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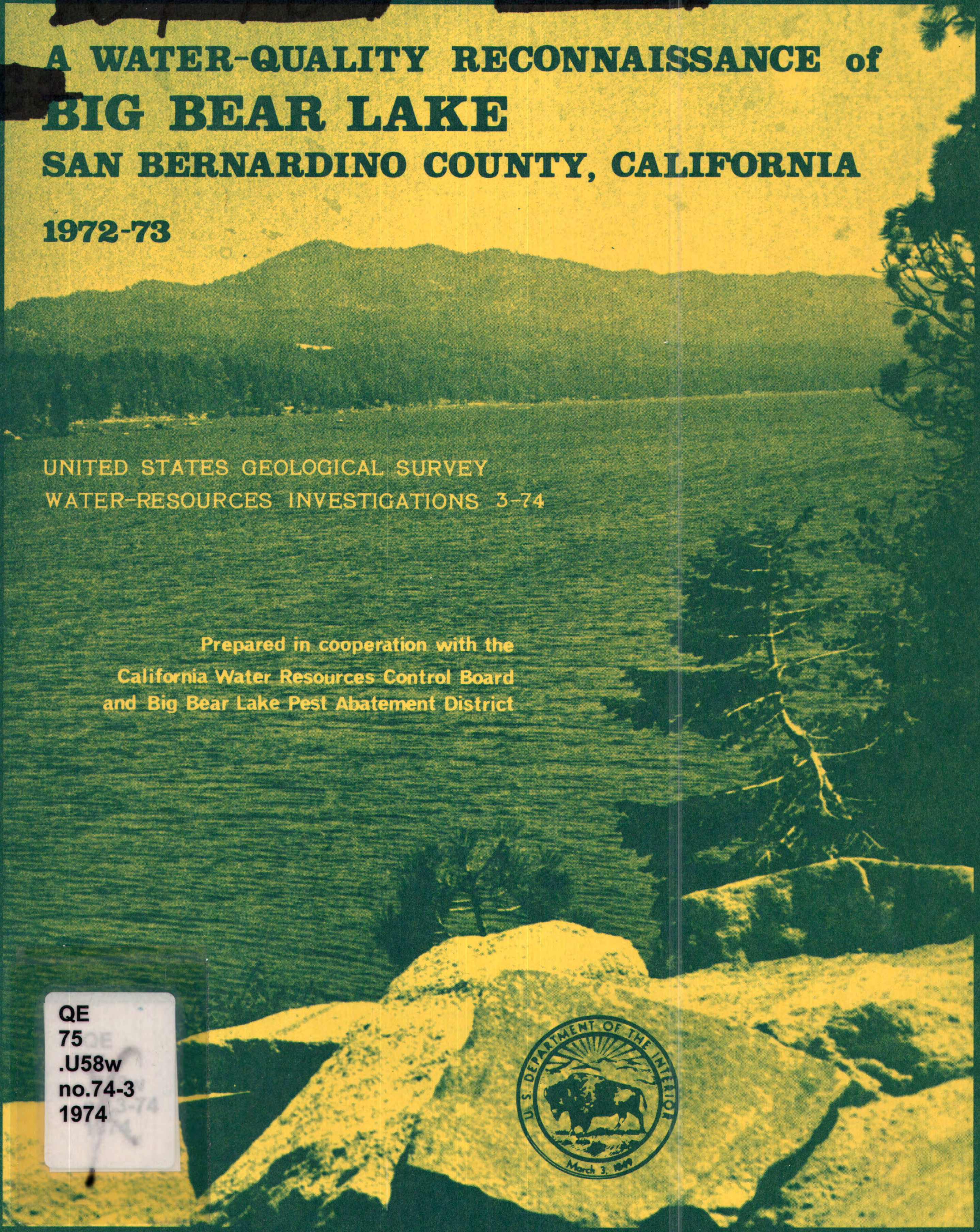
A WATER-QUALITY RECONNAISSANCE of BIG BEAR LAKE SAN BERNARDINO COUNTY, CALIFORNIA

1972-73



UNITED STATES GEOLOGICAL SURVEY
WATER-RESOURCES INVESTIGATIONS 3-74

Prepared in cooperation with the
California Water Resources Control Board
and Big Bear Lake Pest Abatement District

U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849

BIBLIOGRAPHIC DATA SHEET Preliminary

1. Report No.

2.

3. Recipient's Accession No.

4. Title and Subtitle

A WATER-QUALITY RECONNAISSANCE OF BIG BEAR LAKE
SAN BERNARDINO COUNTY, CALIFORNIA, 1972-73

5. Report Date
May 1974

6.

7. Author(s)
George A. Irwin and Michael Lemons

8. Performing Organization Rept. No. 276-01

9. Performing Organization Name and Address
U.S. Geological Survey, WRD
California District
345 Middlefield Rd.
Menlo Park, Calif. 94025

10. Project/Task/Work Unit No.

11. Contract/Grant No.

12. Sponsoring Organization Name and Address
Same as 9 above.

13. Type of Report & Period Covered

14.

15. Supplementary Notes
Prepared in cooperation with the California Water Resources Control Board and Big Bear Lake Pest Abatement District

16. Abstracts

A water-quality reconnaissance study of the Big Bear Lake area in southern California was made by the U.S. Geological Survey during the period April 1972 through April 1973. The primary purpose of the study was to measure seasonally the concentration and distribution of selected primary nutrients, dissolved oxygen, phytoplankton, and water temperature in the lake. In addition, measurements of the nitrogen and phosphorus loading to the lake from surface-water tributaries and precipitation were also made.

Results of the study indicate that Big Bear Lake is moderately eutrophic, at least in regard to nitrogen, phosphorus, and organic content. Seasonal levels of dissolved oxygen indicated that the nutrients and other controlling factors were optimum for relatively high primary productivity. However, production rates varied both seasonally and areally.

17. Key Words and Document Analysis. 17a. Descriptors

Eutrophication, nutrients, primary productivity, regression analysis, synoptic analysis, California

17b. Identifiers/Open-Ended Terms

Big Bear Lake

17c. COSATI Field/Group

18. Availability Statement
No restriction in distribution.

19. Security Class (This Report)
UNCLASSIFIED

20. Security Class (This Page
UNCLASSIFIED

21. No. of Pages
46

22. Price

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5020-41

May 1974

UNITED STATES DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS

Factors for converting English units to the International System of Units (SI) are shown 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	4.047×10^{-3}	km^2 (square kilometer)
acre-ft (acre-foot)	1.233×10^{-3}	hm^3 (cubic hectometer)
ft^3/s (cubic foot per second)	2.832×10^{-2}	m^3/s (cubic meter per second)
ft (foot)	3.048×10^{-1}	m (meter)
gal (gallon)	3.785	l (liter)
in (inch)	2.540×10	mm (millimeter)
mi (mile)	1.609	km (kilometer)
mi^2 (square mile)	2.59	km^2 (square kilometer)
ton (short)	9.072×10^{-1}	t (metric ton)

A WATER-QUALITY RECONNAISSANCE OF BIG BEAR LAKE,
SAN BERNARDINO COUNTY, CALIFORNIA, 1972-73

By George A. Irwin and Michael Lemons

ABSTRACT

A water-quality reconnaissance study of the Big Bear Lake area in southern California was made by the U.S. Geological Survey from April 1972 through April 1973. The primary purpose of the study was to measure the concentration and distribution of selected primary nutrients, organic carbon, dissolved oxygen, phytoplankton, and water temperature in the lake. Estimates of the nitrogen, phosphorus, and silica loading to the lake from surface-water tributaries and precipitation were also made.

Results of the study indicate that Big Bear Lake is moderately eutrophic, at least in regard to nitrogen, phosphorus, and organic content. Nitrate was found in either trace concentrations or below detectable limits; however, ammonia nitrogen was usually detected in concentrations greater than 0.05 milligrams per liter. Orthophosphate phosphorus was detected in mean concentrations ranging from 0.01 to 0.05 milligrams per liter. Organic nitrogen and phosphorus were also detected in measurable concentrations.

Seasonal levels of dissolved oxygen indicated that the nutrients and other controlling factors were optimum for relatively high primary productivity. However, production varied both seasonally and areally in the lake. Primary productivity seemed highest in the eastern and middle parts of the lake. The middle and western parts of the lake exhibited severe oxygen deficits in the deeper water during the warmer summer months of June and July 1972.

INTRODUCTION

Big Bear Lake, in the San Bernadino Mountains of southern California, is a picturesque high-altitude water resource. Although the lake water is used primarily for irrigation in the Redlands-San Bernardino area, recreational use of Big Bear Lake is increasing.

In recent years, algal and submersed-plant production has increased noticeably. Classically, increased algal and submersed-plant production is symptomatic of nutrient enrichment. Nutrient enrichment (eutrophication) of a water resource is a natural process. The enrichment process is the result of erosion and transportation of nutrient materials into the aquatic system. As the nutrients increase in availability, primary (plant) productivity in the system accelerates. Ultimately, the water resource receiving and retaining these nutrients will become luxurient with plantlife and no longer desirable for man's uses. Eutrophication under natural conditions may be measurable only in regard to geologic time. However, man's activities may accelerate this process greatly.

In past years, the density of submersed plants in Big Bear Lake has virtually halted boat traffic near shallow marinas. To control the excessive submersed plant and algal production, the Big Bear Lake Pest Abatement District has periodically applied chemical retardants. As a supplement to chemical control, the District purchased a commercial weed harvester in 1970. From May through October 1972, about 3,400 tons (3,080 t) (wet weight) of submersed plants was removed from the littoral zone of the lake (H. Orval Warren, oral commun., April 1973).

Big Bear Lake is also of concern to the California Water Resources Control Board and its Water Quality Control Board--Santa Ana Region. The Porter-Cologne Water Quality Control Act of 1969 (California Water Resources Control Board, 1969) states:

> "It is the intent of the [California] Legislature that the State board and each regional board shall be the principal State agencies with primary responsibility for the coordination and control of water quality."

The California Regional Water Quality Control Board--Santa Ana Region, which has this responsibility, and the Big Bear Lake Pest Abatement District requested the U.S. Geological Survey to make a reconnaissance study to evaluate selected water-quality conditions in the Big Bear Lake basin. The study was initiated by a cooperative agreement, and fieldwork began in the spring of 1972.

The principal purpose of the study was to describe existing conditions in the Big Bear Lake basin, emphasizing the concentration and distribution of selected primary nutrients and dissolved oxygen. The scope of the study included seasonal sampling to determine the distribution and variation of selected primary nutrients and other related variables in both the lake and its tributaries. In addition to the nutrient-sampling program, field measurements of selected physical and chemical variables were made in the lake. Eight field surveys were made from April 1972 through April 1973.

These data and this report will be used in conjunction with other investigations, primarily by the California Regional Water Quality Control Board--Santa Ana Region, to assist in formulating a water-quality control plan for Big Bear Lake.

A special acknowledgment is made to P. E. Greeson, D. R. Dawdy, G. G. Ehrlich, T. S. Chandler, J. G. Setmire, and R. C. Averett, U.S. Geological Survey, and Mr. H. Orval Warren, Big Bear Lake Department of Parks and Recreation, for their assistance during this study.

DESCRIPTION OF THE AREA

Big Bear Lake was formed by the construction of a multiple-arch dam across Bear Creek in 1911 by the Bear Valley Mutual Water Co. At a spillway altitude of 6,744 ft (2,055.6 m) and gage height at the dam of 72 ft 4 in (22.05 m), the lake has a surface area of about 3,000 acres (12.1 km^2) and a storage capacity of about 72,000 acre-ft (88.8 hm^3). Big Bear Lake has several prominent bays and points, is about 6 mi (9.7 km) long, averages about a mile wide, averages about 24 ft (7.3 m) deep, and is generally less than 50 ft (15 m) deep (fig. 1).

The area has warm summers and cold winters typical of mountainous areas of southern California. Air temperature ranges from a high of about 30°C in July-August to below -17.8°C in January-February. Mean annual precipitation at Big Bear Lake Dam is 36 in (914 mm), and total precipitation from April 1972 through April 1973 was 45 in (1,140 mm).

The drainage area tributary to Big Bear Lake is 32.4 mi^2 (83.9 km^2). The average altitude of the drainage area is about 7,300 ft (2,200 m) above mean sea level.

