, the shore is formed by volcanic ridges. Dominant terrestrial vegetation includes scattered pines, junipers, bitterbrush, and sagebrush.

Land use within the drainage area includes agricultural, urban, and suburban uses. Agricultural lands are mainly irrigated pasture. The cities of Weed and Edgewood are in the drainage basin.

Lake Shastina holds irrigation water for Montague Water Conservation District. During each irrigation period (May to October), water is conveyed by canal from the lake to the service area that lies mainly in the vicinity of Montague, about 15 mi (24 km) north of Lake Shastina. As a result of irrigation discharge and subsequent reservoir drawdown, several feet of lake shoreline exposure is common in the summer.

Prior to 1968, recreational facilities at Lake Shastina were few although the lake was open for public use. The establishment of a large real estate subdivision on the southeast shore of the lake in 1968 has resulted in improved roads to the lake and the construction of recreational facilities such as overnight lodging, campgrounds, a swimming lagoon, and a marina.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Garrick Creek
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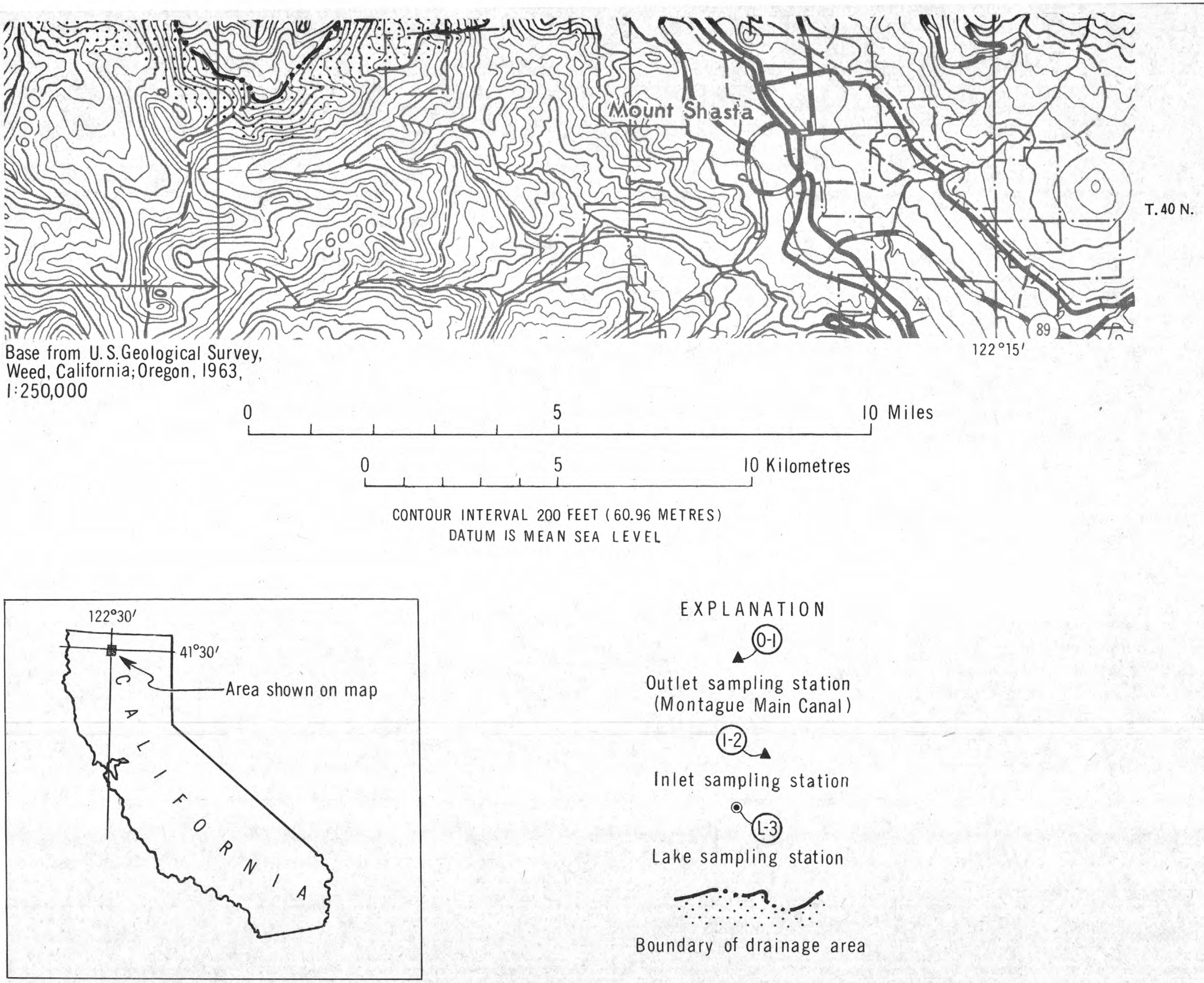
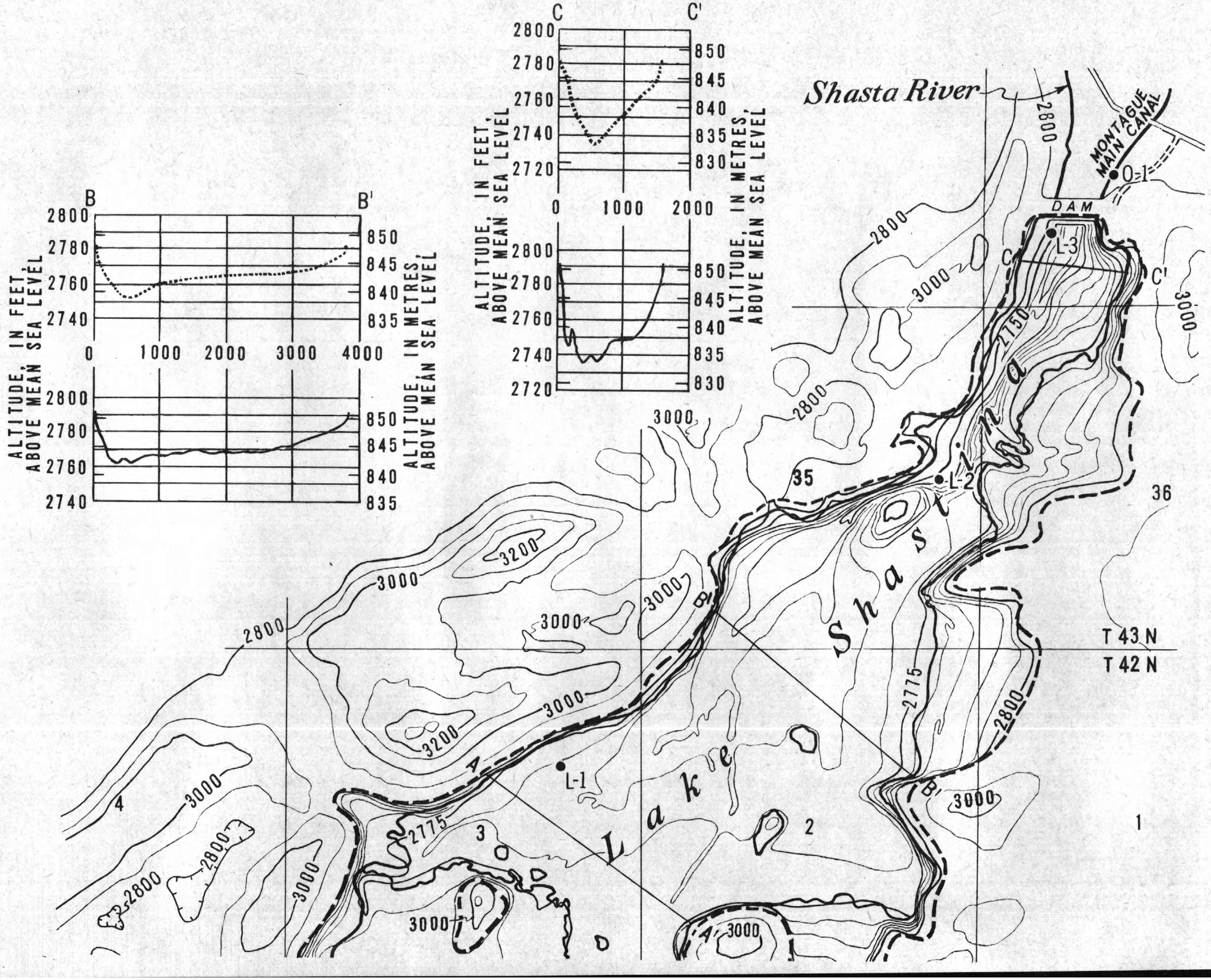


FIGURE 1.--Index map.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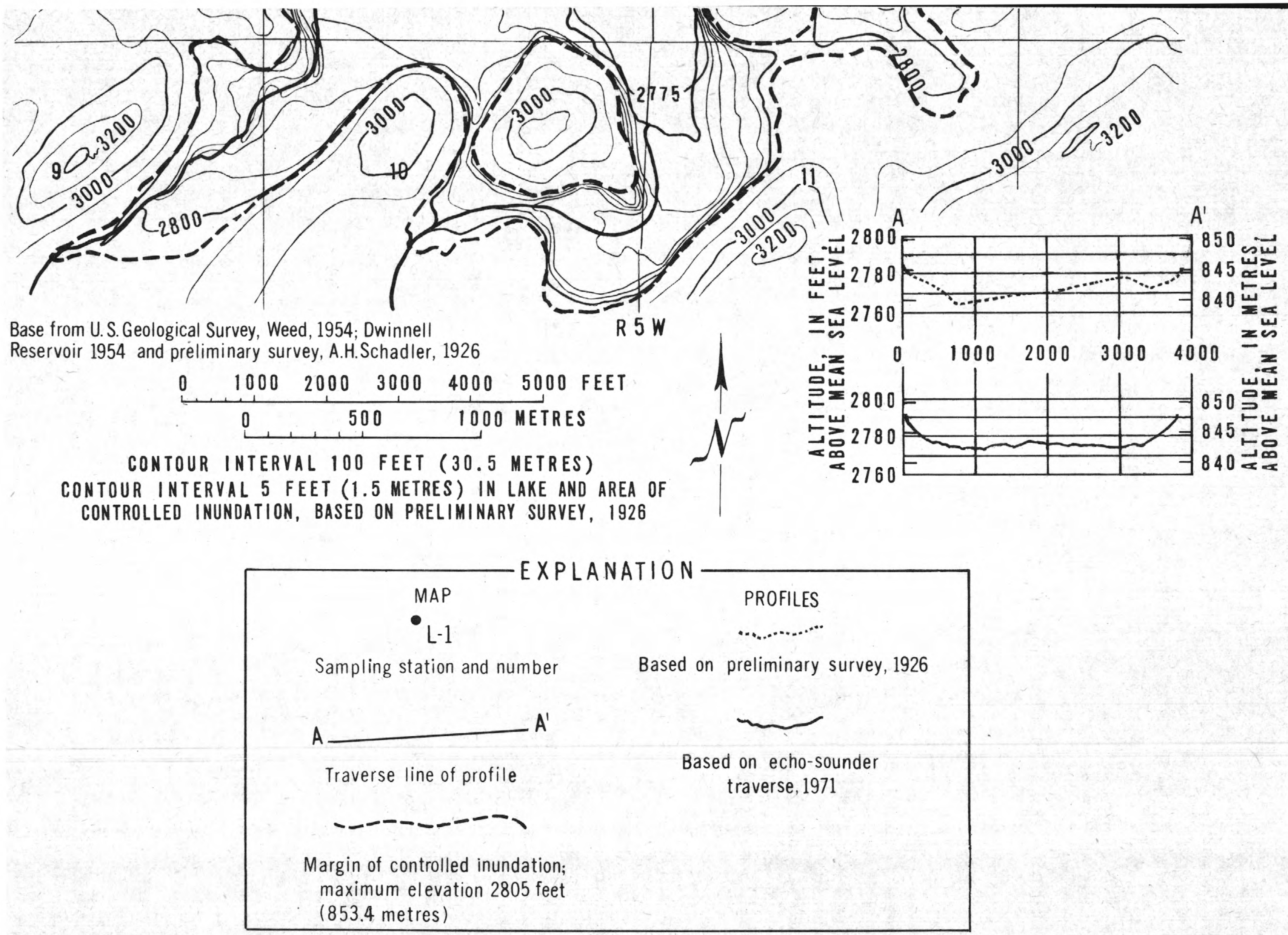


Base from U.S. Geological Survey, Weed, 1954; Dwinnell Reservoir 1954 and preliminary survey, A.H. Schadler, 1926

CONTOUR INTERVAL 100 FEET (30.5 METRES)
CONTOUR INTERVAL 5 FEET (1.5 METRES) IN LAKE AND AREA OF CONTROLLED INUNDATION, BASED ON PRELIMINARY SURVEY, 1926

FIGURE 2.--Lake Shastina and vicinity.

The number of dwellings on the shore of Lake Shastina increased from almost none in 1970 to 60 in 1972. The dwellings are mostly condominiums and chalets and are used either for permanent residence or for temporary housing during the summer. Domestic sewage is piped to septic tanks or settling ponds. Recreational uses of the lake, such as water sports and fishing, have increased rapidly in recent years. An average daily use of 250 man-days was reported for the summer of 1972.

The climate of the Lake Shastina drainage basin is a dry-summer subtropical type. The modest amount of precipitation occurs in the winter and early spring. The wet season extends from October to April. Air temperatures exceeding 100°F (37.8°C) are frequently recorded. A prevailing southwest wind on the lake is normal in the summer. Winters are usually mild with some snowfall, and at times freezing.

Mean annual precipitation on the surface of Lake Shastina is about 16 in (41 cm) (California Region Framework Study Committee, 1971, map 21). However, the mean annual precipitation in the drainage basin varies widely from south to north, ranging from about 50 in (130 cm) near the southern end of the drainage basin to about 18 in (46 cm) near the southeast shore of Lake Shastina. Mean annual evaporation from the lake was estimated to be 41 in (100 cm) (California Region Framework Study Committee, 1971, p. 7).

METHODS

Samples were collected for physical, chemical, and biological analysis on a regular schedule at six stations established in the study area. Two sampling stations, I-1 and I-2, were in the lake inlets, Shasta River and Garrick Creek. Three sampling stations were established in Lake Shastina, one near the mouth of the Shasta River where the lake is shallow (L-1), one at midlake (L-2), and one near the dam (L-3). A single sampling station was established in Montague Main Canal which is the controlled outlet (0-1) immediately downstream from the dam. All sampling stations are shown in figure 1 and table 2.

The frequency of sample collection and measurements was monthly in August, September, and December 1971, and January, March, and May-September 1972.

