REC-ERC-84-23

EFFECTS OF OPERATING MT. ELBERT PUMPED-STORAGE POWERPLANT ON TWIN LAKES, COLORADO: 1982 REPORT OF FINDINGS

September 1984
Engineering and Research Center

U. S. Department of the Interior
Bureau of Reclamation

7-2090 (4-81)
Bureau of Reclamation

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.	[redacted]	3. RECIPIENT'S CATALOG NO.
REC-ERC-84-23		

4. TITLE AND SUBTITLE
Effects of Operating Mt. Elbert Pumped-Storage Powerplant on Twin Lakes, Colorado: 1982 Report of Findings

5. REPORT DATE
September 1984

6. PERFORMING ORGANIZATION CODE
D-1522

7. AUTHOR(S)
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8. PERFORMING ORGANIZATION REPORT NO.
REC-ERC-84-23

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Bureau of Reclamation
Engineering and Research Center
Denver, CO 80225

10. WORK UNIT NO.

11. CONTRACT OR GRANT NO.

12. SPONSORING AGENCY NAME AND ADDRESS
Same

13. TYPE OF REPORT AND PERIOD COVERED

14. SPONSORING AGENCY CODE
DIBR

15. SUPPLEMENTARY NOTES
Microfiche and/or hard copy available at the Engineering and Research Center, Denver, Colo.

Editor: RDM

16. ABSTRACT
A series of studies is being performed to identify and quantify changes that occur in the aquatic ecology of Twin Lakes, Colorado, because of the Mt. Elbert Pumped-Storage Powerplant, which began operation in September 1981. This report presents results of studies done in 1982. These results, along with those from studies presently being done, will be compared with results from preoperational limnology studies at Twin Lakes from 1971 through 1981.

Twin Lakes are a pair of connected, dimictic, montane, drainage lakes of glacial origin. Based on seven limnological parameters, the lakes are classified as oligotrophic. Maximum water temperatures of 9.3 and 12.4 °C were recorded in late August 1982 for the upper and lower lakes, respectively. The lowest measured dissolved oxygen concentration during 1982 was 2 mg/L at the bottom of the lower lake in September. The pH ranged between 6.4 and 8.1, and conductivity levels were between 54 and 93 μS/cm. Total phosphorous concentrations during 1982 ranged from a low of less than 1 μg/L to a high of more than 10 μg/L. Nitrate nitrogen concentrations ranged from less than 1 μg/L up to 150 μg/L. Average daily primary productivity ranged from a low of 0.3 mg C/($m^2 \cdot h$), in the upper lake during July, to a high of 11.2 mg C/($m^2 \cdot h$), in the lower lake during May. Chlorophyll *a* concentrations ranged from a mean of 0.43 mg/m^3, in the upper lake in June, to a mean of 6.87 mg/m^3, in the lower lake in November. Average yearly phytoplankton and zooplankton densities reached maximums of just over 1185 per liter and 21 individuals per liter in the lower lake, and 304 per liter and 9 individuals per liter in the upper lake, respectively. Phytoplankton populations were dominated by the diatoms, *Asterionella* sp. and *Synedra* spp., while zooplankton populations were dominated by copepods and rotifers. Large pelagic cladocerans were notably absent in 1982. The benthos of Twin Lakes includes chironomid larvae, oligochaetes, and fingernail clams; maximum densities of each, respectively, during 1982 were 762, 536, and 651 per square meter in the lower lake and 270, 1585, and 54 per square meter in the upper lake.

The most notable effects of pumped-storage operation to date include increased dissolved oxygen concentrations in the hypolimnion of lower lake during the winter, reduced water clarity in lower lake during winter-spring period, increased flushing and dilution of lower lake by imported Turquoise Lake water, and importation of cladocerans into Mt. Elbert Forebay from Turquoise Lake.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. *DESCRIPTORS*-- /*limnology /*pumped-storage /*reservoirs /*ecology /chemical properties /primary productivity /chlorophyll /phytoplankton /zooplankton /benthos /fauna /aquatic environment /powerplants /*lakes /shrimp /meteorological factors /environmental effects /environment /environmental impacts /lake trout /fish /lake currents / entrainment

b. *IDENTIFIERS*-- /Twin Lakes, CO /Mt. Elbert Pumped-Storage Powerplant, CO

c. *COSATI Field/Group* 06H *COWRR:* 0606 *SRIM:*

18. DISTRIBUTION STATEMENT
Available from the National Technical Information Service, Operations Division, 5285 Port Royal Road, Springfield, Virginia 22161.
(Microfiche and/or hard copy available from NTIS)

19. SECURITY CLASS (THIS REPORT)	21. NO. OF PAGES
UNCLASSIFIED	104
20. SECURITY CLASS (THIS PAGE)	**22. PRICE**
UNCLASSIFIED	

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Division of Research and Laboratory Services
Engineering and Research Center
Denver, Colorado

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UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION

ACKNOWLEDGMENTS

This study is a cooperative effort involving the Bureau of Reclamation, Colorado Division of Wildlife, and the Fish and Wildlife Service's Colorado Cooperative Fishery Research Unit at Colorado State University. Contributions to both field and laboratory portions of this study by S. D. Hiebert, S. G. Campbell, R. A. Roline, J. R. Boehmke, and S. J. Grabowski are gratefully acknowledged. The Chemistry, Petrography, and Chemical Engineering Section performed the chemical analyses.

The research covered by this report was funded under the Bureau of Reclamation Project Related Engineering and Scientific Studies Program, DR-331, Ecology and Limnology of Pumped-Storage Reservoirs; and the Fryingpan-Arkansas Project Lower Missouri Region.

CONTENTS

TABLES

TABLES – Continued

FIGURES

FIGURES – Continued

FIGURES – Continued

INTRODUCTION

The present ecological studies of Twin Lakes began in 1971. Reports on the results of activities prior to this report are found in references [1-27][1]. In addition, quarterly activity reports dating back to 1976 are available as Applied Sciences Referral Memorandums and filed as internal documents at the Bureau of Reclamation, Engineering and Research Center, Denver, Colo. The data presented in this report are primarily from calendar year 1982. The Mt. Elbert Pumped-Storage Powerplant was tested in July and began operation in September 1981. Since operation was somewhat sporadic through the first 16 months of operation, effects on the ecology of Twin Lakes are yet to be clearly defined in all areas. Field studies are planned to continue through September 1985. During that time, the powerplant's second 100-megawatt unit and the new Twin Lakes Dam will be put into operation. The final overall goal of these studies is to present a comprehensive and accurate analysis of the effects of operating the powerplant on the aquatic ecology of Twin Lakes. The desirable form to present the final results of the 15-year study would be a hard-bound monograph, which is currently being considered.

APPLICATION

Results of this study are being compared to biological data collected before powerplant operation began. These data basically describe the physical, chemical, and biological limnology of Twin Lakes, and compare preoperation and postoperation conditions. This information on assessment of the effects of pumped-storage operation is being used by planners and designers of the Bureau of Reclamation in preparing designs and plans of other pumped-storage facilities. Those involved in assessing aquatic environmental effects of pumped-storage and other hydroelectric powerplants will find the data from these studies useful. Results of this study will also be of interest to anyone involved in the study of lake ecosystems, especially those located in montane regions.

[1] Numbers in brackets refer to entries in the Bibliography.

GENERAL DESCRIPTION

Twin Lakes are located on Lake Creek at the eastern foot of the Sawatch Range in the upper Arkansas River Valley of central Colorado (fig. 1). The lakes are 2802 m above mean sea level. The present topography of the western side of the Arkansas River Valley in the Twin Lakes area is largely the result of glacial action on earlier alluvial deposits (Buckles, 1973) [28]. Twin Lakes probably originated with the morainic damming of Lake Creek (Sartoris, et al., 1977) [25]. The shoreline and bottom topography of Twin Lakes are shown on figures 2 and 3, respectively.

Present maximum water surface areas are 263.4 ha for the upper lake and 736.5 ha for the lower, with corresponding depths of about 28 and 27 m, respectively. The lower lake is the largest natural mountain lake in Colorado (Pennak, 1966) [29]. Sartoris, et al., (1977) [25], summarize the literature reporting results of studies done from 1873 to 1977; LaBounty, et al., (1980) [19] and LaBounty and Sartoris (1981 and 1983) [15, 18] update this summary.

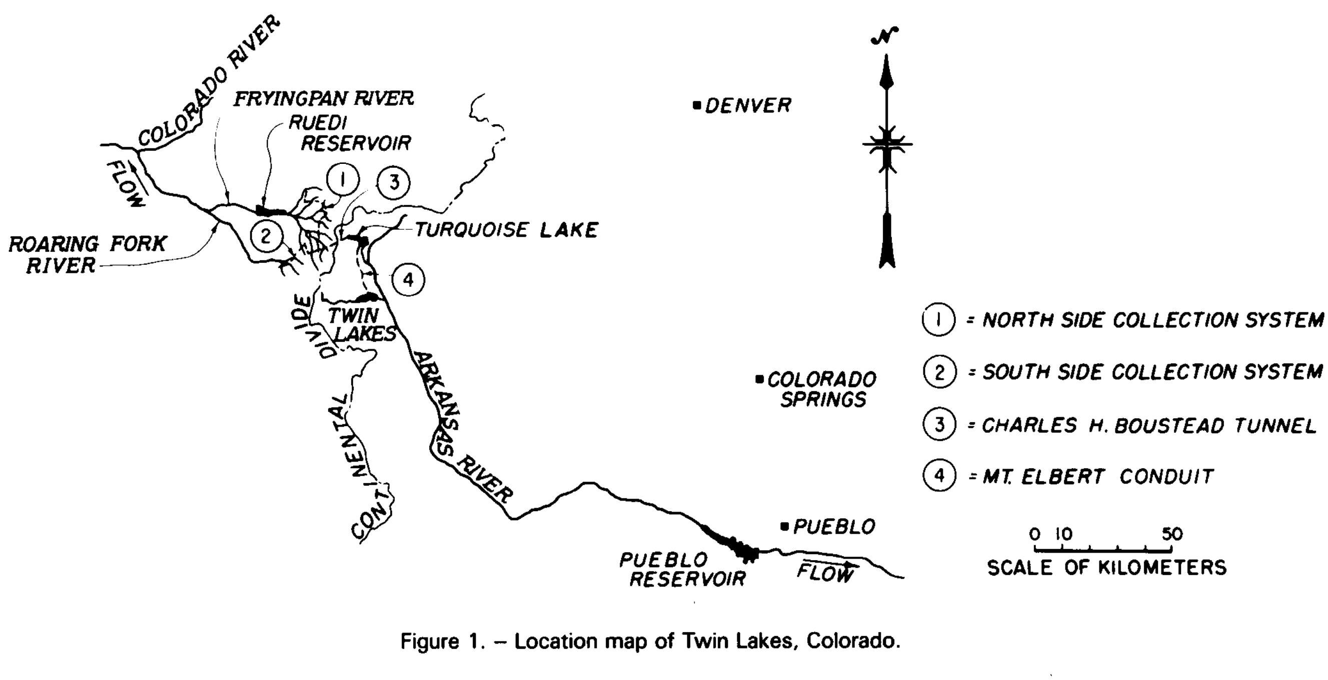


Figure 1. – Location map of Twin Lakes, Colorado.

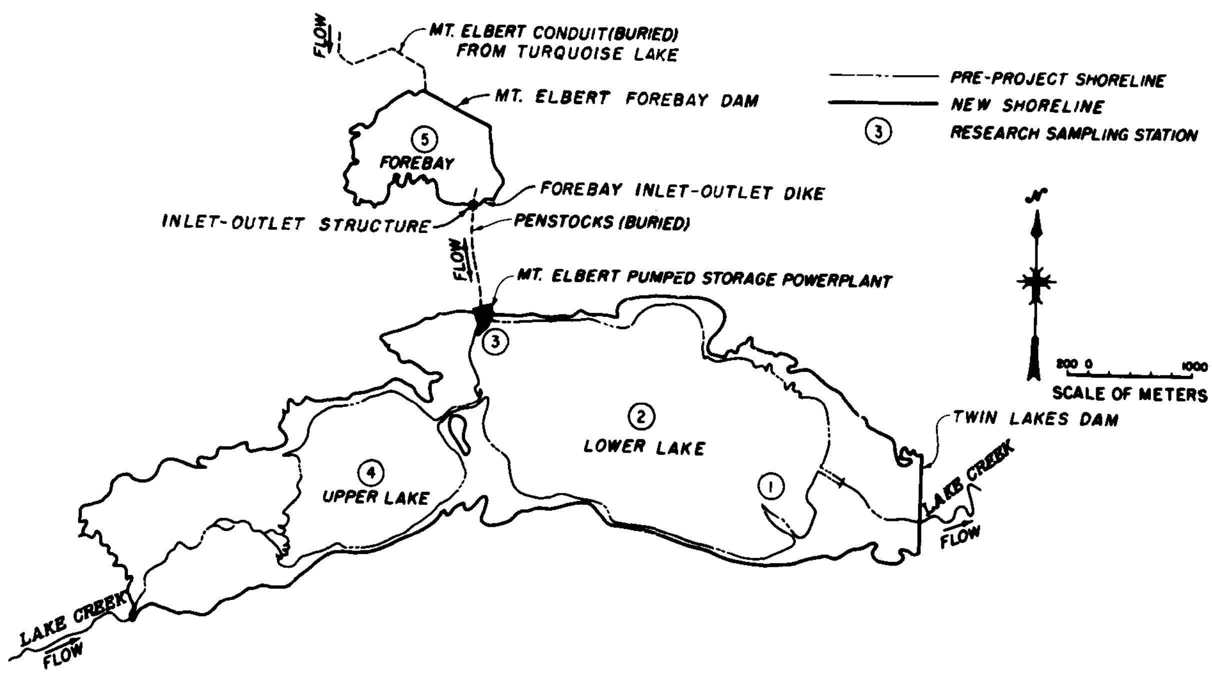


Figure 2. – Twin Lakes shoreline.

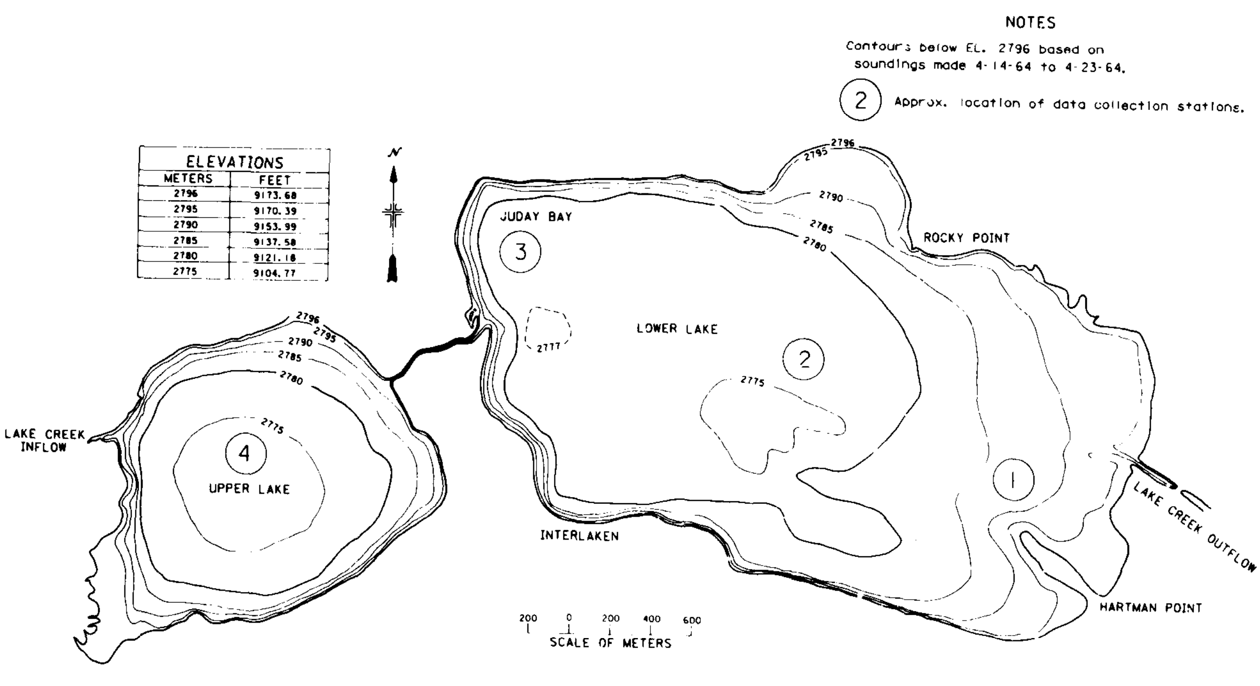


Figure 3. – Bottom topographic map of Twin Lakes.

The physical and biological changes of Twin Lakes during the past 100 years are also discussed in [25].

The installation of controlled outlet works, dredging of the channel between the two lakes, human activities in the area, and introduction of rainbow trout *(Salmo gairdneri)*, lake trout *(Salvelinus namaycush)*, and mysis shrimp *(Mysis relicta)* have altered the original ecology of Twin Lakes since the turn of the century and have interacted to produce the present system. In late 1980, use of the recently constructed Twin Lakes Dam was attempted. In early 1981, its use was terminated pending completion of a number of modifications to control seepage at the dam. Changes in the ecology of the lakes due to inundation of additional land surface are possible when full use of the dam resumes. Further change in the limnology of the lakes is expected to occur when unit 2 of the powerplant begins operation in 1984.

METHODS AND MATERIALS

Table 1 is a summary of the limnological field surveys done during 1982 at Twin Lakes. During each of the surveys, data were collected in the same manner. The following subsections give a brief description of the method used to collect data for each of the activities listed in table 1. The maps on figures 2 and 3 show some of the general features of the area and the sampling locations referred to in the text.

Meteorological-Limnological Monitoring

Specially designed meteorological-limnological instrumentation is being used at Twin Lakes. These instruments were designed and constructed by Hydrolab Corporation. There are five instrument packages in all; four of them were used in 1982. Instruments at stations 2 and 4 in the center of the lower and upper lakes, respectively, monitor underwater parameters of two depths bihourly and hourly. Instruments on station 3, in the powerplant tailrace, and station 5, in the center of Mt. Elbert Forebay, monitor underwater parameters at one depth, as well as selected meteorological parameters. Underwater parameters being monitored include temperature, dissolved oxygen, hydrogen ion concentration (pH), and oxidation-reduction potential (redox or ORP). Meteorological parameters include air temperature, average hourly windspeed, and brightness (light).

Table 1. – Field surveys of Twin Lakes during 1982.

Date of survey	Activity performed						
	Physical factors	Chemical factors	Primary productivity	Chlorophyll	Phytoplankton	Zooplankton	Benthos
Jan. 6-8	X	[1]X		X	X	X	X
Jan. 19-22	X	[2]X	X	X	X	X	X
Feb. 3-5	X	[2]X		X	X	X	X
Feb. 17-19	X	[2]X	X	X	X	X	X
Mar. 9-12	X	[2]X	X	X	X	X	X
Mar. 24-26	X	[2]X		X	X	X	X
Apr. 7-9	X	[2]X	X	X	X	X	X
Apr. 19-21	X	[2]X		X	X	X	X
May 3-5	X	[1]X	X	X	X	X	X
May 19-21	X	[2]X	X	X	X	X	X
June 2-4	X	[2]X	X	X	X	X	X
June 15-17	X	[2]X	X	X	X	X	X
June 30-July 2	X	[2]X	X	X	X	X	X
July 14-16	X	[2]X	X	X	X	X	X
July 27-30	X	[1]X	X	X	X	X	X
Aug. 11-13	X	[2]X	X	X	X	X	X
Aug. 25-27	X	[2]X		X	X	X	X
Sep. 8-10	X	[2]X	X	X	X	X	X
Sep. 22-24	X	[2]X	X	X	X	X	X
Oct. 6-8	X	[1]X	X	X	X	X	X
Oct. 20-22	X	[2]X	X	X	X	X	X
Nov. 3-5	X	[2]X	X	X	X	X	X
Nov. 17-19	X	[2]X	X	X	X	X	X
Nov. 30-Dec. 1	X	[2]X		X	X	X	X

[1] Complete chemistry, heavy metals, and N-P nutrients.
[2] Heavy metals and N-P nutrients only.

Physical-Chemical Parameters

Temperature, dissolved oxygen, conductivity, hydrogen-ion concentration (pH), and oxidation-reduction potential were measured with a Hydrolab Corporation System 8000 multiparameter probe. Water samples were collected with a Van Dorn water sampler. Grab samples were also periodically collected from the inflow and outflow. Water samples were subjected to the following three analyses: (1) major ions, (2) trace metals (copper, zinc, iron, manganese, and lead), and (3) plant nutrients (orthophosphate phosphorus, total phosphorus, total Kjeldahl nitrogen, nitrate nitrogen, nitrite nitrogen, ammonia nitrogen, and silicon). Samples for trace metal analysis were preserved immediately after collection with about 1 mL of concentrated nitric acid per 240 mL of water. Samples for nutrient analysis were frozen immediately following collection. All samples were analyzed according to methods given in chapter 5, "Chemical and Physical Quality of Water and Sediment," of the *National Handbook of Recommended Methods for Water Data Acquisition* (USGS, 1977) [30]. Light penetration was measured using both a standard Secchi disk and a limnophotometer. Light extinction coefficients were calculated from the limnophotometer measurements. Light transmittance was measured using a transmissometer which measures the percent of available light passing through a 0.5-m path of water at any specific depth desired.