Big Bear Lake valley is a prime recreational area for residents in southern California. The base population of Big Bear Lake valley is estimated to be about 6,700 (California Department Public Health, 1972, p. 24). Occasional weekend populations exceeding 100,000 have been recorded; the maximum tourist visitation to the valley recorded by the U.S. Forest Service was 210,871 persons from December 16, 1967, to January 2, 1968 (Neste, Brudin, and Stone, 1970, p. 17).

The domestic water supply for most of the Big Bear Lake valley area is obtained from ground water supplied from local wells by the Southern California Water Co. The average daily water delivery per capita during July (1958-68) was about 120 gal (450 l) (Neste, Brudin, and Stone, 1970, p. 19).

Most of Boulder Bay, Big Bear Lake, Big Bear City, and some of Moonridge are sewered by either Big Bear Community Services District or the Big Bear Fire and Sanitation District. Areas that are currently using individual waste-disposal systems are parts of Moonridge, Fawnskin, and the north shore of Big Bear Lake (California Department Public Health, 1972, p. 27). Most of these individual disposal systems are septic tanks and leach fields.

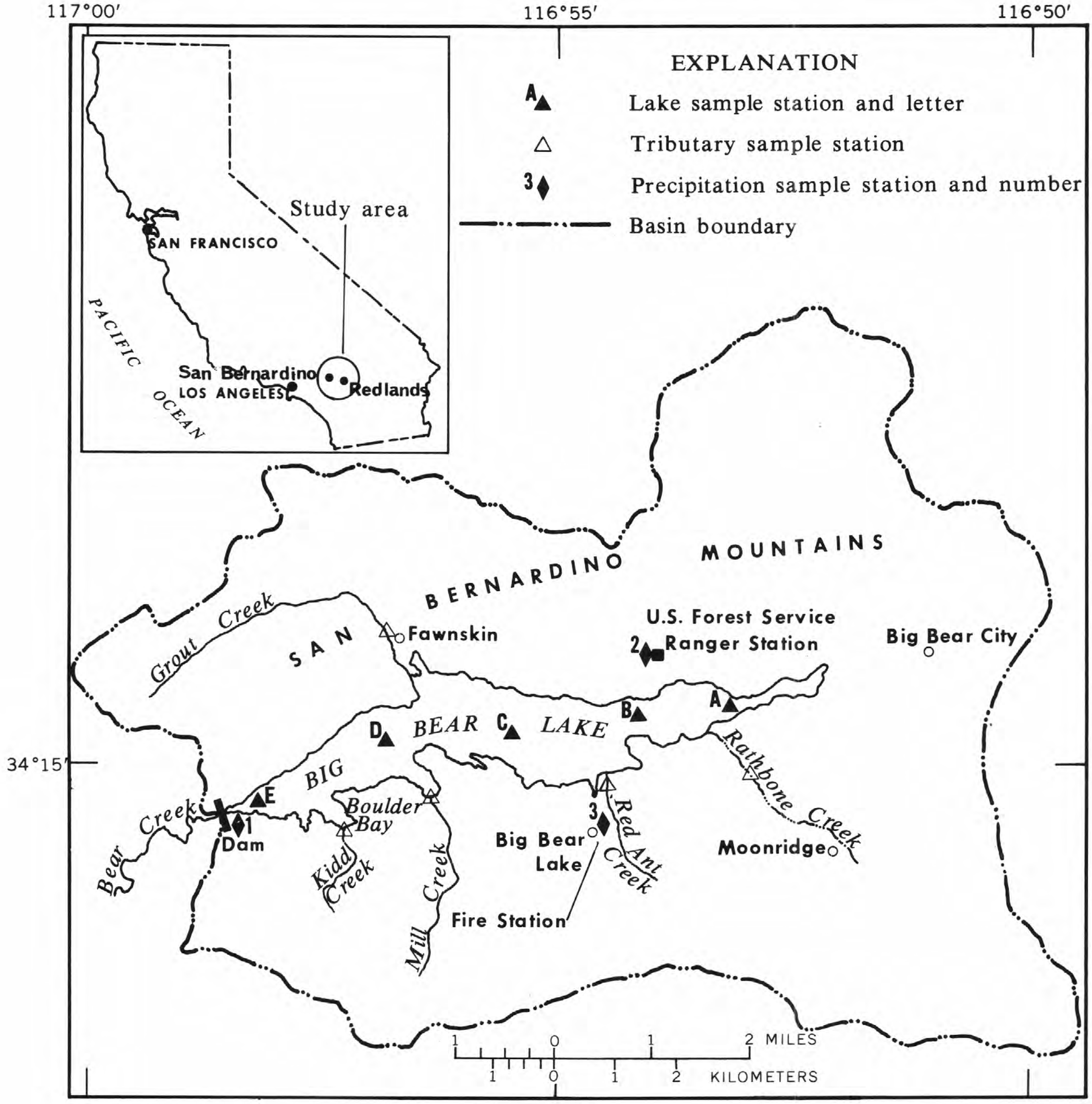

FIGURE 1.--Sampling stations.

METHODS AND PROCEDURES

Analytical Methods

Samples collected for chemical analyses were analyzed by the U.S. Geological Survey laboratory in Salt Lake City, Utah, using the methods of Brown, Skougstad, and Fishman (1970). Phytoplankton samples were analyzed by the California Department of Water Resources in Bryte, Calif.

Sampling Procedures

Samples collected for the determination of nitrite, ammonia nitrogen, nitrate, dissolved organic nitrogen, and orthophosphate phosphorus were filtered in the field at the time of collection through a 0.45-μm (micrometer) membrane filter, preserved with mercuric chloride, and chilled. Samples for the determination of organic nitrogen and total phosphorus were unfiltered, preserved with mercuric chloride, and chilled. Samples for silica, specific conductance, and turbidity were unfiltered and untreated. Samples for total organic carbon were unfiltered and chilled. Phytoplankton samples were preserved with Lugol's solution.

Precipitation samples were collected in a 5-gal (18.9 l) polyethylene jug with an 11-in (280 mm) polyethylene funnel attached to the mouth. Samples were removed from containers as soon as possible after each storm. However, in a few cases, as much as 24 hours lapsed before samples were filtered and preserved.

Samples of the lake-bottom sediments were collected with an Ekman dredge. One or two grabs were collected at each sampling site and mixed in a plastic tray. A subsample was taken from the tray and chilled for subsequent analysis.

Dissolved oxygen, water temperature, and pH were measured in the field with instrumentation after field calibration. Total alkalinity was determined in the field immediately after sample collection by titration with 0.01639 N sulfuric acid to a pH of 4.5.

SAMPLING FREQUENCY AND VARIABLES ANALYZED

Big Bear Lake

Five sites in Big Bear Lake (fig. 1) were surveyed. Selected physical and chemical variables were measured eight times from April 1972 through April 1973. Samples were collected at stations B, C, D, and E 1 m from the surface, about middepth, and 1 m from the bottom. Station A was only about 3 m deep, and samples were collected 1 m from the surface and bottom. At all sites and depths a sample was collected for ammonia nitrogen, nitrate, nitrite, dissolved organic nitrogen, total organic nitrogen, silica, specific conductance, and turbidity analyses. Field measurements determining the concentration of dissolved oxygen and water temperature were made at 1-m depth intervals at all five sites. Secchi disk transparencies were measured at all five sites. At stations A, C, and E, samples were collected for total organic carbon and phytoplankton analyses. In addition, dissolved oxygen, water temperature, pH, and total alkalinity were measured about bihourly at stations A, C, and E July 19-20, 1972.

Big Bear Lake Tributaries

Surface-water tributaries to Big Bear Lake were sampled three to six times from February 1972 through April 1973. Tributaries sampled included Rathbone, Mill, Red Ant, Kidd, and Grout Creeks. Samples were collected for total nitrogen, total phosphorus, and silica analyses. Samples were collected at varying flow conditions.

Precipitation

Precipitation sample collectors were placed near the dam (station 1) and at the U.S. Forest Service ranger station (station 2). Four storms were sampled from April through November 1972. Samples were analyzed for total nitrogen, total phosphorus, silica, and specific conductance.

Lake-Bottom Sediment

Samples of material from the lake bottom were collected at stations A, C, and E in June and September 1972 and April 1973. Samples were analyzed for total nitrogen, total phosphorus, and organic content (loss on ignition). Cross-sectional depth profiles through lake stations A, B, C, D, and E made in September 1972 are not included in this report, but are available at the U.S. Geological Survey office in Menlo Park, Calif.

RESULTS

Seasonal Distribution of Dissolved Oxygen, Oxygen Saturation, and Water Temperature

Monthly dissolved oxygen, percentage of oxygen saturation, and water-temperature profiles from April 1972 through April 1973, measured at stations A, C, and E, are shown in tables 1, 2, and 3. (Oxygen saturation was calculated from the dissolved-oxygen concentration and water temperature, adjusted for altitude and barometric pressure (American Public Health Association and others, 1971, p. 480). Individual surveys were generally completed in 4 to 6 hours, commencing about 0800 hours. However, in April, May, and June 1972 all stations were not measured on the same day. Data collected at stations B and D are not included in this report as the trends were similar to those of stations A, C, and E. However, data for stations B and D are available in the U.S. Geological Survey office in Menlo Park, Calif.

In April and May 1972 the dissolved oxygen was vertically uniform at station A, and supersaturation existed throughout the water column (table 1). By June, the dissolved-oxygen concentrations were lower than in previous months. In July, the dissolved-oxygen concentrations had increased slightly, and most of the water column was supersaturated. Concentrations of dissolved oxygen were noticeably lower and vertically nonuniform in August, and only the surface was supersaturated. However, in September, most of the water column was supersaturated with dissolved oxygen. The dissolved-oxygen distribution in October was completely uniform, but concentrations had decreased from September. In April 1973 the dissolved oxygen was vertically uniform, and the percentage of saturation ranged from 91 to 98.

Water temperature at station A varied monthly, having a maximum of 23.0°C in July 1972 and a minimum of 7.5°C in April 1973. Temperature distribution was generally uniform, and the maximum vertical variation was 2.0°C in April 1973.

Dissolved-oxygen distribution was nonuniform at station C (table 2). The maximum vertical variation in concentration occurred in July 1972 and was 8.4 mg/l (surface) to 0.4 mg/l (9 m). Dissolved-oxygen saturation levels in the deeper water at station C were always below 100 percent, but they ranged from 5 to 93 percent saturation at the 9-m level.

The maximum water temperature at station C was 21.8°C in July 1972, and the minimum was 5.0°C in April 1973. In June and July 1972 the temperature distribution was noticeably nonuniform, the vertical variations were 3.7°C and 4.0°C, respectively.

At station E the maximum vertical variation (surface to bottom) in dissolved-oxygen concentration was 6.5 to <0.1 mg/l in July 1972 (table 3). The minimum vertical variation within the water column was 0.1 mg/l in October.

At station E the water temperature ranged from a maximum of 20.2°C in July to a minimum of 4.0°C in April 1973. The maximum vertical variation within the water column was 4.8°C in July. In April, September, and October 1972, and April 1973 the temperature distribution was uniform, and the minimum vertical variation was 0.1°C in September.

TABLE 1.--*Concentration of dissolved oxygen, oxygen saturation, and water temperature at station A*

Depth (meters)	1972							1973
	April	May	June	July	August	September	October	April
				Dissolved oxygen (milligrams per liter)				
Surface	9.8	9.5	5.8	7.3	7.2	9.0	7.0	8.6
1	10.0	9.5	5.6	7.3	5.9	9.0	7.0	8.4
2	10.2	9.4	5.6	7.3	4.8	9.0	7.0	8.5
3	10.4	9.4	5.5	7.2	4.4	7.6	7.0	8.6
3+	9.6	9.4	4.9	5.4	3.7			8.5
				Dissolved oxygen (percent saturation)				
Surface	115	117	79	109	103	114	77	98
1	118	117	77	109	84	114	77	96
2	120	115	77	109	66	114	77	97
3	122	115	75	107	60	95	77	96
3+	113		67	80	51			91
				Water temperature[1] (degrees Celsius)				
Surface	11.2	14.5	18.9	23.0	20.5	15.6	9.2	9.5
1	11.2	14.5	19.0	23.0	20.3	15.6	9.2	9.5
2	11.0	14.3	19.0	23.0	20.1	15.5	9.1	9.5
3	10.8	14.2	19.0	23.0	20.0	15.0	9.0	8.5
3+	10.8		18.8	22.5	20.0			7.5

[1] Water temperature reported to nearest 0.1°C to more precisely define variation; instrumentation accuracy ±0.1°C.