Table 2.--*Sampling stations*

Station number[1]	USGS reference number	Altitude	Drainage area (mi^2)	Station name
I-1	11-5167.50	2,960	70.3	Shasta River near Edgewood
I-2	11-5167.70	3,040	8.18	Garrick Creek near Edgewood
L-1	11-5167.92	[2]2,800	117	Lake Shastina sampling point No. 1, near Edgewood
L-2	11-5167.96	[2]2,800	117	Lake Shastina sampling point No. 2, near Edgewood
L-3	11-5167.98	[2]2,800	117	Lake Shastina sampling point No. 3, near Edgewood
O-1	11-5167.90	[3]2,750	--	Montague Main Canal below Dwinnell Dam, near Edgewood

[1] See figure 1 for location of stations.
[2] Full-pool altitude.
[3] Approximate.

Physical Measurements

The water budget for Lake Shastina was approximated by using the equilibrium equation:

$$\Delta S = I_S + I_G + I_P - O_S - O_E - O_L$$

Where: ΔS = annual change of lake storage

I_S = surface-water inflow

I_G = ground-water inflow

I_P = direct precipitation on lake surface

O_S = surface outflow

O_E = evaporation loss from lake surface

O_L = ground-water leakage

Data on the annual change of lake storage were furnished by the California Department of Water Resources from a continuous recorder installed near the dam. Surface-water inflow was determined for the major inlets (Shasta River and Garrick Creek). Surface inflow from Shasta River was obtained from the continuously gaged station, Shasta River near Edgewood (station I-1). Runoff at the Garrick Creek station (I-2) was estimated from 10 periodic instantaneous discharge measurements (Corbett and others, 1943), and comparison with the continuous stage records from the Shasta River station. Data on surface outflow from the lake into Montague Main Canal were provided by the California Department of Water Resources.

Ground-water inflow was calculated from estimated transmissivity of glacial debris on the east side of the lake, the length of the interface along the shore that ground water crosses in transit to the lake, and the hydraulic gradient in the water table, using a form of Darcy's law (Todd, 1959, p. 46). Direct precipitation on the lake and evaporation were estimated by using the long-term averages provided by the California Region Framework Committee (1971, map 21 and p. 7). Ground-water leakage was estimated as a residual.

Temperature of the lake was measured at two lake stations (L-1 and L-3) using a thermistor, and at two tributary stations (I-1, I-2) and the outlet station (O-1) with a hand-held thermometer. In the lake, temperature was measured at approximately 3-ft (1-m) depth intervals from the surface to the bottom.

Light penetration in the lake (at stations L-1 and L-3) was measured with a Secchi disk having a diameter of 8 in (20 cm) (Welch, 1948, p. 159).

Profiles of the lake bottom (fig. 2) were made in August 1971 using an echo sounder. Topographic contours of the lake basin before dam construction were obtained from the files of the Montague Water Conservation District.

Chemical Measurements

Field measurements of dissolved oxygen, specific conductance, pH, and alkalinity were made at stations L-1 and L-3 at about 3-ft (1-m) depth intervals from surface to bottom. Measurements were made using the techniques described by Brown and others (1970).

Water samples for major chemical constituents were collected at stations L-1, L-2, and L-3 with a PVC (polyvinyl chloride) sampler. Samples were collected only near the surface and bottom in August 1971 at L-2 and January 1972 at L-1 and L-3. Additional samples were collected from the two inlets (Shasta River and Garrick Creek) and the lake outlet (Montague Main Canal) in August 1971 (stations I-1, I-2, and O-1). All samples were analyzed by the U.S. Geological Survey chemical laboratory in Salt Lake City, Utah, using the methods given in Brown and others (1970).

Water samples for selected plant nutrients, nitrate plus nitrite, ammonium, total Kjeldahl nitrogen (ammonium plus organic nitrogen) and ortho- and total phosphorus were collected at stations L-1, L-3, I-1, I-2, and O-1. Selected plant-nutrient samples were collected from two tributaries to the Shasta River, Boles Creek and Beaughton Creek (fig. 1), in August 1971 and March 1972. Lake samples were collected near the surface and near the bottom with a PVC water sampler. The samples were chilled immediately after collection and preserved by the addition of 1 ml (millilitre) mercuric chloride solution per 250 ml of sample. The mercuric chloride solution contained 40 mg (milligrams) of mercury per litre. The water samples were packed in ice and shipped to the U.S. Geological Survey chemical laboratory in Salt Lake City, Utah, for analysis, using the techniques in Brown and others (1970).

Three core samples from the lake bottom, at stations L-1, L-2, and L-3, were collected in April 1972. The samples were obtained with a gravity-operated sampler that cut a vertical core 10 in (25 cm) deep and 1.4 in (3.5 cm) in diameter. After retrieval from the lake, the core was immediately chilled in an upright position. Cores were subsequently frozen prior to shipment to the laboratory for analysis of particle size, loss on ignition (organic matter), total phosphorus, iron, and manganese. Core analyses were made using methods described by H. P. Guy and others (written commun., 1960), Brown and others (1970), and Anderson and Jenne (1970). The cores were analyzed for various constituents at 0.8-in (2-cm) intervals.

Biological Measurements

Water samples for phytoplankton analyses were collected at stations L-1 and L-3 with a PVC water sampler. Samples were collected mostly at 0-, 7-, 16-, and 33-ft (2-, 5-, and 10-m) intervals. Immediately after collection, the samples were preserved with 1 ml of Lugol's solution (Slack and others, 1973, p. 73). In the laboratory, the organisms were counted and the codominant organisms were identified to genus, and, when possible, to species, using the inverted microscope method (Utermöhl, 1958, and Slack and others, 1973, p. 72).

Water samples for zooplankton analyses were collected at stations L-1 and L-3 with a number 20 mesh (0.84-mm opening) closing net (Slack and others, 1973, p. 79-80). Samples were collected near the surface, in the upper metalimnion, and near the bottom. After collection, the samples were preserved in a 5-percent formaldehyde solution. Laboratory analysis of the zooplankton consisted of identifying the three codominant organisms and making total counts. The methods given in Carlson (1968) and Slack and others (1973) were followed.

Benthic macroinvertebrate samples were collected at stations L-1 and L-3. One sample was collected at each station during each visit, using an Ekman dredge with a jaw opening of 36 in^2 (232 cm^2). Upon retrieval of the dredge, samples were placed in containers and preserved with a 5-percent formaldehyde solution. In the laboratory, the samples were sorted by the sugar flotation method (Beatty, 1968). Organisms that did not pass through a U.S. Standard no. 30 sieve (0.589-mm space) were identified and counted.

RESULTS

Field measurements and water-sample collection for laboratory analysis of chemical and biological constituents took place during daylight hours. Therefore, the results cannot be extrapolated to describe diel conditions of nonconservative constituents (altered biologically or at the boundaries) such as dissolved oxygen, pH, alkalinity, and carbon dioxide.

Water Budget

Surface water is the dominant element of inflow in the water budget (fig. 3) for Lake Shastina. More than 90 percent of the inflow to the lake, during the 1972 water year (October 1, 1971 to September 30, 1972) came from the Shasta River and Garrick Creek. Most of the surface-water inflow occurs during winter and spring. About 80 percent of the runoff recorded in the 1972 water year at the gaging station on the Shasta River near Edgewood (table 3) occurred between December 1971 and April 1972.

The quantities of water from precipitation on the lake surface and from ground-water underflow into the lake are small relative to surface-water inflow. They total less than 10 percent of the water budget for the 1972 water year.

Surface-water outflow from the lake is controlled via the Montague Main Canal and used for irrigation. In the estimated water budget for the 1972 water year, surface water constituted about 40 percent of outflow.

Water lost by evaporation from the 2.85-mi^2 (7.38 km^2) area of the lake surface was estimated to be about 6,000 acre-ft (7.40 hm^3). Evaporative losses are 5 to 10 percent of the annual outflow during most years.

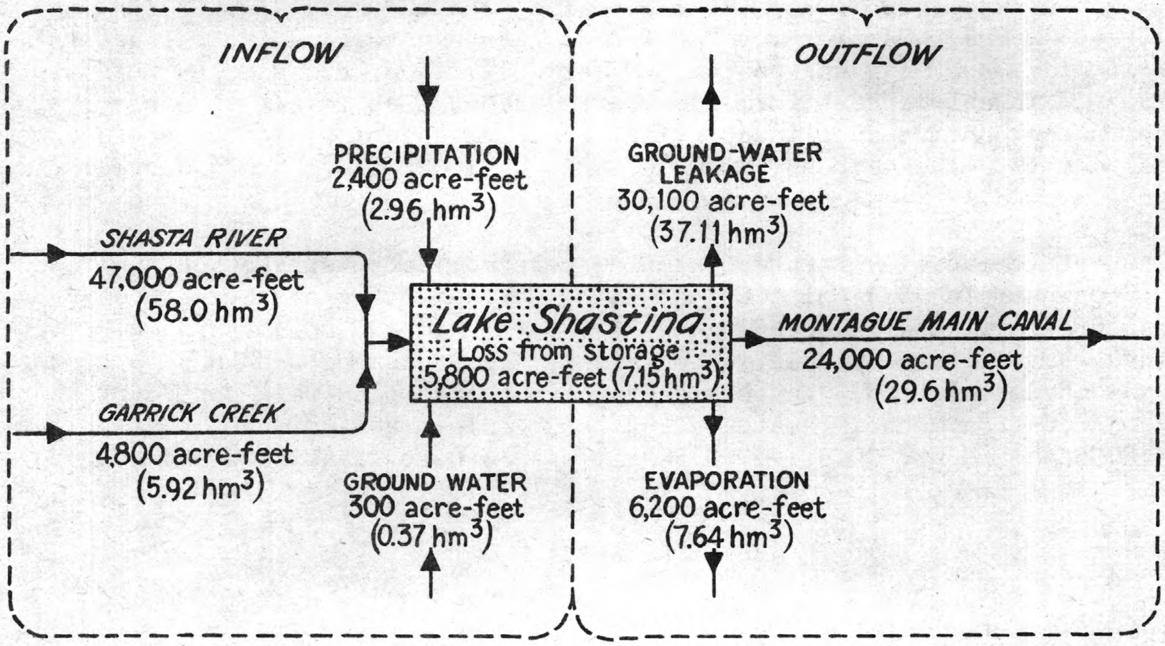


FIGURE 3.--Estimated water budget of Lake Shastina, 1972 water year.

Table 3.--*Monthly runoff at Shasta River near Edgewood*

Water year	Runoff, in acre-ft											
	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.
1953	841	1,644	6,121	13,400	4,854	5,127	6,853	8,555	6,889	3,041	495	571
1954	1,242	6,914	4,338	6,869	8,075	6,807	7,363	7,222	2,251	344	728	910
1962	1,152	2,608	4,925	2,971	8,396	5,720	6,801	4,647	2,713	496	346	480
1963	9,330	5,498	11,730	6,411	16,570	6,046	10,800	7,732	3,586	942	[1]800	[1]900
1964	1,458	5,508	4,118	5,576	3,517	2,473	1,402	2,110	3,168	552	284	451
1965	1,294	2,039	27,600	9,909	5,722	4,502	9,854	6,048	3,570	1,122	795	558
1966	1,605	6,885	3,925	9,656	4,614	7,819	6,411	3,604	1,484	408	346	540
1967	886	8,148	10,490	7,543	5,435	9,945	7,976	[1]17,590	10,110	1,830	464	373
1972	1,650	3,170	3,960	7,460	5,800	12,280	5,050	3,260	2,640	563	297	895

[1] Estimated.

Ground-water leakage has been a problem since the reservoir was first filled. Paulsen (1963) reported on the problem but did not present figures on the quantity of water lost by leakage. Leakage occurs mainly along the northeastward-trending ridge that forms the western shore of the lake. Closely spaced fractures in the andesite that forms the ridge provide accessible routes for water flow. Leakage from the lake caused the occurrence of numerous springs in the valley of Park Creek along the western base of the ridge. Two constantly flowing springs with flow rates of 2.7 and 6.0 ft^3/s (0.08 and 0.17 m^3/s) in the area were reported by Mack (1960, p. 58-59).

Annual storage change in Lake Shastina has varied considerably from year to year (table 4). The major cause of storage changes has been annual fluctuations in surface-water inflow. The effect of other factors on the quantity of water in storage has been less significant because they are small relative to surface-water inflow or are nearly constant.

Table 4.--*Annual runoff, lake release, and change in storage*

Water year	Annual runoff (acre-ft)		Annual release to Montague Main Canal (acre-ft)	Annual change in lake storage (acre-ft)
	Shasta River near Edgewood[1]	Garrick Creek near Edgewood		
1953	58,400		--	-50
1954	53,100		26,600	-5,900
1962	41,300		22,500	-4,700
1963	80,300		--	--
1964	30,600		24,700	-12,400
1965	73,000		24,200	+14,400
1966	47,300		30,600	-11,200
1967	80,800		26,000	+14,400
1968	--		26,200	-14,500
1969	--		24,100	+15,200
1970	--		27,500	-6,800
1971	--		26,500	-9,300
1972	47,000	4,800	23,500	-5,800

[1] See table 3 for monthly record.

Physical Characteristics

Thermal Properties

Temperature is an important factor in biological processes, chemical reaction rates, and many physical events in the aquatic environment. The water temperature of Lake Shastina varied widely with the seasons (fig. 4). At station L-1, the lake surface temperatures ranged from 3°C on January 27, 1972, to 30°C on August 7, 1972. Station L-3 also exhibited a wide range of temperature variation.

When a lake undergoes seasonal temperature variations, thermal stratification occurs. Lake Shastina would be considered a warm monomictic lake as defined by Hutchinson (1957, p. 535). Warm monomictic lakes are described as being homothermous in the winter and heterothermous (thermally stratified) in the summer. Water at the surface in Lake Shastina started warming rapidly in March (fig. 4). By late spring, mixing in the water column stopped because of differences in thermal resistance, and the lake became thermally stratified. The lake was strongly thermally stratified throughout June, July, and August. During these months, the upper layer of warm water, the epilimnion, was isolated from the cold water layer, the hypolimnion, by the metalimnion, a water layer having a rapid decrease in temperature with depth. Within the metalimnion is the thermocline, a plane or planes of maximum rate of decrease in temperature (Hutchinson, 1957, p. 428). In September, the air temperature decreased, resulting in a cooling of the epilimnion. Successive cooling and sinking of this denser water through the metalimnion and into the hypolimnion resulted in a homothermous temperature profile. The lake entered the autumn free-circulation period (autumn overturn) in September.

Temperature differences between the surface and bottom waters were large during the periods of summer thermal stratification in Lake Shastina. The maximum thermal stratification observed at station L-1 occurred on August 7, 1972. A surface temperature of 30.0°C and bottom temperature of 20.5°C resulted in a 9.5°C difference. Maximum recorded thermal stratification at station L-3 was on July 3, 1972; the difference between surface and bottom water temperatures on this day was 15.0°C, with a surface temperature of 26.0°C and a bottom temperature of 11.0°C.