Primary Productivity

The net rate of primary production was measured in terms of carbon fixation using radioactive carbon (^{14}C), and following the methods of Wood (1975) [31]. Measurements were always made during peak daylight hours.

Chlorophyll

Samples for chlorophyll analysis were collected from 0.1-, 1-, 3-, 5-, 9-, and 15-m depths in each lake. Following collection, 750-mL samples were filtered through Millipore glass filter pads. Chlorophyll extraction and analysis were done according to methods outlined in Parsons and Strickland (1963) [32].

Phytoplankton and Zooplankton

Plankton were collected with a No. 20 (mesh opening = 0.076 mm) silk closing net and bucket. Vertical hauls were made from 0 to 5 m, 5 to 10 m, 10 to 15 m, and from 15 m to the lake bottom. Samples were preserved with a 2 percent formalin solution for laboratory analysis. Laboratory methods followed those of Welch (1948) [33].

Benthos

Two benthic mud samples were collected from each station using a No. 6 Ekman dredge. These samples were screened through a U.S. Standard Series No. 30 sieve size (sieve opening = 0.589 mm), and then preserved in a 10 percent formalin solution for laboratory analysis. All organisms were identified according to type, and then counted and weighed. The dry mass was obtained by methods from APHA (1971) [34].

RESULTS AND DISCUSSION

Monitoring Equipment

Tables 2 through 5 summarize data collected with the Hydrolab monitoring equipment. Four stations were instrumented: one in the center of the forebay (sta. 5), one in the center of the upper lake (sta. 4), and two in the lower lake (stas. 2 and 3). Data were monitored bihourly and hourly and stored in the data control unit's memory. Stations 2 and 4 have instruments that collect underwater data at depths of 1 and 13 meters: temperature, dissolved oxygen, pH, and oxidation-reduction potential. Stations 3 and 5 have instruments that monitor underwater data at 1-m depths only, plus the following meteorological parameters: air temperature, average hourly windspeed, and brightness.

Tables 2 through 5 show the monthly averages for each of the parameters monitored at a particular sampling location. Figures 4 through 8 plot temperatures, pH values, and dissolved oxygen values from these tables. The values displayed are based on readings taken bihourly with many readings taken hourly. This summarization is a generalization of the conclusions that could be gleaned from the mass of information collected. However, for purposes of this report, the presented averages will suffice. More detail will be left for future segment reports. Table 6 summarizes the four parameters comparing the 1981 and 1982 data and data from the two lakes.

Inflow-Outflow Volumes

Table 7 lists the monthly volume of inflow and outflow at Twin Lakes during 1982. The total inflow is broken down into two general categories: native and imports, and the imported inflows are broken down to three sources. Native inflows are those from the Lake Creek watershed that flow into the upper lake by way of Lake Creek. Diversions from Roaring Fork River are carried through Twin Lakes Tunnel to Lake Creek. This import enters the upper lake mixed with native inflow from Lake Creek. The Halfmoon and Turquoise imports flow through Mt. Elbert Conduit

Table 2. – Monthly averages from monitoring instrumentation on lower lake at station 2.

	May[1]	June	July	Aug.[2]	Sept.	Oct.	Nov.[3]
1-m Depth							
Temperature (°C)	7.4	9.4	13.9	15.4	ND	8.8	5.6
Dissolved oxygen (mg/L)	9.21	8.68	7.91	7.26	7.2	8.19	8.68
pH	6.7	7.45	7.60	7.87	7.42	7.12	7.0
Redox (mV)	332	356	ND	ND	ND	ND	ND
13-m Depth							
Temperature (°C)	6.5	8.9	10.1	11.0	11.7	8.9	5.2
Dissolved oxygen (mg/L)	9.32	8.33	7.75	8.08	7.48	7.78	8.48
pH	6.9	6.97	6.68	6.65	6.55	7.16	7.35
Redox (mV)	261	317	338	340	344	338	372

[1] May 20-31 only
[2] Aug. 1-22 only
[3] Nov. 1-17 only
ND indicates no data

Table 3. – Monthly averages from monitoring instrumentation on lower lake at station 3.

	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Water temperature (°C)	6.1	10.2	14.1	15.6	13.4	8.8	4.4	1.9
Air temperature (°C)	5.2	9.7	13.4	13.3	9.0	2.4	-3.1	-5.9
Wind (km/h)	8.0	11.3	6.4	9.7	11.3	12.9	17.7	16.1
Brightness, g-cal/(cm^2·h)	28.1	27.2	26.5	26.7	21.3	21.4	ND	ND
Dissolved oxygen (mg/L)	9.83	8.83	9.08	7.77	7.33	7.32	9.59	12.04
pH	6.97	7.1	6.8	ND	ND	6.59	6.7	6.47
Redox (mV)	ND	ND	391	ND	ND	353	347	415

ND indicates no data

Table 4. – Monthly averages from monitoring instrumentation on upper lake at station 4.

	May[1]	June	July	Aug.	Sept.[2]	Oct.	Nov.[3]
1-m Depth							
Temperature (°C)	7.2	8.0	11.4	14.7	12.5	7.2	4.7
Dissolved oxygen (mg/L)	8.79	8.84	8.24	7.26	8.00	8.14	8.7
pH	6.83	6.74	6.64	6.98	6.92	6.81	7.12
13-m Depth							
Temperature (°C)	6.9	6.8	7.5	8.4	9.0	7.8	5.3
Dissolved oxygen (mg/L)	10.38	9.76	9.88	11.1	ND	9.52	ND
pH	6.84	6.48	6.37	6.37	6.34	6.74	6.9
Redox (mV)	273	333	339	449	431	398	405

[1] May 21-31 only
[2] Sept. 1-18 and 23-30 only
[3] Nov. 1-17 only
ND indicates no data

Table 5. – Monthly averages from monitoring instrumentation on Mt. Elbert Forebay at station 5.

	May[1]	June	July	Aug.[2]	Sept.	Oct.	Nov.[3]
Water temperature at 1m, (°C)	7.5	9.3	12.9	12.3	12.6	7.7	4.8
Air temperature (°C)	–	–	–	–	7.45	2.2	-2.2
Wind (km/h)	–	–	–	–	8.0	12.9	9.2
Brightness, g-cal/(cm^2·h)	–	–	–	–	ND	ND	6.9
Dissolved oxygen (mg/L)	9.94	8.91	8.17	8.21	8.56	11.07	12.97
pH	7.05	6.99	7.19	6.65	6.76	6.80	6.88
Redox (mV)	–	371	376	408	400	–	–

[1] May 20-31 only
[2] Aug. 1-16 and 26-31 only
[3] Nov. 1-17 only
ND indicates no data

to Mt. Elbert Forebay, then through Mt. Elbert Pumped-Storage Powerplant into the lower lake. This diversion, which is an operating feature of the Fryingpan-Arkansas Project, began in September 1981. Figures 9 and 10 are graphs of the inflow and outflow volumes for 1982, respectively, along with the 10-year average volumes for 1971-81. Figure 11 is a histogram of total annual inflow volumes to Twin Lakes for 1972-82. Imports to the lower lake from Mr. Elbert Conduit are differentiated from other inflows.

The quantity of inflow has a tremendous influence on the ecology of Twin Lakes [16]. The lakes are influenced both by the flushing of seasonal runoff and the infusion of certain nutrients needed for aquatic productivity. The average monthly inflow during 1982 was greater than the 1971 – 81 average (table 7, fig. 9). While peak runoff occurred in June as usual, inflow was from 5 to 25 times greater during the months of low runoff (Jan.-Apr. and Sept.-Dec.) than average. Outflow (table 7, fig. 10) likewise was greater during all 12 months, especially during the winter and fall. Outflow during June, when inflow was also greatest, was more than 50 percent greater than the average. Since the volumes of water being passed through the lakes at this time were so substantial, flushing influenced the aquatic ecology of Twin Lakes during 1982 to a greater degree than during other years. The total annual volume of inflow to Twin Lakes during 1982 was double the 1972-81 average inflow volume. The inflow volume from 1972 through 1981 was greatest during 1978; however, the inflow volume during 1982 was 1.67 times greater than that of 1978. This above average volume of inflow was due in part to flows from Lake Creek (native plus imported through Twin Lakes Tunnel) due to an above normal snowpack in the two watersheds involved. However, over 38 percent of the inflow during 1982 was from flows through Mt. Elbert Powerplant (imported through Mt. Elbert Conduit from Halfmoon and Turquoise). This inflow goes directly into the lower lake and has little or no influence on the upper lake. Thus, the lower lake was even more affected by inflow than the upper lake during 1982.

Over 1.5 times more water passed through the lower lake in 1982 than in any of the previous years (1972-82) of this study. We have seen a variety of changes in the ecology of Twin Lakes during and following other years when inflow was greater than normal. These changes resulted from the direct and indirect influence of greater flushing, increased turbidity, and a larger import of nutrients and trace elements. However, we have not previously seen either the volume of the 1982 inflow or its discriminatory influence on the lower lake only. In addition, the influence of any pumped-back operation adds another dimension to assessing how inflow governs the ecology of Twin Lakes as this report progresses and another yearly chapter of the story of Twin Lakes reveals new mysteries while answering some of the old. The fact that the inflow volume during 1982 was so very high must be kept in mind when considering each of the chemical and biological parameters.

Average Water Temperature

The average monthly water temperatures in the upper and lower lakes for all depths on each of the 1982 sampling dates are displayed on figure 12. The monthly averages from the 8 years (1973-81) of this study are also shown on figure 12. Both lakes were generally cooler from January to August. The lower lake became, on the average, slightly warmer in late August and remained so into December. The upper lake was 2 °C colder than the 8-year average during June and July because of the cold inflows from runoff. By mid-September, average water temperatures

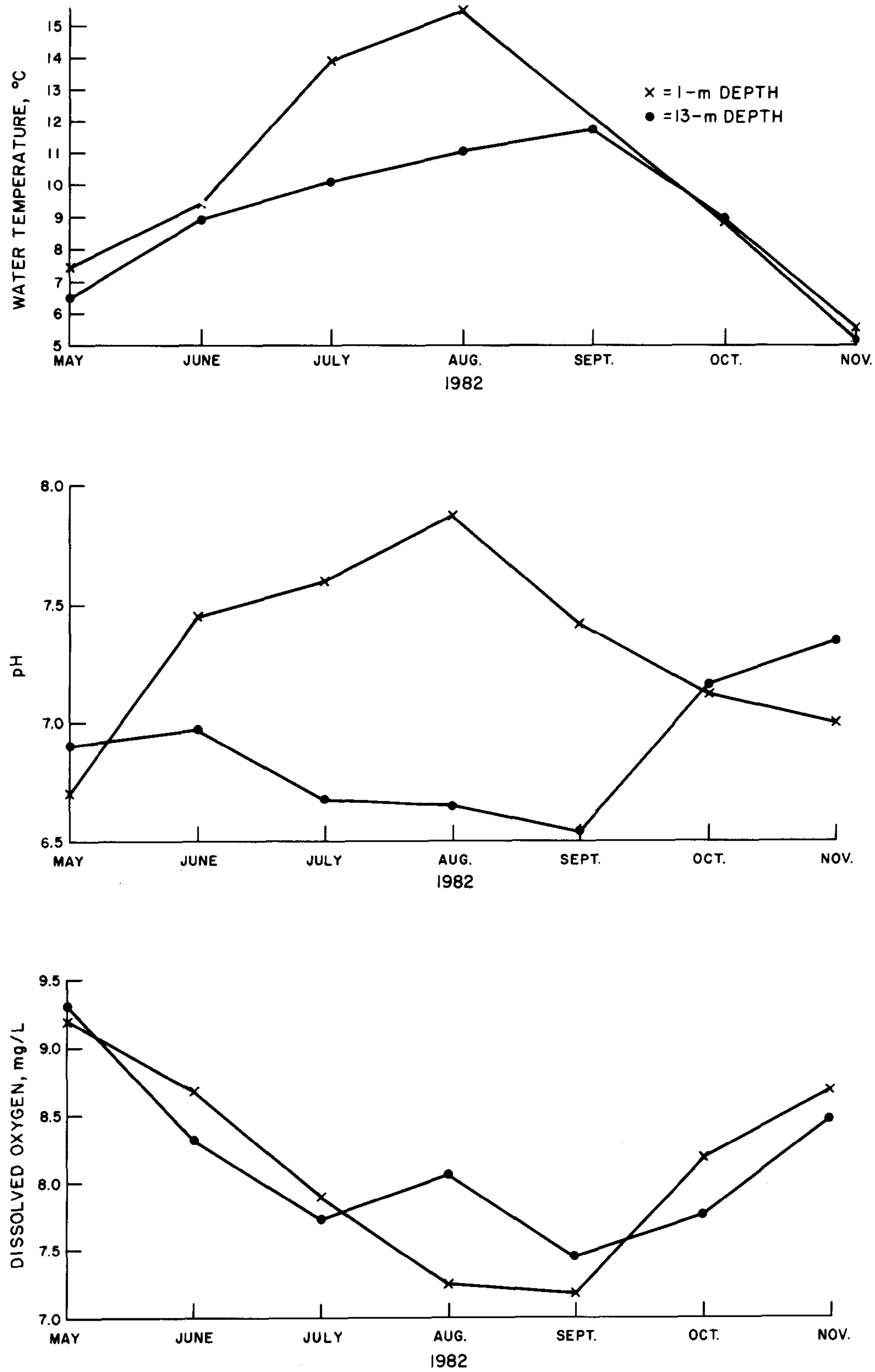


Figure 4. – Average monthly water temperature, pH, and dissolved oxygen values from station 2 in lower lake monitored at 1- and 13-m depths during 1982.

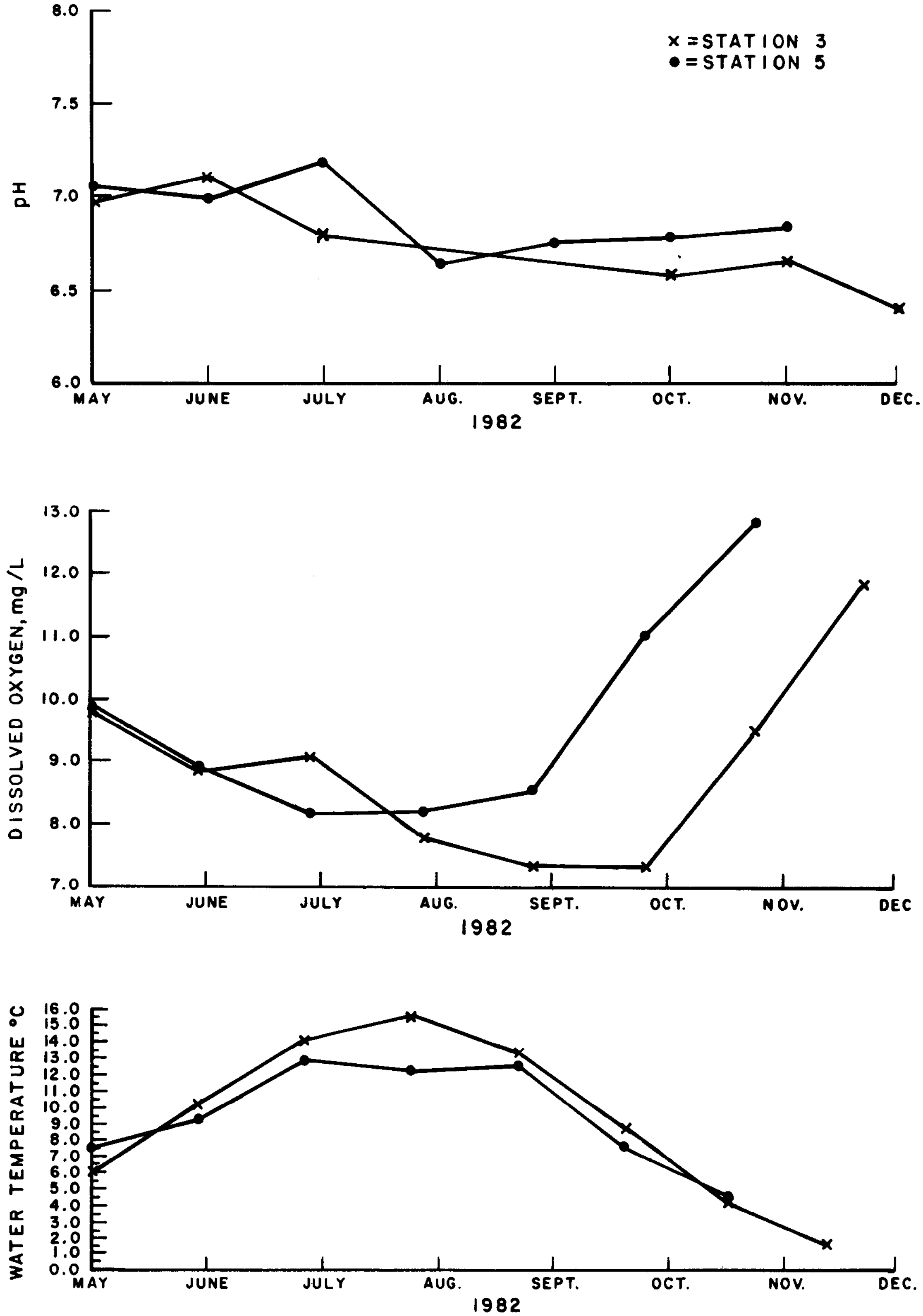


Figure 5. – Average monthly water temperature, pH, and dissolved oxygen values from station 3 in lower lake and station 5 in forebay monitored at 1-m depth during 1982.

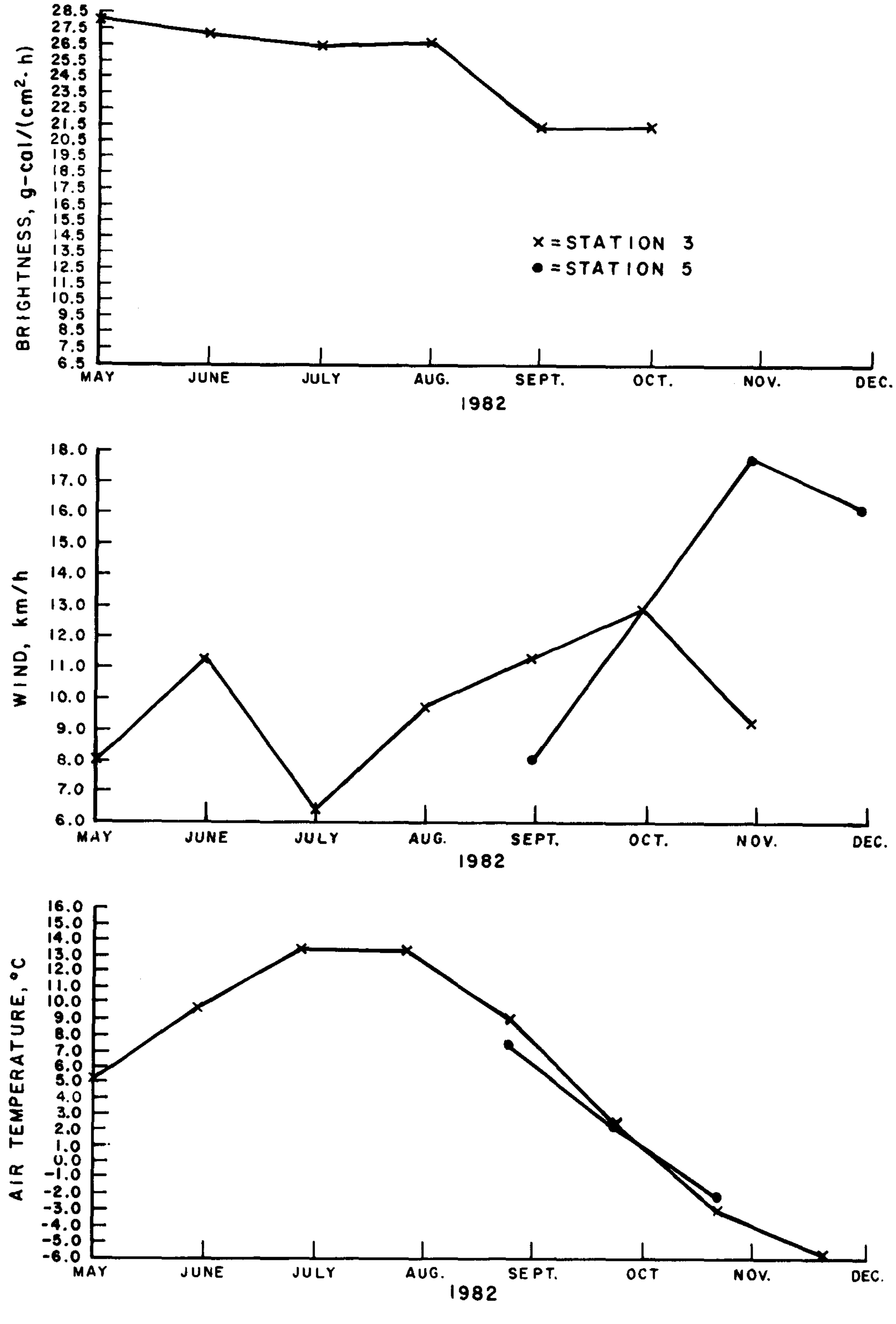


Figure 6. – Average monthly air temperature, wind, and brightness from station 3 in lower lake and station 5 in forebay during 1982.