TABLE 2.--*Concentration of dissolved oxygen, oxygen saturation, and water temperature at station C*

Depth (meters)	1972							1973
	April	May	June	July	August	September	October	April
				Dissolved oxygen (milligrams per liter)				
Surface	9.2	8.8	7.0	8.4	6.1	7.2	5.4	8.7
1	9.1	8.8	7.0	8.4	6.7	7.3	5.4	8.8
2	9.1	8.7	6.8	8.2	6.0	7.1	5.4	8.9
3	9.0	8.7	6.7	8.2	5.5	6.9	5.1	8.9
4	8.8	8.7	6.7	8.0	5.2	6.8	5.0	8.8
5	8.6	8.6	6.6	7.4	4.6	6.7	4.9	8.8
6	8.6	8.2	6.2	7.3	3.5	6.5	4.7	8.5
7	8.4	8.2	5.7	6.9	2.8	6.4	4.1	8.4
8	8.2	8.2	3.0	5.8	2.8	6.2	3.3	8.3
9	7.8	7.6	1.3	0.4	2.6	6.0	2.0	6.7
9+	7.6	6.4	1.2	0.4				6.3
				Dissolved oxygen (percent saturation)				
Surface	106	110	96	120	84	91	60	92
1	105	110	96	122	92	91	60	93
2	105	107	93	119	82	90	60	92
3	105	106	93	117	75	87	57	92
4	101	106	93	114	71	86	56	91
5	99	105	88	106	63	82	54	91
6	99	100	83	104	48	81	52	88
7	97	100	76	100	38	78	46	86
8	94	100	38	82	38	76	37	86
9	90	93	17	5	36		22	67
9+	87	78	15	5				63
				Water temperature[1] (degrees Celsius)				
Surface	10.0	15.0	18.9	21.5	20.1	15.6	10.2	7.0
1	10.0	14.8	18.9	21.8	20.1	15.5	10.2	7.0
2	10.1	14.5	18.8	21.8	19.9	15.5	10.2	6.0
3	10.0	14.2	18.8	21.5	19.9	15.5	10.2	6.0
4	10.0	14.2	18.8	21.5	19.8	15.5	10.2	6.0
5	10.0	14.0	17.6	21.2	19.8	15.5	10.2	6.0
6	9.9	13.8	17.9	21.0	18.2	15.5	10.2	6.0
7	9.9	13.8	17.4	21.0	19.0	15.5	10.2	6.0
8	9.8	13.8	16.4	20.8	19.0	15.4	10.1	6.0
9	9.1	13.1	15.8	18.8	18.9	15.4	10.0	6.0
9+	9.1	13.0	15.2	17.8				5.0

[1] Water temperature reported to nearest 0.1°C to more precisely define variation; instrumentation accuracy ±0.1°C.

TABLE 3.--*Concentration of dissolved oxygen, oxygen saturation, and water temperature at station E*

Depth (meters)	1972							1973
	April	May	June	July	August	September	October	April
				Dissolved oxygen (milligrams per liter)				
Surface	9.2	7.6	6.4	6.5	4.4	5.9	5.4	5.7
1	9.1	7.6	6.3	6.4	4.4	5.8	5.4	5.6
2	9.1	7.6	6.2	6.3	4.4	5.9	5.4	5.6
3	9.1	7.5	6.2	6.3	4.6	5.9	5.4	5.4
4	9.4	7.4	6.1	5.2	4.1	5.9	5.4	5.3
5	9.5	7.4	6.1	4.2	4.0	5.9	5.4	5.0
6	9.5	7.2	6.1	3.8	3.9	5.8	5.4	4.9
7	9.4	7.2	6.1	3.0	3.8	5.8	5.4	4.8
8	9.4	7.1	6.0	0.7	3.7	5.8	5.4	4.8
9	9.4	7.1	6.0	0.2	3.6	5.8	5.3	4.7
10	9.5	7.1	6.0	0.2	3.4	5.9	5.3	4.6
11	9.4	7.1	2.0	<0.1	3.3	5.9	5.3	4.4
12	9.4	7.0	0.9	<0.1	3.2	5.9	5.3	4.1
13	9.2	6.9	0.6	<0.1	3.1	6.0	5.3	4.0
14	9.1	6.6	0.3	<0.1	3.0	6.0	5.3	3.8
				Dissolved oxygen (percent saturation)				
Surface	106	93	83	89	60	74	61	57
1	105	93	83	88	60	72	61	56
2	105	93	82	86	60	74	61	56
3	105	91	82	86	63	74	61	54
4	108	90	78	71	56	74	61	52
5	109	90	78	56	53	74	61	49
6	109	88	78	52	52	72	61	48
7	108	86	78	41	51	72	61	47
8	108	84	77	9	49	72	61	47
9	108	84	77	3	48	72	59	46
10	109	84	77	2	45	74	59	45
11	108	84	25	1	44	74	59	43
12	108	81	11	1	43	74	59	40
13	106	80	7	1	41	75	59	39
14	106	77	4	1	40	75	59	37
				Water temperature[1] (degrees Celsius)				
Surface	10.1	13.5	16.6	20.2	19.8	15.2	10.8	4.5
1	10.0	13.2	16.6	20.1	19.7	15.2	10.8	4.5
2	9.9	13.1	16.5	20.1	19.1	15.2	10.8	4.5
3	9.9	13.1	16.4	20.1	19.0	15.1	10.9	4.5
4	9.8	12.9	16.2	20.0	18.8	15.1	10.9	4.0
5	9.8	12.9	16.2	19.8	18.2	15.1	10.9	4.0
6	9.7	12.8	16.2	19.2	18.2	15.1	10.9	4.0
7	9.6	12.5	16.2	19.0	18.2	15.1	10.9	4.0
8	9.6	12.5	16.1	17.8	18.1	15.1	10.9	4.0
9	9.6	12.5	16.1	17.0	18.1	15.1	10.9	4.0
10	9.6	12.5	16.1	16.2	18.0	15.1	10.8	4.0
11	9.6	12.4	14.9	16.0	18.0	15.1	10.5	4.0
12	9.6	12.2	14.0	16.0	18.0	15.1	10.5	4.0
13	9.7	12.2	14.0	15.8	18.0	15.1	10.5	4.0
14	9.7	12.0	13.9	15.4	18.0	15.1	10.5	4.0

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[1] Water temperature reported to nearest 0.1°C to more precisely define variation; instrumentation accuracy ±0.1°C.

24-Hour Measurements

Primary Productivity and Respiration

Primary productivity is the rate at which radiant energy is stored by photosynthetic and chemosynthetic activity of producer organisms (chiefly green plants) in the form of organic substances that can be used as food materials (Slack and others, 1973, p. 164). This process is often measured in terms of carbon uptake in the plant cells. However, during photosynthesis oxygen is released to the surrounding environment. The quantity of oxygen produced is an indirect measure of the primary productivity. In an effort to characterize the oxygen dynamics in Big Bear Lake, diel measurements of dissolved oxygen and water temperature were made bihourly from about 1200 hours July 19, through 1400 hours July 20, 1972.

Net primary productivity and respiration rates were estimated using the method of Odum (1956) and others. Briefly, the mean concentrations of dissolved oxygen in the euphotic zone were calculated at stations A, C, and E for each sampling period. The euphotic zone was estimated to have been five times the depth of the Secchi disk transparency (Slack and others, 1973, p. 96). The dissolved oxygen rate-of-change curves were constructed from the mean concentrations and were corrected for oxygen diffusion (Odum and Hoskin, 1958, p. 20). Varying physical conditions existed among stations, particularly with regard to wind, and, therefore, the diffusion rates used for diffusion corrections were calculated individually after Eley (1970, p. 142).

Those intervals of the corrected rate-of-change curves representing daytime dissolved-oxygen fluctuations were integrated to obtain an estimate of the net daytime productivity. The intervals representing nighttime fluctuation were integrated to obtain an estimate of the nighttime oxygen respiration. This method eliminates the necessity of estimating daytime respiration (R. L. Cory, written commun., 1972).

Estimates of the net primary productivity at stations A, C, and E during July 19-20, 1972, are given in table 4. Considerable variability existed in the estimates of both production and respiration rates in the lake. Net daytime productivity was the highest at station A and was estimated to have been about 10.3 g O_2/m^2 (grams of oxygen per square meter); the nighttime respiration was about 3.8 g O_2/m^2. The P/R ratio (the ratio of net daytime oxygen productivity to nighttime respiration) was 2.7, indicating the excess of oxygen production over respiration.

At station C the estimated net daytime productivity was about 0.2 g O_2/m^2, and the nighttime respiration was 2.1 g O_2/m^2, resulting in a P/R ratio of 0.1. During the daylight period a net loss of dissolved oxygen was estimated to have occurred at station E, indicating that the oxygen respiration exceeded the oxygen production. This resulted in a net daytime productivity of -1.7 g O_2/m^2. The P/R ratio for station E was -0.9.

During the 24-hour study only station A showed a net gain of dissolved oxygen. Station C, while marginally productive during the daytime, showed a net loss over the 24-hour study. Station E showed a net loss not only over the entire 24-hour period, but also during the daylight hours when production of oxygen by photosynthesis occurs.

TABLE 4.--*Estimates of net primary productivity and respiration at stations A, C, and E, July 19-20, 1972*

Station	Depth to bottom (m)	Depth of euphotic zone[1] (m)	Net daytime productivity (g O_2/m^2)	Nighttime respiration (g O_2/m^2)	P/R ratio
A	3.8	3.8	10.3	3.8	2.7
C	9.2	8.0	0.2	2.1	0.1
E	17.2	12.0	-1.7	1.8	-0.9

[1] Estimated. Depth of Secchi disk transparency multiplied by 5 (Slack and others, 1973, p. 96).

Alkalinity and pH

The range in total alkalinity at station A was 107 to 112 mg/l, and at station C it was 109 to 113 mg/l (table 5). At station E the total alkalinity ranged from 112 to 123 mg/l, and the mean concentration was 117 mg/l.

At stations A and C the pH ranged from 8.8 to 9.1 and 8.5 to 9.0, respectively, and did not vary greatly between the two stations. The pH at station E was generally lower than at stations A and C, and ranged from 7.1 to 8.4. Although the pH at station E did not change noticeably during the measurement period, it varied with depth. The lower values were measured in the deeper water.

Alkalinity and pH did not vary greatly as a function of depth at either station A or C. However, at station E both the total alkalinity and the pH were vertically nonuniform; a lower pH and a higher total alkalinity occurred in the deeper water. This condition was probably the result of bacterial respiration which commonly occurs in many lakes during summer stagnation (Hutchinson, 1957, p. 671-674).

TABLE 5.--*Concentration of total alkalinity (as $CaCO_3$) and pH at stations A, C, and E at selected times, July 19-20, 1972*

	Time (hours)	Depth (meters)	pH	Total alkalinity (as $CaCO_3$) (milligrams per liter)
Station A				
July 19, 1972	1230	1	8.8	112
		3	8.8	109
	1700	1	8.9	112
		3	9.0	109
	2115	1	9.0	108
		3	9.1	108
July 20, 1972	0130	1	8.9	108
		3	8.9	107
	0700	1	9.0	109
		3	-	-
Station C				
July 19, 1972	1300	1	8.9	109
		4	8.6	111
		8	8.5	113
	1730	1	9.0	112
		4	9.0	113
		8	8.8	113
	2130	1	9.0	110
		4	8.9	112
		8	8.8	111
July 20, 1972	0200	1	8.9	110
		4	8.9	109
		8	8.7	112
	0715	1	8.8	112
		4	8.8	112
		8	8.6	112
Station E				
July 19, 1972	1330	1	8.3	112
		8	7.4	116
		16	7.1	121
	1800	1	8.4	115
		8	7.5	117
		16	7.3	121
	2200	1	8.0	113
		8	7.8	114
		16	7.4	121
July 20, 1972	0245	1	8.2	113
		8	8.1	114
		16	7.2	123
	0730	1	8.3	113
		8	7.3	117
		16	7.3	122

Nitrogen

A summary of the nitrogen data collected in Big Bear Lake during the period April 1972 through April 1973 is given in table 6.