Two thermoclines were recorded at station L-3 during the sampling period of July 3, and again of August 8, 1972. On July 3, the two thermoclines were at 4.9 and 49 ft (1.5 and 15 m); on August 8, they were at 8.2 and 43 ft (2.5 and 13 m). The two upper thermoclines (4.9 and 8.2 ft or 1.5 and 2.5 m) are secondary or epilimnetic thermoclines, while the lower two (49 and 43 ft or 15 and 13 m) are classical thermoclines (Hutchinson, 1957, p. 448).

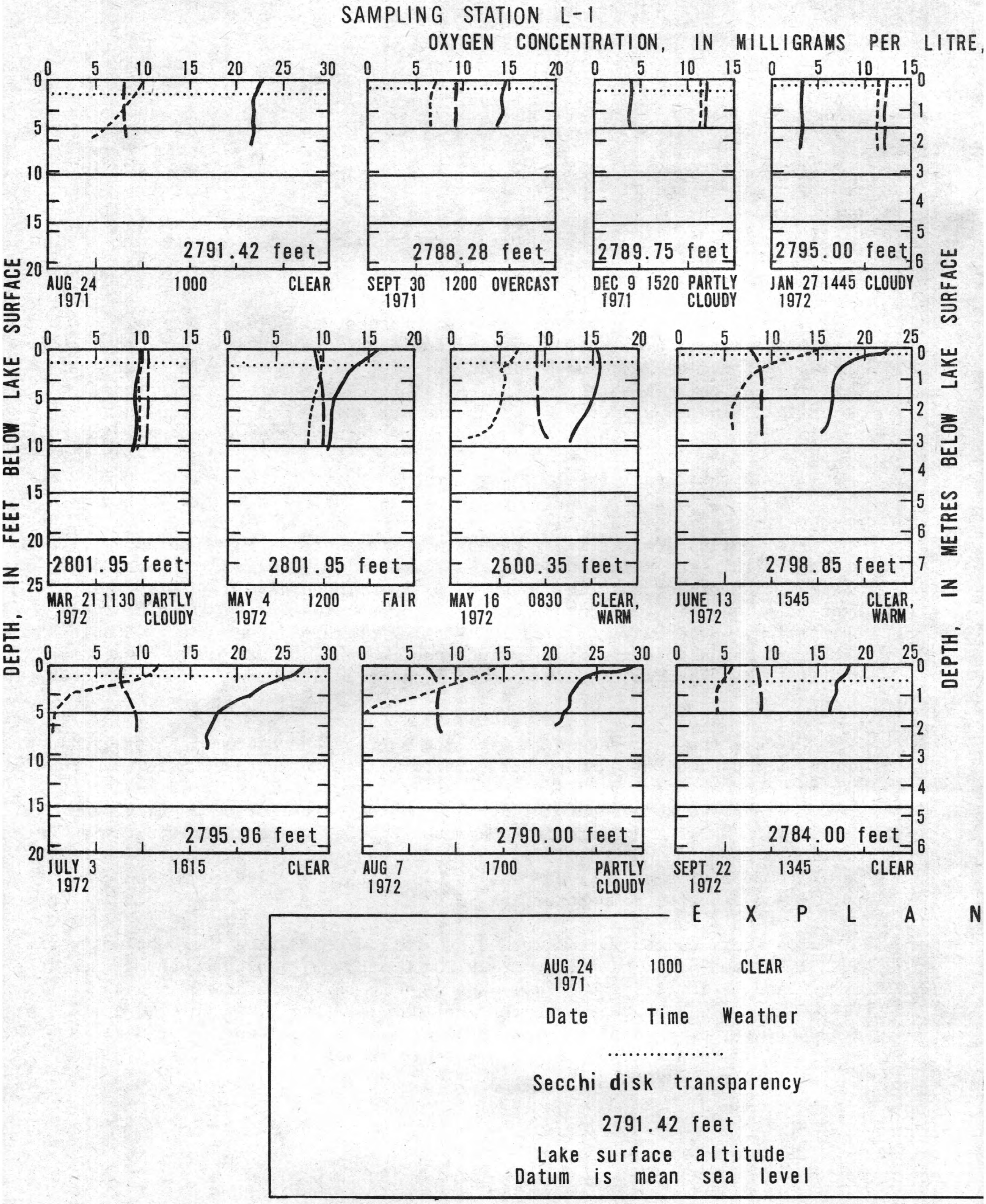
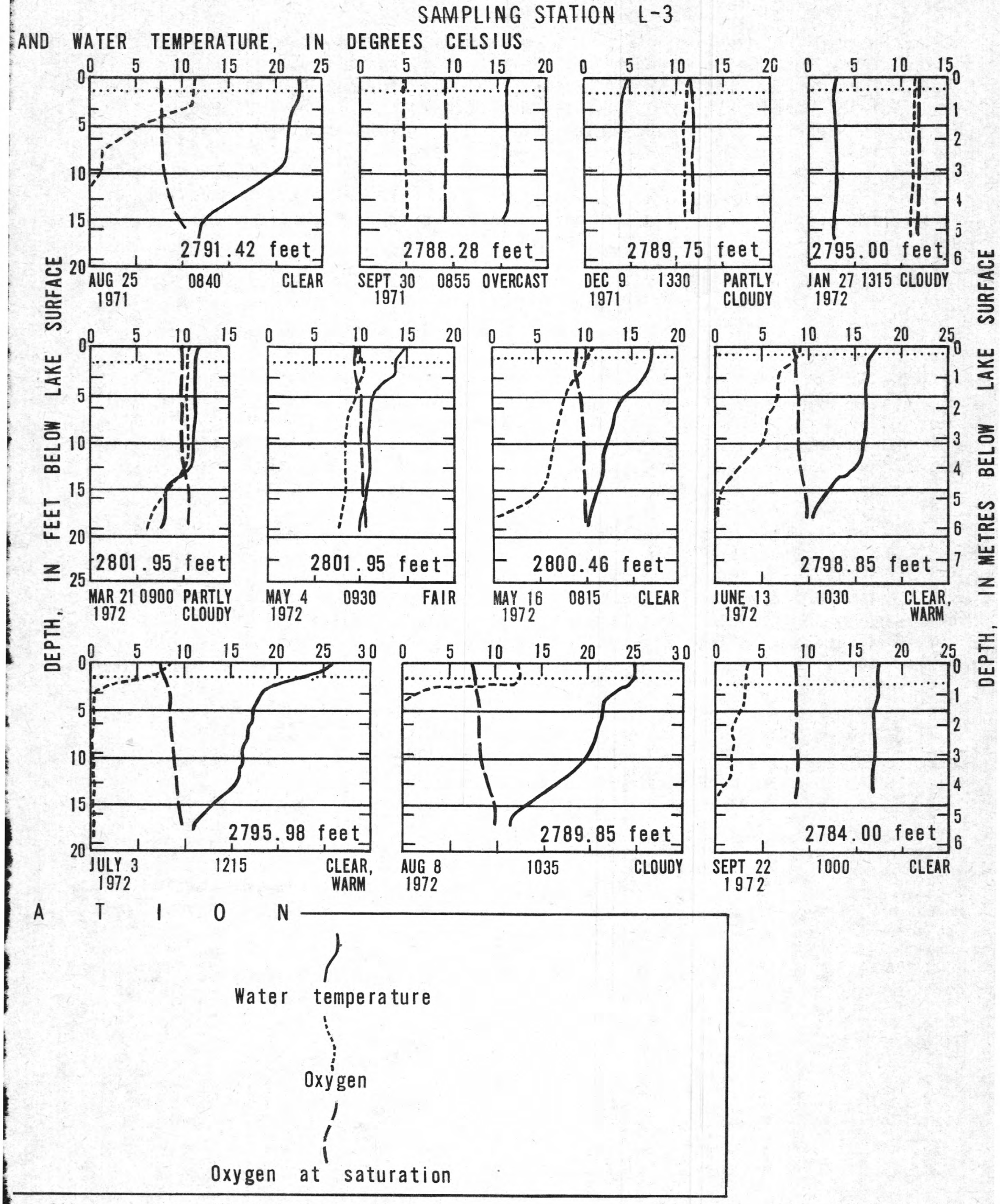


FIGURE 4.--Dissolved oxygen and temperature



profiles, and Secchi disk transparency.

Epilimnetic thermoclines are generally caused by the intense heat of a warm day, which results in a marked temperature gradient near the water surface. These phenomena are diel. During the July and August sampling periods in 1972 when epilimnetic thermoclines were recorded, the lake was calm and warm with water temperatures greater than 25°C. This temperature was markedly higher than those of the other sampling periods.

At station L-1, the metalimnion was always near the surface. Because of the shallower depth at this station, the water was more frequently and completely mixed by wind action (fig. 4).

Light Penetration

Light is the basic energy source for photosynthesis and is thus an important factor in controlling the rate of biological processes in a lake. Measuring the depth of light penetration in the water provides an estimate of the depth of the zone of photosynthesis. Moreover, the degree of light penetration in a lake can reveal its esthetic condition because the transparency of light is closely affected by water color and turbidity.

Light penetration, measured with a Secchi disk (Welch, 1948, p. 159), was low in Lake Shastina (fig. 4 and table 5). This was consistent with the highly colored and turbid appearance of the lake throughout the study period. The average Secchi disk reading was 4.6 ft (1.4 m), but there appeared to be no consistency in seasonal variations. For example, a reading of 2.6 ft (0.8 m) was recorded in September 1971 at station L-1; at the same station in September 1972, the reading was 6.6 ft (2.0 m).

Multiplying the Secchi disk reading by five gives an approximation of the depth of the euphotic (photosynthetic) zone (Verduin, 1956). This is the area where there is sufficient light penetration for photosynthesis. The monthly Secchi disk depths for sites L-1 and L-3 are in table 5.

Table 5.--*Secchi disk transparency*

Month	Secchi disk transparency (Depth, in metres)	
	Station L-1	Station L-3
August 1971	1.5	1.4
September	.8	1.1
December	1.2	1.5
January 1972	.9	1.1
March	1.5	1.7
May	1.7	1.7
	1.5	1.2
June	.6	.8
July	1.0	1.5
August	1.3	1.5
September	2.0	2.2
Average	1.3	1.4

Chemical Characteristics

Water Samples

Dissolved Oxygen.--In addition to the prime importance of dissolved oxygen to the survival of aquatic life, a great deal about a lake can be learned from a series of oxygen determinations. In unproductive lakes, the water mass is usually saturated with oxygen. In highly productive lakes, supersaturation of dissolved oxygen due to photosynthesis, or undersaturation of dissolved oxygen because of respiration and oxidation of organic matter, is common.

At the height of summer stagnation, the surface water of Lake Shastina was supersaturated with oxygen. In contrast, the hypolimnion had an acute dissolved-oxygen deficit (fig. 4). For example, on August 8, 1972, at 1035 hours, the surface was at 160 percent of saturation of dissolved oxygen at station L-3. On the previous day, at station L-1, the dissolved-oxygen saturation at the surface reached 200 percent at 1700 hours. During the July and August sampling periods in 1972, the lake was virtually devoid of dissolved oxygen below the 16-ft (5-m) depth.

A substantial dissolved-oxygen deficit occurred during the September sampling periods of 1971 and 1972 at a time when thermal stratification had nearly disappeared (fig. 4). This was a result of the mixing of oxygen-deficient water in the hypolimnion with the oxygen-rich water in the epilimnion during the autumn overturn.

There was no dissolved-oxygen stratification in Lake Shastina in the winter, as can be seen from December 1971 and January 1972 results (fig. 4). The winter free-circulation period permitted full aeration of the lake from surface to bottom resulting in saturated dissolved oxygen throughout the water column. In the shallower part of the lake (station L-1) circulation persisted at least through the latter part of March.

Bicarbonate, Carbonate, Carbon Dioxide, and pH.--Like dissolved oxygen, the carbon dioxide concentration and its correlative measurements (pH, bicarbonate, and carbonate) vary in response to photosynthesis, respiration, and oxidation of organic matter. In the photosynthetic process, carbon is assimilated, usually in the form of carbon dioxide, releasing oxygen as an end product, whereas respiration and oxidation of organic matter utilize oxygen and release carbon dioxide as an end product.

During the summer thermal stratification period of Lake Shastina, definite vertical stratification of carbon dioxide, bicarbonate, carbonate, and pH was apparent (table 6). As expected, carbon dioxide and bicarbonate concentrations increased as a function of depth, while carbonate concentrations and pH values decreased.

Table 6.--*Vertical profiles*

Depth (metres)	Bicarbonate (HCO_3) (mg/l)	Carbonate (CO_3) (mg/l)	Specific conductance (micromhos at 25°C)	pH (units)	Carbon dioxide (CO_2) (mg/l)
Station L-1					
Aug. 24, 1971 at 1000					
0	126	24	250	9.3	0.1
5	136	20	280	9.0	.3
Sept. 30, 1971 at 1200					
0	140	20	290	8.7	.4
2	140	20	--	9.0	.1
4	154	14	291	8.8	.5
Dec. 9, 1971 at 1520					
0	180	4	305	8.5	.9
1	179	4	304	8.4	1.1
3	180	4	304	8.4	1.1
5	180	3	304	8.4	1.1
Jan. 27, 1972 at 1445					
0	167	4	282	8.4	1.0
1	166	4	281	8.4	1.0
7	170	2	283	8.4	1.0
Mar. 21, 1972 at 1130					
0	156	3	258	8.4	.9
1	158	2	260	8.4	.9
5	156	2	256	8.4	.9
10	156	2	256	8.4	.9
May 4, 1972 at 1200					
0	152	4	256	8.5	.8
1	152	4	256	8.5	.8
3	150	4	255	8.5	.8
5	154	2	256	8.4	.9
10	158	0	255	8.3	1.3

Table 6.--*Vertical profiles--Continued*

Depth (metres)	Bicarbonate (HCO_3) (mg/l)	Carbonate (CO_3) (mg/l)	Specific conductance (micromhos at 25°C)	pH (units)	Carbon dioxide (CO_2) (mg/l)
Station L-1					
May 18, 1972 at 0830					
0	156	0	260	8.2	1.6
1	160	0	260	8.2	1.6
2	160	0	260	8.2	1.6
3	162	0	260	8.2	1.6
5	160	0	260	8.2	1.6
7	160	0	259	7.8	4.0
9	160	0	259	7.7	5.1
June 13, 1972 at 1545					
0	100	30	256	9.1	.1
1	104	28	--	9.0	.1
3	136	12	262	8.6	.5
5	150	4	--	8.4	.9
7	160	0	263	8.2	1.6
July 3, 1972 at 1615					
0	124	22	264	8.6	.5
1	120	22	--	8.7	.4
3	166	0	263	8.2	1.7
5	162	0	--	7.8	4.0
7	162	0	262	7.6	6.5
Aug. 7, 1972 at 1700					
0	120	28	--	9.1	.1
1	120	28	281	9.0	.2
2	137	20	--	8.8	.4
4	162	6	292	8.5	.5
6	174	0	--	8.0	2.8
Sept. 22, 1972 at 1345					
0	180	6	314	8.5	.9
1	--	--	--	8.5	--
2	--	--	--	8.4	--
3	--	--	--	8.4	--
4	186	2	317	8.4	1.1