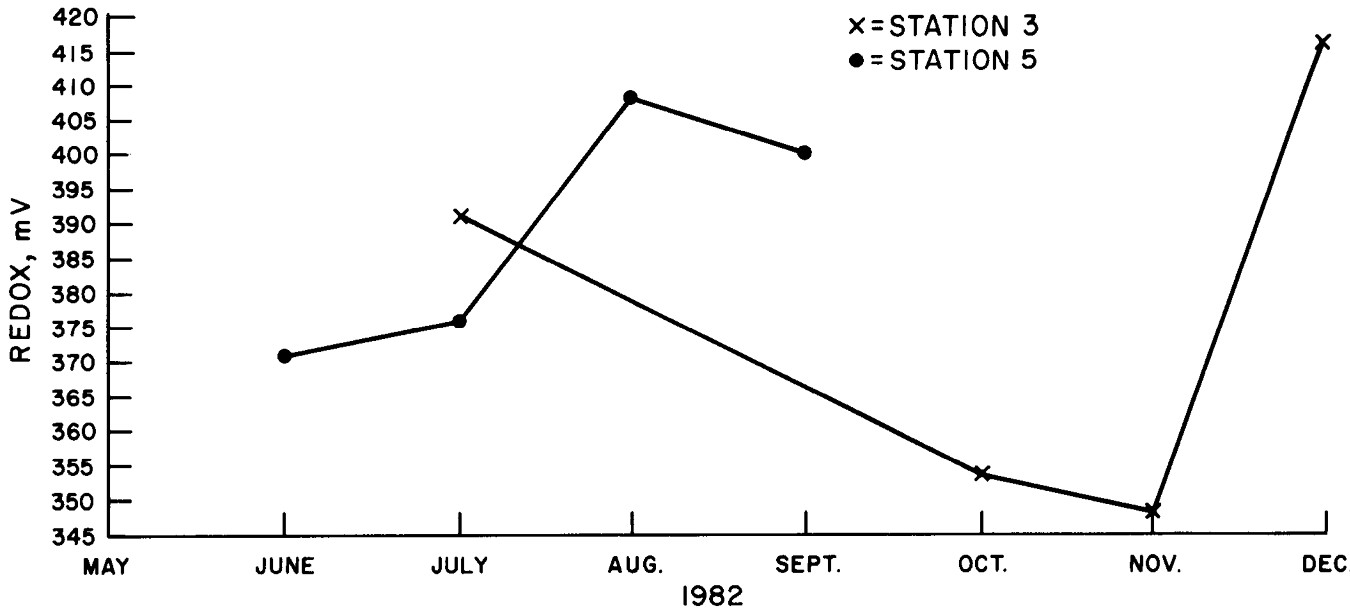


Figure 7. – Average redox readings from station 3 in lower lake and station 5 in forebay during 1982.

of the upper lake were at or slightly greater than the 8-year averages, and remained so until December. The peak average temperatures of 9.3 and 12.4 °C for the upper and lower lakes, respectively, occurred in late August. The upper lake remained about 3 °C cooler than the lower lake from June through September. The upper lake is generally about 2 °C cooler than the lower lake during these months. The volume of Lake Creek inflow into the upper lake is the primary influence on the upper lake's average temperature. This cool inflow goes to the bottom of the upper lake while the lower lake receives the relatively warmer epilimnetic water from the upper lake. Figure 13 compares water temperatures averaged over all depths of the lower lake and Mt. Elbert Forebay. While the forebay remained cooler than the lower lake because of the cool inflow from Mt. Elbert Conduit, the similarity of the curves indicates the influence that the inflow from the forebay has on the water temperature of the lower lake. Correlating average water temperatures in the forebay with those in the lower lake results in a correlation coefficient (r) of 0.99. Water temperatures in the lower lake are now influenced by three factors: (1) meteorological conditions, (2) inflow from the upper lake, and (3) inflow from the forebay. The influence of relatively cooler inflow (38 percent of the volume for 1982) from the forebay seems to be a major influence on the average water temperature of the lower lake. The next section discusses temperature structure, which also may have been affected by inflow from the forebay.

Physical-Chemical Profiles

Figures 14 through 19 are isopleth drawings of temperature, dissolved oxygen, and pH for the upper and lower lakes. Ice cover thickness is indicated on each figure, and the top line varies in position to reflect changes in water surface elevation.

Temperature. – The upper lake was ice free from May 6 to November 24, or 202 days. The lower lake was ice free from May 8 to December 9, or 215 days. The lakes were both ice free in 1981 for 244 days and in 1980 for 208 days. Two significant observations are notable from these data: (1) the lower lake was ice free 15 days longer in 1982 than the upper lake, and (2) the lakes were ice free for a moderate length of time based on data from other years. The difference in dates of ice formation on the two lakes was due to two factors. First, there was a series of storms, including strong winds from the southeast, during the late fall period. The lower lake is very exposed to southeasterly winds, while the upper lake is shielded in this direction. These storms were especially notable since we had continuous problems with our boats, which are moored on the north shore of the lower lake, being blown, mooring and all, toward shore. Winds were so strong and the fetch is such that by the time waves reached the north shore they were high enough to fill the moored boats with water. We have not had such problems in past years. This constant mixing delayed ice cover formation on the lower lake, while an ice cover formed on the relatively protected upper lake. Operation of the powerplant was the second cause of increased turbulence in the lower lake which also contributed to the delay in ice cover formation.

The lower lake was thermally stratified from about May 30 to October 6, or 130 days. The upper lake

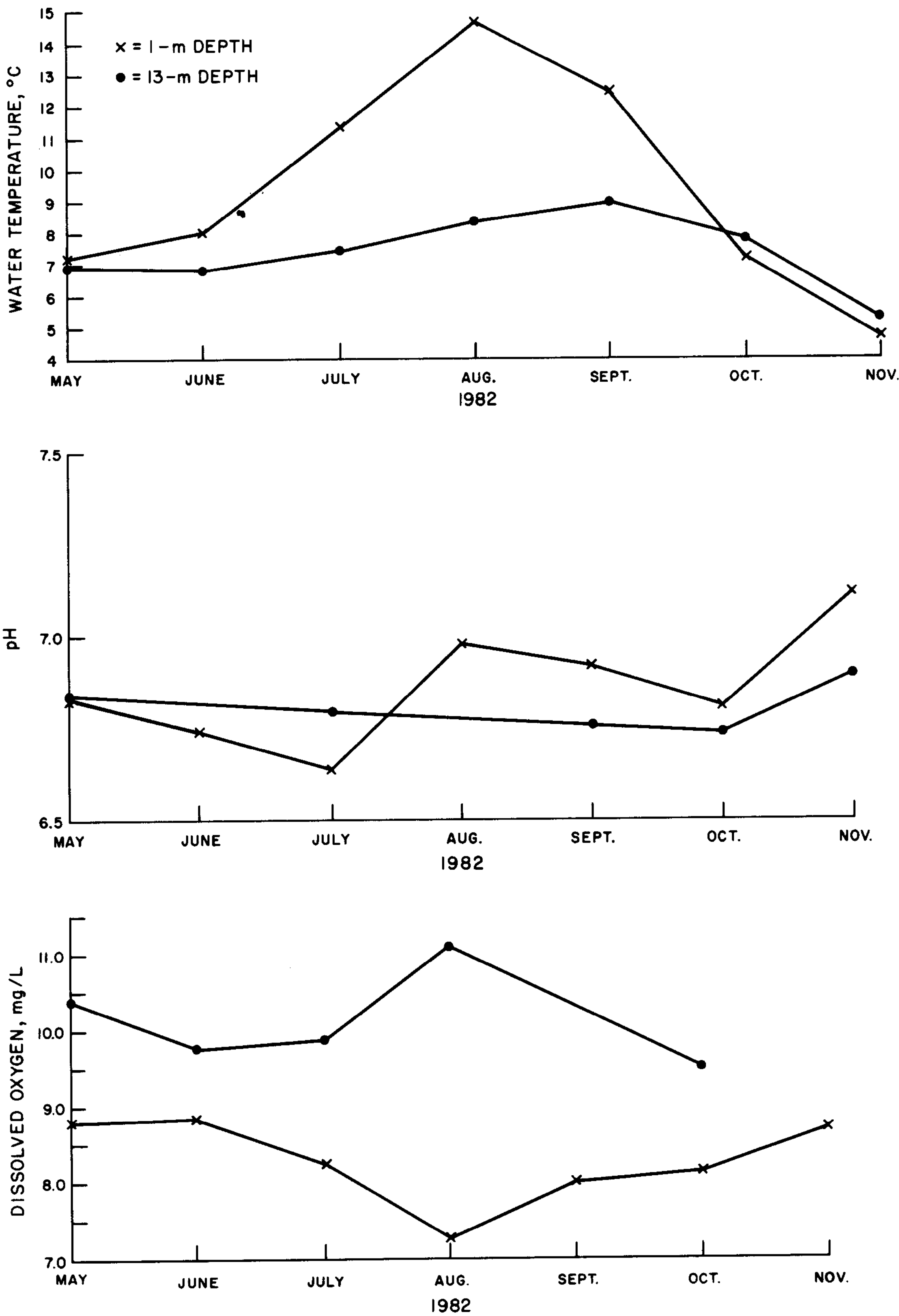


Figure 8. – Average monthly water temperature, pH, and dissolved oxygen values from station 4 in upper lake monitored at 1- and 13-m depths during 1982.

Table 6. – Average values of four parameters monitored on common dates[1].

Location and depth	Temperature, °C		Dissolved oxygen, mg/L		pH		Redox, mV	
	1981	1982	1981	1982	1981	1982	1981	1982
Station 2 (1 m)	12.05	10.9	7.60 (100)*	8.18	7.10	7.38	596	N/A
Station 4 (1 m)	10.93	10.0	7.64 (98)	8.19	7.01	6.83	390	N/A
Station 2 (13 m)	9.76	9.1	7.64 (94)	8.10	6.60	6.89	553	330
Station 4 (13 m)	8.09	7.6	7.77 (92)	10.50	6.69	6.57	368	381
Station 5 (1 m)		10.0		9.51		6.87		384
Station 3 (1 m)		9.5		8.93		6.75		381

[1] Common dates were May 1 through Nov. 10, 1981 (4632 samples) and May 20 through Nov. 17, 1982 (3237 samples).
* Number in parenthesis indicates percent of saturation.

Table 7. – Inflow and outflow volumes for 1982.

Month	Inflow					Outflow
	Native	Imports			Total	
		Twin Lakes Tunnel	Halfmoon	Turquoise		
January	0	0.16	0	1.12	1.28	1.37
February	0	0.12	0	0.86	0.98	1.76
March	0.10	0.05	0	0.36	0.51	1.92
April	0.22	0.02	0	1.30	1.54	0.88
May	1.28	0.63	0.11	0.68	2.70	2.54
June	4.23	3.31	0.36	0.96	8.86	6.70
July	3.22	1.92	0.35	0.60	6.09	4.92
August	1.39	0.43	0.15	1.12	3.09	3.73
September	0.72	0.15	0	0.15	1.02	1.37
October	0.47	0.10	0	0.42	0.99	1.13
November	0.15	0.19	0	1.12	1.46	1.62
December	0.05	0.11	0	2.42	2.58	2.63
Totals	11.83	7.19	0.97	11.11	31.10	30.57

Note: All values are $m^3 \times 10^7$.

was thermally stratified from May 20 to October 10, or about 143 days. Both instances are shorter periods of thermal stratification than have previously been observed at Twin Lakes, especially in the lower lake. This situation can be attributed to three factors: (1) weather, (2) volume and timing of natural inflow, and (3) mixing caused by powerplant operation. First, the weather was generally cooler and windier during 1982. This resulted in less warming of the surface and increased wind mixing, which delayed thermal stratification. Second, runoff from Lake Creek (fig. 11) was greater than we have previously experienced. Since this runoff is cooler than the surface water in the upper lake, the turbulence it causes as it plunges to the lake bottom results in increased mixing and delay of stratification. Also, when runoff peaks or continues later than normal, stratification is delayed and disrupted. Third, turbulence caused by inflow of relatively cooler (2 °C) water from the forebay delays the onset of thermal stratification, contributes to weaker stratification throughout the summer, and enhances breakdown of stratification

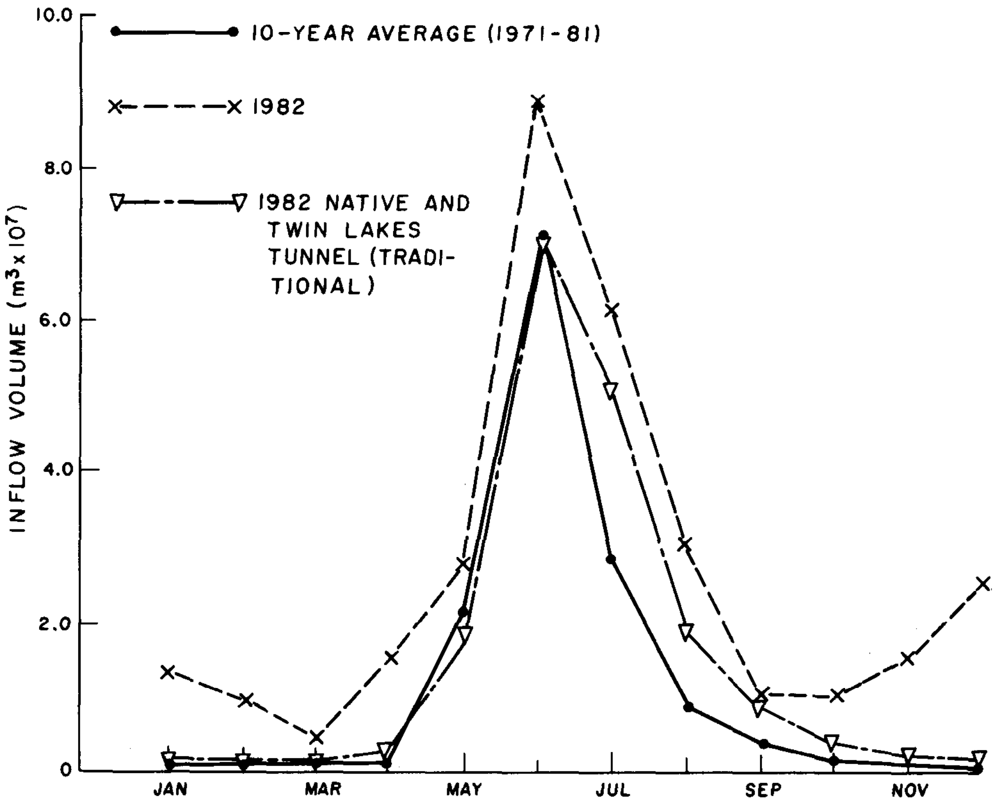


Figure 9. – Inflow volumes to Twin Lakes.

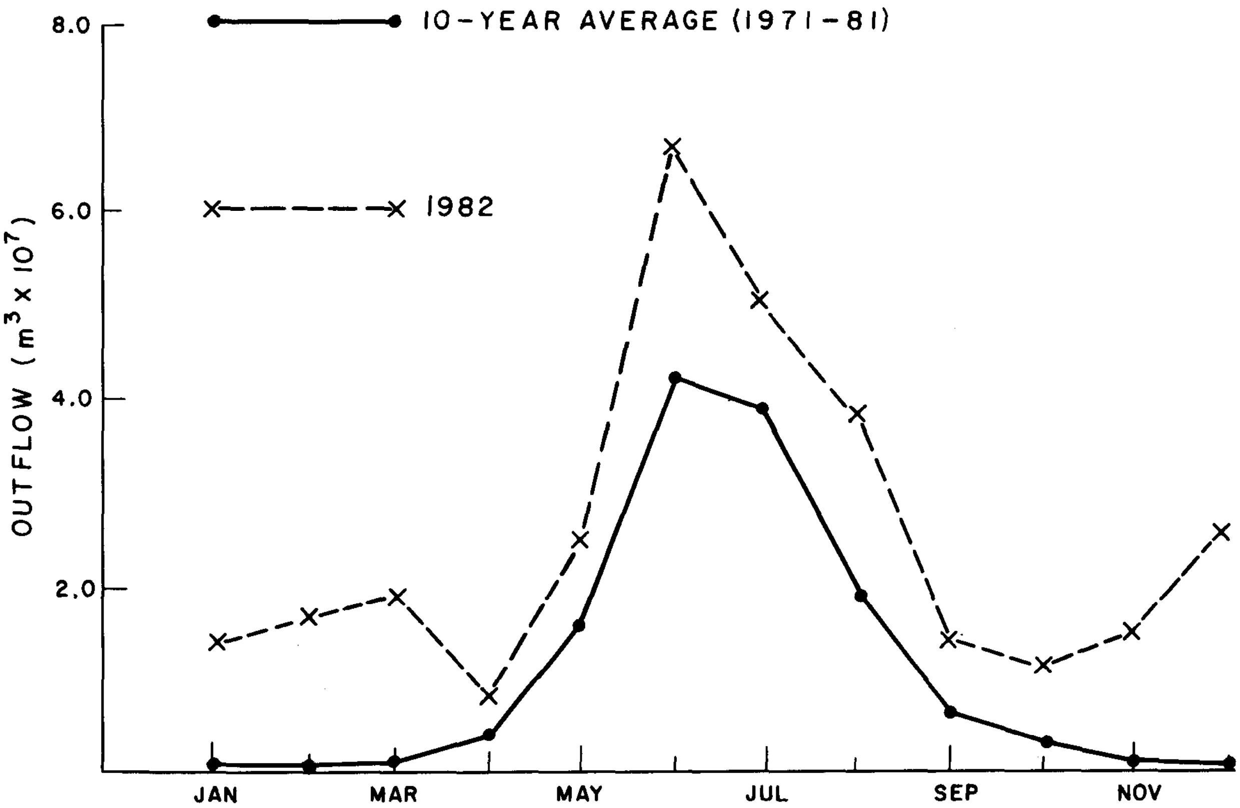


Figure 10. – Outflow volumes from Twin Lakes.