Ammonia Nitrogen

At station E the maximum mean concentration of ammonia nitrogen was 0.23 mg/l and was considerably higher than the means at stations A, B, C, and D, which ranged from 0.09 to 0.11 mg/l (table 6). At station E concentrations of ammonia nitrogen were the most variable.

Mean concentrations of ammonia nitrogen for all stations and depths by months are shown in figure 2. The maximum mean concentration was 0.17 mg/l in October and the minimum was 0.06 mg/l in August. Concentrations of ammonia nitrogen in the lake varied areally, as indicated by wide confidence limits about the means.

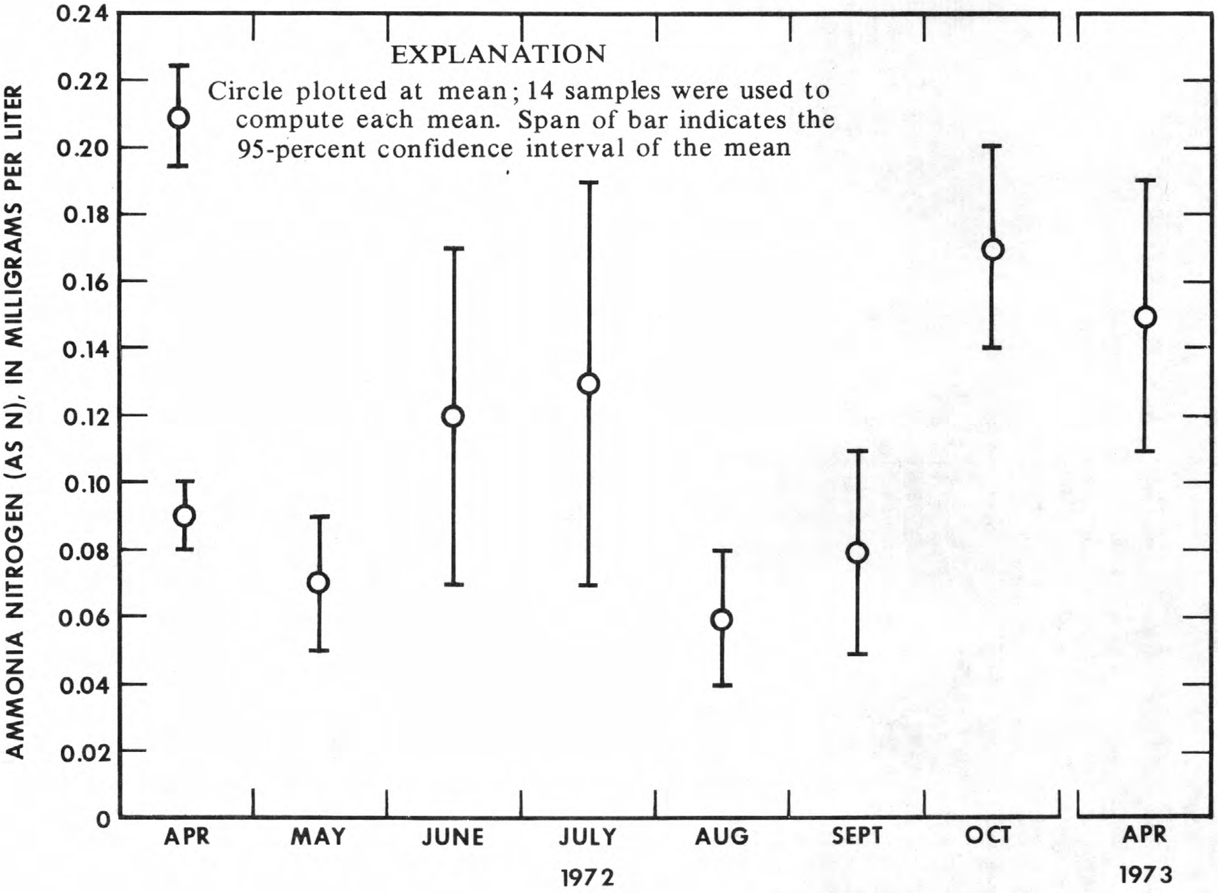

FIGURE 2.--Mean concentrations of ammonia nitrogen for all stations and depths.

TABLE 6.--*Summary of nitrogen data collected at stations A-E during the period April 1972 through April 1973*

[Concentrations are in milligrams per liter]

Station	Number of samples	Ammonia nitrogen (as N)		Nitrate (as N)		Total organic nitrogen (as N)		Dissolved organic nitrogen (as N)		Particulate organic nitrogen (as N)	
		Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
A	16	0.11	0.04	0.02	0.05	1.2	0.56	0.70	0.20	0.48	0.49
B	24	.10	.04	.02	.05	1.1	.43	.73	.18	.35	.37
C	24	.11	.07	.02	.04	.98	.40	.72	.22	.26	.27
D	24	.09	.06	.02	.04	.97	.31	.74	.20	.23	.17
E	24	.23	.32	.02	.03	.88	.42	.62	.26	.26	.25

Nitrite

Nitrite was usually not detected in Big Bear Lake, except in October when it was found at all stations in concentrations of about 0.01 mg/l.

Nitrate

The mean concentration of nitrate was 0.02 mg/l at all stations, and the concentrations were highly variable (table 6). Mean concentrations of nitrate for all stations and depths by months are shown in figure 3. The nitrate distribution from April through September 1972 was patchy, and concentrations were either in trace quantities or not detected. In October trace quantities of nitrate were generally present throughout the lake. The mean concentration was about 0.02 mg/l. In April 1973 the mean concentration of nitrate was 0.13 mg/l, a considerable increase from October 1972. In April 1973 the distribution of nitrate was quite uniform as the confidence interval about the mean was only 0.01 mg/l.

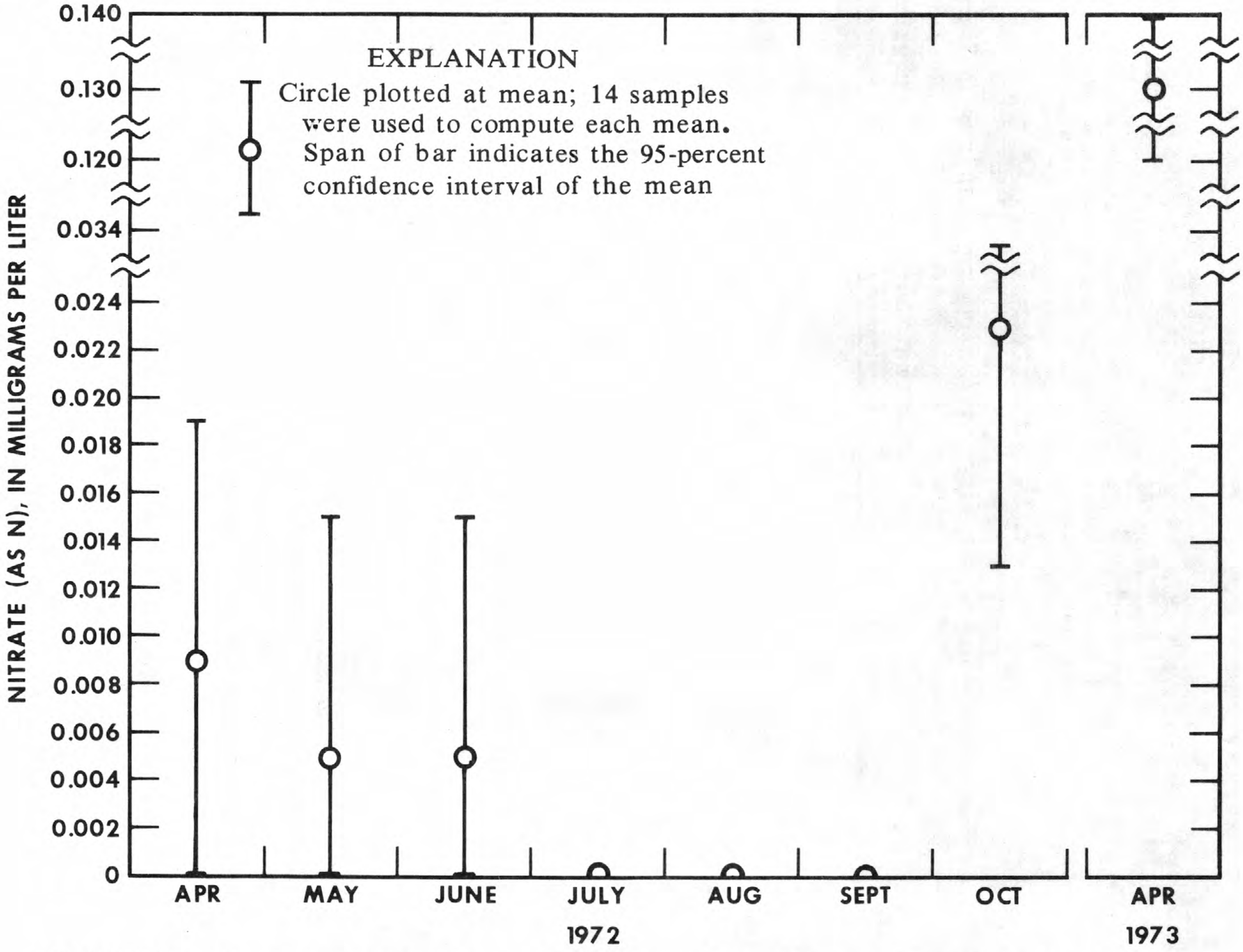

FIGURE 3.--Mean concentration of nitrate for all stations and depths.

Organic Nitrogen

The maximum mean concentration of total organic nitrogen was 1.2 mg/l at station A and the minimum mean was 0.88 mg/l at station E (table 6). Concentrations of dissolved organic nitrogen generally exceeded those of particulate organic nitrogen at a ratio of about 2.4 to 1.

Mean concentrations of total, dissolved, and particulate organic nitrogen for all stations and depths by months are shown in figure 4. The maximum mean concentration of dissolved organic nitrogen was 0.95 mg/l in October 1972 and the minimum mean was 0.44 mg/l in April 1972. Particulate organic nitrogen had a maximum mean concentration of 0.79 mg/l in August 1972 and a minimum mean of 0.13 mg/l in April 1973. Concentrations of dissolved organic nitrogen were higher in the summer and autumn and did not decrease in September as did the concentration of particulate organic nitrogen. Dissolved organic nitrogen was generally stable from July through October, whereas the particulate organic nitrogen varied considerably. For the entire study period, the distribution of dissolved organic nitrogen was generally uniform by months in the lake, as indicated by the narrow confidence limits.