Table 6.--*Vertical profiles--Continued*

Depth (metres)	Bicarbonate (HCO_3) (mg/l)	Carbonate (CO_3) (mg/l)	Specific conductance (micromhos at 25°C)	pH (units)	Carbon dioxide (CO_2) (mg/l)
Station L-3					
Aug. 25, 1971 at 0840					
0	102	31	254	9.2	.1
2	--	--	253	9.2	--
3	98	37	--	9.2	.1
4	114	30	259	9.1	.2
6	--	--	259	8.8	--
7	--	--	248	--	--
8	150	10	258	8.5	.8
10	--	--	280	8.3	--
12	172	0	275	8.1	2.2
14	--	--	250	7.8	--
16	174	0	280	7.5	8.7
Sept. 30, 1971 at 0855					
0	156	12	291	8.8	.5
3	150	16	290	8.9	.3
6	154	12	290	8.9	.3
9	146	16	291	9.0	.3
12	152	14	291	8.8	.5
15	144	18	291	8.9	.3
Dec. 9, 1971 at 1330					
0	182	3	305	8.4	1.1
1	178	5	306	8.5	.9
2	178	5	306	8.5	.9
3	180	4	305	8.5	.9
5	180	4	305	8.5	.9
7	179	5	306	8.5	.9
10	182	3	306	8.4	1.1
14	184	2	306	8.4	1.1
Jan. 27, 1972 at 1315					
0	171	4	299	8.5	.9
1	154	6	297	8.6	.6
5	176	4	297	8.4	1.1
10	176	4	297	8.4	1.1
16	176	5	298	8.5	.9
Mar. 21, 1972 at 0900					
0	149	7	261	8.7	.4
1	151	8	260	8.8	.5
5	148	7	261	8.7	.4
10	--	--	261	8.7	--
13	146	8	263	8.7	.4
15	163	2	269	8.4	1.0
19	168	0	272	8.3	1.3

Table 6.--*Vertical profiles--Continued*

Depth (metres)	Bicarbonate (HCO_3) (mg/l)	Carbonate (CO_3) (mg/l)	Specific conductance (micromhos at 25°C)	pH (units)	Carbon dioxide (CO_2) (mg/l)
Station L-3					
May 4, 1972 at 0930					
0	152	2	256	8.4	.9
1	150	4	257	8.5	.8
2	152	4	257	8.5	.8
3	152	4	256	8.5	.8
4	152	4	256	8.5	.8
5	156	2	256	8.4	.9
7	156	0	258	8.3	1.2
10	156	0	260	8.3	1.2
15	156	0	259	8.2	1.6
19	156	0	259	8.1	2.0
May 16, 1972 at 0815					
0	162	0	265	8.3	1.3
1	162	0	264	8.2	1.6
2	172	0	262	8.2	1.4
3	156	0	260	8.2	1.6
5	156	0	262	7.8	3.9
10	158	0	261	7.6	6.3
15	158	0	260	7.6	6.3
18	158	0	261	7.3	12.6
June 13, 1972 at 1030					
0	96	34	267	9.1	.1
1	120	20	--	8.9	.2
3	120	20	--	8.8	.4
5	140	4	--	8.9	.8
7	150	0	264	8.2	1.5
10	154	0	--	8.1	2.0
15	158	0	--	7.2	16
18	158	0	264	7.1	20
July 3, 1972 at 1215					
0	146	10	264	8.5	.7
1	156	8	--	8.4	.9
3	170	0	--	8.1	2.2
5	174	0	260	8.0	2.8
7	174	0	--	7.7	5.6
10	160	0	--	7.4	10
15	158	0	--	7.2	16
17	166	0	262	6.7	53

Table 6.--*Vertical profiles--Continued*

Depth (metres)	Bicarbonate (HCO$_3$) (mg/l)	Carbonate (CO$_3$) (mg/l)	Specific conductance (micromhos at 25°C)	pH (units)	Carbon dioxide (CO$_2$) (mg/l)
Station L-3					
Aug. 8, 1972 at 1035					
0	121	29	--	9.0	.2
1	129	25	289	8.9	.3
2	130	27	--	8.9	.3
3	178	0	--	8.1	2.3
4	178	0	--	8.0	2.8
5	176	0	--	8.0	2.8
6	176	0	--	8.0	2.8
10	176	0	--	7.8	4.4
12	170	0	274	7.5	8.5
15	172	0	--	6.9	34
Sept. 22, 1972 at 1000					
0	176	8	313	8.5	.9
1	176	8	--	8.5	.9
2	--	--	--	8.5	--
3	--	--	--	8.5	--
4	--	--	--	8.5	--
5	184	6	312	8.5	.9
6	--	--	--	8.4	--
7	--	--	--	8.4	--
8	--	--	--	8.4	--
9	--	--	--	8.4	--
10	196	0	--	8.3	1.6
11	--	--	--	8.3	--
12	--	--	--	8.3	--
13	194	0	312	8.3	1.6

Utilization of carbon dioxide and bicarbonate during photosynthesis undoubtedly accounted for the lower concentration of these two constituents near the lake surface. Carbon dioxide may be assimilated directly by plants, whereas bicarbonate can be assimilated by two routes (Ruttner, 1972, p. 68). The first of these is the direct uptake of the bicarbonate ion and the second is the uptake of carbon dioxide produced by the dissociation of the bicarbonate ion.

The increased carbon dioxide and bicarbonate concentration at depth may be caused by a combination of several processes. Carbon dioxide concentration can be increased as a result of respiration and the oxidation of organic matter. The decrease of photosynthetic uptake of carbon dioxide and bicarbonate ion with depth could also appear by contrast as an increase in carbon dioxide concentration in bottom water. The increased carbon dioxide concentration raised the bicarbonate level through the reaction sequence:

$$CO_2 + H_2O \rightleftharpoons H_2CO_3$$

$$H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$

Bicarbonate ion could also increase by the reaction between carbon dioxide and the sparingly soluble calcium carbonate which originated either from the bottom sediments or from the euphotic zone.

The excess accumulation of carbonate ion near the lake surface was mainly due to photosynthesis, during which carbon dioxide was removed from the bicarbonate ion, and carbonate ion was formed as a byproduct. The carbonate ion eventually combines with calcium or magnesium to form a sparingly soluble precipitate which may sink to the bottom and enter the carbonate cycle again in the hypolimnion.

While the higher pH near the lake surface resulted from photosynthesis, the lower pH in the deeper water resulted from respiration and oxidation of organic matter. Photosynthesis increased hydroxide and carbonate ions in the water, but reduced the carbon dioxide concentration. The net result of this was to decrease the hydrogen ion concentration or to raise the pH. In contrast, carbon dioxide produced by respiration and oxidation of organic matter increased the hydrogen ion level or lowered the pH. During the winter free-circulation period, Lake Shastina had nearly uniform concentrations of bicarbonate, carbonate, and carbon dioxide concentrations and pH values throughout the water column.

Mineral Constituents.--Analyses of the major chemical constituents in Lake Shastina are given in table 7. The lake water was of the magnesium calcium bicarbonate type and could be classified as moderately hard (Hem, 1970, p. 225). Except for bicarbonate, carbonate, carbon dioxide, and pH, the vertical variations in concentrations of major chemical constituents in Lake Shastina were generally slight. This was true even when temperature and dissolved-oxygen stratification was strong, such as on August 24, 1971 (table 7). During this sampling period, only manganese and sulfate showed a definite change in concentration with depth. The manganese concentration at the 32-ft (10-m) depth was higher because the anoxic condition at this depth is favorable for chemical reduction of the lake-bottom sediment from insoluble manganic hydroxide to soluble manganous bicarbonate. Anoxic conditions often exist at depth during the summer thermal-stratification period. The formation of hydrogen sulfide from sulfate by bacterial oxidation in the hypolimnion on August 24, 1971, could account for the decrease of sulfate ion at the 32-ft (10-m) depth at station L-2 (Mortimer, 1942).

Table 7.--*Analyses of common*

[The lake was stratified in temperature and in dissolved

Date	Time	Depth (metres)	Dissolved silica (SiO_2) (mg/l)	Dissolved iron (Fe) (ug/l)	Dissolved manganese (Mn) (ug/l)	Dissolved calcium (Ca) (mg/l)	Dissolved magnesium (Mg) (mg/l)	Dissolved sodium (Na) (mg/l)	Dissolved potassium (K) (mg/l)
						Dissolved Oxygen and Thermal			
		Station L-2							
Aug. 24, 1971	1400	3	34	20	0	11	24	10	1.5
Do.	1545	10	35	20	330	11	23	10	1.7
						Dissolved Oxygen and Thermal			
		Station L-1							
Jan. 27, 1972	1445	1	33	20	10	12	25	11	1.6
Do.	1500	7	33	30	10	12	25	11	1.7
		Station L-3							
Jan. 27, 1972	1315	1	34	20	0	13	26	12	1.8
Do.	1330	16	34	30	10	13	25	12	1.7

---

[1] Field-measured values.

Lake Shastina was in a homothermous and consequently free-circulation period on January 27, 1972. Vertical variations of all major chemical constituents at stations L-1 and L-3 were essentially non-existent (table 7).

Areal variations in concentrations of major constituents in Lake Shastina were small. Only subtle differences were detected in the results of chemical analyses between L-1 and L-3 on January 27, 1972 (table 7). The nearly identical values for specific conductance between stations L-1 and L-3 during each sample period (fig. 5) also indicate the areal chemical homogeneity of the lake, as specific conductance is a surrogate measurement of the total concentration of major chemical constituents.

chemical constituents

oxygen concentration during both sampling periods]

Bicarbonate[1/] (HCO_3) (mg/l)	Carbonate[1/] (CO_3) (mg/l)	Dissolved sulfate (SO_4) (mg/l)	Dissolved chloride (Cl) (mg/l)	Dissolved fluoride (F) (mg/l)	Dissolved boron (B) (ug/l)	Dissolved solids (sum of determined constituents, mg/l)	Hardness (Ca,Mg) (mg/l)	Specific conductance (micromhos at 25°C)	pH[1] (units)
Stratification Present									
				Station L-2					
104	32	4.5	3.1	0.1	100	172	130	264	9.2
172	0	3.5	3.3	.1	100	177	120	261	8.3
Stratification Absent									
				Station L-1					
166	4	5.7	6.7	.2	110	184	130	290	8.4
170	2	6.0	6.2	.2	110	184	133	293	8.4
				Station L-3					
171	4	6.1	7.0	.2	120	193	139	307	8.6
176	5	6.0	7.2	.2	120	192	135	311	8.5

In contrast to the uniform areal distribution of constituents, temporal variation in concentrations of major constituents does occur (table 7). Higher values for most constituents were found in the water samples collected on January 27, 1972, compared to the samples obtained on August 24, 1972. Further evidence of temporal variation is provided by the results of the periodic specific-conductance measurements at stations L-1 and L-3 (fig. 5). Average specific conductance ranged from 256 micromhos in May 1972 to 316 in September 1972 at station L-1. At station L-3, average values ranged from 257 micromhos in May to 312 in September 1972. Specific-conductance measurements varied inversely with lake storage (fig. 5). The lowest specific conductance, recorded in May, occurred near the maximum lake storage, whereas the highest specific conductance recorded, in September 1972, occurred when lake storage was low.

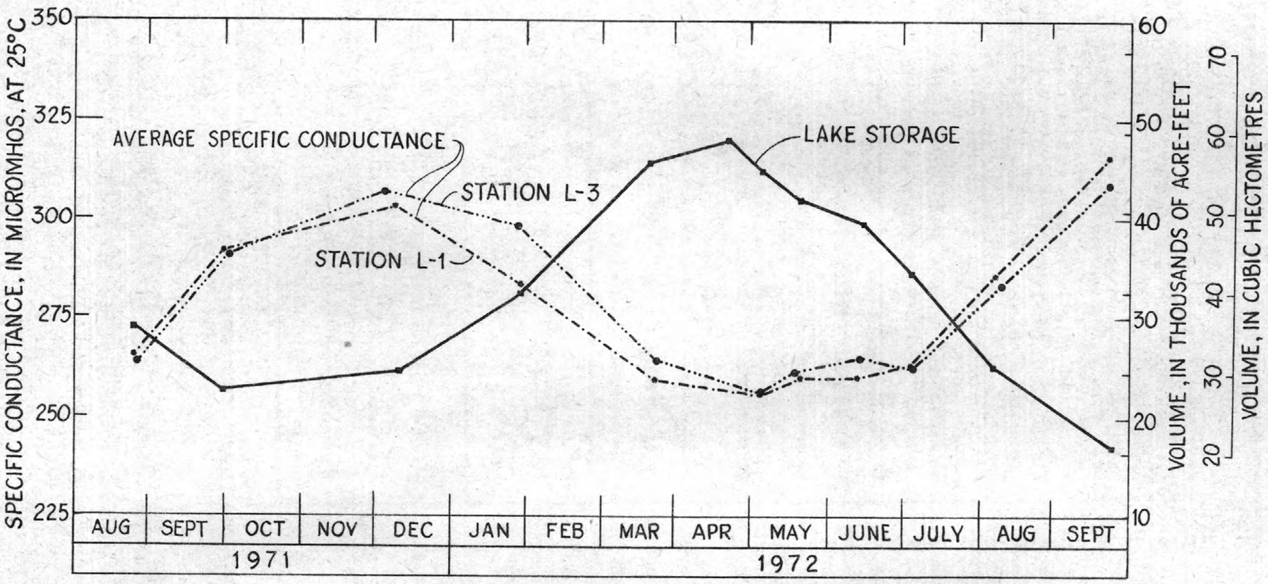
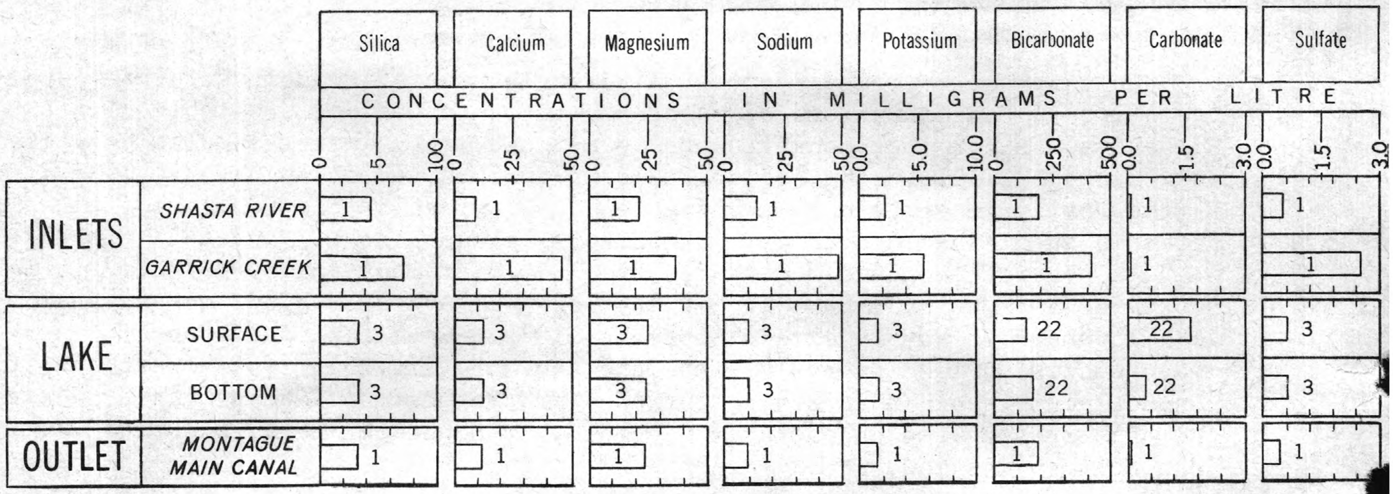


FIGURE 5.--Lake storage and average specific conductance.