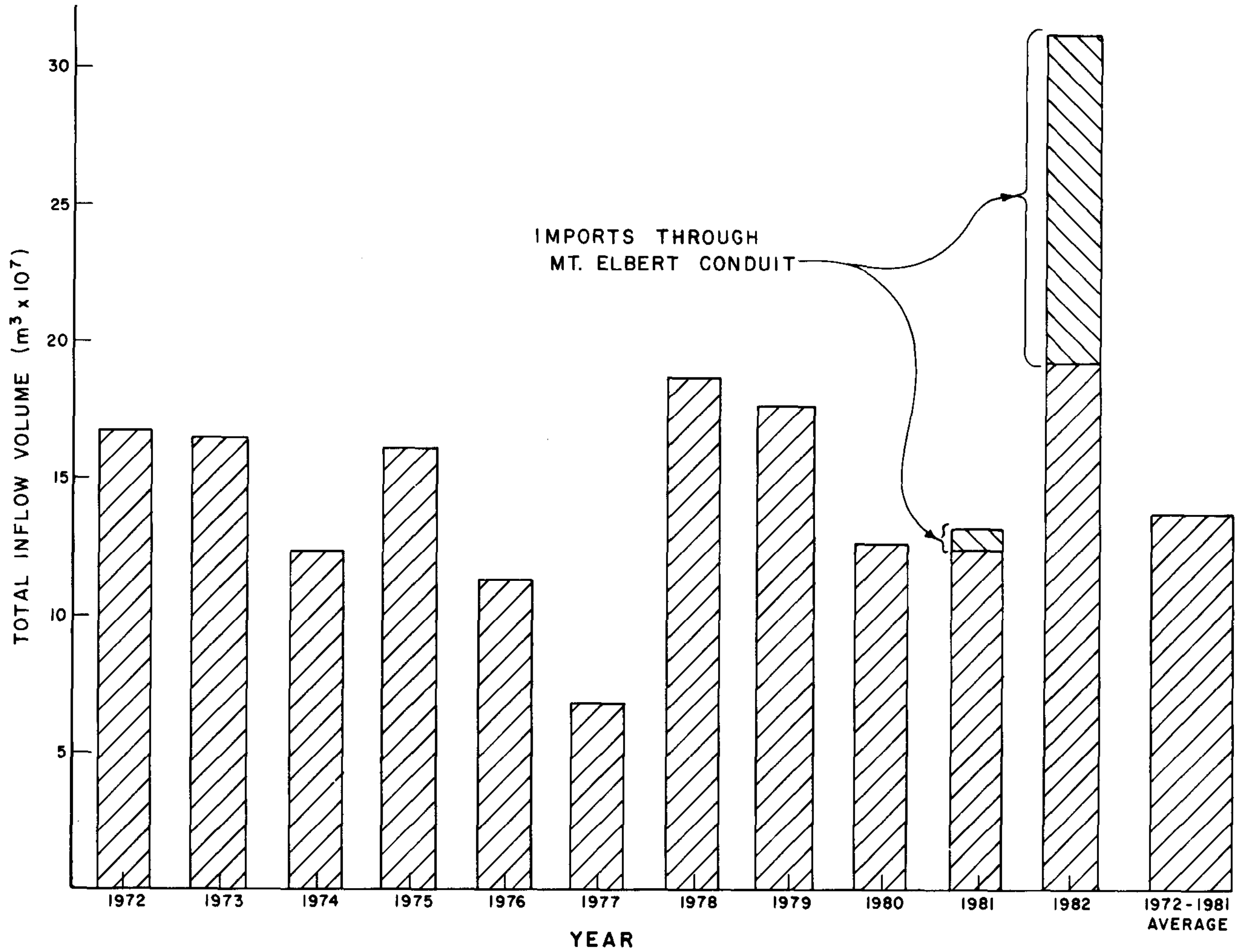


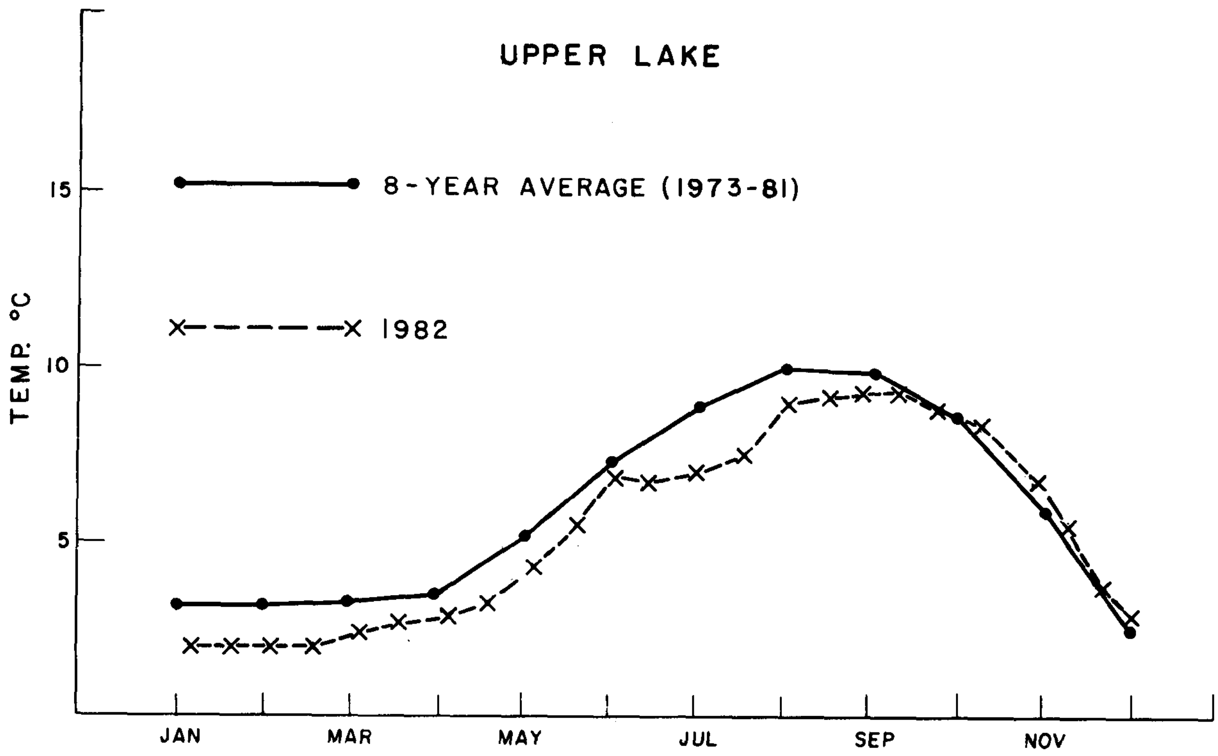
Figure 11. – Annual inflow volumes to Twin Lakes, 1972-82.

in the fall. The upper lake was thermally stratified almost 2 weeks longer than the lower lake, which supports the contention that powerplant operations had noticeable influence on the lower lake's thermal regime in 1982.

The data on figures 14 and 15 show that thermal stratification in both lakes was relatively weak in 1982. Peak stratification, such as it was, occurred in early August, which is normal for Twin Lakes. Surface and 1-m water temperatures greater than 16 °C were sustained in the lower lake only during mid-August. By comparison with 1981, the lower lake remained above 17 °C in the top 4 meters from mid-July to mid-August. While surface temperatures of the lower lake were 1 to 2 °C cooler than in 1981, temperatures at and near the bottom were about 1 °C warmer. Therefore, thermal stratification in the lower lake was weaker in 1982.

Unlike the lower lake, the thermal regime of the upper lake showed some similarities to 1981. The difference being that in 1982, the entire water column was about 1 to 2 °C cooler due to the influence of cooler than average inflow water. Maximum temperatures of upper lake surface waters in 1981 were above 16 °C from mid-July to mid-August, while in 1982 measurements at about this same time showed 14 to 15 °C maximum temperatures. Also in 1982, a bottom temperature between 5 and 6 °C remained until late September, while in 1981 temperatures below 7 °C were not observed in the upper lake past mid to late August. Thus, what existed at Twin Lakes in 1982, besides two weakly stratified lakes, was an upper lake somewhat cooler than normal, due mostly to a greater than average volume of relatively cool inflow water; and a lower lake that was cooler on the surface and warmer on the bottom, due probably to the three reasons discussed above for the shorter stratification period in the lower lake. Again, the possibility of powerplant operation enhancing mixing in the lower lake seems quite real.

Because ice formation for the 1981-82 winter was later in 1981 (Dec. 23) than in previous years (Dec. 1-10), the temperature of the lakes did not reach 4°C



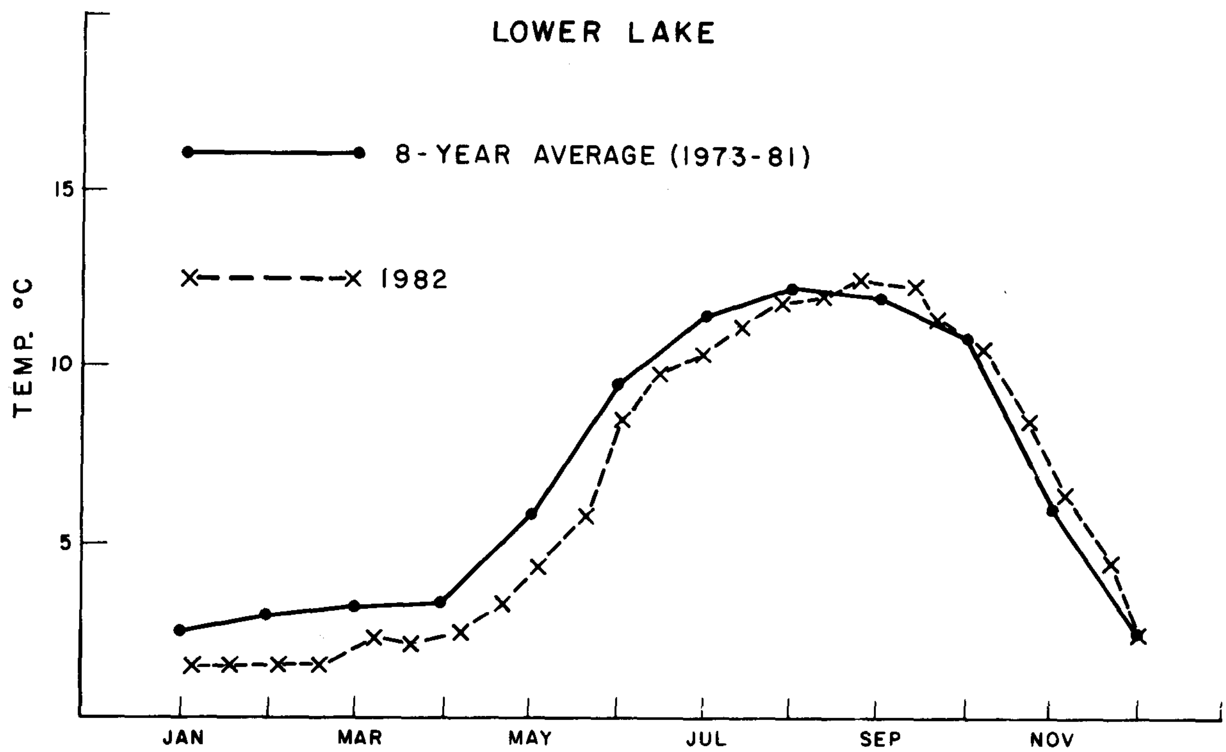


Figure 12. – Average monthly water temperatures for Twin Lakes.

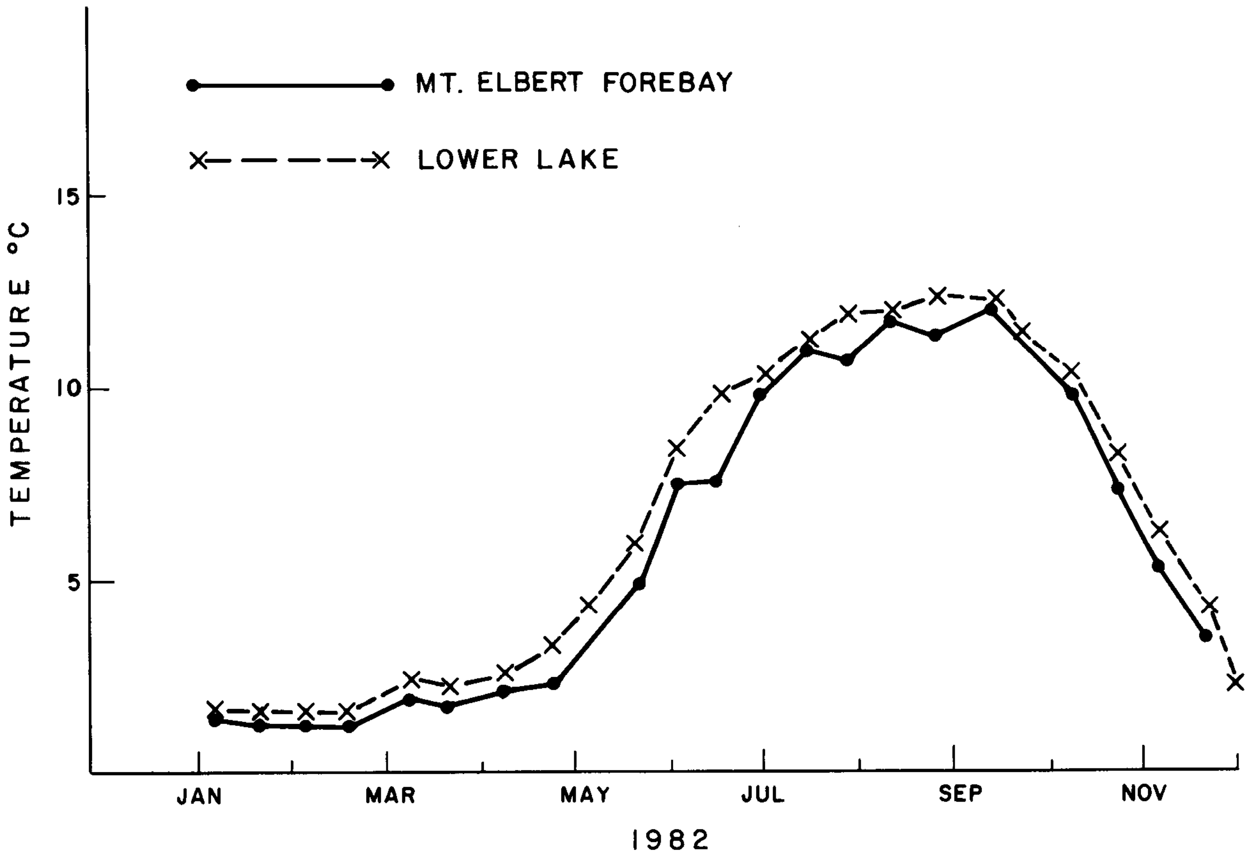


Figure 13. – Average water temperatures for lower lake and forebay during 1982.

(densest water) until just before spring ice-off. In fact, temperatures above 3 °C were not achieved until late winter. Since water is densest at 4 °C, the earlier ice forms, the warmer the lakes begin the winter. By contrast, the longer ice formation is delayed, the longer the lakes are exposed to the supercooling influence of December winds and frigid temperatures. The day ice forms is the day that the lakes begin to warm up. The warming continues, however slowly, until the day in mid-summer when maximum surface temperatures are reached. Then, the trend is reversed.

One final observation related to temperature is that a large portion of the volume of both lakes include water temperatures at or below 10 °C. Therefore, because optimum temperature for lake trout is below 10 °C, Twin Lakes remain excellent lake trout habitat, at least thermally.

Dissolved Oxygen. –Figures 16 and 17 present dissolved oxygen data from Twin Lakes during 1982. The highest dissolved oxygen concentrations (>12 mg/L) occurred in the lower lake during April. Concentrations above 10 mg/L were recorded several times in both lakes, mostly during the winter. All concentrations above 10 mg/L were associated with events causing turbulence. During June and July, turbulent inflow from Lake Creek sufficiently aerated the upper lake so that dissolved oxygen concentrations above 10 mg/L occurred. During the winter, these high concentrations were usually observed (especially in the lower lake) during or following a substantial period of powerplant operation. This turbulence seems to have kept dissolved oxygen concentrations at the bottom of the lake above 5 mg/L (50 percent saturation) the entire winter. During previous years, observed winter dissolved oxygen concentrations have always been below 20 percent saturation in the hypolimnion of the lower lake.

Oxygen concentrations at the bottom of the upper lake also seem to have been increased by powerplant operation during 1982. Bottom dissolved oxygen concentrations only dropped to 20 percent saturation once (mid-April) during the 1981-82 winter. Thus, the inflow from the powerplant is having the beneficial effect of recharging the dissolved oxygen under the ice. There have been years when dissolved oxygen concentrations at and near the bottom of both lakes have become so low that the ecology of Twin Lakes has been adversely affected [25]. Those events may now only be history with the powerplant so efficiently aerating the lakes during the winter.

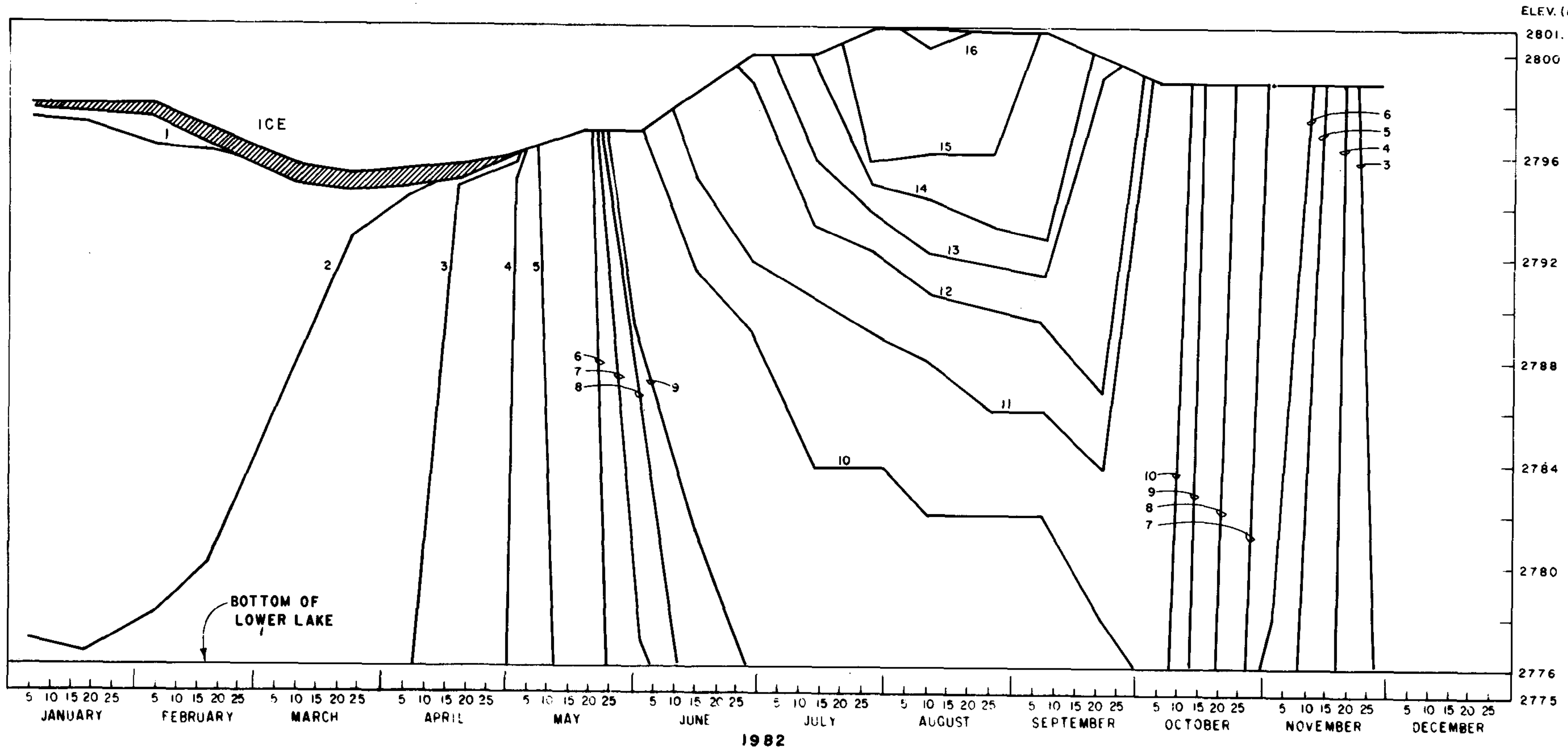


Figure 14. – Temperature isopleths for station 2 in lower lake during 1982.

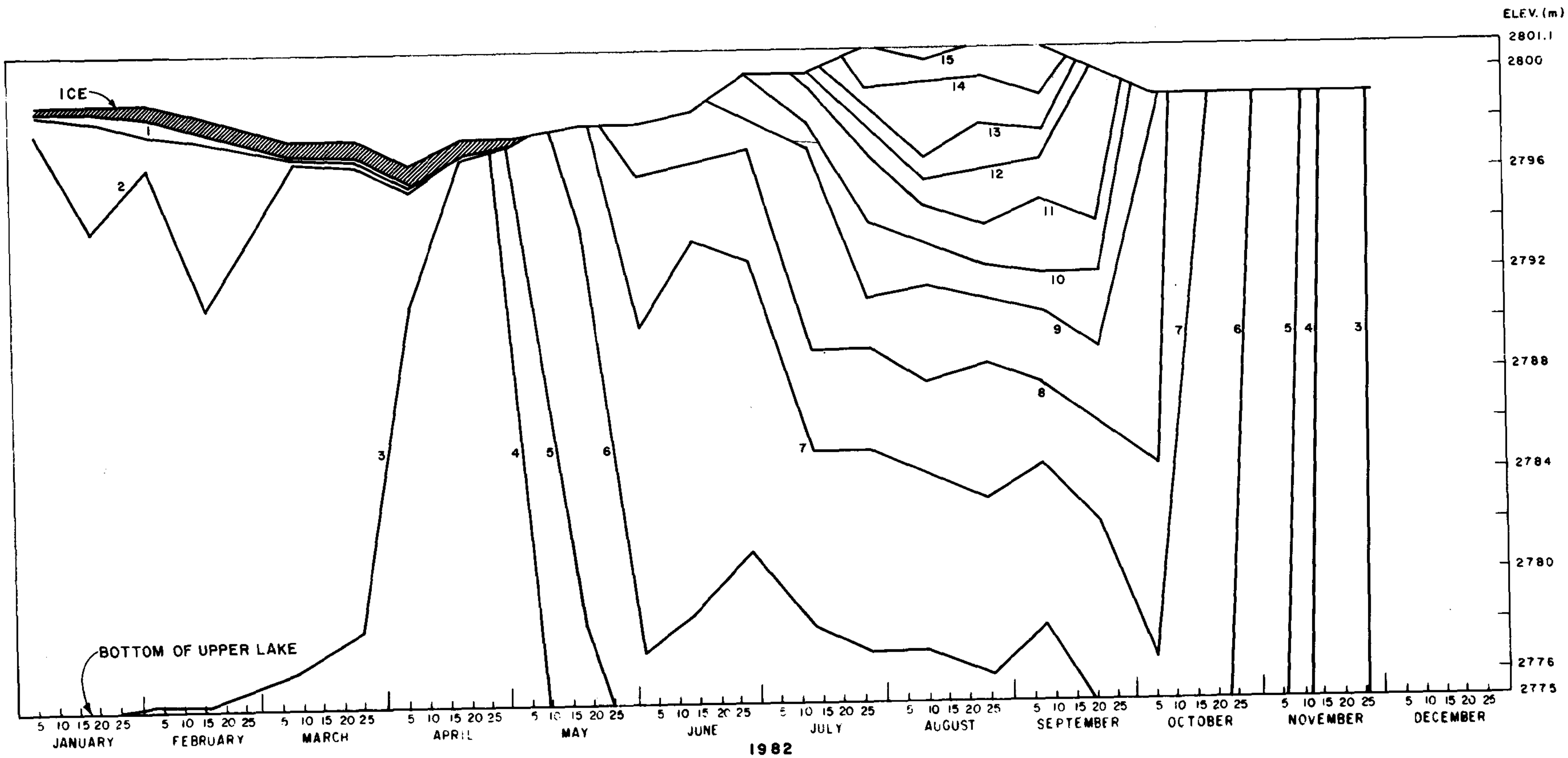


Figure 15. – Temperature isopleths for station 4 in upper lake during 1982.