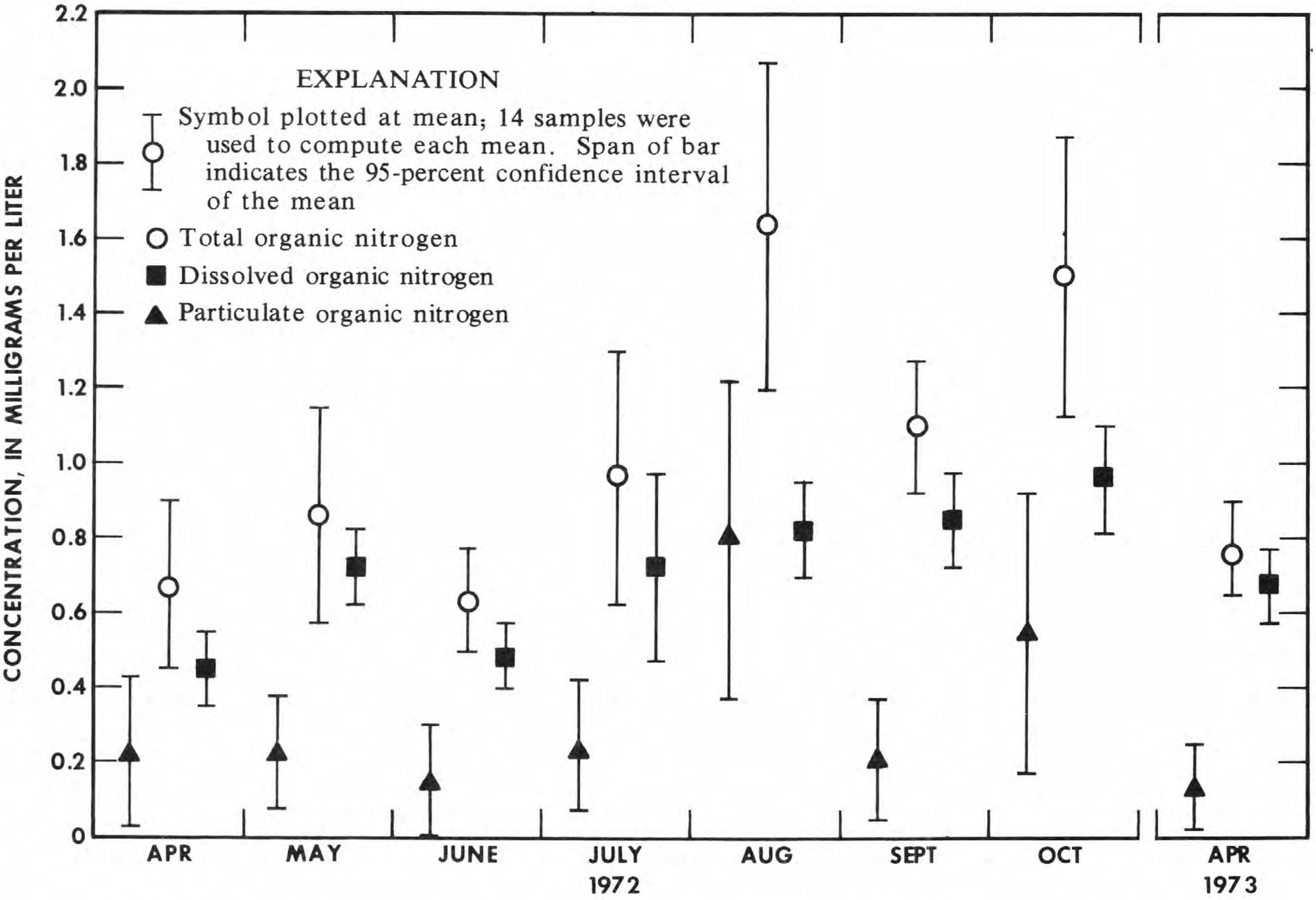

FIGURE 4.--Mean concentrations of organic nitrogen for all stations and depths.

Phosphorus

Orthophosphate Phosphorus

Mean concentrations of orthophosphate phosphorus at stations A, B, C, D, and E are given in table 7. Concentrations were low and variable at individual stations, resulting in standard deviations that approximated the means.

Mean concentrations of orthophosphate phosphorus for all stations and depths by months are shown in figure 5. The maximum mean concentration was 0.06 mg/l in August 1972 and the minimum mean was 0.01 mg/l, which occurred in both April and May 1972. Concentrations of orthophosphate phosphorus were higher July through September 1972.

Total Phosphorus

The maximum mean concentration of total phosphorus was 0.13 mg/l at station E, and the minimum mean was 0.09 mg/l at both stations C and D (table 7). Concentration variability was the greatest at station E and the least at station D.

The mean concentrations of total phosphorus for all stations and depths by months ranged from 0.17 mg/l in August 1972 to 0.05 mg/l in April 1973 (fig. 5). As indicated by the wide confidence limits, the concentrations for individual months were highly variable, particularly in May 1972. The monthly trend in total phosphorus was similar to that of orthophosphate phosphorus, except in July 1972 when the concentration of total phosphorus decreased slightly and that of orthophosphate phosphorus increased.

TABLE 7.--*Summary of phosphorus data collected at stations A-E during the period April 1972 through April 1973*

[Concentrations are in milligrams per liter]

Station	Number of samples	Dissolved orthophosphate phosphorus (as P)		Total phosphorus (as P)	
		Mean	Standard deviation	Mean	Standard deviation
A	16	0.03	0.02	0.12	0.07
B	24	.03	.02	.10	.06
C	24	.02	.02	.09	.07
D	24	.02	.02	.09	.04
E	24	.03	.03	.13	.10

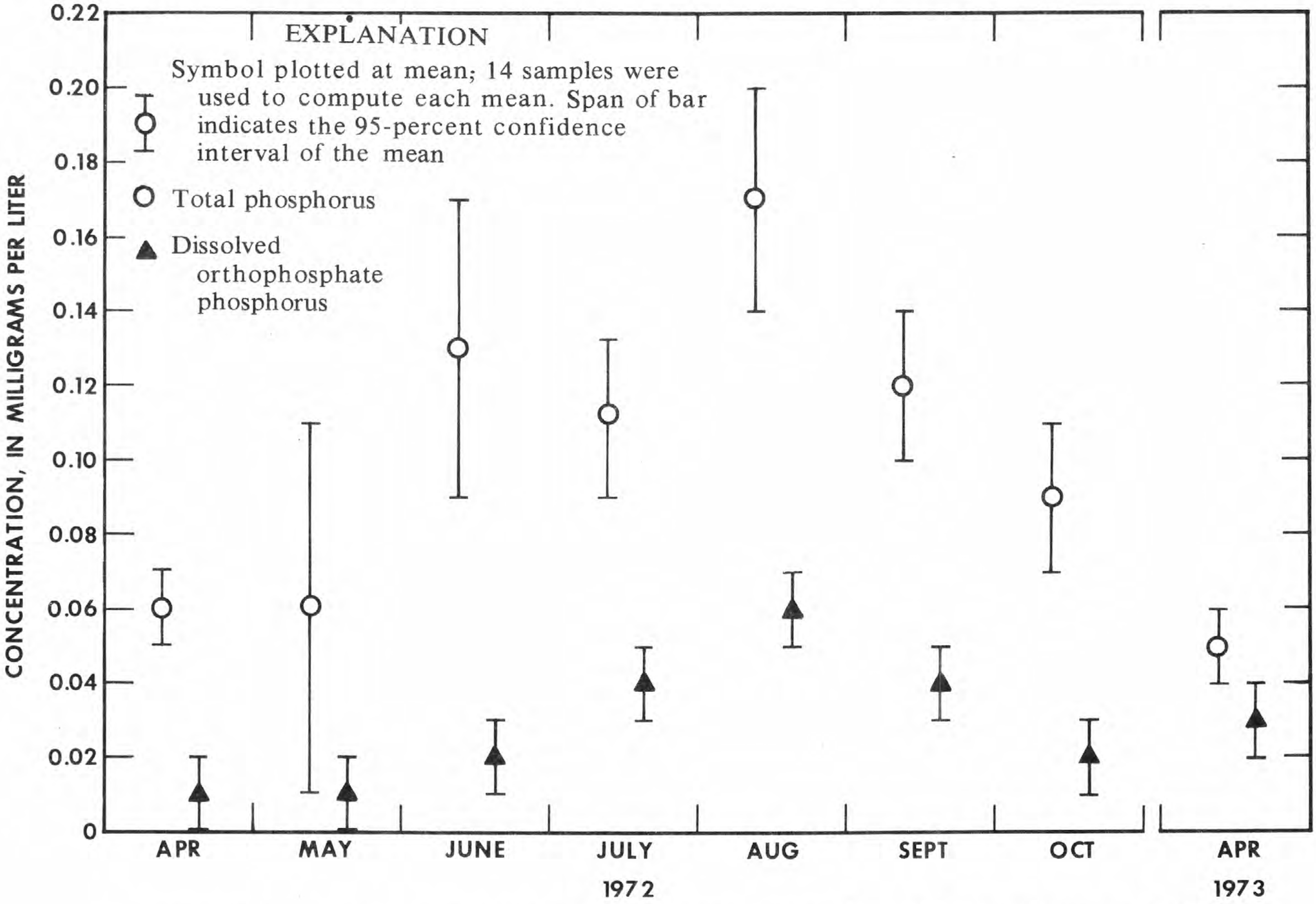

FIGURE 5.--Mean concentrations of phosphorus for all stations and depths.

Total Organic Carbon

A summary of the total organic carbon data collected in Big Bear Lake from May 1972 through April 1973 is given in table 8. Concentrations at stations A and E were variable, ranging from 9.5 to 27 mg/l and 10 to 40 mg/l, respectively. The concentrations at station C ranged only from 10 to 15 mg/l.

The maximum mean concentration of total organic carbon at stations A, C, and E by months was 26 mg/l, which occurred in September 1972, and the minimum mean was 10 mg/l in April 1973. Except in August and September 1972, the distribution of total organic carbon in the lake was uniform.

TABLE 8.--*Summary of total organic carbon data collected at stations A, C, and E*

[Concentrations are in milligrams per liter]

	Number of samples	Total organic carbon		
		Mean	Standard deviation	Range
Summary by station, all months				
A	9	15	6	9.5-27
C	8	12	2	10-15
E	9	15	9	10-40
Summary by month, stations A, C, and E				
May 1972	3	12	1	11-13
June 1972	3	11	1	10-12
July 1972	5	14	1	13-16
August 1972	3	17	8.5	11-27
September 1972	3	26	13	14-40
October 1972	3	13	0	---
April 1973	6	10	.5	9.5-11

Silica

A summary of the silica data collected in Big Bear Lake during the period April 1972 through April 1973 is given in table 9. At individual stations mean concentrations of silica were similar, ranging from 1.7 to 1.9 mg/l; however, for the entire period concentrations were quite variable.

TABLE 9.--*Summary of silica data collected at stations A-E*

[Concentrations are in milligrams per liter]

	Number of samples	Silica		
		Mean	Standard deviation	Range
Summary by station, all months				
A	16	1.9	1.3	0.0-3.8
B	24	1.9	1.3	.3-4.0
C	24	1.8	1.3	.4-4.2
D	24	1.7	1.3	.4-4.1
E	24	1.9	1.5	.6-6.3
Summary by month, all stations				
April 1972	14	0.5	0.2	0.0-0.7
May 1972	14	.5	.1	.3- .7
June 1972	14	.7	.2	.5-1.3
July 1972	14	1.2	.4	.7-2.0
August 1972	14	2.4	.3	2.1-2.9
September 1972	14	2.3	.2	2.1-2.5
October 1972	14	2.1	.2	2.8-3.5
April 1973	14	4.1	.6	3.8-6.3

Specific Conductance

Mean specific conductance ranged from a minimum of 261 micromhos at station A to a maximum of 265 micromhos at station E (table 10). The greatest variability in specific conductance occurred at station E and the least variability occurred at station D.

Specific conductance generally increased during the observation period, ranging from a minimum mean of 256 micromhos at all stations and depths in April 1972 to a maximum mean of 277 micromhos in April 1973. The distribution of specific conductance was usually uniform for individual months and the maximum standard deviation was 18 micromhos in April 1973.

TABLE 10.--*Summary of specific conductance data collected at stations A-E*

[Conductivities are in micromhos at 25°C]

	Number of samples	Specific conductance		
		Mean	Standard deviation	Range
Summary by station, all months				
A	16	261	12	249-282
B	24	263	10	252-285
C	24	262	9	252-280
D	24	262	5	253-276
E	24	265	15	253-331
Summary by month, all stations				
April 1972	14	256	2	251-258
May 1972	14	259	4	252-265
June 1972	14	258	6	249-272
July 1972	14	259	7	249-275
August 1972	14	259	2	256-262
September 1972	14	262	3	259-267
October 1972	14	273	7	256-281
April 1973	14	277	18	253-331

Transparency and Turbidity

The mean Secchi disk transparency ranged from a maximum of 2.9 m at station E to a minimum of 1.3 m at station A (table 11). Transparencies seemed to be generally higher and less variable at stations C, D, and E.

Mean transparencies for stations A, B, C, D, and E by months were somewhat variable, decreasing noticeably July through September 1972. The minimum mean transparency was 1.3 m in August 1972. The maximum mean transparency was 2.8 m in June 1972 and was uniform throughout the lake, as the standard deviation was only 0.2 m.

Turbidity was higher and more variable at stations A and B, ranging respectively from 2 to 60 and 1 to 70 JTU (Jackson turbidity units).

The mean turbidity levels in the lake by months were low and uniformly distributed, except in July 1972 when the turbidity in the lake ranged from 10 to 70 JTU.