Analyses of water samples from the inlets and outlet of the lake indicated that specific conductance and concentration of most chemical constituents were highest in Garrick Creek (fig. 6). Most major chemical constituents of the Shasta River water were similar to the lake water, suggesting chemical control of the lake water by the river inflow. The chemical quality of the outlet water was, as expected, similar to that of the lake.



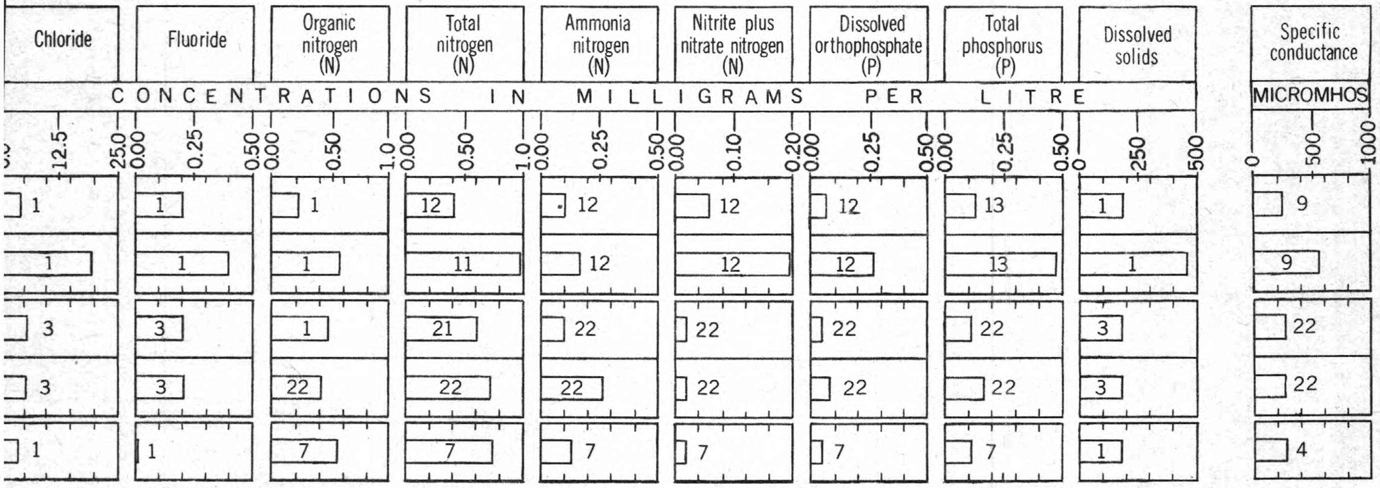
NOTE: Figures with bars indicate number of analyses. Dissolved solids is sum of determined constituents.

FIGURE 6.--Summary of water analyses for chem

Nutrients.--Nitrogen and phosphorus are considered to be two major limiting nutrients for phytoplankton production. The concentration needed depends upon the type and physiological state of the phytoplankton; therefore, limiting concentrations cannot be given. However, nitrogen and phosphorus usually occur in low concentrations in most water, and may essentially be completely removed from solution by phytoplankton during profuse production periods (blooms). When these nutrients are removed from the water, further phytoplankton production ceases.

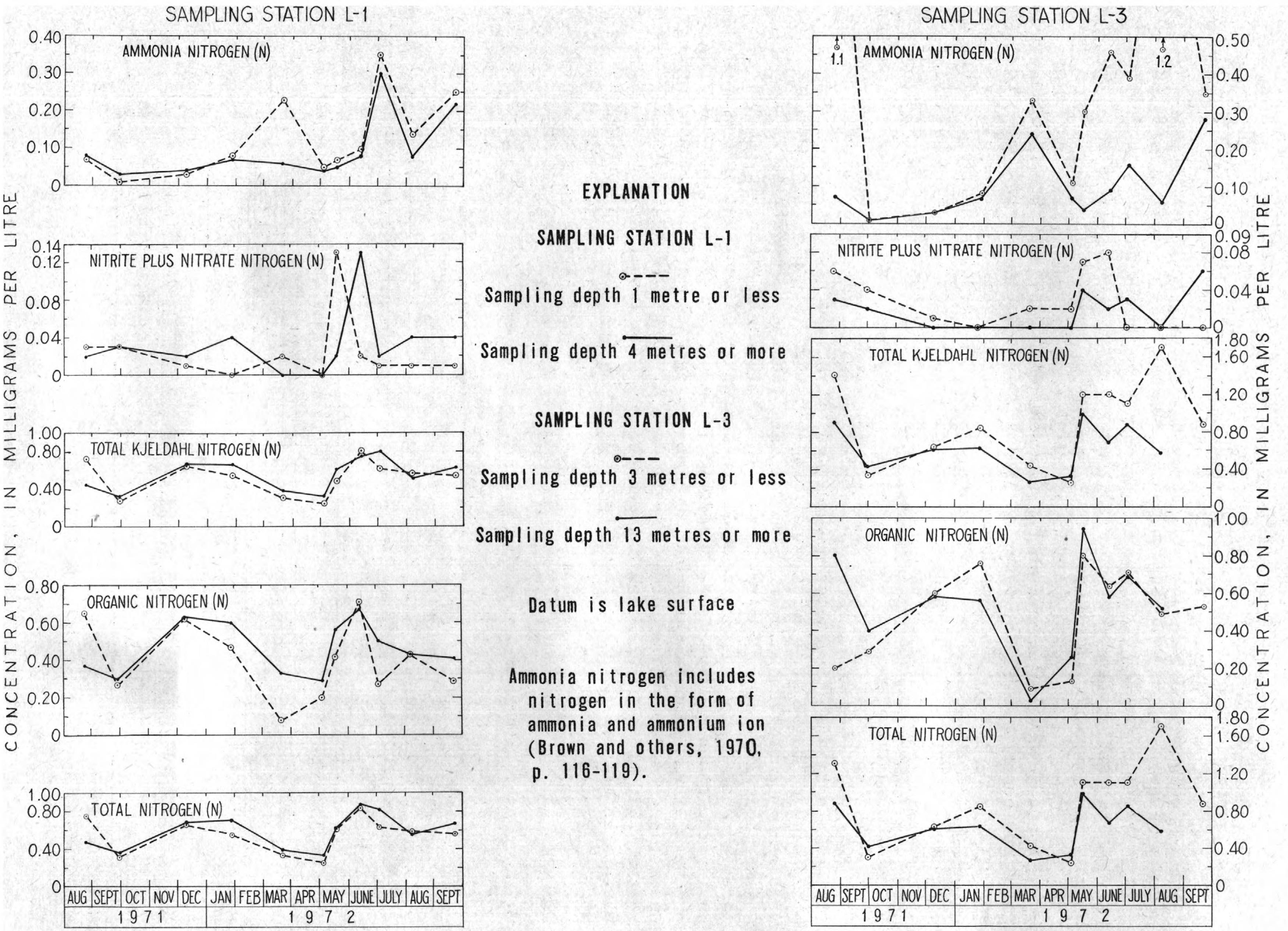
Nitrogen in water occurs in the two reduced forms, organic nitrogen (nitrogen bound in cellular material) and ammonium ion (NH_4^{+1}). Both are analyzed using the Kjeldahl method, and are collectively called Kjeldahl nitrogen. Nitrogen also occurs in water in the two oxidized forms as nitrite (NO_2) and nitrate (NO_3). Phosphorus occurs in a number of forms, but it is frequently analyzed as the inorganic form orthophosphate (PO_4) and as total phosphorus (P).

Periodic determinations of the several forms of nitrogen and phosphorus in Lake Shastina indicate distinct vertical stratification of ammonium, orthophosphate and total phosphorus, and total nitrogen (organic plus inorganic) at station L-3 during the summer thermal stratification period (figs. 7 and 8). Concentrations of these constituents were considerably higher in the bottom water because of the anaerobic condition that existed near the lake bottom during the stagnation period. Anaerobic decomposition of organic matter produces excess ammonia which becomes trapped beneath the metalimnion. Anaerobic conditions also permit the release of insoluble phosphates from lake bottom sediments (through chemical reduction), with resultant increase in phosphorus concentration in the water. Higher total nitrogen concentrations at the greater depths were mainly caused by the increased ammonium. Organic nitrogen concentrations were similar for the surface and bottom lake water.



Ammonia nitrogen includes nitrogen in the form of ammonia and ammonium ion (Brown and others, 1970, p. 116-119).

onstituents, Lake Shastina and vicinity.



EXPLANATION

SAMPLING STATION L-1

⊙- - - Sampling depth 1 metre or less

•—— Sampling depth 4 metres or more

SAMPLING STATION L-3

⊙- - - Sampling depth 3 metres or less

•—— Sampling depth 13 metres or more

Datum is lake surface

Ammonia nitrogen includes nitrogen in the form of ammonia and ammonium ion (Brown and others, 1970, p. 116-119).

FIGURE 7.--Results of nitrogen analyses at sampling stations L-1 and L-3.

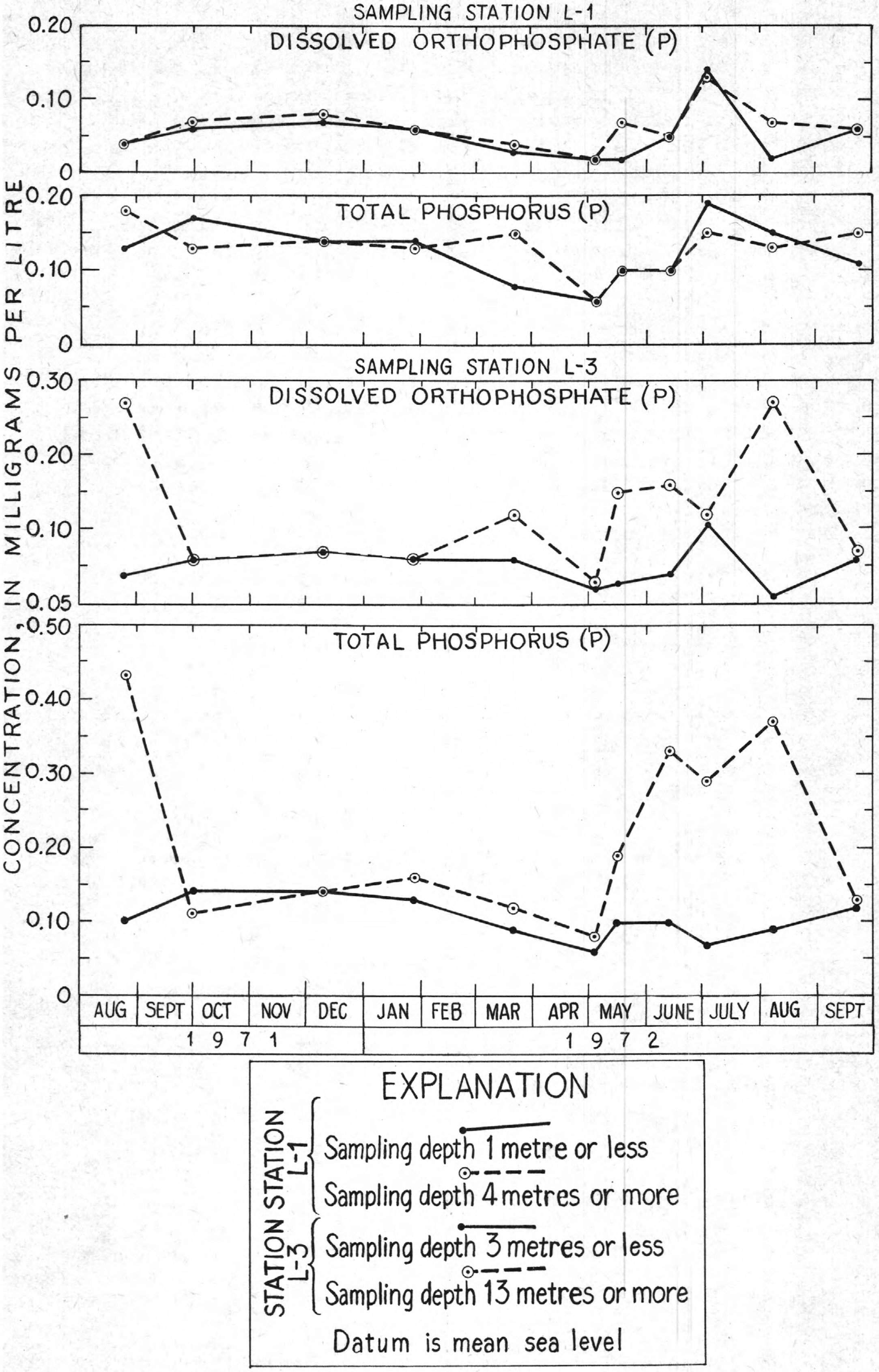


FIGURE 8.--Results of phosphorus analyses at sampling stations L-1 and L-3.

Limited data showed generally higher nitrogen and phosphorus concentrations in two selected tributaries of the Shasta River (Boles Creek and Beaughton Creek, fig. 1) than in the river itself (tables 8 and 9). These tributaries are possible point contributors of nitrogen and phosphorus to the river and lake system. Results of nitrogen and phosphorus analyses in samples from the principal tributaries and the outlet are given in table 9.

Vertical stratification of nitrogen and phosphorus was minimal during the sampling periods from late September through April. During these periods, the lake was well oxygenated.

The concentrations of nitrogen and phosphorus varied between stations L-1 and L-3, especially during summer stagnation periods (figs. 7 and 8). The average concentrations of nitrogen and phosphorus in the lake were highest during the period from the latter part of May through September (fig. 9). The highest average total nitrogen and phosphorus loads (table 10) occurred from March through August. During early May, average concentrations were lowest. This was probably caused by dilution, as the quantity of water stored in the lake was close to maximum at that time.