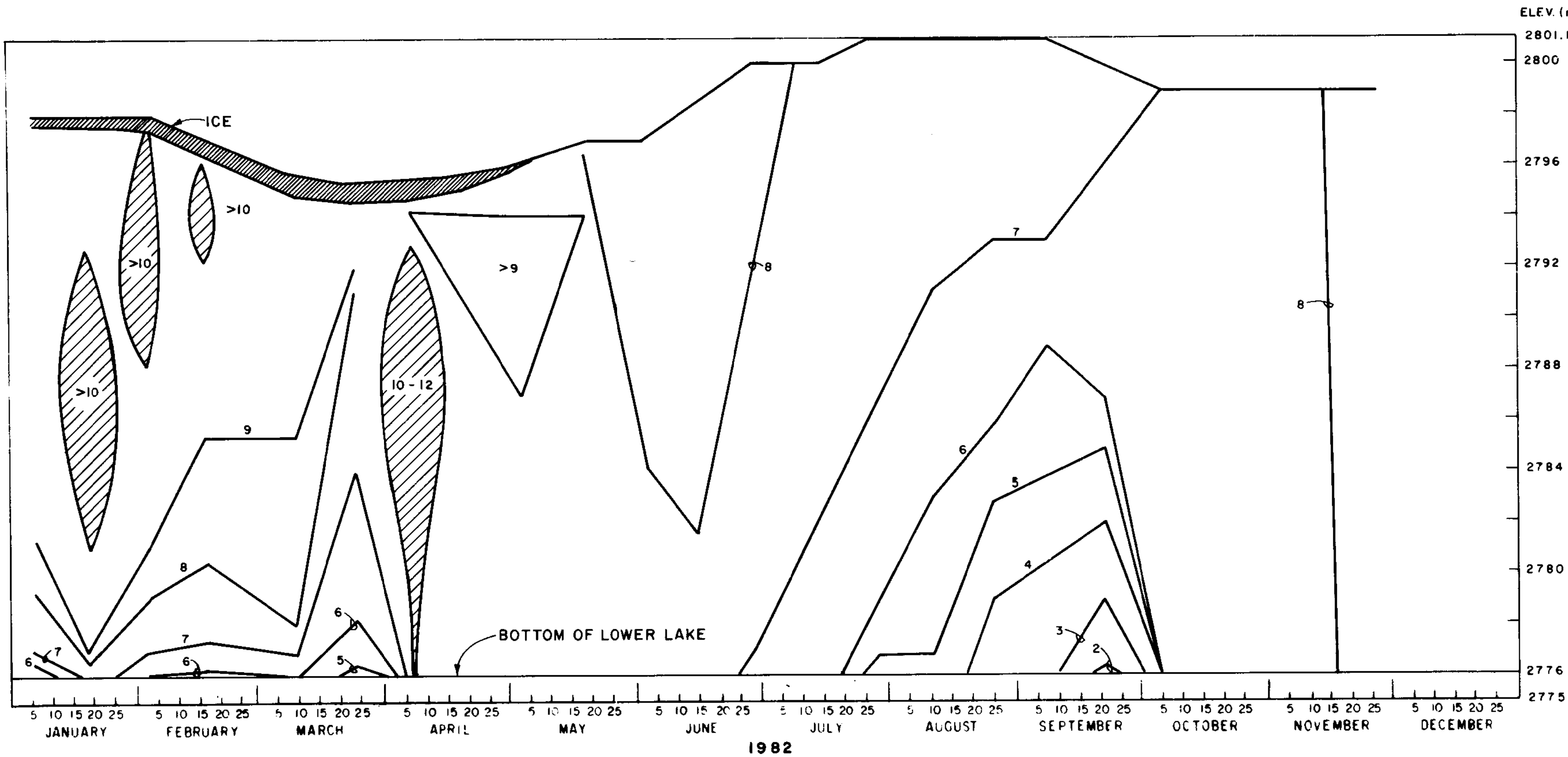


Figure 16. – Dissolved oxygen isopleths for station 2 in lower lake during 1982.

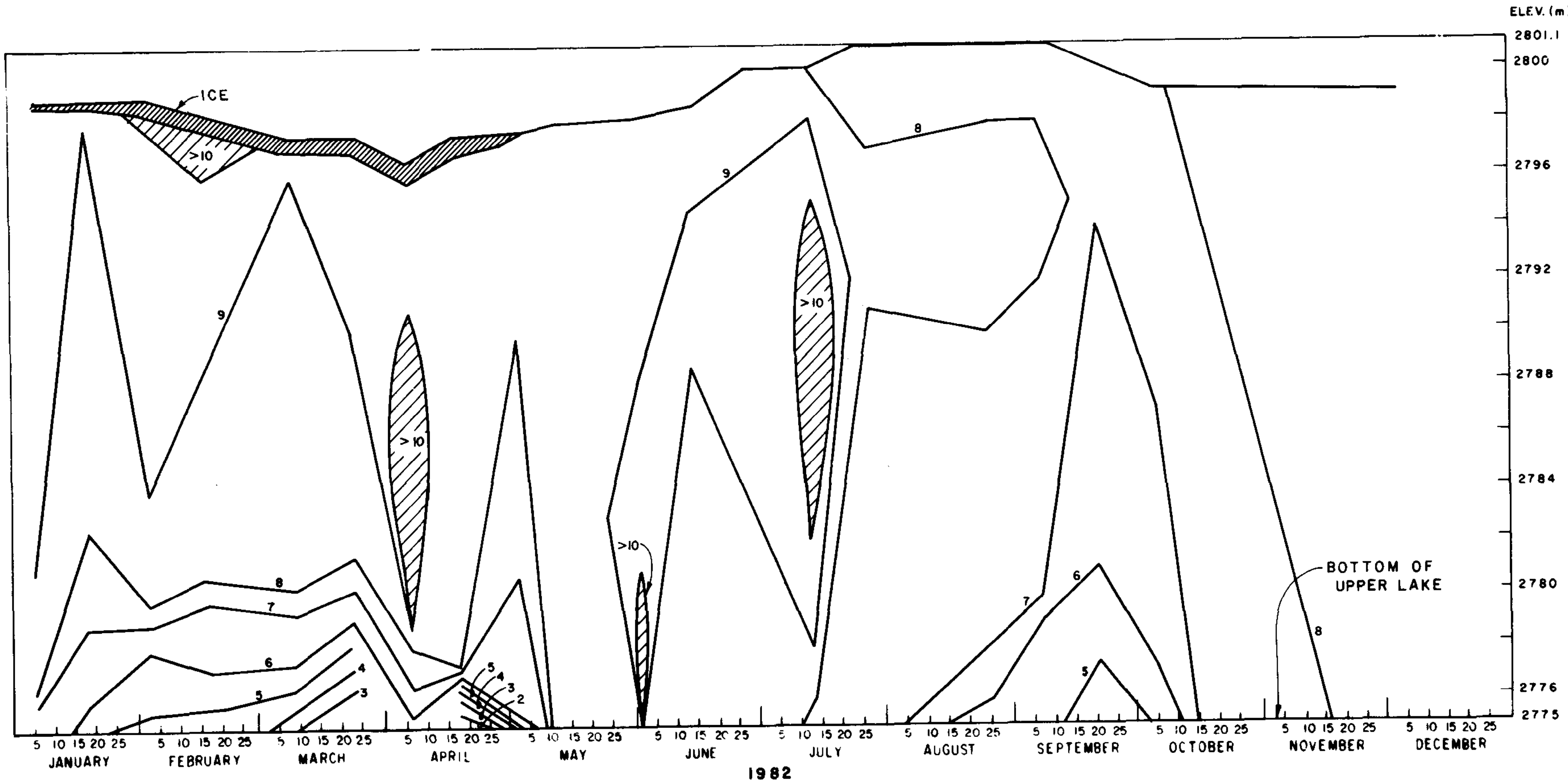


Figure 17. – Dissolved oxygen isopleths for station 4 in upper lake during 1982.

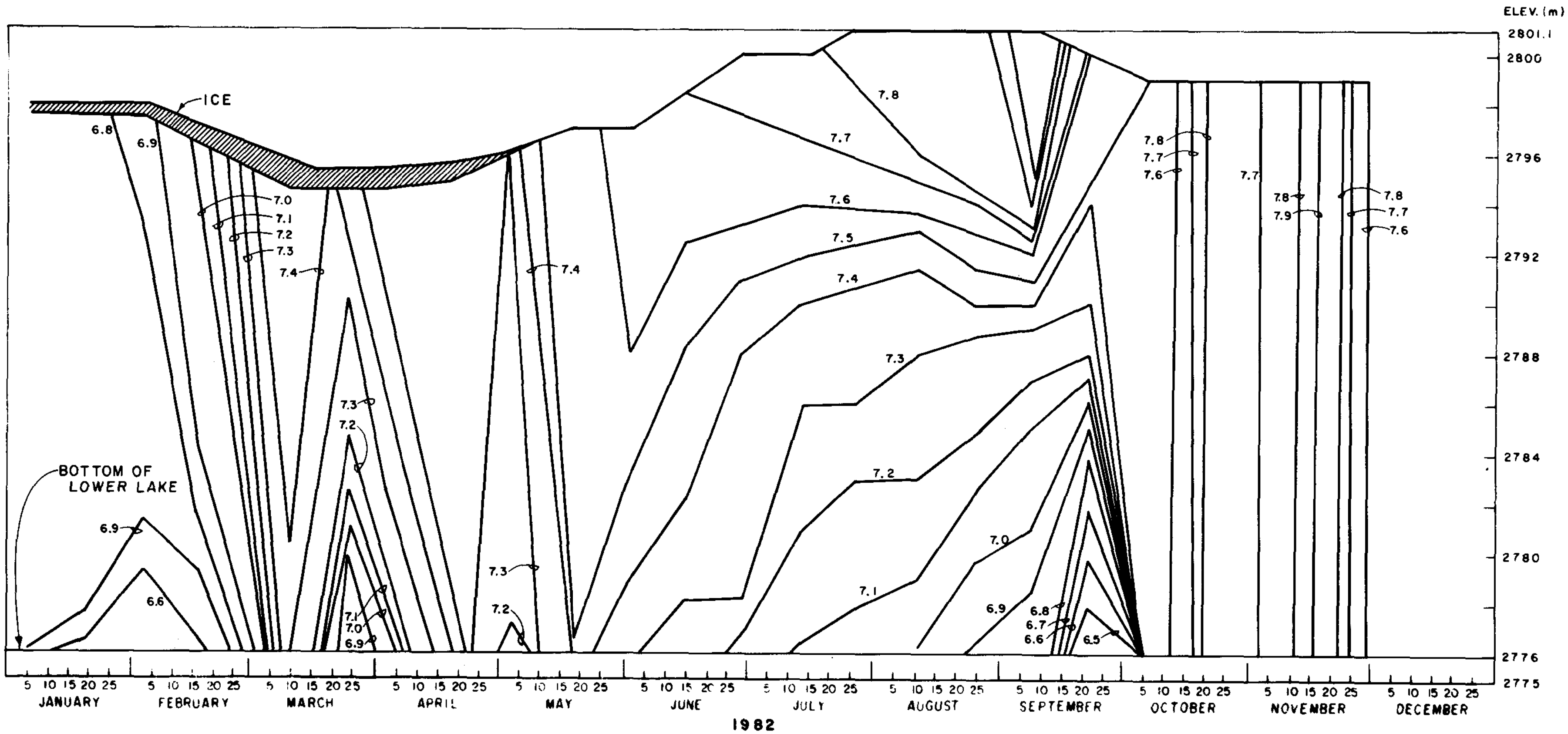


Figure 18. – Hydrogen ion concentration (pH) isopleths for station 2 in lower lake during 1982.

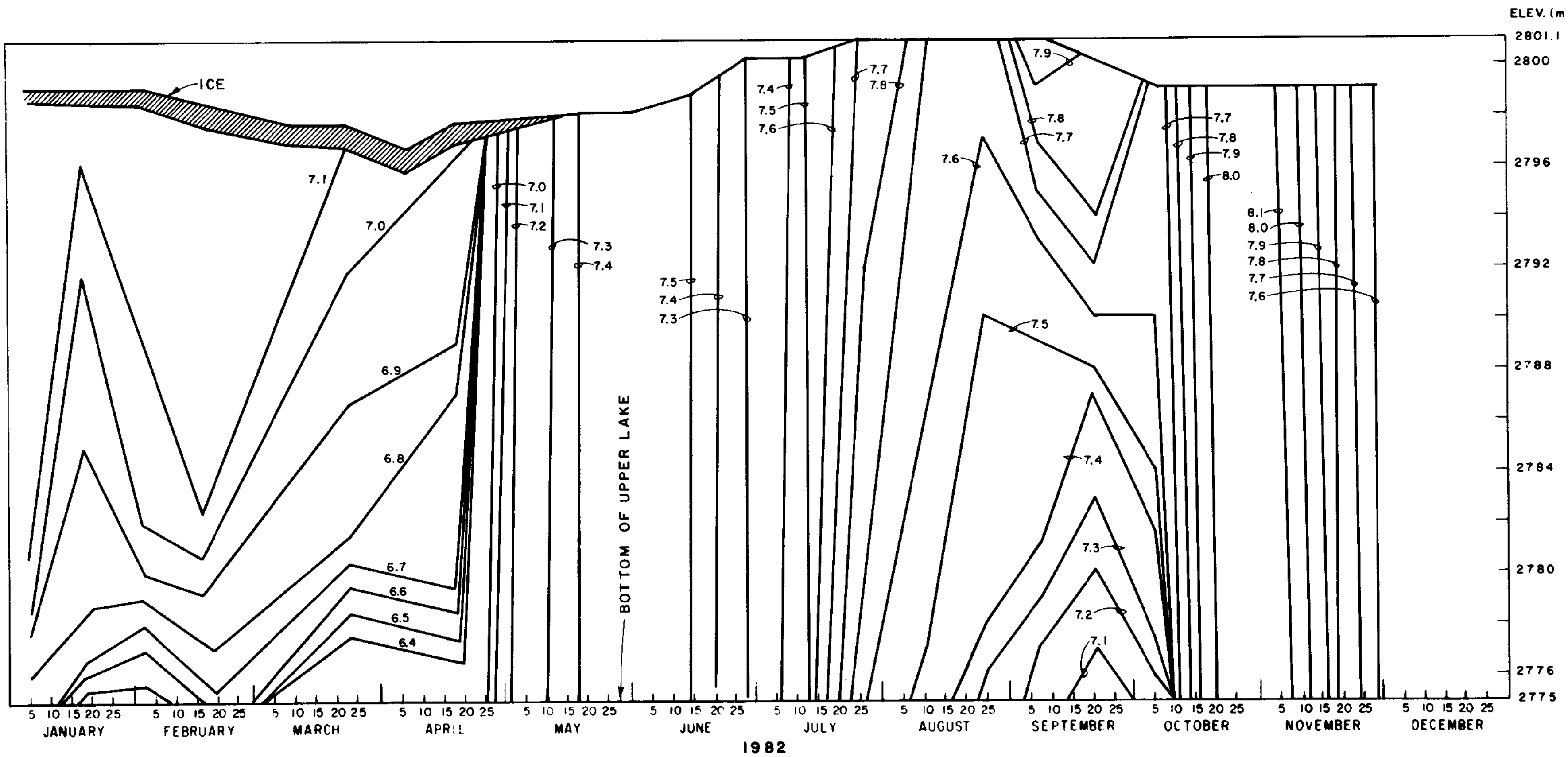


Figure 19. – Hydrogen ion concentration (pH) isopleths for station 4 in upper lake during 1982.

Hydrogen Ion Concentration (pH). – Figures 18 and 19 present pH isopleths for Twin Lakes during 1982. These diagrams are almost artist's concepts as pH data from 1982 were extremely variable and much extrapolation had to be done. During the winter, the pH dropped below 6.4 near the bottom of each lake. During the summer, pH values ranged from lows in the lower lake of below 6.5, and between 7.0 and 7.1 in the upper lake (both measured in September) to highs of between 8.0 and 8.1 following fall turnover in both lakes. Since 1973, pH values have ranged from 6.3 to 8.3 at Twin Lakes. The pH values measured during 1982 were within this expected range. In general, the pH of Twin Lakes varies greatly because the water has a low conductance (<90 μ S/cm) and is thus poorly buffered. The amount of biological activity, benthic chemical processes, and the quality and volume of inflowing water all affect the variation of pH. Biological activity and chemical processes in the benthic environment during stratification periods particularly influence pH. That is, when reduction occurs (breakdown of animal and plant material), pH decreases. Conversely, as oxidation occurs (production of algae), pH increases. As water with a lower conductance (e.g., inflow from the forebay) is introduced into Twin Lakes, it mixes and lowers the buffering capacity even more, so that the pH is even more susceptible to shifts. Because of the variable, and at times quite large, inflow of water with relatively low conductance from the forebay, the pH during 1982 shifted dramatically ($>$ 0.3 pH units) over short periods (e.g., less than 1 day). Stability in pH did not occur until definite stratification and biological production occurred; that is, following spring turnover. Following fall turnover, the pH throughout the water column again became variable.

Conductivity. – Figure 20 presents average conductivity data during 1982. Plotted values were averaged from surface to bottom for each sampling date. Conductivities ranged from 54 to 93 μS/cm for the upper lake, 56 to 71 μS/cm for the lower lake, and 35 to 52 μS/cm for the forebay. The 1982 average conductivities for the upper lake, lower lake, and forebay, were 75, 61, and 44 μS/cm, respectively. By comparison, averages for the upper and lower lakes in 1981 were 87 and 81 μS/cm, respectively. During 1982, the conductivities were thus 14 and 25 percent less in the upper and lower lakes, respectively, than in 1981. The difference between the upper and lower lakes mean conductivities was greater in 1982 than has been previously observed, which can be attributed to the infusion of water of very low conductivity from the forebay.

The data on figure 20 for the forebay and lower lake do not indicate any dramatic seasonal trends. However, data from the upper lake do show a seasonal trend because water of low conductivity, entering as runoff via Lake Creek, has the normal diluting effect, primarily in June and July. Two subtle observations from the plots on figure 20 should be made. First, the influence of forebay water on the conductivity of the lower lake can be seen by comparing April and May data. The dip in the curve of the lower lake data is attributed to the influence of water of low conductivity from the forebay. The influence of this water may even be seen in conductivity data from the upper lake in late February, early May, and again in early September. The second observation is the relative low conductivity of forebay water compared to Twin Lakes. This item has been previously discussed.

In summary, inflow, whether from Lake Creek or the powerplant, influences the conductivity of Twin Lakes by its diluting influence. Overall, the water of Twin Lakes has a very low conductivity, which results in a very poor buffering capacity.

Oxidation-Reduction Potential. – Figure 21 presents the oxidation-reduction (redox) potential values measured at the bottom of both lakes and the forebay during each of the 24 surveys in 1982. Data from the January 6, 1983, survey are included to show trends. Since redox potential is a highly qualitative measure, values are grouped for graphing purposes. Actual values ranged between 298 and 471 mV in the upper lake, between 261 and 490 mV in the lower lake, and between 342 and 494 mV in the forebay. Noted trends from data plotted on figure 21 are lows found just after spring turnover in May in both lakes, and again in late September in the lower lake. Values below 300 mV are somewhat significant in that a reducing state is reached below this value and metals begin to go into solution (e.g., iron and manganese). Redox potential values are lowest at turnover when the water column mixes, conductivity values are lowest, and the water is relatively less buffered. Values are generally higher when the water is more buffered, conductivity is highest, or production is greatest.