TABLE 11.--*Summary of Secchi disk transparency and turbidity data at stations A-E*

	Transparency in meters			Number of samples	Turbidity, in Jackson turbidity units		
	Mean	Standard deviation	Range		Mean	Standard deviation	Range
Summary by station, all months							
A	1.3	0.8	0.6-1.8	16	10	20	2-60
B	2.1	1.0	.7-3.4	24	9	20	1-70
C	2.4	.6	1.5-3.0	24	4	4	1-20
D	2.4	.4	1.8-3.0	24	3	3	1-10
E	2.9	.3	2.3-3.3	24	4	6	1-30
Summary by month, all stations							
April 1972	2.6	.7	1.5-3.4	14	3	1	2-7
May 1972	2.5	1.0	.7-3.3	14	2	1	1-2
June 1972	2.8	.2	2.5-3.1	14	2	1	1-4
July 1972	1.9	.5	1.2-2.3	14	30	20	10-70
August 1972	1.3	.7	.6-2.0	14	3	2	1-8
September 1972	1.6	1.0	.6-3.1	14	3	2	2-7
October 1972	2.6	.5	1.8-3.0	14	2	1	2-3
April 1973	2.4	.6	1.5-3.0	14	4	1	2-5

HYDROLOGY AND SELECTED NUTRIENT LOAD DISTRIBUTION

Surface-Water Inflow

The total drainage area of Big Bear Lake is, including the surface area of the lake, 32.4 mi^2 (83.9 km^2). The area north of the east-west axis of the lake is about 13.0 mi^2 (33.7 km^2) and that of the south is about 19.4 mi^2 (50.2 km^2) (fig. 1).

Surface-water discharge to the lake from tributaries for the period April 1972 through April 1973 was estimated from changes in storage after subtracting the quantity estimated to have entered the lake as precipitation. These estimates probably include a small quantity of ground-water inflow. Change-in-storage and evaporation data were supplied by the Bear Valley Mutual Water Co. Most of the surface-water runoff to the lake was snowmelt, which began about March 1973; however, some of the tributaries flowed during the entire study period.

For lack of a better method, inflows to the lake from the northern and southern parts of the basin were estimated on the basis of drainage area. Although precipitation in Big Bear Lake basin is quite variable from west to east, the long-term mean annual precipitation data indicate that the north and south parts of the basin have very similar quantities of precipitation (San Bernardino County Flood Control District, 1970). Therefore, of the estimated 6,400 acre-ft (7.9 hm^3) of inflow to the lake, 40 percent, or 2,560 acre-ft (3.2 hm^3), was estimated to have originated from the northern part of the basin, and 60 percent, or 3,840 acre-ft (4.7 hm^3), was from the southern part (table 12).

Samples used to estimate the quantities of nitrogen, phosphorus, and silica that entered the lake from the northern part of the basin were collected at Grout Creek, which has a drainage area of 4.38 mi^2 (11.3 km^2). The nutrient loads entering from the southern part of the basin were estimated from samples collected at Rathbone Creek (5.21 mi^2) (13.49 km^2), Red Ant Creek (0.94 mi^2) (2.43 km^2), Mill Creek (0.88 mi^2) (2.28 km^2), and Kidd Creek (1.11 mi^2) (2.87 km^2). The total drainage area sampled was about 8.14 mi^2 (21.08 km^2). Sampling sites are shown in figure 1.

Concentrations of nitrogen, phosphorus, and silica for the four southern tributaries were averaged, and these mean values were used to estimate the total loads. Although considerable concentration variability existed among the tributaries, an analysis of variance indicated that mean concentrations were not significantly different. Therefore, because of the rather large within-stream concentration variance and the lack of precise discharge data, calculations of loads by individual tributaries were not made. Estimates of the nitrogen and phosphorus loads that were transported to the lake by tributary inflow may seem low when compared to the quantities contributed by precipitation, which are discussed in the next section. This difference may be explained by the fact that most of the precipitation in Big Bear Lake basin from November 1972 through mid-March 1973 fell as snow. There was generally very little surface runoff until the melting period, which started in about mid-March 1973. Surface-water contributions as shown in table 12 were estimated only through April 30, 1973. A considerable snowpack was still present in the basin after that date, and that runoff is not included in the estimate.

TABLE 12.--*Estimated total loads of nitrogen, phosphorus, and silica entering Big Bear Lake from surface-water tributaries during the period April 1972 through April 1973*

Source	Inflow (acre-ft)	Number of samples	Total nitrogen[1]			Total phosphorus			Silica		
			Mean (mg/l)	Standard deviation (mg/l)	Load[2] (tons)	Mean (mg/l)	Standard deviation (mg/l)	Load[2] (tons)	Mean (mg/l)	Standard deviation (mg/l)	Load[2] (tons)
Northern part of basin	2,560	4	0.35	0.14	1.2	0.10	0.07	0.35	19	4.5	66
Southern part of basin	3,840	20	.78	1.06	4.1	.41	1.09	2.1	18	4.8	94
Total					5.3			2.4			160

[1] Total nitrogen = sum of concentrations of nitrogen ammonia, nitrate, nitrite, and total organic nitrogen.

[2] Load (tons) = acre-ft x milligrams per liter x 0.00136.

Total loads of nitrogen, phosphorus, and silica transported to Big Bear Lake were estimated to have been 5.3, 2.4, and 160 tons (4.8, 2.2, and 145 t), respectively, during the period April 1972 through April 1973. However, because of the concentration variability, as indicated by the large standard deviations about the means, and because of the probable inaccuracy of the discharge data, a wide confidence interval exists for these load estimates. Of the nitrogen and phosphorus loads transported to the lake, most seemed to have been contributed from the southern part of the basin, while the silica contribution from the northern part of the basin was only slightly less than that from the southern part.

Direct Precipitation on Big Bear Lake

The analytical results of seven precipitation samples collected at two stations from April 27 to November 14, 1972, are given in table 13. Concentrations of total kjeldahl nitrogen and nitrate were quite variable, ranging from 0.46 to 1.6 and 0.03 to 1.5 mg/l, respectively. Although only two storms--June 6 and 21, 1972--were sampled at both stations, concentration differences between stations were also indicated. The concentrations of phosphorus ranged from 0.01 to 0.30 mg/l and were also variable between and within the stations.

The collection of precipitation samples has inherent problems, one of which is contamination in the sample collector. In addition, sample recovery and preservation is often not accomplished within optimum time limits. Therefore, the following precipitation-chemical data collected in the Big Bear Lake basin are to be considered only as approximations.

Estimated loads of nitrogen and phosphorus entering the lake through direct precipitation are given in table 14. The depth of precipitation on the lake was estimated by averaging rainfall recorded at the dam (station 1), at the ranger station (station 2), and at the Big Bear Lake fire station (fig. 1). Mean concentrations of nitrogen and phosphorus used for the estimates were 1.6 and 0.16 mg/l, respectively. These mean concentrations are based on samples collected after five storms from April through November 1972 (table 13). All storms that occurred during the study period were not sampled. The mean lake-surface area used for the study period was 2,625 acres (10.6 km^2). On the basis of these assumptions, it is estimated that 16 tons (15 t) of nitrogen, 1.6 tons (1.5 t) of phosphorus, and 2 tons (1.8 t) of silica were carried directly to the lake surface by precipitation from April 1972 through April 1973. These load estimates are, however, approximate as the variability about the means for both concentration and precipitation values are large. Also, the number of samples is small. An additional error factor is involved in these estimates--much of Big Bear Lake was ice-covered during periods of some of the heaviest precipitation. As a result, some of the precipitation and its associated nutrient material that fell to the surface did not immediately enter the lake system but remained as ice and snow on the lake surface.

TABLE 13.--*Concentrations of selected variables in precipitation*[1] *collected at two stations near Big Bear Lake*

[Location of stations are shown in figure 1]

Date	Total kjeldahl nitrogen (as N)	Nitrate (as N)	Total phosphorus (as P)	Silica	Specific conductance
	Concentrations, in milligrams per liter				Micromhos at 25°C
Station 1 1972					
April 21	1.3	1.1			
June 6	1.6	1.5	0.30		
June 21	.46	.89	.16	0.3	23
Station 2 1972					
June 6	.70	.03	.26		
June 21	.52	.56	.30	.1	23
October 27	.72	.06	.01		
November 14	1.5	.05	.05		35
Mean	0.97	0.60	0.16	0.2	27

[1] Precipitation occurred as snow November 14 and as rain all other dates.

TABLE 14.--*Estimated loads of nitrogen, phosphorus, and silica entering directly to Big Bear Lake by precipitation during the period April 1972 through April 1973*

	Number of samples	Mean	Standard deviation	Load[1] (tons)
Precipitation (acre-ft)		7,320	2,370	
Total nitrogen[2] (milligrams per liter)	7	1.6	0.88	16
Total phosphorus (milligrams per liter)	6	0.16	0.12	1.6
Silica (milligrams per liter)	2	0.2		2.0

[1] Load (tons) = acre-feet x milligrams per liter x 0.00136.

[2] Total nitrogen = sum of concentrations of nitrogen ammonia, nitrate, nitrite, and total organic nitrogen.

Big Bear Lake

Loads of total nitrogen, total phosphorus, total organic carbon, and silica for selected months in Big Bear Lake are given in table 15. Individual mean tonnages were estimated using the lake contents at the time of sampling and the mean concentration for each of the variables, generally 14 samples per month (all stations and depths) for nitrogen, phosphorus, and silica, and at least three samples per month (1 m below the surface at stations A, C, and E) for total organic carbon.

The maximum loads of nitrogen and phosphorus were 129 and 13 tons (116 and 12 t), respectively, which occurred in August. The minimum nitrogen load was 61 tons (55 t) in June 1972, whereas the minimum phosphorus load was 4.2 tons (3.8 t) in April 1973. The total organic carbon load ranged from 1,900 tons (1,700 t) in September 1972 to 830 tons (760 t) in April 1973. Silica load ranged from 41 to 340 tons (37 to 310 t), respectively, in May 1972 and April 1973.

Except for small quantities of direct precipitation, little surface-water inflow to the lake occurred from about mid-June through late October 1972. Ground-water inflow to the lake during this same period was estimated to have also been minimal, although no quantitative data were collected to verify this conjecture. Therefore, the changes in loads in the lake were probably largely because of internal processes. Monthly changes in loads of nitrogen, phosphorus, organic carbon, and silica during this period can probably be attributed to biochemical regeneration, deposition, and wind-induced sediment resuspension.

As supplementary data, concentrations of total nitrogen and phosphorus, and percentage of organic content (loss on ignition) were determined in bottom sediments on three occasions (table 16). The nitrogen concentrations were quite high in June 1972 and April 1973 and noticeably lower in September 1972. It is not known, however, whether the September decrease was significant and representative or due to sampling and (or) analytical error. The concentrations of phosphorus were generally much less than those of nitrogen, except at stations A and E in September. These samples also indicated that between 12 and 32 percent of the bottom sediment was composed of organic matter.

TABLE 15.--*Estimated loads of nitrogen, phosphorus, organic carbon, and silica in Big Bear Lake*

Date	Contents[1] (acre-ft)	Total nitrogen[2]		Total phosphorus		Total organic carbon		Silica	
		Mean (mg/l)	Load[3] (tons)	Mean (mg/l)	Load[3] (tons)	Mean (mg/l)	Load[3] (tons)	Mean (mg/l)	Load[3] (tons)
April 1972	61,270	0.76	63	0.06	5.0			0.5	42
May 1972	60,540	.92	76	.06	4.9	12	990	.5	41
June 1972	59,690	.75	61	.13	11	11	890	.7	57
July 1972	58,120	1.2	95	.11	8.7	14	1,100	1.2	95
August 1972	55,800	1.7	129	.17	13	17	1,300	2.4	180
September 1972	53,480	1.2	87	.12	8.7	26	1,900	2.3	170
October 1972	51,830	1.7	120	.09	6.3	13	920	3.1	220
April 1973	61,270	1.1	92	.05	4.2	10	830	4.1	340

[1] Contents data supplied by Bear Valley Mutual Water Co.

[2] Total nitrogen = sum of concentrations of ammonia nitrogen, nitrate, nitrite, and total organic nitrogen.

[3] Load (tons) = acre-feet x milligrams per liter x 0.00136.