Table 8.--*Chemical analyses of water samples from Boles and Beaughton Creeks*

		Concentration, in milligrams per litre					
Location	Date	Total nitrogen (N)	Total Kjeldahl nitrogen (N)	Dissolved nitrite plus nitrate (N)	Dissolved ammonia nitrogen (N)[1]	Total phosphorus (P)	Dissolved orthophosphorus (P)
Boles Creek near Weed	Aug. 25-26, 1971	0.60	0.36	0.24	0.11	0.16	0.12
	Mar. 22, 1972	.85	.47	.38	--	.59	--
Beaughton Creek at Edgewood	Aug. 25-26, 1971	.69	.51	.18	.16	.35	.26
	Mar. 22, 1972	2.1	1.5	.60	--	1.2	--

[1] Includes nitrogen in the form of ammonia (NH_3) and ammonium ion (NH_4^{+1}) reported as ammonia nitrogen (Brown and others, 1970, p. 116-119).

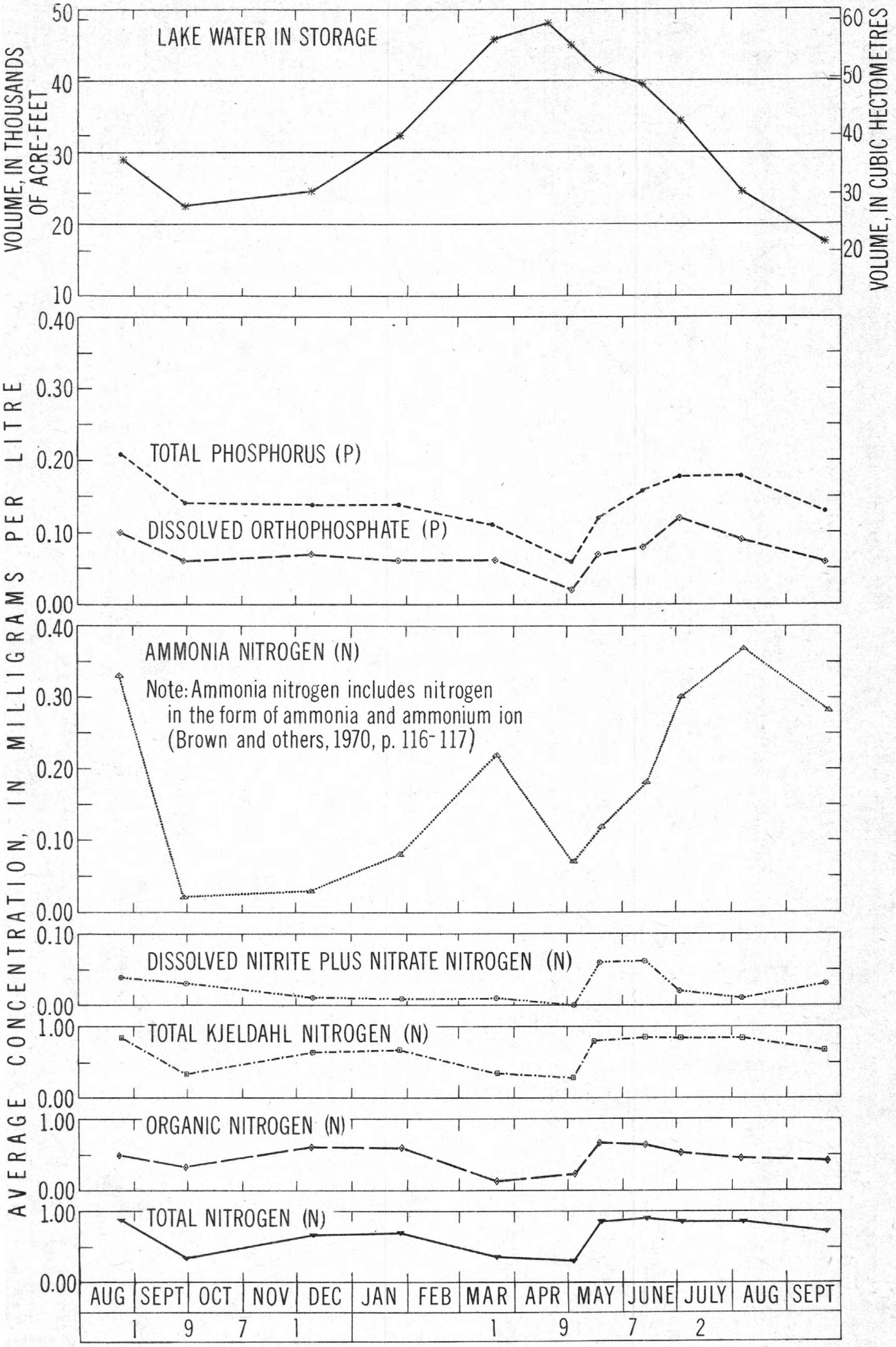


FIGURE 9.--Average concentrations of nitrogen and phosphorus.

Table 9.--*Nitrogen and phosphorus analyses of water samples*

DATE	TIME	DIS-CHARGE (FT^3/S)	TEMPER-ATURE (DEG C)	ORGANIC NITRO-GEN (N) (MG/L)	TOTAL NITRO-GEN (N) (MG/L)	TOTAL KJEL-DAHL NITRO-GEN (N) (MG/L)	DIS-SOLVED NITRITE (N) (MG/L)	DIS-SOLVED NITRITE PLUS NITRATE (N) (MG/L)	DIS-SOLVED AMMONIA NITRO-GEN (N)[1] (MG/L)	DIS-SOLVED NITRATE (N) (MG/L)	TOTAL PHOS-PHORUS (P) (MG/L)	DIS-SOLVED ORTHO. PHOS-PHORUS (P) (MG/L)
(I-1) 11-5167.50 SHASTA RIVER NEAR EDGEWOOD (tributary)												
AUG., **1971**												
26...	1010	7.4	20.5	.21	.37	.34	.000	.03	.13	.03	.14	.090
SEP.												
29...	1130	16	11.0	.38	.44	.40	--	.04	.02	--	.14	.10
DEC.												
08...	1050	64	4.0	.32	.47	.37	.000	.10	.05	.10	.16	.12
JAN., **1972**												
21...	1015	--	--	.21	.62	.46	--	.16	.25	--	.11	.060
26...	1115	119	1.5	.26	.55	.35	--	.20	.09	--	.12	.080
MAR.												
03...	1115	--	6.5	.16	.36	.30	--	.06	.14	--	.030	.010
22...	1310	281	7.5	.01	.33	.28	--	.05	.27	--	.15	.14
MAY												
03...	0845	37	10.0	.23	.30	.28	--	.02	.05	--	.060	.040
JUNE												
15...	1000	40	16.0	.15	.20	.17	--	.03	.02	--	.070	.030
JULY												
12...	1320	8.9	21.5	.19	.26	.23	--	.03	.04	--	.12	.080
AUG.												
11...	1110	3.7	23.0	.58	.62	.62	--	.00	.04	--	.14	.080
SEP.												
21...	1205	--	16.0	.28	.34	.34	--	.00	.06	--	.12	.070

(I-2) 11-5167.70 GARRICK CREEK NEAR EDGEWOOD (tributary)

AUG., 1971												
26...	0900	.10	15.5	.23	.42	.41	.000	.01	.18	.01	.46	.39
SEP.												
29...	1010	2.6	8.5	.52	.67	.54	--	.13	.02	--	.31	.25
DEC.												
08...	1015	9.6	4.0	.86	1.2	.98	.000	.17	.12	.17	.38	.020
JAN., 1972												
21...	0950	--	--	.57	1.2	.89	--	.34	.32	--	.30	.22
26...	1030	10	1.5	.80	1.4	.94	--	.42	.14	--	.27	.22
MAR.												
03...	1105	--	9.0	.48	1.2	.83	--	.41	.35	--	.36	.24
22...	1220	20	7.5	1.3	1.9	1.6	--	.28	.32	--	.51	.32
MAY												
03...	1205	.87	12.5	.56	.85	.65	--	.20	.09	--	.27	.23
JUNE												
15...	0825	1.7	14.0	.58	.88	.71	--	.17	.13	--	.32	.20
JULY												
12...	1420	.09	20.0	.28	.58	.36	--	.22	.08	--	.49	.35
AUG.												
11...	1240	.10	19.5	--	--	--	--	.05	.07	--	.44	.38
SEP.												
21...	1000	1.8	10.5	.38	.49	.47	--	.02	.09	--	.29	.24

(O-1) 11-5167.90 MONTAGUE MAIN CANAL BELOW DWINNELL DAM, NEAR EDGEWOOD (outlet)

AUG., 1971												
25...	1330	68	22.0	.29	.44	.42	.000	.02	.13	.02	.19	--
SEP.												
29...	1600	--	15.5	.42	.47	.44	--	.03	.02	--	.13	--
MAY, 1972												
03...	1430	74	11.5	.20	.28	.28	--	.00	.08	--	.060	.030
18...	1030	--	14.5	.81	.90	.88	--	.02	.07	--	.10	.060
JUNE												
13...	1200	--	--	1.0	1.2	1.2	--	.04	.18	--	.12	.070
AUG.												
08...	1650	--	--	.51	.59	.59	--	.00	.08	--	.070	.020
SEP.												
21...	1400	--	18.0	.82	1.2	1.2	--	.00	.38	--	.13	.070

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[1] Includes nitrogen in the form of ammonia (NH_3) and ammonium ion (NH_4^{+1}) reported as ammonia nitrogen (Brown and others, 1970, p. 116-119).

Table 10.--*Estimated nitrogen and phosphorus loads*

Period	Average load (in tons)[1]	
	Total nitrogen (N)	Total phosphorus (P)
Aug. 24-25, 1971	35	8.3
Sept. 30	11	4.3
Dec. 9	22	4.7
Jan. 27, 1972	30	6.2
Mar. 21	23	7.1
May 4	18	4.3
May 16-18	49	6.8
June 13	48	8.6
July 3	40	8.4
Aug. 7-8	29	6.1
Sept. 22	17	3.0

[1] Based on average of concentrations in samples from stations L-1 and L-2.

Lake-Bottom Samples

Samples of the lake-bottom sediment were obtained with a core sampler. The core sample from station L-2 was considerably different from those from stations L-1 and L-3 in terms of physical appearance and measured characteristics (table 11). The sample from L-2 was mostly brown and gray sand, whereas the samples from L-1 and L-3 were dominantly dark green to gray muds. The vertical distribution of sediment sizes was uniform in the sample at L-2 but was uneven in those from L-1 and L-3. The percentage of organic material and concentration of total Kjeldahl nitrogen (ammonium and organic nitrogen), iron, and manganese were relatively higher in cores from L-1 and L-3 than in the cores from station L-2. The total phosphorus content appeared to be slightly higher in the core from L-2.

Table 11.--*Chemical and particle-size analyses of core samples*

[Chemical results given on dry-weight basis]

Depth (cm)	Total iron (Fe)		Total manganese (Mn)		Ratio, Fe/Mn	Total Kjeldahl nitrogen (N) (mg/g)	Total phosphorus (P) (mg/g)	Percentage of organic material	Particle-size distribution, in percent		
	Concentration (mg/g)	Percentage	Concentration (mg/g)	Percentage					Clay (smaller than 0.004 mm)	Silt (0.004 to 0.062 mm)	Sand (0.062 to 2.0 mm)
						Station L-1					
0- 2	28.3	2.8	0.33	0.03	86	1.1	0.11	17	17	55	28
3- 5	27.9	2.8	.43	.04	65	1.2	.10	16	11	24	65
8-10	28.5	2.9	.42	.04	68	1.2	.08	10	9	27	64
13-15	28.5	2.9	.43	.04	66	.8	.11	13	27	72	1
23-25	22.1	2.2	.34	.03	65	2.7	.13	17	33	67	0
						Station L-2					
0- 2	6.7	.7	.12	.01	56	.7	.13	4	4	10	86
3- 5	8.0	.8	.18	.02	44	.6	.13	4	6	14	80
8-10	7.9	.8	.14	.01	56	.5	.12	4	3	10	87
13-15	7.5	.8	.18	.02	42	.4	.11	4	4	12	84
						Station L-3					
0- 2	28.9	2.9	.33	.03	88	1.3	.12	15	63	35	2
3- 5	23.6	2.4	.27	.03	88	.8	.09	8	29	71	0
8-10	12.9	1.3	.16	.02	81	.8	.06	6	16	81	3
13-15	6.3	.6	.07	.01	90	.4	.09	3	33	65	2
23-25	20.0	2.0	.30	.03	67	1.3	.09	11	15	31	54

Biological Characteristics

Phytoplankton

The phytoplankton (suspended algae) play an important role in lakes. Not only are they the primary producers, that is, the first link in the food chain of lakes, but they are often the organisms that cause nuisance conditions. When sufficient sunlight and nutrients are present, phytoplankton production may be excessive, causing a discoloration of the water and undesirable taste and odors. When they die and sink, their decomposition by bacteria removes large amounts of dissolved oxygen from the water, often resulting in anoxic conditions in the deeper water of thermally stratified lakes.

Most phytoplankton, as expected, were collected near the surface of the lake (fig. 10). This was true at both stations; however, at station L-3 (over deep water near the dam), samples collected in mid-summer below the 16-ft (5-m) depth contained insignificant numbers of cells. During the remainder of the year there was little difference at either station between the cell counts near surface or at the 16-ft (5-m) depth.

In Lake Shastina, 33 algal species were identified in samples collected during the study period. Green algae (Phylum Chlorophyta) were the most frequently collected group (figs. 11 and 12), followed by the diatoms (Phylum Bacillariophyta). The green algae averaged about 1 million cells per litre, a population density that remained surprisingly consistent throughout the study period. The diatom cell counts were somewhat more erratic, ranging at station L-3 from a low of 0.03 million cells per litre in early July to an estimated 30 million cells per litre in late July. This explosion of diatom numbers was almost exclusively *Fragillaria crotonensis*.

The blue-green algae (Phylum Cyantophyta) were found in water samples collected in August and September, and May and June (fig. 12). Their numbers approached 5 million cells per litre at station L-1 in June, but at other times, they did not exceed 1 million cells per litre. They were noticeably absent through most of the year. The blue-green algae were represented by three species, *Aphanocapsa sp.*, *Anabaena apriroides*, and *Marssoniella elegans*, with *A. apriroides* the most abundant. The flagellates and dinoflagellates had a frequency distribution similar to that of the blue-green algae.

The percentage abundance of the phytoplankton groups for the study period is shown in figure 11 for the two sampling stations L-1 and L-3. The results are expressed as phytoplankton group composition at 0 and 16-ft (0 and 5-m) depths for L-1 and at 0 and 32-ft (0 and 10-m) depths for L-3.