Decomposition of biota as well as trace metal and nutrient release from the sediments near the bottom of Twin Lakes has always been important in determining the ecology of the lakes for the season following turnover. To present an even clearer picture of what the benthic environment was like during 1982, figure 22 is presented. The percent of dissolved oxygen saturation and E_7 (redox) readings shown on this figure indicate the oxidation and reduction of trace elements. The 300-mV line on the E_7 scale represents the redox potential at which the trace elements iron and manganese are reduced to an ionic state. In turn, the amount of nutrients (i.e., ammonia, orthophosphorus) and trace metals (i.e., iron, copper, zinc, manganese) being reduced into a soluble state is dependent on this degree of reduction. The significance of this is two-fold. First, the

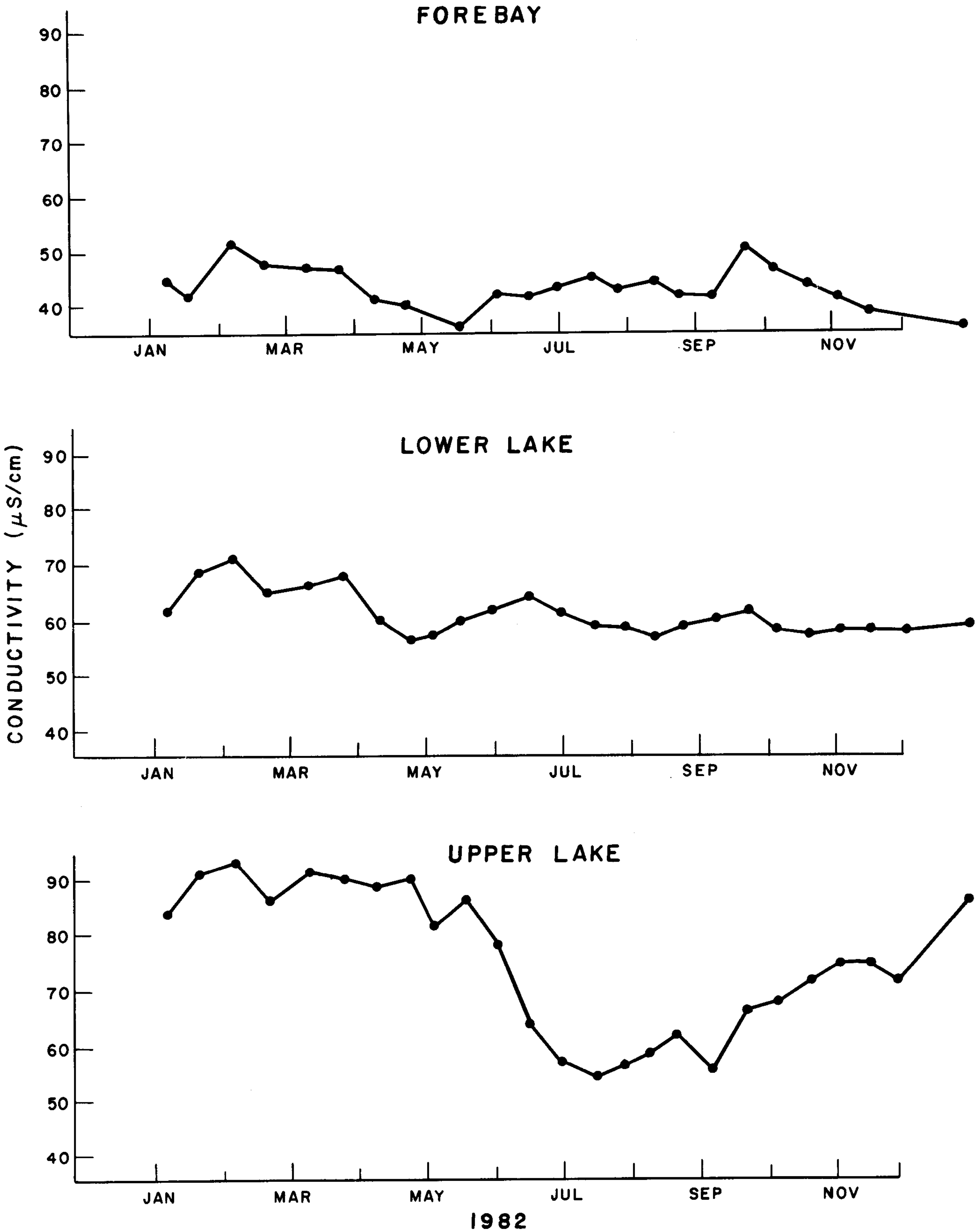


Figure 20. – Average conductivity data from Twin Lakes and Mt. Elbert Forebay during 1982.

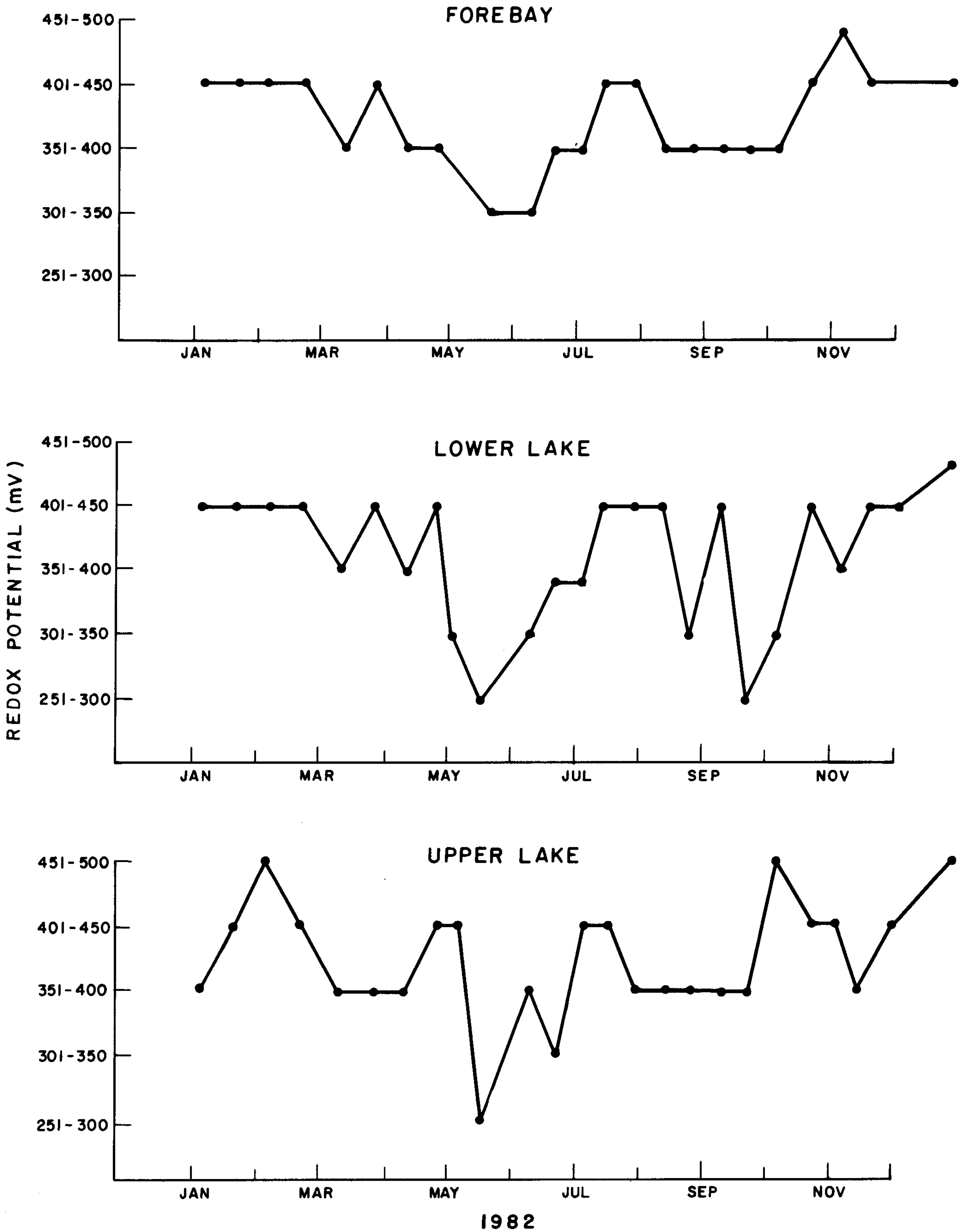
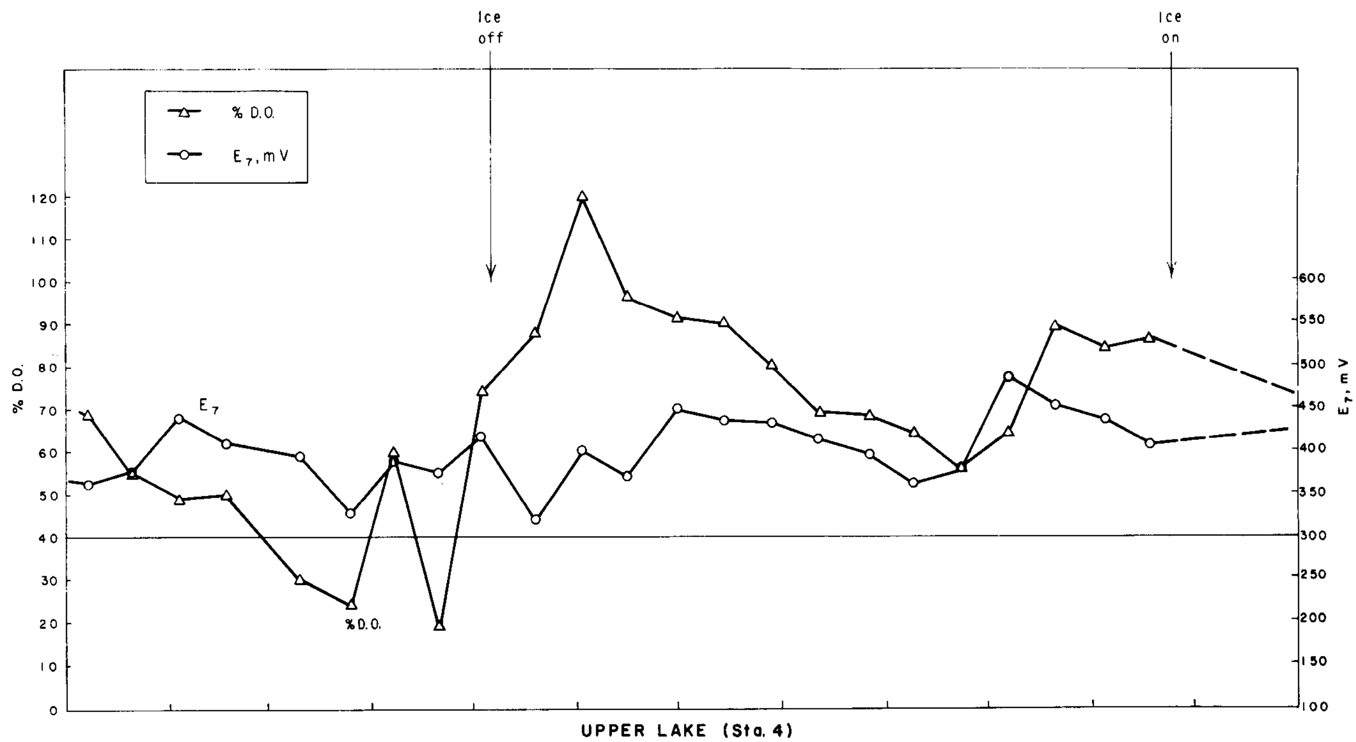


Figure 21. – Oxidation-reduction potential at bottom of Twin Lakes and Mt. Elbert Forebay during 1982.



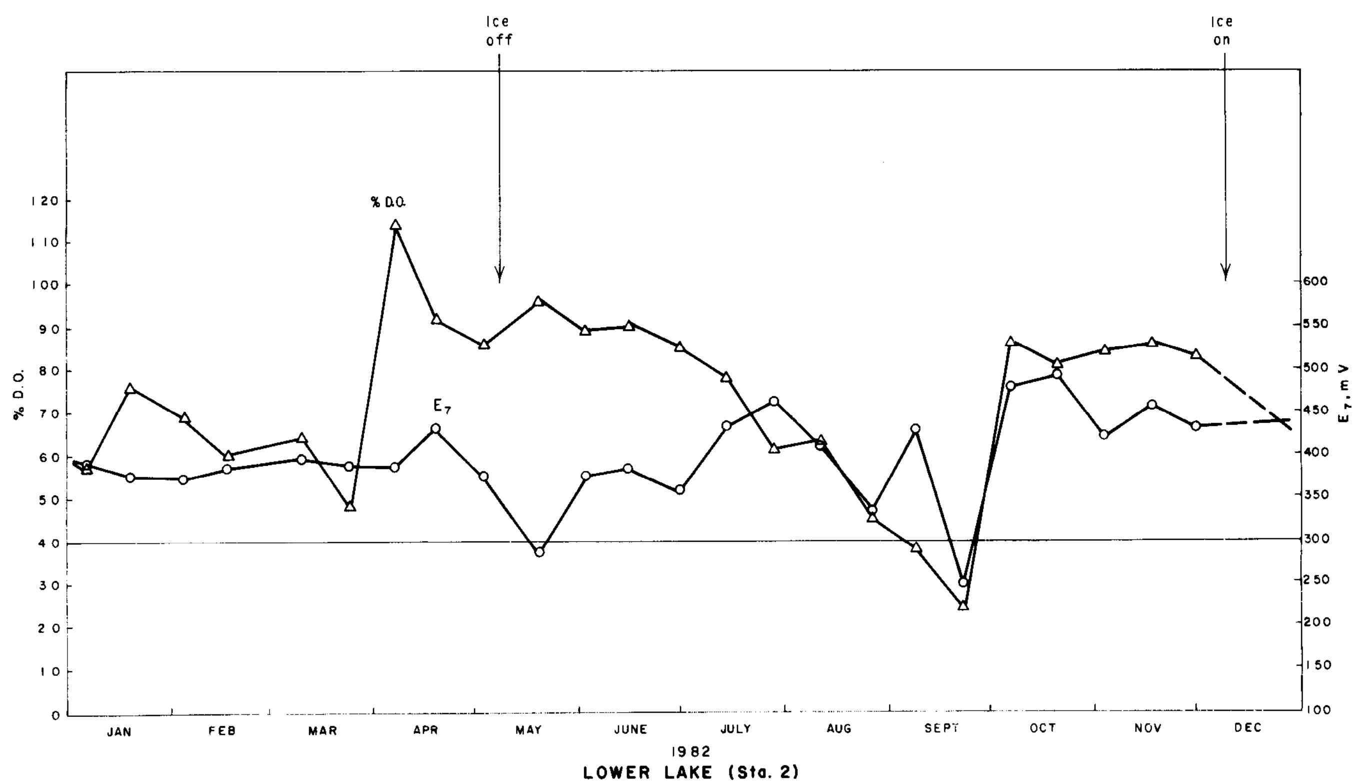


Figure 22. – Dissolved oxygen percent saturation and E_7 values at bottom of upper and lower lakes in 1982.

greater the abundance of nutrients being reduced into their soluble form, the greater the amount of biological production during and following turnover. Second, the greater the abundance of trace metals being reduced into their soluble form, the lesser the amount of biological production due to the very toxic nature of many of the trace metals in soluble form. Fortunately for the ecology of Twin Lakes, and many other bodies of water as well, nutrients are reduced far sooner or at a far higher E_7 than are the toxic elements. The unfortunate thing for Twin Lakes is that there is an abundance of trace metals available in the bottom sediments because the area is in the mineralized belt of Colorado.

The lake water is relatively unbuffered as indicated by the low conductivity values. This means there is little in the water to naturally buffer any undissociated elements or compounds. Thus, if conditions are right (e.g., low dissolved oxygen, low E_7 value), a toxic substance such as copper could remain at lethal concentrations long enough to cause damage to the food chain of the lakes for that season, and perhaps longer if fish are affected.

The percent of dissolved oxygen saturation at the bottom of Twin Lakes was never below 20 percent during the entire year. During most years, the percent was frequently below 10 percent at the bottom of the upper lake in late winter and at the bottom of the lower lake in late summer. The E_7 values fell below the 300-mV level in the lower lake twice in 1982 (May and September), indicating that some iron could have been reduced into a soluble state. However, the E_7 values generally remained high. It should be noted that these values are all for the deep part of each lake where stations 2 and 4 are located. Conditions in localized areas of each lake, such as in the powerplant tailrace area, will vary tremendously, especially considering the relatively low buffering capacity of the water in those areas.

In summary during 1982, the quality of water at the bottom (with the possible exception of the tailrace area) of each lake rendered a healthy environment for aquatic life. This condition is a direct result of the operation of the power plant, which caused aeration of both lakes.

Light Extinction Coefficients

Figure 23 shows light extinction coefficients for 1982 and the average coefficients for 1974-81. The value of the coefficient is inversely proportional to water clarity. Therefore, lower values mean higher clarity, while higher values reflect greater turbidity or less clarity. The general pattern of extinction coefficients for 1982 somewhat resembles the 1974-81 trend except for some glaring perturbations in January, February, April, and November, and an offset in the time of highest coefficients of about 1 month in the upper lake. The latter may reflect a later than normal runoff into the upper lake. The upper lake during August and September was less turbid than normal.

The perturbations, which have not been noted previously, probably resulted from turbidity stirred up by powerplant operation. Extinction values were higher in the lower lake, but not in the upper lake, during the winter of 1981-82 than the 8-year average. Powerplant operation may cause glacial flour from the bottom of the lake to become stirred and distributed through the water column, which is rather weakly stratified at this time. The extinction coefficients were probably high during the first survey on January 6 because the lakes had been ice covered for only about 2 weeks. This meant that mixing due to wind was occurring for at least several weeks before ice formed, so these higher values probably indicate transparency of the water before all settling had occurred. The other peaks in extinction coefficient values are attributed to powerplant operation. There seems to be little or no influence of powerplant operation on extinction coefficient values during summer stratification. This may be due to the stratification itself because extinction coefficients are a measure of the percent of light entering from the surface. Thus, the turbulence may be more restricted to the hypolimnion during the summer months.

Data on figure 23, besides showing differences from season to season, also show that clarity of the upper lake is much less than that of the lower lake during the time of greatest runoff. The upper lake acts as a silt and debris settling basin for the Lake Creek inflow. During years of high runoff, such as 1982, this influence is more pronounced. The ultimate effect of normal or above-normal runoff on the upper lake is twofold. First, the lake remains turbid longer, and, second, the lake is greatly flushed. Both factors cause the upper lake to be relatively less biologically productive, especially during June and July.

Transmissivity

Figure 24 includes profiles of light transmittance for the upper and lower lakes for 23 sampling dates during 1982. Transmissivity is a measure of the water clarity at a given depth, and is expressed as the percentage of transmitted light received by a photo cell at the opposite end of a 0.5-m horizontal frame from a conventional light source. Analysis of data on figure 24 reveals many significant qualities of the lakes at the time of each survey. During the winter under the ice, transmissivity frequently is greatest in the mid to lower depth range and is lowest near and at the bottom. This generalization, although true for the upper lake through March, did not apply to the lower lake as turbulence from powerplant operation disrupted the integrity of the weak stratification, and

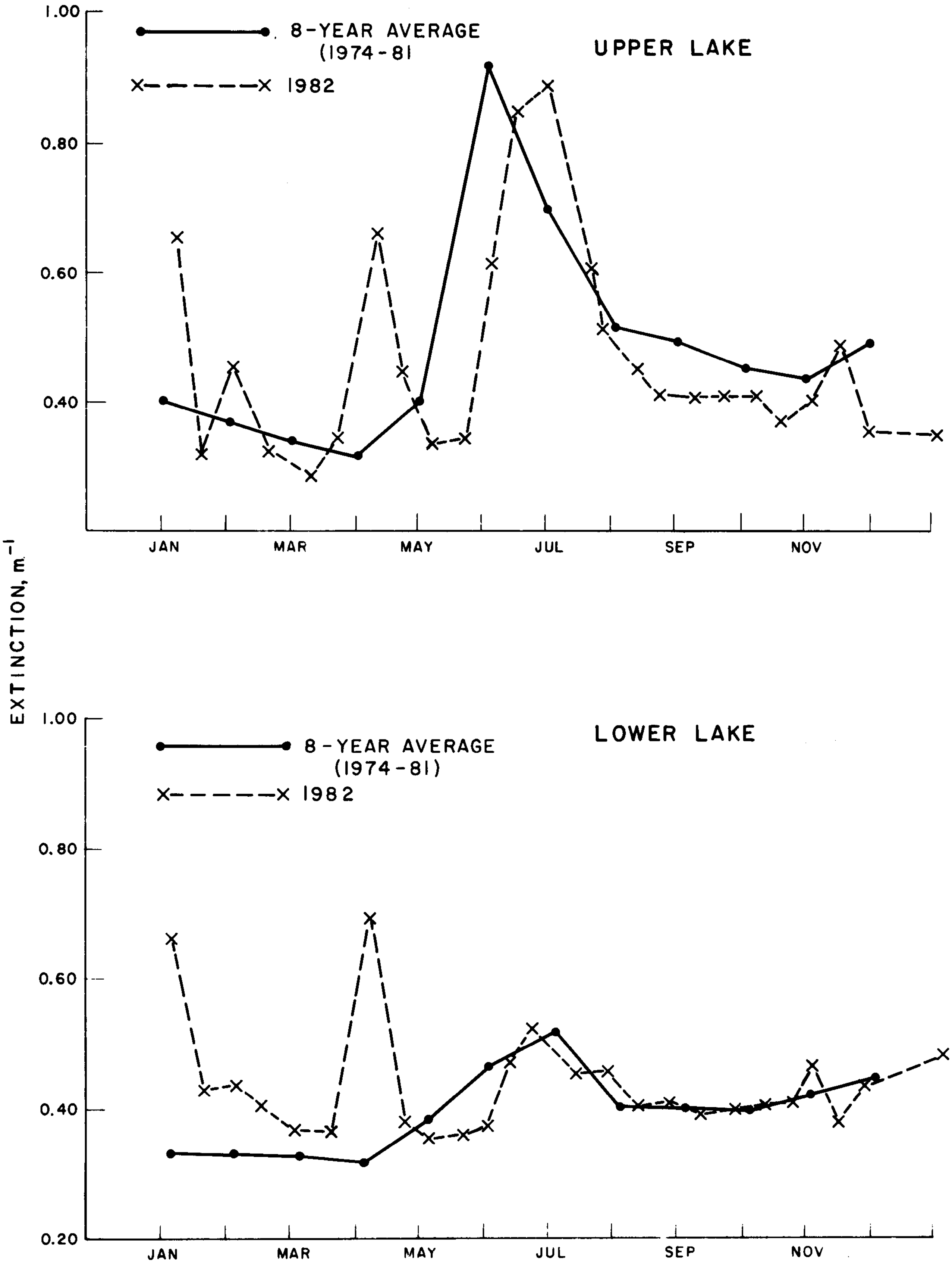


Figure 23. – Light extinction coefficients for Twin Lakes during 1982.