TABLE 16.--*Concentrations of total nitrogen and phosphorus, and percentage of organic content in bottom sediments at stations A, C, and E*

Date	Total nitrogen (mg/kg)	Total phosphorus (mg/kg)	Organic content (percent)
Station A			
June 20, 1972	6,900	156	32
September 26, 1972	390	480	14
April 24, 1973	2,900	300	
Station C			
June 20, 1972	3,500	87	16
September 26, 1972	750	260	22
April 24, 1973	9,800	220	
Station E			
June 20, 1972	1,700	145	12
September 26, 1972	260	640	12

Surface-Water Outflow

The principal water outlet from Big Bear Lake is Bear Creek (fig. 1). Water discharge from the lake to Bear Creek is regulated by the Bear Valley Mutual Water Co. Water is discharged to Bear Creek through a gate which has a sill about 4 ft (1.2 m) from the bottom of the dam. From April 1972 through April 1973, controlled releases from the lake occurred from mid-July until early October 1972. The monthly discharges for this period are given in table 17 and were furnished through the courtesy of Mr. Horace F. Hinckley of the Bear Valley Mutual Water Co.

The concentrations of nitrogen, phosphorus, organic carbon, and silica determined at lake station E were used to compute the loads discharged to Bear Creek. A sample collected in August at the outlet was comparable with those collected concurrently at station E, and, therefore, additional samples collected precisely at the release point were not necessary. The mean concentrations for the entire period (July-October 1972) were used for the computations. Loads were estimated using both the mean concentrations for the entire period and for the individual months, and the results obtained were similar.

From July through October 1972 an estimated 5.9, 0.54, 81, and 9.5 tons (5.4, 0.49, 73 and 8.6 t) of nitrogen, phosphorus, organic carbon, and silica were discharged from Big Bear Lake into Bear Creek. However, as indicated by the wide standard deviations about the means, particularly for phosphorus and organic carbon, these are approximations.

TABLE 17.--*Estimated total loads of nitrogen, phosphorus, organic carbon, and silica discharged from Big Bear Lake to Bear Creek*

		July	August	September	October	Total
Outflow (acre-ft)		360	1,520	1,070	390	3,340
Mean nitrogen (mg/l)	1.3					
Standard deviation (mg/l)	.37					
Load (tons)[1]		0.64	2.7	1.9	0.69	5.9
Mean phosphorus (mg/l)	.12					
Standard deviation (mg/l)	.07					
Load (tons)		0.06	0.25	0.17	0.06	0.54
Mean organic carbon (mg/l)	18					
Standard deviation (mg/l)	12					
Load (tons)		8.8	37	26	9.6	81
Mean silica (mg/l)	2.1					
Standard deviation (mg/l)	.6					
Load (tons)		1.0	4.3	3.1	1.1	9.5

[1] Load (tons) = acre-feet x milligrams per liter x 0.00136.

Submersed Vegetation

From May through October 1972 the Big Bear Lake Pest Abatement District harvested about 205 dry-weight tons (186 t) of submersed vegetation in Big Bear Lake. On September 26, 1972, a composite sample comprised of *Chara*, *Elodea*, *Ceratophyllum*, and filamentous algae was collected for chemical analysis. This sample contained 16, 5.5, and 780 grams per kilogram (dry weight) of nitrogen, phosphorus, and organic content (loss on ignition), respectively. On the basis of the results, 3.3, 1.1, and 160 tons (3.0, 1.0, and 145 t), respectively, of nitrogen, phosphorus, and organic matter were estimated to have been removed by weed cutting. However, these harvested plants were not removed from the basin, as they were piled on the shore very near to where they were cut; therefore, much of their nutrient content was perhaps only temporarily removed from the lake.

PHYTOPLANKTON

Phytoplankton collected at stations A, C, and E from April 1972 through April 1973 are shown in figures 6, 7, and 8. These graphs show the results as total number of cells with the four main component algal groupings: green algae (Chlorophyta), blue-green algae (Cyanophyta), diatoms (Chrysophyta), and flagellates (Chlorophyta, Euglenophyta, and Pyrrophyta).

At station A, changes in the number of cells indicated that three periods of accelerated growth occurred in April 1972, August-September 1972, and April 1973 (fig. 6). The maximum mean concentration of phytoplankton was about 3,500 cells/ml (cells per milliliter) in September 1972. The population composition was almost entirely flagellates at this time, dominated by Ceratium and Crytomonas. Except for the codominance of green algae (Oocystis-Schroederia) in May 1972, flagellate forms were dominant at station A for the entire study period.

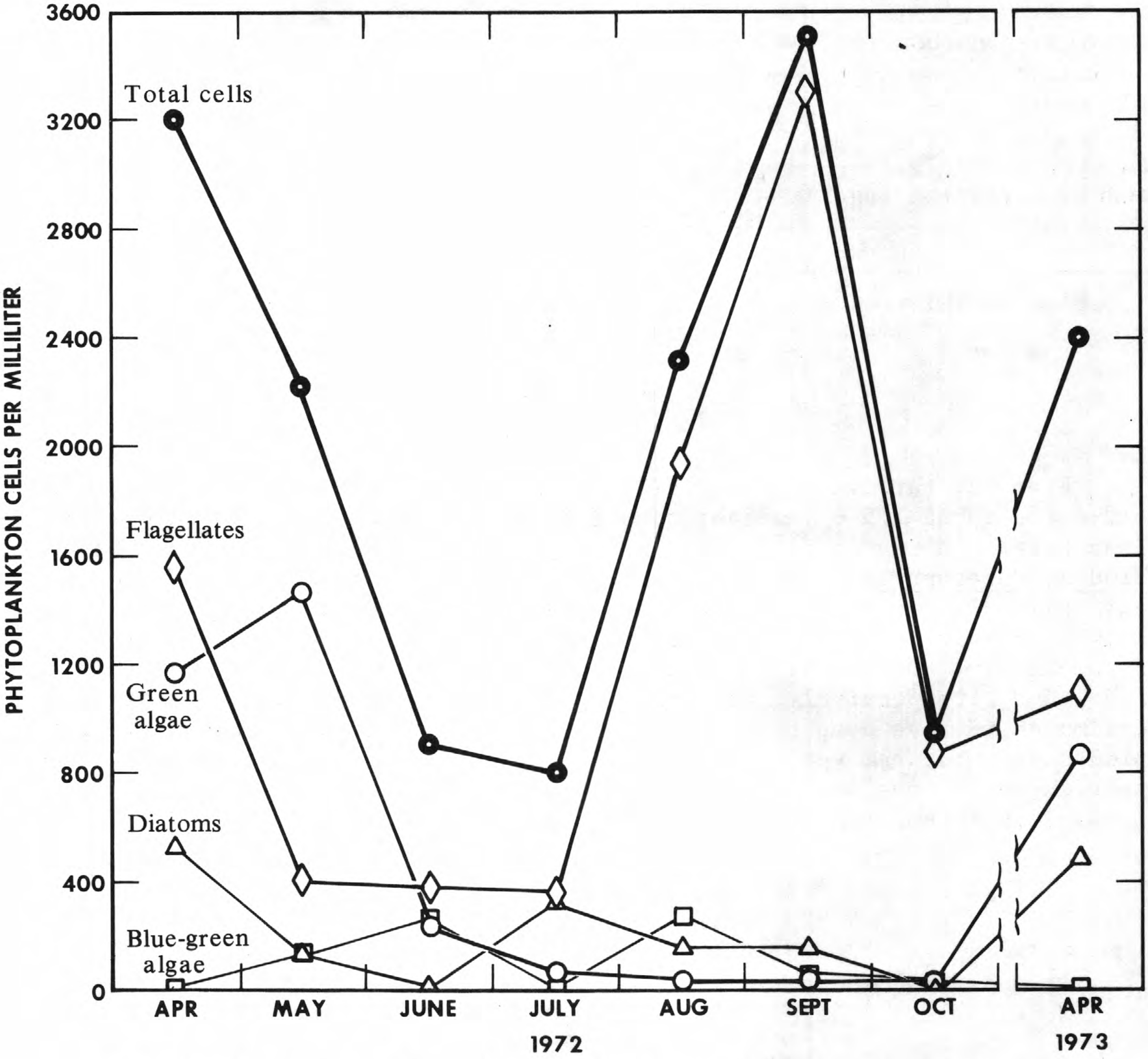

FIGURE 6.--Mean number of phytoplankton cells at station A.

The phytoplankton population increased at station C, once in April-May 1972 and again in April 1973 (fig. 7). Both of the population increases had concentrations of about the same magnitude (2,200 cells/ml). Unlike station A, where flagellates were the dominant algal forms, at station C green algae were dominant during both periods of increased growth--in April-May 1972 Oocystis and Schroederia were codominant and in April 1973 Schroederia was solely dominant. Station C did not exhibit an August-September 1972 population increase. The algal population seemed generally stable from June through October 1972 and was dominated by flagellate forms.

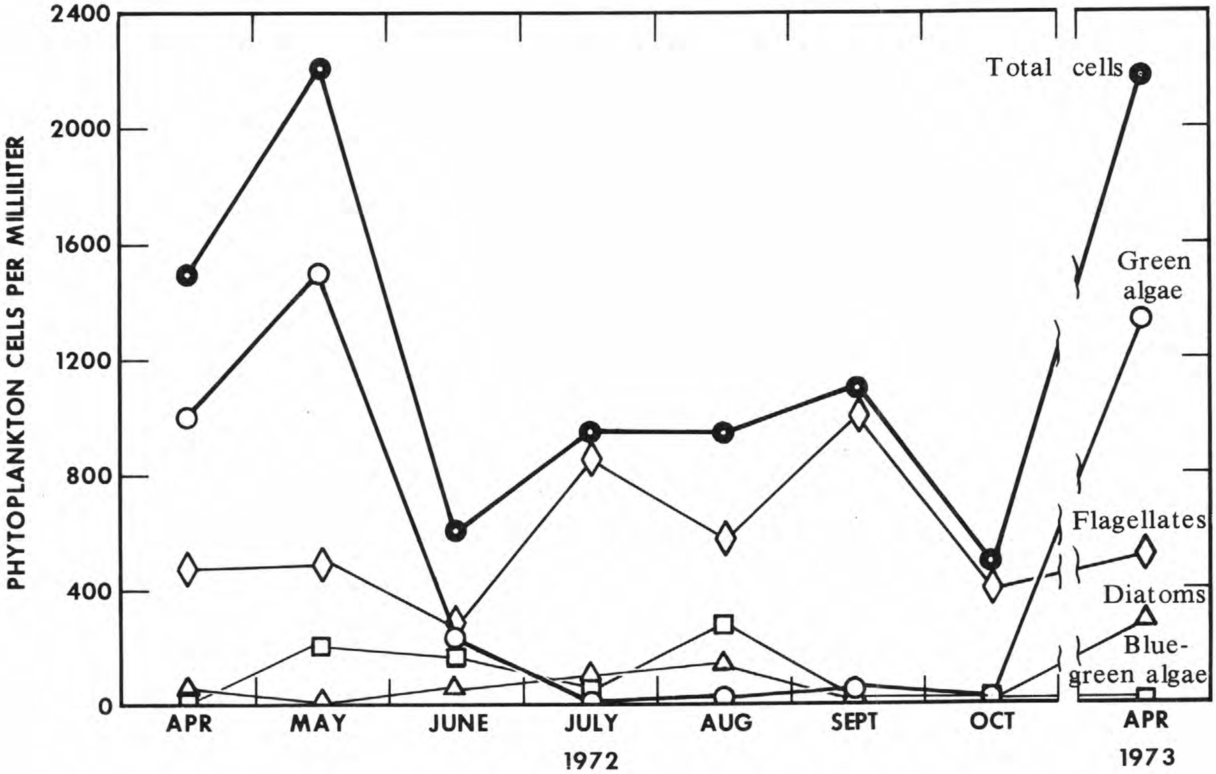

FIGURE 7.--Mean number of phytoplankton cells at station C.

At station E the phytoplankton population was similar to that found at station C, however the algal concentrations were usually lower (fig. 8). The maximum mean concentration of phytoplankton at station E was about 1,500 cells/ml in May 1972 and was dominated by Oocystis, Schroederia, and Spaerocystis.

As was previously discussed, a considerable change in the number of phytoplankton cells occurred between months in Big Bear Lake. However, there was also a considerable change in the volume of phytoplankton cells (table 18). Cell number/cell volume ratios were much greater during the spring and early summer than they were during the late summer and autumn.