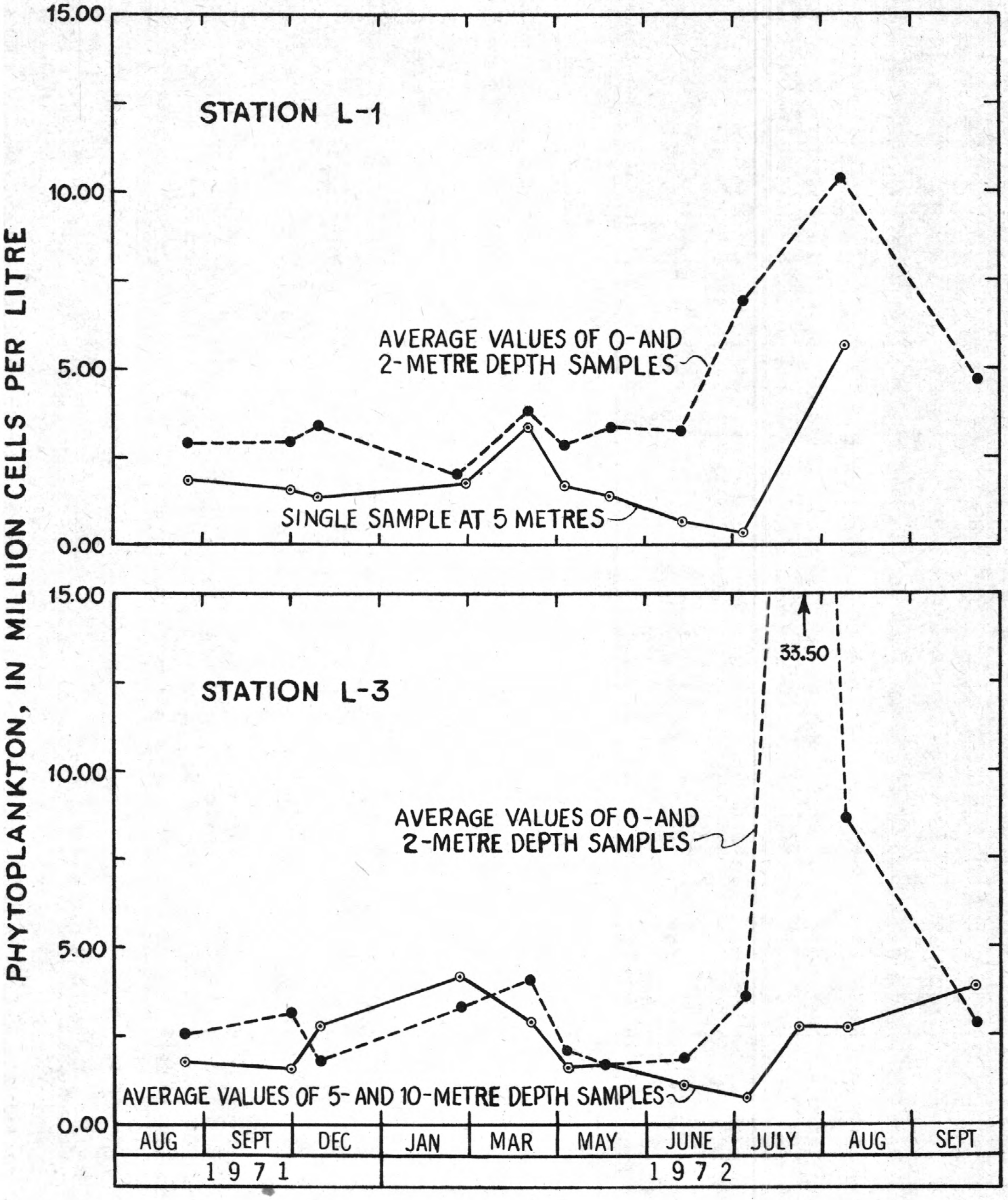

FIGURE 10.--Phytoplankton counts for sampling stations L-1 and L-3.

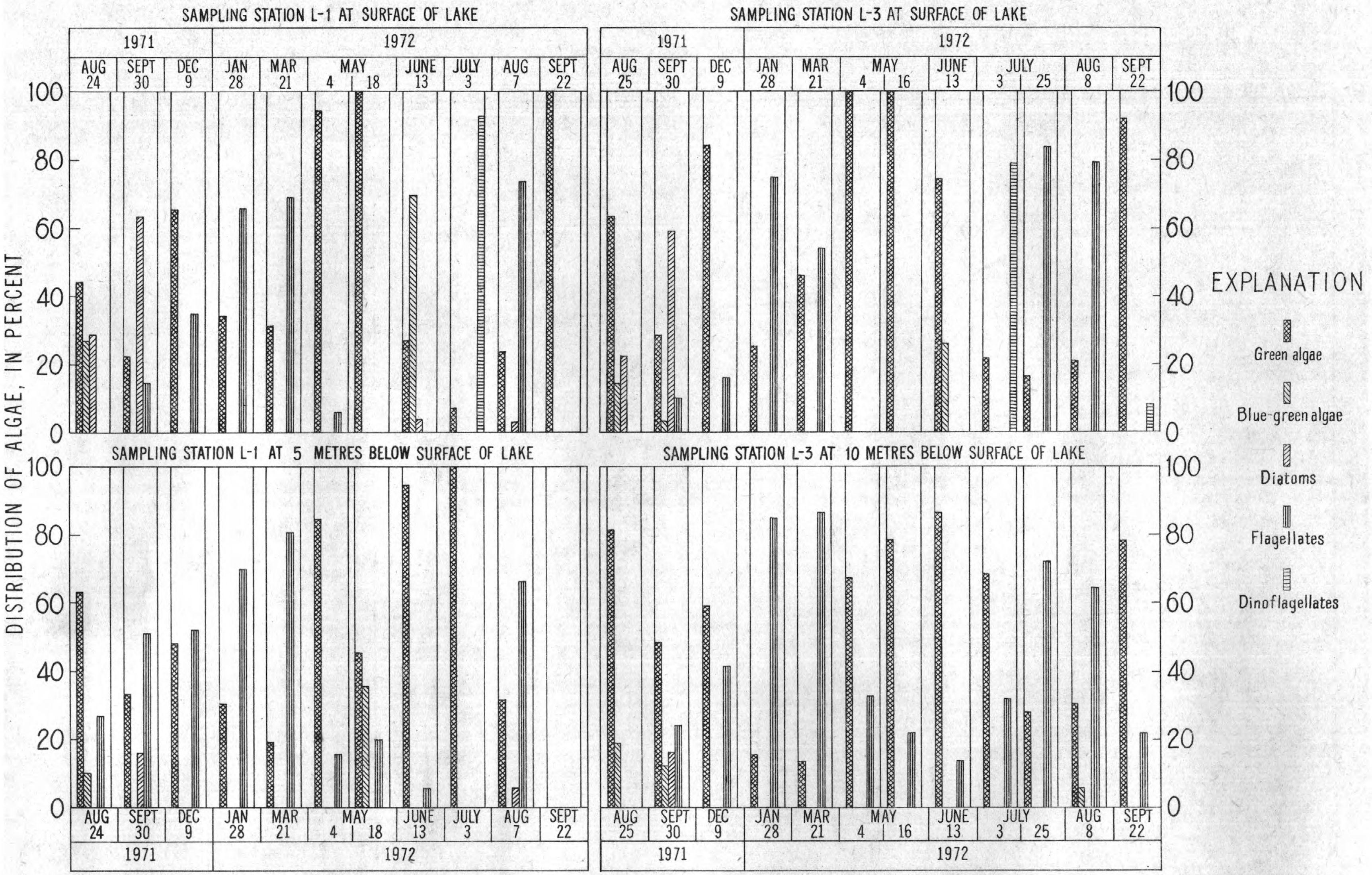

FIGURE 11.--Percentage abundance of major groups of algae.

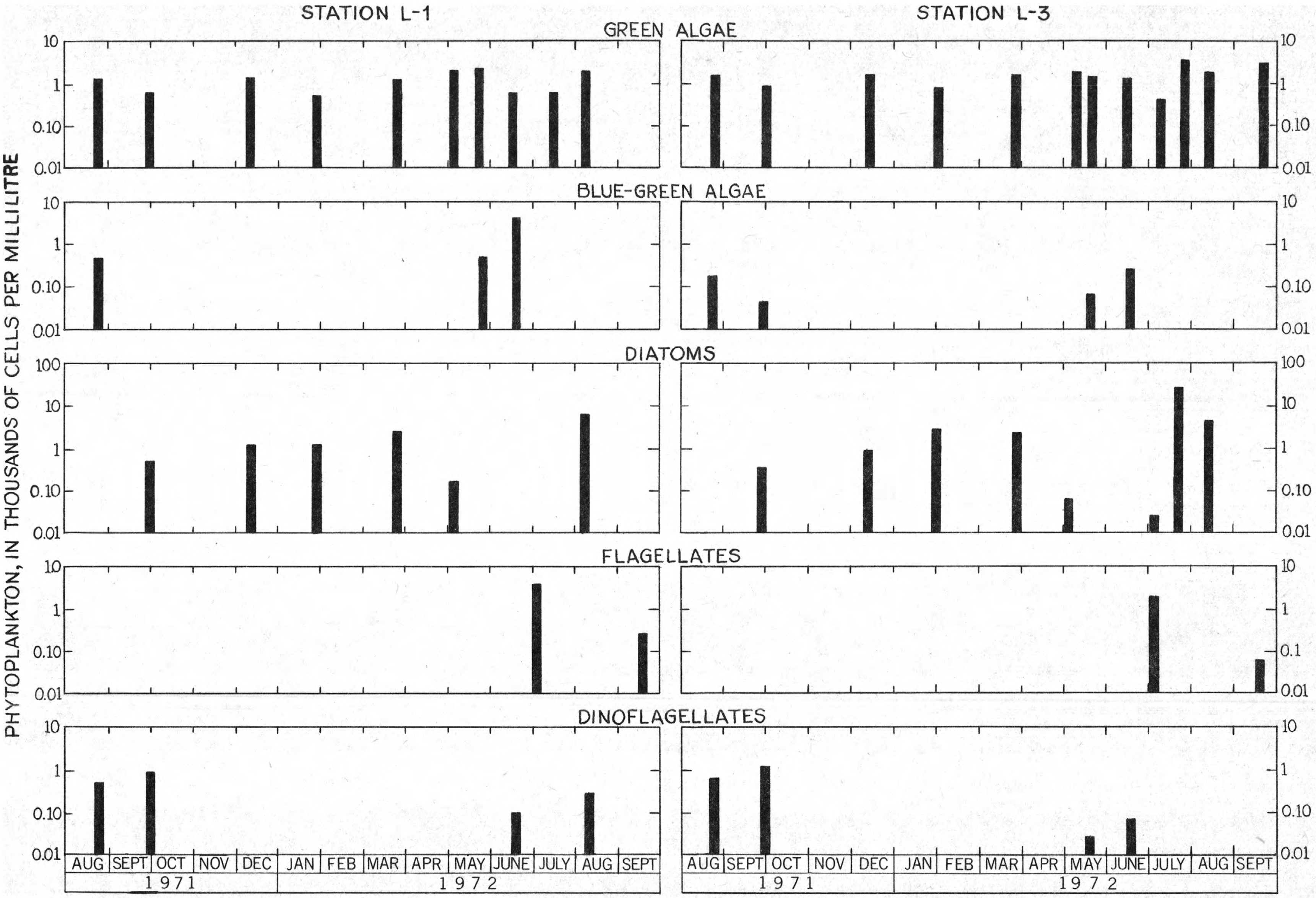

FIGURE 12.--Abundance of major groups of algae.

Zooplankton

Unfortunately, too little is known of the role of zooplankton as indicators of changes in water quality. Brooks (1969) has reviewed the studies concerned with zooplankton changes in lakes undergoing enrichment. While there is some evidence of response and species-composition changes as a result of enrichment, the findings are, at this time, inconclusive. Only a reconnaissance investigation of zooplankton types was made in Lake Shastina.

The greatest total number of zooplankton occurred in the March, July, and September samples (table 12). One group of zooplankton in Lake Shastina, the Cladocera or water fleas (primarily *Bosmina sp.*), are found in most fresh water systems. They are between 0.008 and 0.118 in (0.2 and 3.0 mm) in length. The largest number of Cladocera occurred in the June, July, and August samples.

The Copepoda, both adults and their immature forms (nauplii) were most abundant in March and July, with the largest numbers occurring in the March samples. Like the Cladocera, the Copepoda are widely distributed in fresh water. Most have a body length of less than 0.08 in (2.0 mm).

Rotifers were the third group of zooplankton in Lake Shastina. There are at least 1,750 known species of rotifers, most of which are restricted to fresh water (Pennak, 1953). In Lake Shastina, rotifers were most abundant in samples collected in March and September and were frequently codominant with the Cladocera.

Table 12.--*Dominant zooplankton*

[Number above line is the number of organisms per litre of sample; number below line is percentage of total of all organisms in sample]

Date	Zooplankton group: Cladocera	Zooplankton group: Copepoda (adults and Nauplii)	Zooplankton group: Rotifera	Total
Station L-1, depth zone from 0-3 metres				
Aug. 24, 1971	87 40	77 36	51 24	215
Sept. 30	19 6	68 23	209 71	296
Dec. 9	18 10	85 47	79 43	182
Jan. 28, 1972	1 1	31 42	42 57	74
Mar. 21	92 4	644 26	1,753 70	2,489
Apr. 14	1 0	157 49	162 51	320
May 2	43 22	80 41	72 37	195
May 4	22 20	31 28	59 53	112
May 17	184 56	43 14	96 30	325
June 13	646 71	114 13	175 19	905
July 3	3,753 86	566 13	27 1	4,346
Aug. 7	64 25	10 4	186 72	260
Sept. 22	3 0	1 0	1,315 100	1,319
Station L-1, depth zone from 3-7 metres				
Aug. 24, 1971	33 14	52 22	152 64	237
Sept. 30	20 7	61 21	207 72	288
Mar. 21, 1972	0 0	374 22	1,316 78	1,690
May 2	4 5	78 95	0 0	82
May 4	0 0	81 79	22 21	103
May 17	173 44	101 25	121 31	395
June 13	677 91	52 7	15 2	744
July 3	141 71	54 27	3 2	198
Aug. 7	68 74	7 8	17 18	92
Station L-3, depth zone from 0-3 metres				
Aug. 25, 1971	4 2	66 36	116 62	186
Sept. 30	3 13	1 4	20 83	24
Dec. 9	15 8	88 48	79 44	182

Table 12.--*Dominant zooplankton--Continued*

[Number above line is the number of organisms per litre of sample; number below line is percentage of total of all organisms in sample]