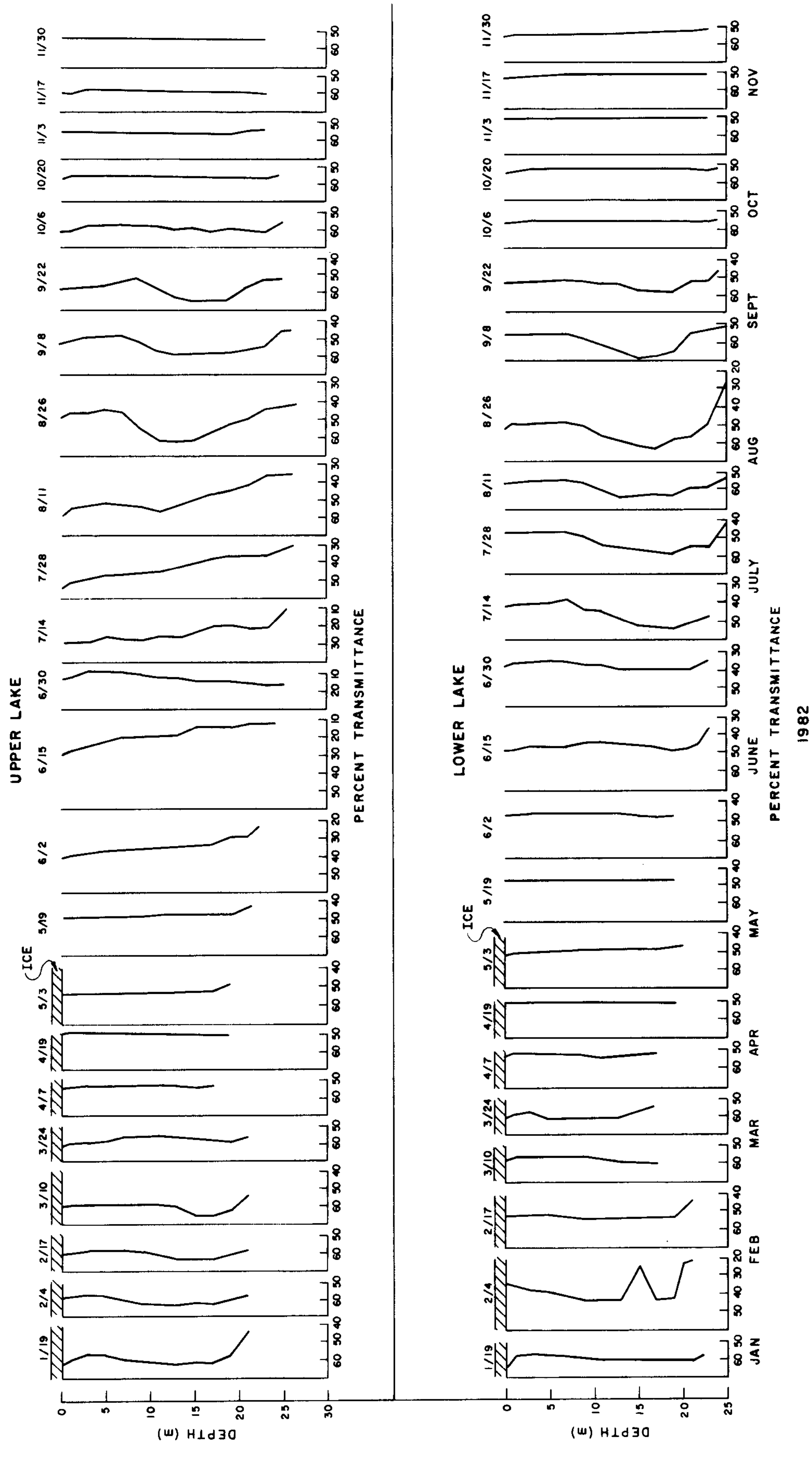


Figure 24. – Light transmittance profiles for Twin Lakes during 1982.

resulted in an overall decreased clarity of the water. Following ice off (early May) and throughout June to mid-July, transmissivity was influenced by heavy runoff, especially in the upper lake. Clarity of the upper lake at station 4 decreased with depth during June and July due to sediment brought in by the plunging inflow. Transmissivity in the lower lake was not affected to the same extent as that in the upper lake; however, during peak runoff periods the finer particles of sediment and debris do not settle out completely in the upper lake, resulting in a reduction in the clarity of the lower lake at this time. During July, August, and September, the transmissivity profiles reflect the influence of thermal stratification. Clarity of water in the epilimnion is decreased due to phytoplankton and zooplankton, and may be at its lowest at the thermocline because of the abundance of plankton populations concentrated at this level. Clarity of water in the upper portion of the hypolimnion increased due to the lack of biota, while at the bottom, clarity is low due to both the plunging inflow (colder sediment-laden water) in the upper lake and the presence of resuspended material from the bottom.

Fall turnover occurred around October 6, and resulted in water clarity being constant thereafter from surface to bottom. Influence of powerplant operation on the integrity of the profiles during the summer stratification period is not apparent.

Figure 25 shows average transmissivity data from the upper and lower lakes during 1981 and 1982. The transmissometer was first used successfully in 1981, which is why no long-term averages for these data exist. The powerplant began operation in September 1981. Plotted data on figure 25 for the last 3 or 4 months of 1981 and 1982 are very similar. Average percent transmissivity from January to September differs radically in 1982 from that in the same period of 1981. However, during this period in 1981, the powerplant was not operating, while in 1982 it was. Runoff from Lake Creek, which is very turbid when at its peak, was far greater in 1982. This accounts for the vast difference in transmissivity in June and July, especially in the upper lake which receives the Lake Creek inflow. However, the differences that prevailed between transmissivity data during the January to May periods in 1981 and 1982 cannot be attributed to any factor of the lake's ecology other than operation of the powerplant. There was an average 17 percent decrease in percent transmissivity of both lakes from January through May 1982. Average transmissivity of the upper and lower lakes from January through May 1981 were 71 and 68 percent, respectively, while in 1982 they were 51 and 54 percent, respectively. This comparison eliminates the influence of peak runoff. Therefore, it appears as if powerplant operation has caused an overall decrease in transmissivity (water clarity) in both lakes by an average of 17 percent.

Water Chemistry

Tables 8 through 12 list results of chemical analyses of water samples collected from the Lake Creek inflow, Twin Lakes outflow, upper and lower lakes, and Mt. Elbert Forebay. Sartoris, et al., (1977) [25], discuss in detail the water chemistry of Twin Lakes for 1971-76. Annual reports since 1976 [15, 18, 19] update the water quality data from Twin Lakes. The generalizations made here apply to data collected in 1982. That is, in general, the quality of water in Twin Lakes resembles that of other Colorado montane lakes. The water is extremely soft and can be characterized as being dominated by calcium bicarbonate and/or calcium sulfate water with decidedly low phosphorus concentrations. The TDS (total dissolved solids) concentration or the concentration of any specific anion or cation is strongly influenced by the volume of runoff. Generally, the greater the inflow, the less the TDS. Also, TDS decreases going downstream. Maximum TDS values, shown in tables 8 through 12, are in the Lake Creek inflow, with the upper lake having the next highest values. Water entering Twin Lakes from Turquoise Reservoir by way of Mt. Elbert Conduit and Mt. Elbert Forebay is even lower in TDS and specific anions and cations. The lower lake receives this imported water directly, so the natural TDS of the lower lake is further diluted, resulting in even softer or purer water than would otherwise be found there. Although this would seem to be a positive effect, there are some detrimental aspects. Since the water is now purer, it is less capable of "scrubbing" (precipitating) the more biologically harmful impurities. That is, the lack of attachment sites for copper, cadmium, zinc, etc., allows them to remain in the more toxic ionic form for a longer period of time. A concentration of 120 mg/L has been estimated by Cole, 1979 [35], as the average TDS for the world's rivers. The TDS of the lower lake is almost always at least half this value, while the TDS of the forebay is sometimes only one-sixth of that average. Therefore, the lower lake and the forebay have from one-half to one-sixth the ability of the world's average freshwater to scrub out harmful impurities. As more water enters Twin Lakes from the forebay, this ability decreases. Therefore, problems of metal toxicity will continue to be a threat at Twin Lakes.

Analyses were done for the following heavy metals in water collected in and around Twin Lakes: zinc, copper, iron, manganese, lead, and cadmium. Figures 26 through 32 present results of these analyses. Discussions of the annual cycle of these metals prior to 1982 are found in Sartoris (1977) [25]; LaBounty, et al., (1980) [19]; LaBounty and Sartoris (1981) [15]; and LaBounty and Sartoris (1983) [18]. The Lake

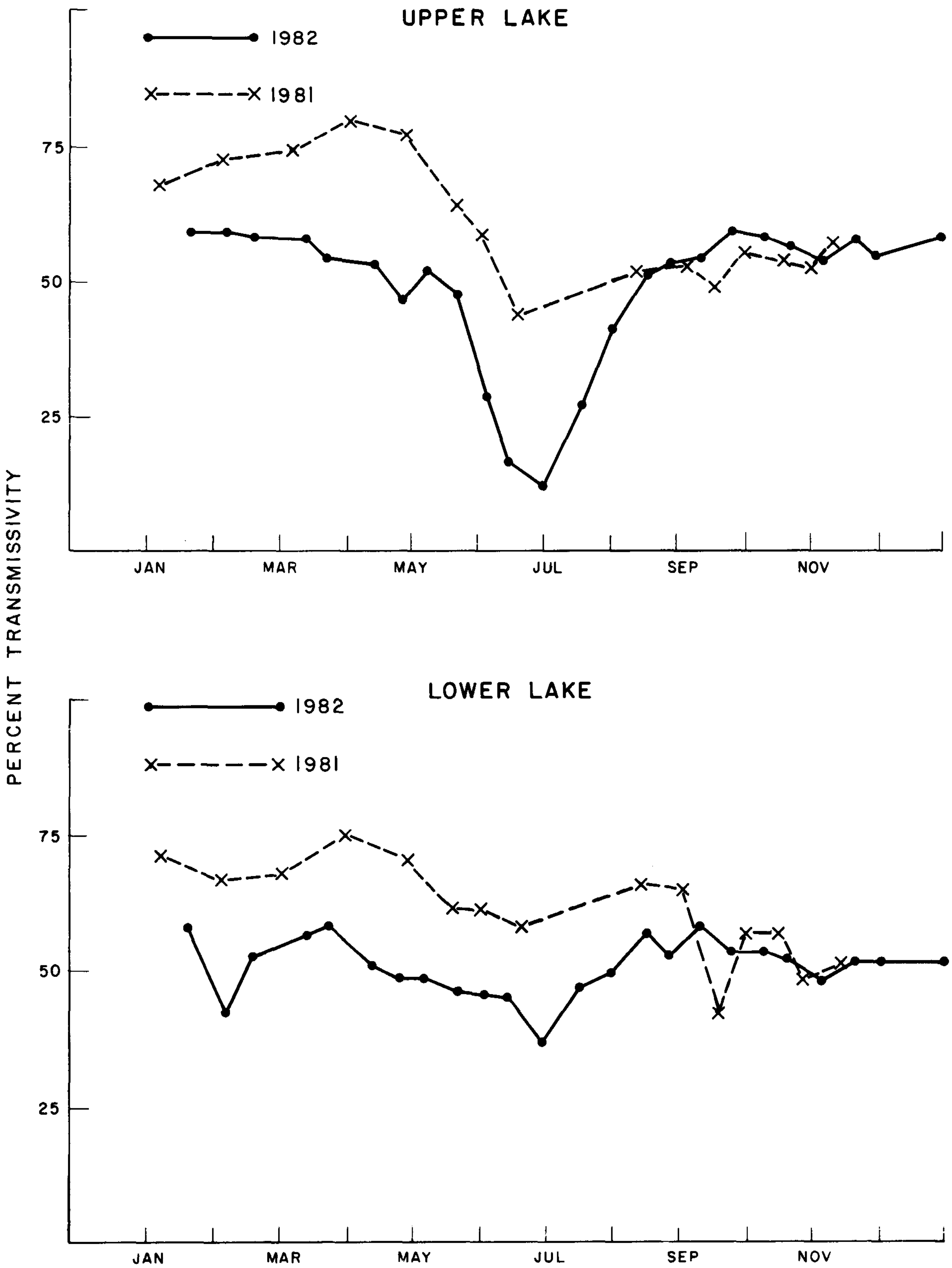


Figure 25. – Average percent of light transmittance at Twin Lakes, 1981-82.

Table 8. – Results of water chemistry analyses on Lake Creek inflow during 1982.

	1982			
	Jan. 8	May 5	July 30	Oct. 22
Conductivity, µS/cm	118	73	54	86
TDS	92	70	54	80
Calcium	20.8	12.8	9.6	12.8
Magensium	0.98	1.95	0.98	2.93
Sodium	2.76	2.07	1.84	2.30
Potassium	1.17	0.78	0.78	0.78
Carbonate	0	0	0	0
Bicarbonate	27.5	28.1	18.9	28.1
Sulfate	33.1	20.6	13.0	20.6
Chloride	2.84	0.71	2.84	2.84
Total phosphorus	0.007	0.005	<0.001	<0.001
Orthophosphorus	<0.001	<0.001	<0.001	<0.001
Ammonia – N	0.006	<0.001	0.006	<0.001
Nitrate – N	0.138	0.020	0.035	0.083

Note: All values in mg/L except as noted for conductivity.

Creek inflow carries large concentrations of metals which are generally precipitated and settle to the lake bottoms. Therefore, the bottoms of the lakes contain large accumulations of heavy metals. Results of analyses for metals at various depths within the sediments are presented by Bergersen (1976) [1]. During periods of maximum stratification, both summer and winter, the concentrations of heavy metals are quite high in the water at and near the lake bottom, due to benthic processes. Concentrations of lead in Twin Lakes and Lake Creek (fig. 26) were always less than 2 µg/L, showed no annual cycle, occurred at random, and were highest in the Twin Lakes outflow. Conversely, iron did display some annual cycle (fig. 27), occurred in greatest concentrations in the inflow, and decreased going downstream. Iron concentrations in the inflow exceeded 800 µg/L in April and again in May, while in the lower lake they barely exceeded 100 µg/L in July. Iron concentrations in the outflow exceeded 200 µg/L on several occasions, which may reflect some flushing in the outfall. Copper concentrations during 1982 (fig. 28) were greatest in the Lake Creek inflow, and lowest in the lower lake. There were detectable amounts during 1982 in Twin Lakes of greater than 4 µg/L from early June on in the upper lake (with one exception) and only in July in the lower lake. Concentrations in the inflow were least when volume of flow was greatest (June). Concentrations of copper in the outflow water reflected those of the lower lake. Manganese concentrations during 1982 (fig. 29) were greatest in the upper lake during late winter and lowest in the inflow during the peak runoff period. Zinc concentrations during 1982 (fig. 30) were not found in detectable (>1 µg/L) amounts in either the upper or lower lakes and only once in the outflow. Detectable concentrations in the Lake Creek inflow were found 5 out of 23 times during 1982, exceeding 25 µg/L only in April. Cadmium concentrations during 1982 (fig. 31) were greater than 0.02 µg/L most often in the Lake Creek inflow. However, the two greatest concentrations (1.85 and 0.5 µg/L) were found during early June in the upper and lower lakes, respectively.

Concentrations of the six aforementioned heavy metals in Mt. Elbert Forebay are plotted on figure 32. The general trend was increased concentrations of copper, zinc, cadmium and lead, and decreased concentrations of iron and manganese after May. Some of the concentrations of heavy metals detected in samples of water from the forebay were unexplainably high, a fact that could be biologically important in this poorly buffered water. That is, some of the heavy metals may have at times exceeded lethal levels for some biota. Of major concern are cadmium, which is known to be toxic at relatively low concentrations and is also known to act synergistically with other metals: lead, which causes formation of mucus over fish gills and results in smothering; copper, which is found to stop diatom growth at 5 µg/L; and zinc, which is known to be harmful to aquatic life in soft water at concentrations above 50 µg/L. The recommended upper limits for aquatic life were exceeded for the most part by copper and lead. Perhaps of greatest concern is cadmium; the recommended upper limit for this metal is 0.4 µg/L. Cadmium concentrations of 1.85 and 0.50 µg/L were found in samples collected on June 2, 1982, in the middle of the upper and lower lakes, respectively. Concentrations in the inflow samples at this time did not indicate Lake Creek as the source of this cadmium, although there was a large concentration (0.4 µg/L)

Table 9. – Results of water chemistry analyses on upper lake during 1982.

	January 8, 1982			May 3, 1982			July 30, 1982			October 20, 1982		
	Surface	Middle	Bottom	Surface	Middle	Bottom	Surface	Middle	Bottom	Surface	Middle	Bottom
Conductivity (μS/cm)	69	76	75	75	79	81	52	54	52	70	72	72
TDS	56	74	52	66	76	70	40	26	32	62	70	70
Calcium	11.2	12.8	12.8	11.2	12.8	14.4	8.0	9.6	8.0	8.0	10.4	10.4
Magnesium	1.95	1.46	0.49	2.44	1.95	0.98	1.95	0.98	1.95	1.95	0.98	1.46
Sodium	1.15	1.38	2.07	1.61	2.76	3.22	1.38	1.38	0.92	2.07	2.30	2.99
Potassium	0.78	0.78	0.78	1.17	1.17	1.17	0.78	0.78	0.78	0.78	0.78	0.78
Carbonate	0	0	0	0	0	0	0	0	0	0	0	0
Bicarbonate	23.2	24.4	25.0	25.6	25.0	27.5	20.7	20.7	19.5	21.3	24.4	23.2
Sulfate	14.9	18.7	17.3	17.3	22.6	20.6	10.1	14.4	13.9	11.0	13.4	17.8
Chloride	2.13	0.71	0.71	3.55	0.71	1.42	0.71	0.71	0.71	2.84	0.71	0.71
Total phosphorus	0.003	0.004	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Orthophosphorus	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Ammonia – N	0.009	0.011	0.019	<0.001	<0.001	<0.001	0.010	0.008	0.015	<0.001	<0.001	<0.001
Nitrate – N	0.038	0.038	0.042	0.060	0.090	0.010	0.032	0.038	0.056	0.048	0.048	0.048

Note: All values in mg/L except as noted for conductivity

Table 10. – Results of water chemistry analyses on lower lake during 1982.

	January 6, 1982			May 3, 1982			July 27, 1982			October 20, 1982		
	Surface	Middle	Bottom	Surface	Middle	Bottom	Surface	Middle	Bottom	Surface	Middle	Bottom
Conductivity (μS/cm)	62	60	72	54	54	58	47	50	57	57	55	57
TDS	56	52	60	50	42	56	36	42	36	56	52	50
Calcium	3.2	9.6	9.6	9.6	8.0	9.6	8.0	9.6	8.0	9.6	9.6	8.0
Magnesium	4.88	1.95	1.95	0.49	2.93	0.98	0.98	0.98	0.96	0.98	0.98	1.95
Sodium	2.99	1.84	0.92	2.07	1.84	1.84	1.38	1.38	1.15	2.53	1.84	2.07
Potassium	1.95	0.78	0.78	0.78	1.17	0.78	0.78	0.78	0.78	0.78	0.78	0.78
Carbonate	0	0	0	0	0	0	0	0	0	0	0	0
Bicarbonate	23.8	20.7	22.0	19.5	22.0	20.7	20.7	20.7	17.1	22.0	20.7	21.3
Sulfate	15.4	16.8	16.8	12.5	14.4	15.4	10.1	14.4	15.4	13.4	13.4	11.0
Chloride	0.71	0.71	0.71	2.13	2.13	0.71	0.71	0.71	1.42	0.71	1.42	2.84
Total phosphorus	0.004	0.021	0.006	0.005	<0.001	<0.001	0.003	0.002	0.001	<0.001	<0.001	<0.001
Orthophosphorus	0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Ammonia – N	0.007	0.011	0.016	<0.001	<0.001	<0.001	0.017	0.019	0.035	<0.001	<0.001	<0.001
Nitrate – N	<0.001	<0.001	0.004	0.020	0.021	0.068	0.010	0.015	0.041	0.010	0.010	0.010

Note: All values in mg/L except as noted for conductivity.

Table 11. – Results of water chemistry analyses on Twin Lakes outflow during 1982.

	1982			
	Jan. 8	May 5	July 30	Oct. 22
Conductivity (μS/cm)	59	50	54	59
TDS	56	28	22	58
Calcium	11.20	8.00	8.00	8.80
Magnesium	1.46	1.95	1.95	2.44
Sodium	0.92	2.53	1.15	2.07
Potassium	0.78	1.17	0.78	0.78
Carbonate	0	0	0	0
Bicarbonate	22.0	18.9	19.5	23.2
Sulfate	16.3	18.2	12.0	15.8
Chloride	2.13	0.71	2.84	2.13
Total phosphorus	0.002	<0.001	<0.001	<0.001
Orthophophorus	<0.001	<0.001	<0.001	<0.001
Ammonia – N	0.009	<0.001	0.008	<0.001
Nitrate – N	<0.001	0.090	0.009	0.010

Note: All values in mg/L except as noted for conductivity.