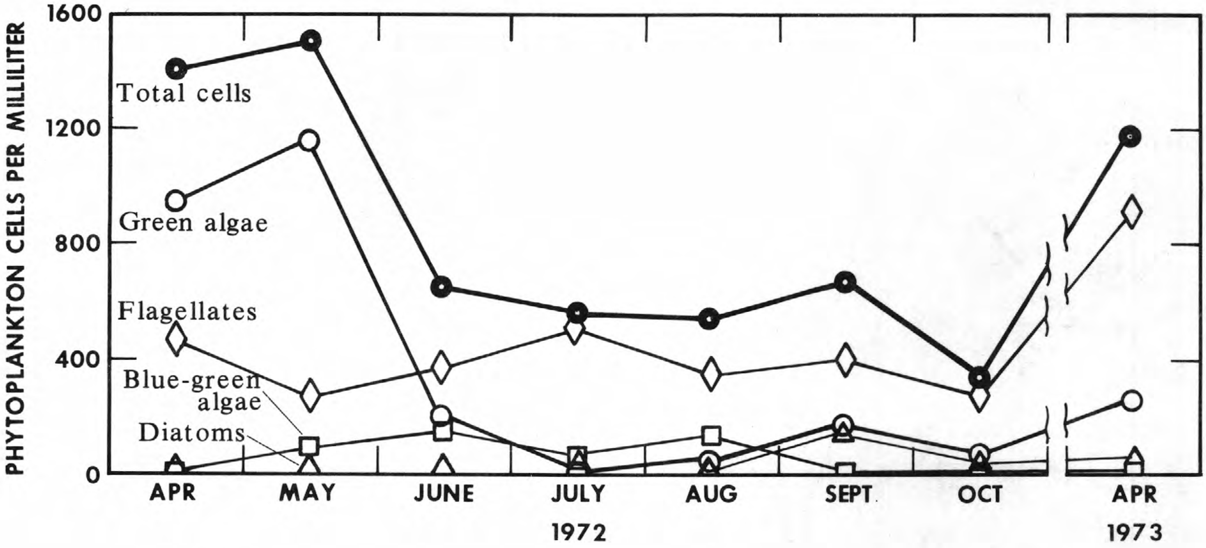

FIGURE 8.--Mean number of phytoplankton cells at station E.

TABLE 18.--*Summary of number and volume of phytoplankton cells at stations A, C, and E*

Date	Station A			Station C			Station E		
	Number of cells (cells/ml)	Volume of cells (CSU[1])	Cell number/ cell volume ratio	Number of cells (cells/ml)	Volume of cells (CSU[1])	Cell number/ cell volume ratio	Number of cells (cells/ml)	Volume of cells (CSU[1])	Cell number/ cell volume ratio
April 1972	3,200	500	6.4	1,500	170	8.8	1,400	260	5.4
May 1972	2,200	230	9.6	200	410	5.4	1,500	240	6.2
June 1972	890	69	13	630	42	15	640	85	7.5
July 1972	820	1,800	.5	960	2,400	.4	560	550	1.0
August 1972	2,300	5,800	.4	950	1,400	.7	510	580	.9
September 1972	3,500	9,600	.4	1,100	2,100	.5	660	510	1.3
October 1972	900	580	1.6	470	270	1.7	340	180	1.9
April 1973	2,400	110	22	2,200	66	33	1,200	23	52

[1] One cubic standard unit (CSU) = 8,000 cubic micrometers (μm^3) of algal cell volume.

DISCUSSION

Although in recent years the term "eutrophic" has been assigned several connotations, the original concept of the term referred to an abundance of plant nutrients. Using this definition, Big Bear Lake would be classified as eutrophic, at least in regard to selected nutrients. It is well documented that numerous nutrients are required for primary productivity other than those determined in this investigation. However, considering concentrations of nitrogen, phosphorus, silica, and organic matter (carbon), the supply in Big Bear Lake seems ample for high plant production.

Inorganic nitrogen forms were always present in detectable concentrations in the lake water. Although the distribution of nitrate was patchy and often below detectable limits, ammonia nitrogen was always present in relatively high concentrations. Orthophosphate phosphorus and silica in the lake were also generally present in detectable concentrations.

Even during algal bloom events, inorganic nitrogen and phosphorus were generally present, at least in some parts of the lake. This was particularly noticeable during the 1973 spring bloom when nitrate was at its maximum concentration, and ammonia nitrogen was only slightly less than its maximum level.

In addition to inorganic nitrogen and phosphorus, high concentrations of organic nitrogen and phosphorus were usually present in Big Bear Lake. Organic compounds of nitrogen and phosphorus, if not immediately available as a nutrient source, are ultimately available after sufficient bacterial oxidation.

Using regression analysis, the concentrations of the primary nutrients--ammonia nitrogen, nitrate, and orthophosphate phosphorus--were compared with the number and volume of phytoplankton cells. The nutrients were assigned as the independent variable. Stations A, C, and E were analyzed individually. Results did not indicate that simple relations existed between these selected nutrients and the number or volume of phytoplankton cells. The standard errors of estimate almost always approximated the standard deviations, and coefficients of correlation were generally nonsignificant, even at the 0.05 probability level. This suggests that additional factors were involved in regulating the phytoplankton population.

The phytoplankton population itself indicated that other factors along with the availability of selected nutrients were important in controlling the primary productivity in the lake. As an example, during late summer, when an algal bloom occurred in the eastern part of the lake (station A), the middle and western parts (stations C and E) did not exhibit bloom conditions. However, the concentrations of inorganic nitrogen and phosphorus were about the same throughout the lake at this time. Variable population structure also indicated that other factors along with these selected nutrients probably regulate phytoplankton growth in the lake. For example, the spring bloom of 1973 was virtually dominated by flagellates (Cryptomonadales) in the eastern and western parts of the lake; whereas in the middle part green algae (Chlorococcales) were dominant. Again, the concentrations of inorganic nitrogen and phosphorus were very nearly the same throughout the lake.

Overall, the controlling factors in Big Bear Lake were such as to result in relatively high primary productivity. While several factors may affect the oxygen concentration in water, such as atmospheric reaeration and respiration, dissolved-oxygen concentrations exceeding 100-percent saturation can usually be attributed to plant photosynthesis.

Dissolved-oxygen saturation levels indicated high rates of primary production in the eastern part of the lake (station A). Also, saturation levels in the middle part of the lake (station C) indicated higher production than in the western part (station E). The western part of the lake exhibited supersaturation only in April 1972. These assumptions of primary productivity, however, must be qualified. The monthly surveys represent a single profile of measurements, and, because primary productivity is highly dynamic, these measurements are not absolute evidence the rates remained unchanged throughout any daylight period. During the investigation, measurements were made among the stations as rapidly as possible, but they should still be considered only the best estimate.

Direct measurements of the net daytime primary productivity and the nighttime respiration were made during a 24-hour period in July 1972. The selected observation period was arbitrary, but it later proved to have been during a time when the concentrations of dissolved oxygen were the most variable, both vertically and laterally among the different parts of the lake. The estimates of production rates resulting from this survey generally substantiated the conditions that were surmised from the monthly observations.

The net daytime primary productivity in the eastern part of the lake far exceeded that of the middle and western parts. Both production and respiration rates were high in the eastern part, but the P/R ratio was above 2.0. The P/R ratio was less than 1.0 in the middle and western parts of the lake indicating that respiration exceeded production.

Oxygen depletion was measured only in the deeper middle and western parts of the lake during the months of June and July 1972. During other periods these parts of the lake had a measurable dissolved-oxygen content. The western part of the lake (station E) had lower concentrations of dissolved oxygen than did the middle part (station C).

Interestingly, in August 1972, when the external conditions of long, warm summer days were still prevalent, oxygen depletion was not measured in any part of the lake. In the middle of July 1972, the Bear Valley Mutual Water Co. began to release water at a rate of about 15 ft^3/s (0.42 m^3/s) from the outlet near the bottom of the dam. This water release, in conjunction with wind action, was probably sufficient to circulate the lake water. Sometime between July and August 1972 the deeper anaerobic water in the middle and western parts of the lake seems to have been circulated to the surface and reoxygenated. Changes in water temperature between July and August also indicate the possibliity of water movement, particularly in the western part, as the vertical (top to bottom) difference changed respectively from over 4.0°C to less than 2.0°C.

When the deeper water of the lake was anaerobic, the bottom sediments seemed to have served as a nutrient reservoir. In particular, concentrations of ammonia nitrogen and phosphorus were quite high in the deeper zones during this period and were probably the result of anaerobic bacterial respiration. High concentrations of these variables were particularly noticeable in the western part of the lake. During the July 1972 survey the water samples collected near the bottom at station E had a strong hydrogen sulfide odor. However, the regulatory mechanisms are obviously complex, as high concentrations of ammonia nitrogen and phosphorus were also detected during periods when the lake water was oxygenated. Physical factors such as wind-induced resuspension of bottom sediments or deposition and the biological processes of growth and death greatly affect concentration variability.

Although the nutrient concentrations and their relations to primary productivity seem quite variable and complex, the results of this reconnaissance indicate that Big Bear Lake is at least moderately eutrophic. At present, however, Big Bear Lake remains an extremely popular and picturesque water resource.

SUMMARY

In Big Bear Lake the concentrations of dissolved oxygen were variable both seasonally and internally. Monthly measurements indicated concentrations of dissolved oxygen and percentage of oxygen saturation were highest in the shallower eastern part of the lake. Dissolved-oxygen saturation levels in the lake decreased from east to west; station A at the east end of the lake exhibited supersaturation in five of the eight surveys, whereas station E at the west end was supersaturated only in April 1972. On the basis of saturation levels, primary productivity seemed highest at station A, decreasing to the west. Dissolved-oxygen distribution at station A was almost always vertically uniform, and large oxygen deficits were not measured. At stations C and E the oxygen distribution was vertically nonuniform much of the time, and severe oxygen deficits were measured in June and July 1972.

Estimates of the net primary productivity and respiration rates indicated that only at station A was the daytime production higher than the nighttime respiration. At station A the P/R ratio was estimated to have been about 2.7, and at station E it was -0.9.

Water temperature in Big Bear Lake varied considerably from April 1972 through April 1973, ranging from about 0° to $23^{\circ}C$. Water in the eastern part of the lake (station A) was usually warmer than in the middle and western parts (stations C and E).

Monthly samples indicated that concentrations of nitrogen varied seasonally and areally in Big Bear Lake. Seasonally, concentrations of organic nitrogen had the most definite monthly trend, and ammonia nitrogen was too variable to evaluate trends with a high degree of confidence. Nitrate distribution was patchy for most of the period and was in either trace concentrations or not detected, except in October 1972 and April 1973.

SUMMARY

As a function of individual sampling stations, the concentrations of ammonia nitrogen were generally higher and more variable at station E. The higher concentrations of ammonia nitrogen at station E were probably the result of bacterial respiration in the deeper zone. The maximum mean concentration of particulate organic nitrogen occurred at station A, while the mean concentrations of dissolved organic nitrogen and nitrate varied only slightly among stations.

Phosphorus varied seasonally, and concentrations of both orthophosphate phosphorus and total phosphorus were somewhat higher in the summer. The summer increases were also probably caused by anaerobic bacterial activity in the deeper water and bottom sediments.

Although confidence limits were wide, an estimated 5.3, 2.4, and 160 tons (4.8, 2.2, and 145 t) of nitrogen, phosphorus, and silica were transported to the lake by surface-water tributaries, and 16, 1.6, and 2.0 tons (15, 1.5, and 1.8 t) of nitrogen, phosphorus, and silica entered the lake through direct precipitation.

The loads of nitrogen, phosphorus, and silica in Big Bear Lake were variable by months, ranging from 61 to 129 tons (55 to 116 t), 4.2 to 13 tons (3.8 to 12 t), and 41 to 340 tons (37 to 310 t), respectively. Particularly during the summer, some of the increases in monthly loads could not be accounted for by external sources, therefore indicating that the bottom sediments of the lake are perhaps a major reservoir for some constituents.

The eastern part of the lake (station A) exhibited three phytoplankton population increases; the middle and western parts (stations C and E) exhibited only two increases. Flagellates were generally the dominant algae at station A. The two bloom events in the middle part of the lake (station C) were dominated by green algae, while in the western part of the lake (station E) the April 1972 bloom was dominated by green algae and the April 1973 bloom was dominated by flagellates. The number of phytoplankton cells was highest at station A, decreasing to the west. In addition to the seasonal fluctuation in the number of phytoplankton cells, a considerable fluctuation also occurred in the volume of phytoplankton cells. The volume was noticeably greater during the summer months at all stations.

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