Date	Zooplankton group Cladocera	 Copepoda (adults and Nauplii)	 Rotifera	Total
Station L-3, depth zone from 0-3 metres--Continued				
Jan. 28, 1972	1 1	25 40	37 59	63
Mar. 21	0 0	1,023 50	1,023 50	2,046
Apr. 14	9 2	157 45	184 53	350
Apr. 28	3 6	19 37	30 58	52
May 2	46 41	8 7	59 52	113
May 4	79 53	14 9	57 38	150
May 16	18 7	26 11	198 82	242
June 13	732 82	62 7	104 12	898
July 3	1,499 65	742 32	57 3	2,298
July 22	319 45	40 6	352 49	711
Aug. 8	144 38	13 4	219 58	376
Sept. 22	56 8	9 1	678 91	743
Station L-3, depth zone from 3-7 metres				
Aug. 25, 1971	39 65	9 15	10 20	60
Sept. 30	14 12	4 3	102 85	120
Dec. 9	22 8	96 35	159 57	277
Jan. 28, 1972	8 11	34 48	29 41	71
Mar. 21	0 0	552 26	1,564 74	2,116
Apr. 28	0 0	24 71	10 29	34
May 2	3 8	17 47	16 45	36
May 4	22 15	26 18	98 67	146
May 16	46 28	50 30	68 42	164
June 13	1,250 92	73 5	27 2	1,350
July 3	29 18	117 9	15 73	161
July 22	181 64	20 7	81 29	282
Aug. 8	7 27	0 0	19 73	26
Sept. 22	49 16	4 1	258 83	311

Station L-3, depth zone from 7-10 metres

Aug. 25, 1971	25/64	8/21	6/15	39
Sept. 30	24/14	10/6	133/80	167
Dec. 9	24/9	111/43	123/48	258
Jan. 28, 1972	5/12	20/48	17/40	42
Mar. 21	92/4	1,012/44	1,196/52	2,300
Apr. 28	3/2	94/77	26/21	123
May 2	0/0	59/91	6/9	65
May 4	1/0	219/97	7/3	227
May 16	3/3	39/43	49/54	91
June 13	1,965/96	57/3	12/1	2,034
July 3	19/22	62/70	7/8	88
July 22	7/50	1/7	6/43	14
Aug. 8	3/25	1/8	8/67	12
Sept. 22	52/8	8/1	567/91	627

Station L-3, depth zone from 10-15 metres

Aug. 25, 1971	5/71	2/29	0/0	7
Sept. 30	2/1	6/5	108/94	116
Dec. 9	12/8	65/41	81/51	158
Jan. 28, 1972	4/12	18/53	12/35	34
Mar. 21	92/11	555/67	184/22	831
May 2	1/0	157/99	2/1	160
May 4	2/1	145/88	18/11	165
May 16	3/5	31/48	30/47	64
June 13	1,434/96	63/4	2/0	1,499
July 3	11/38	14/48	4/14	29
July 22	2/20	0/0	8/80	10
Aug. 8	4/67	0/0	2/33	6
Sept. 22	193/16	37/3	974/81	1,204

Benthic Organisms

Benthic organisms live on or in lake-bottom sediments, and may be represented by a large number of organism types. Because they spend part or all of their life history in the bottom of lakes, they are useful indicators of past water-quality conditions. Generally, under aerobic (oxygenated) conditions, a large number of types of benthic organisms are present, but each group is represented by only a few individuals. Under anaerobic (anoxic) conditions, only a few types of organisms are found, but there are relatively large numbers of each type.

Only three groups of organisms were found in the Lake Shastina samples, Oligochaetes (aquatic earthworms), Chironomidae (blood worms), and Chaoborus, a midge fly larvae (table 13). These types of organisms are all adapted to living under conditions of very low dissolved oxygen and in unconsolidated substrates. The Chironomidae have hemoglobin in their blood, which acts not only to transport oxygen, but increases the rate of recovery from periods of insufficient oxygen (Jónasson, 1969, p. 290-291). They construct and live in burrows in the lake bottom sediments.

The Oligochaeta are typified by *Tubifex sp.* (segmented worms), commonly found in streams and lakes where high concentrations of organic matter are present. According to Jónasson (1969, p. 289), the Oligochaeta and the Chironomidae are among the best adapted organisms for living under very low oxygen tensions.

Chaoborus larvae migrate vertically from the lake bottom where they spend the daylight hours, into the surface water of the lake during the hours of darkness. They also are able to maintain respiration at low oxygen levels, but not at levels as low as the Oligochaeta and Chironomidae.

Table 13.--*Dominant benthic organisms*

		Number of organisms per square metre		
Station	**Date**	**Oligochaete**	**Chironomidae**	**Chaoborus**
L-1	Mar. 21, 1972	3,350	130	4,640
L-3	Mar. 21	2,100	430	8,450
L-1	May 4	130	0	0
L-3	May 4	0	0	0
L-1	May 17	1,330	260	1,200
L-3	May 16	530	300	3,225
L-1	June 13	2,700	890	940
L-3	June 13	4,050	45	1,330
L-3	Aug. 8	1,600	0	1,850
L-1	Sept. 22	1,550	130	7,440
L-3	Sept. 22	2,750	0	4,340

The wide variation in numbers of organisms per sample in table 13 can be attributed in part to emergence of some Chironomidae and Chaoborus during the study period. These two insects undergo a metamorphosis in which the larvae transform into sexually mature adults which leave the water and become terrestial. The females deposit their eggs over the water and thus renew the cycle. Oligochaeta do not undergo a metamorphosis, and are thus completely aquatic. Their numbers were less variable between sample periods than the Chironomidae and the Chaoborus larvae.

The collection of a single sample (area, 36 in^2 or 232 cm^2) at each station is obviously insufficient to describe the population density. The results are useful only in providing insight as to the types of organisms present in the lake sediments. Nevertheless the presence of these oxygen-facultative types and the absence of more oxygen-demanding types are indicative of the character of the profundal environment of Lake Shastina.

DISCUSSION

Lake Shastina is thermally stratified throughout most of the year (spring, summer, and autumn). Only during winter months is the water in the lake well-mixed. At the present time, in Lake Shastina, nutrient concentrations are sufficient to support large algal blooms.

When the algae in the lake die, they sink and decompose, causing an oxygen demand in the deeper water. Below the epilimnion, thermal stratification prevents contact between the water and the atmosphere. Decomposition of organic material consumes oxygen, which results in an acute hypolimnetic dissolved-oxygen deficit, a common phenomenon in eutrophic lakes. The dissolved-oxygen deficit is harmful to higher aquatic life in that it restricts their environment. Anaerobic conditions in bottom water of the lake also create a reducing environment where plant nutrients in the bottom sediment become soluble. Resolution of plant nutrients from the bottom-sediment materials into the water column may partly account for the high phosphorus concentrations and loads recorded during the summer sampling period.

The hypolimnetic dissolved-oxygen deficit also influences the type of organisms in the benthic environment. In Lake Shastina, the dominant groups of benthic organisms were Oligochaetes, Chironomidae, and Chaoborus, typical organisms in unconsolidated substrate and oxygen-poor water.

A hypolimnetic, oxygen-poor condition probably is not new in Lake Shastina, as shown by comparison of iron and manganese deposition data in core samples from other lakes. Gorham and Swaine (1965) reported average iron-manganese ratios were 6.6 in oxidized sediment and 31 in reduced sediment. In core samples from Lake Shastina, iron-manganese ratios were very large, ranging from 42 to 90 (table 11). This range was similar to the range of 42 to 86 reported for the highly eutrophic Lake Kinneret (Serruya and others, 1969). In the oligotrophic environment of Fern Lake, iron-manganese ratios in bottom sediment ranged from 2.5 to 11 (Olsen and others, 1967).

In the epilimnion, algal production is extensive as indicated by supersaturation of dissolved oxygen (as much as 200 percent) during summer daylight hours. Intense photosynthetic oxygenation during daylight hours is often accompanied by heavy respiratory oxygen demand at night.

In the autumn, the thermal stratification collapsed in an overturn that probably occurs at about the same time each year. After overturn, the lake remained in a well-mixed condition and thermal stratification did not occur again until spring. When the autumn overturn occurs, the oxygen demand of the water from the hypolimnion may be so great that all of the water in the lake will have a general oxygen deficiency until atmospheric aeration introduces additional oxygen into solution.

Fishkills in Lake Shastina may be related to oxygen deficiency. Under stratified conditions, nocturnal respiratory demand for oxygen in the epilimnion could result in a reversal of dissolved-oxygen saturation from supersaturation during sunlit hours to undersaturation at night. During the overturn, oxygen demand of the anaerobic zone could cause a temporary oxygen shortage. Oxygen deficiency from either of these events could contribute to reported fishkills, and if they occurred simultaneously, the oxygen deficiency could be severe.

A lake usually undergoes eutrophication through enrichment of the water by nutrients from external and internal sources. External sources of nutrients include surface runoff, ground water (including septic tank seepage), and precipitation. Internal sources include return of nutrients from lake-bottom sediment and from decomposition of organic matter. In Lake Shastina, inflow of nutrients from surface runoff is mainly from Shasta River and Garrick Creek. Nitrogen and phosphorus inputs from these two sources probably are related, in part, to agricultural and residential development in the drainage basin.

Nutrients dissolved from bottom sediment in Lake Shastina are difficult to evaluate because knowledge of the lake's sedimentary chemistry is incomplete and evidence in literature is contradictory (Armstrong and Schindler, 1971). However, it has been generally suggested that sediment acts as a buffer in nutrient content of the overlying water. This means that the concentration of a nutrient in the overlying water reaches an equilibrium level; when the concentration tends to exceed equilibrium, the nutrient will be incorporated into the sediment, or vice versa. As a result, plant nutrients in sediments are potential nutrients to support algal growth. Analyses indicate higher phosphorus and nitrogen concentrations in the bottom water of Lake Shastina than in water near the surface. These data support the concept that nutrients in the bottom sediments become soluble as a result of the decomposition of organic matter by bacteria and the attendant reduction of dissolved oxygen.

An important source of nutrients for Lake Shastina which cannot be evaluated at this time is the cultural development around the lake. The recent shoreline development is still in its infancy, but it undoubtedly represents a part of man's activities that can accelerate the eutrophication process of the lake.

NOTES ON ALGAL CONTROL

Control of undesirable algal growth may be required to preserve or improve recreational values of Lake Shastina. Generally, algal-control methods are of four types: biological, physical, ecological, and chemical.

Biological control involves the use of competitive organisms, such as grazers or animals which feed on algae. However, the results of introducing grazers are uncertain, and current research has not progressed to a point where biological control is predictable.

Physical control involves elimination of light, deepening of shallow areas by dredging, and harvesting rooted plants. Reducing light transmission by addition of dyes, charcoal, or colloidal substances to the lake water can be a simple and effective control of algal growth. However, the method impairs esthetic values. Harvesting rooted plants along the perimeter and other parts of the lake often improves the esthetic appearance of the lake and removes nutrient-rich plant cell material.

Ecological control involves reduction of essential algal nutrient supplies by aeration of oxygen-poor bottom water, selective withdrawal of bottom water, and preventing inflow of nutrient-rich water to the lake. Aeration during summer months would reduce thermal stratification of the reservoir and increase the dissolved-oxygen level in the hypolimnion. Elimination of anaerobic conditions in the lake would discourage regeneration of nutrients from bottom sediment and therefore help to reduce the quantity of nutrients available to support algal growth. Results of this approach to algal control probably would be marginal in Lake Shastina because of the present large supply of essential nutrients, even during the winter free-circulation period. Preventing nutrient inflow to Lake Shastina by diverting water from Shasta River and Garrick Creek is impractical as more than 90 percent of the water resources of the lake depend upon these tributaries. The annual release of water from the hypolimnion during the irrigation season (May to October) through Montague Main Canal is a desirable selective withdrawal of stratified water and removes nutrients from the lake. The deeper water in Lake Shastina contains higher concentrations of nitrogen and phosphorus than water near the surface.

Chemical control involves the use of various algicides such as copper sulfate and sodium arsenite. While algicides are the most immediately effective means of algal control, the effect is one of temporary relief, and the quantity of chemical additives may have harmful effects on fish and other biota.

Presently, copper sulfate is the most popular type of algicide used (Mackenthun, 1969). The solubility of copper sulfate is a function of the pH, alkalinity, and the temperature of the water. Consequently, the quantity required for algal control may vary widely between lakes. Lakes that have a total alkalinity of 40 mg/l or greater should be treated at a rate of 1 mg/l of copper sulfate ($CuSO_4 \cdot 5 H_2O$) for the upper 2 ft (0.6 m) of water. This is 5.4 lb (2.4 kg) of copper sulfate for each surface acre. Because of the high alkalinity, the copper sulfate forms a precipitate below the 2-ft (0.6-m) depth and thus becomes inactive as an algicide.

Lakes that have a total alkalinity less than 40 mg/l can be treated at the rate of 0.3 mg/l for the entire water depth. This application rate is 0.9 lb (0.4 kg) of copper sulfate per acre-foot of water (Mackenthun, 1969, p. 241).

Undesirable effects of algicide treatment can be partly avoided by spot treatment. The early detection and treatment of troublesome algae before the number of organisms increases to the level of bloom will greatly reduce the quantity of organic matter reaching the lake bottom and hence assist in the reduction of anoxic conditions.

Specific methods for the application of algicides and rates of application are given by Mackenthun (1969) and Monie (1956).

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Dong, Beatty, and Averett—LIMNOLOGICAL STUDY OF LAKE SHASTINA, SISKIYOU COUNTY, CALIFORNIA WRI 19-74

KALINITY···GAINING STREAM···SPECIFIC YIELD··MILLIGRAMS PER LIT
RANSMISSIVITY···TEST WELL···HYDRAULIC CONDUCTIVITY···MOIST RE
PRINGS···FLOOD FREQUENCY···DIGITAL MONITOR···RAIN GAGE···F OO
SSOLVED SOLIDS···WATER QUALITY···TEMPERATURE···STAGE-DIS HA
IC···FLOODFLOW··PERCOLATION···CONFINING BED···METEORIC WA R·
CABLEWAY···TOTAL KJELDAHL NITROGEN···RUNOFF···PRECIPITATI N·
UTOMATIC ANALYZER···TURBIDITY···BIODEGRADATION···E. COLI··· AL
ONE OF SATURATION···BASE OF FRESH WATER···DEPOSITION··· SO
ECTRICAL LOGS···SAFE YIELD···EFFECTIVE PRECIPITATION···SEI ME
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D···HYDROLOGIC BUDGET···LIMNOLOGY···AQUICLUDE···WATER YEA ··
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···HEAD DECLINE···EUTROPHICATION···MOISTURE EQUIVALENT···B SE
ECORDER···SEDIMENT TRANSPORT···DYE TRACER···STREAM GAGIN ··
DISSOLVED OXYGEN···SODIUM ADSORPTION···BIOCHEMICAL OXYGEN DE
OTENTIOMETRIC SURFACE···INFILTRATION···HEAD···ACRE-FEET·· FL
EVE SIZE···STREAMS···TOTAL NITROGEN···GRAIN SIZE···GRA SA
···CUBIC FEET PER SECOND···SLOPE-AREA METHOD···DRAINAGE AS
GANIC POLLUTION···SPECIFIC CONDUCTANCE···TOTAL ORGANIC CARBO
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OOD PLAIN···COMPUTER READOUT···NO-FLOW BOUNDARY···AQUITARD
···EVAPOTRANSPIRATION···RECHARGE···VELOCITY···STREAM PROFILE