Table 12. – Results of water chemistry analyses on Mt. Elbert Forebay during 1982.

	1982			
	Jan. 7	May 5	July 30	Oct. 22
Conductivity (μS/cm)	38	30	39	41
TDS	24	30	38	34
Calcium	6.40	4.80	4.80	6.40
Magnesium	1.46	1.83	1.95	1.46
Sodium	1.38	1.61	1.61	1.84
Potassium	0.78	0.78	0.78	0.78
Carbonate	0	0	0	0
Bicarbonate	15.9	13.4	19.5	17.1
Sulfate	8.64	9.60	4.80	8.16
Chloride	2.13	2.13	2.13	2.13
Total phosphorus	0.002	<0.001	<0.001	<0.001
Orthophosphorus	<0.001	<0.001	<0.001	<0.001
Ammonia – N	0.012	<0.001	0.034	<0.001
Nitrate – N	0.010	<0.001	0.042	<0.001

Note: All values in mg/L except as noted for conductivity.

in the stream in late April. The powerplant had been operating fairly regularly (11 of 17 days) in the generation mode since mid-May, and concentrations of cadmium found in samples collected from the forebay provide evidence that powerplant inflow was the source of cadmium input. More evidence includes two notable fish kills around this same time. The first kill, on May 15, 1982, consisted of 45 dead fish floating in the powerplant tailrace; and the second, on June 17, 1982, produced 3 dead rainbow trout in the same location. The fish were not physically damaged, and had to have died of some toxic substance, which suspiciously seems to be cadmium. As noted earlier, the water coming from the forebay, and ultimately from Turquoise Reservoir, has up to one-sixth the buffering capacity of average freshwater. Therefore, this water is more than six times less capable of precipitating metals such as cadmium than average freshwater.

In summary, metal concentrations in the forebay are higher on the average than those in Twin Lakes and Lake Creek. The source of these metals is presently unknown. This is of high concern because water in the forebay is extremely low in TDS and thus relatively unbuffered. This means that some harm to

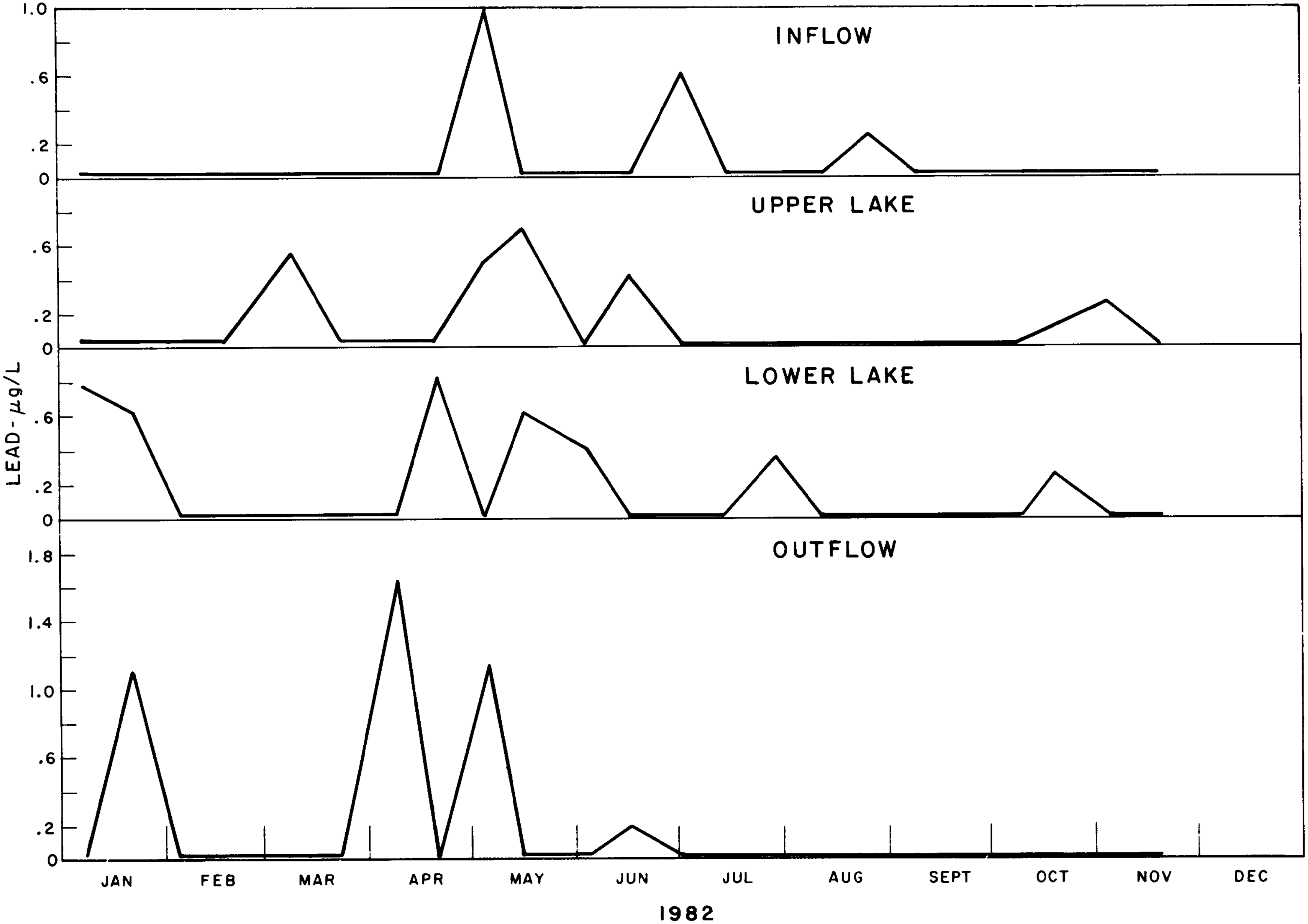


Figure 26. – Lead concentration in Twin Lakes and Lake Creek during 1982.

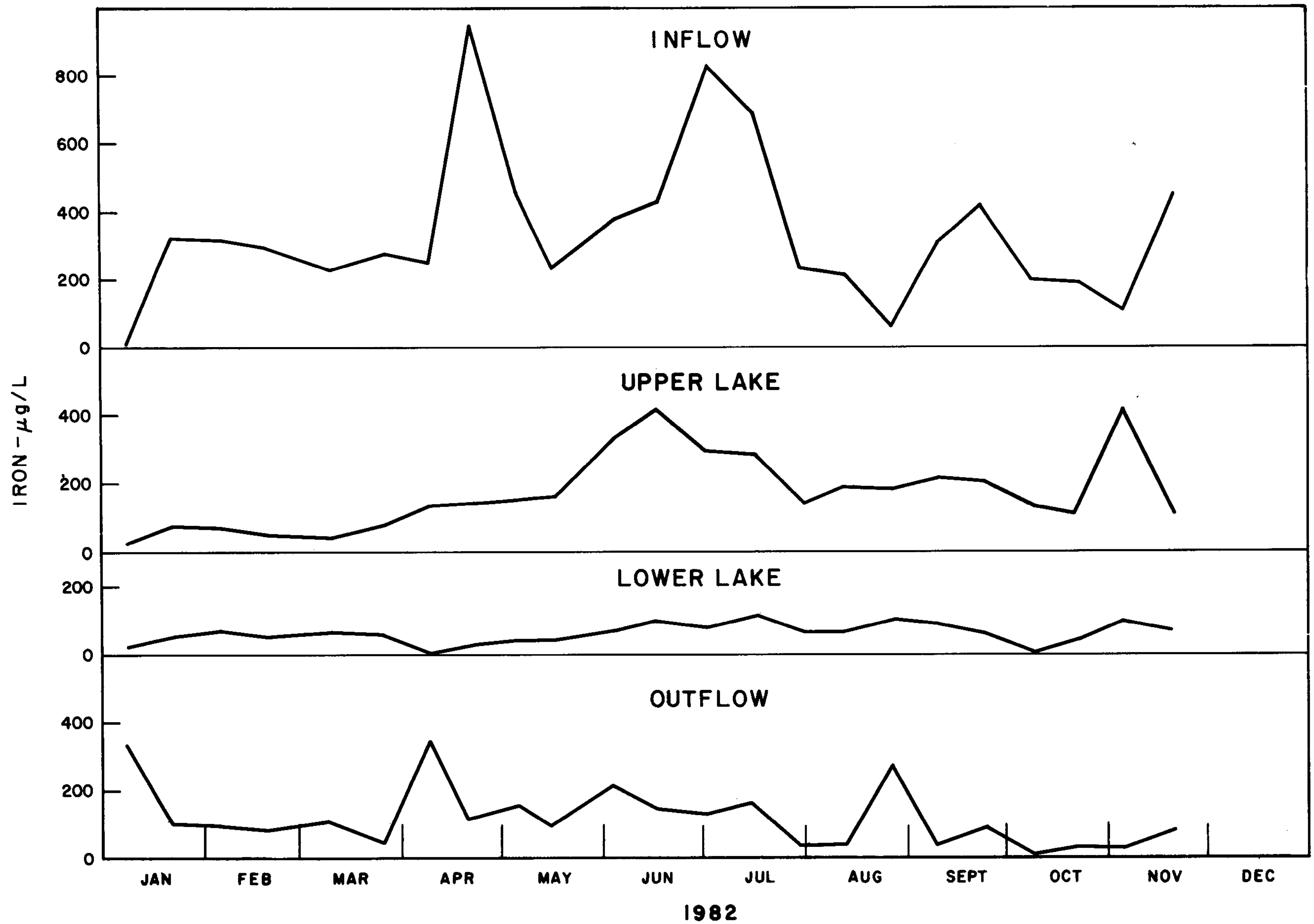


Figure 27. – Iron concentration in Twin Lakes and Lake Creek during 1982.

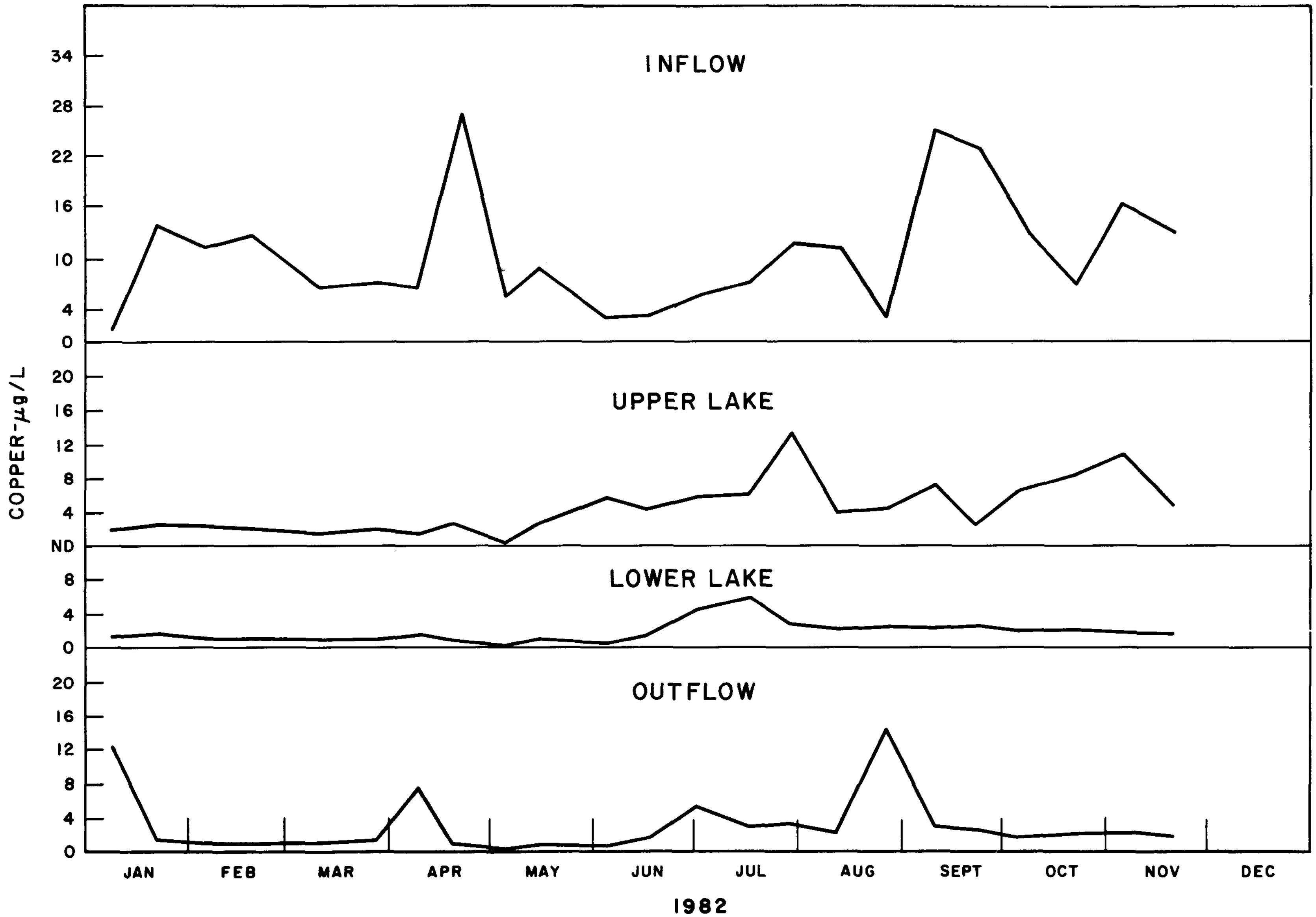


Figure 28. – Copper concentration in Twin Lakes and Lake Creek during 1982.

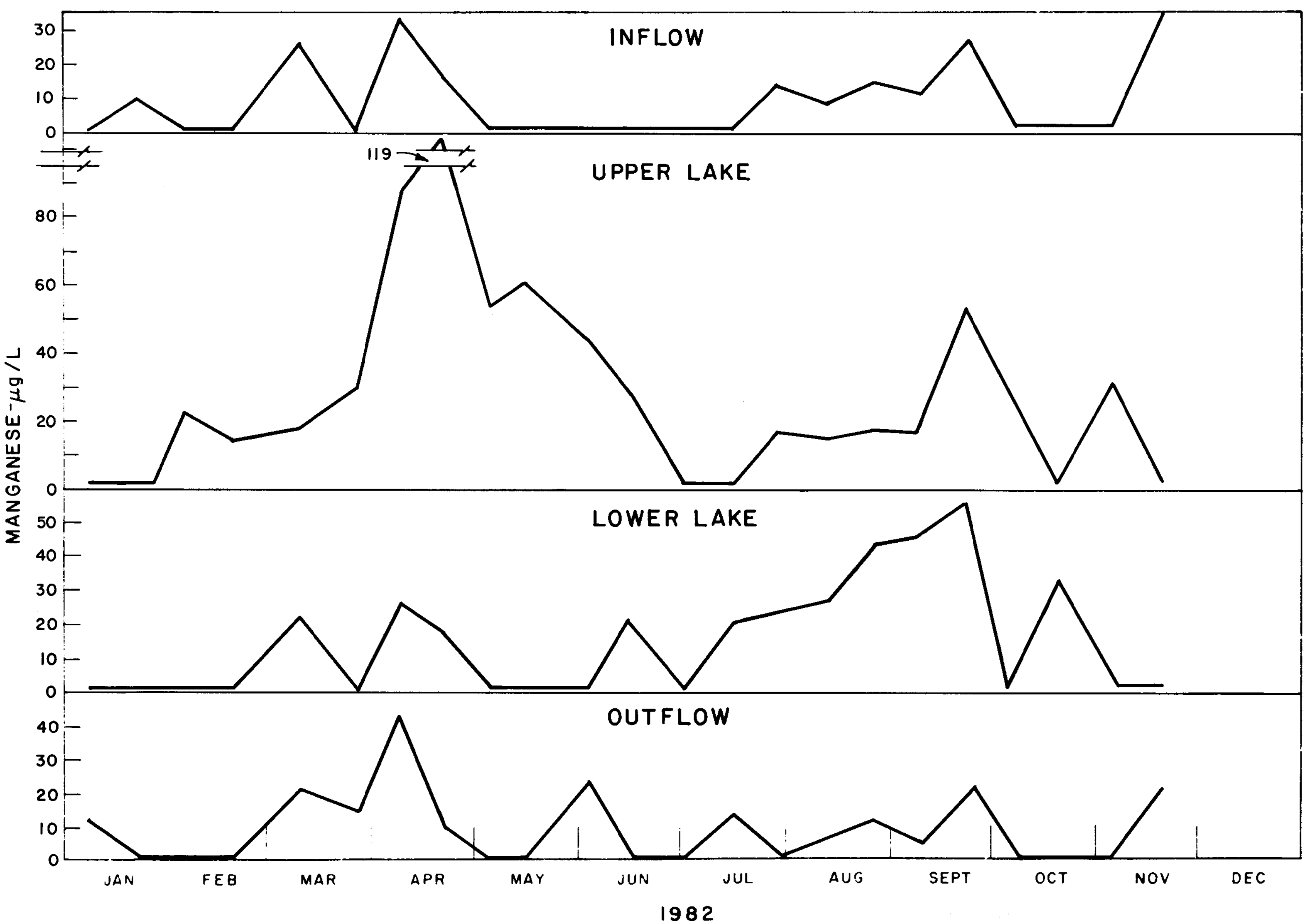


Figure 29. – Manganese concentration in Twin Lakes and Lake Creek during 1982.

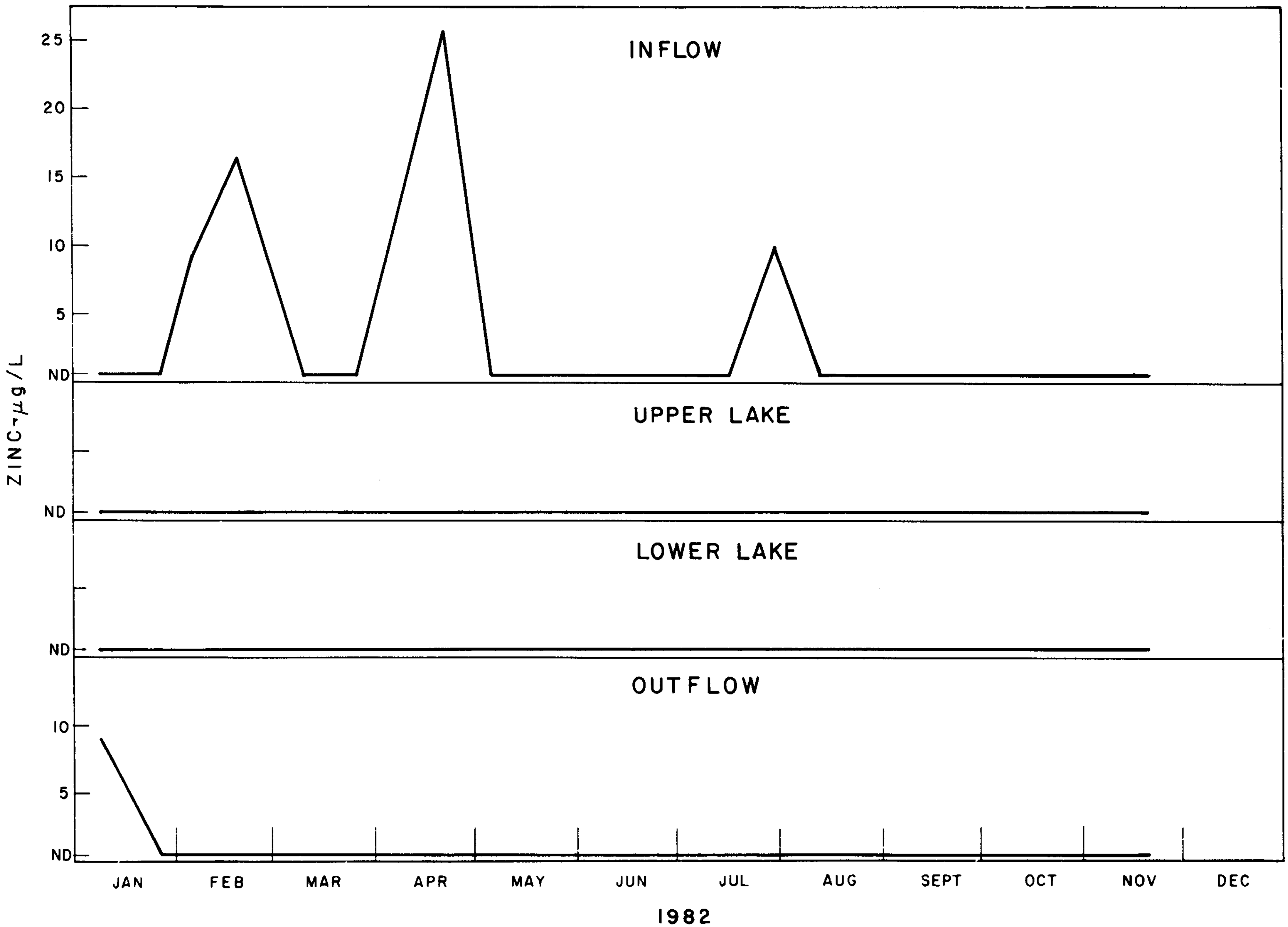


Figure 30. – Zinc concentration in Twin Lakes and Lake Creek during 1982.

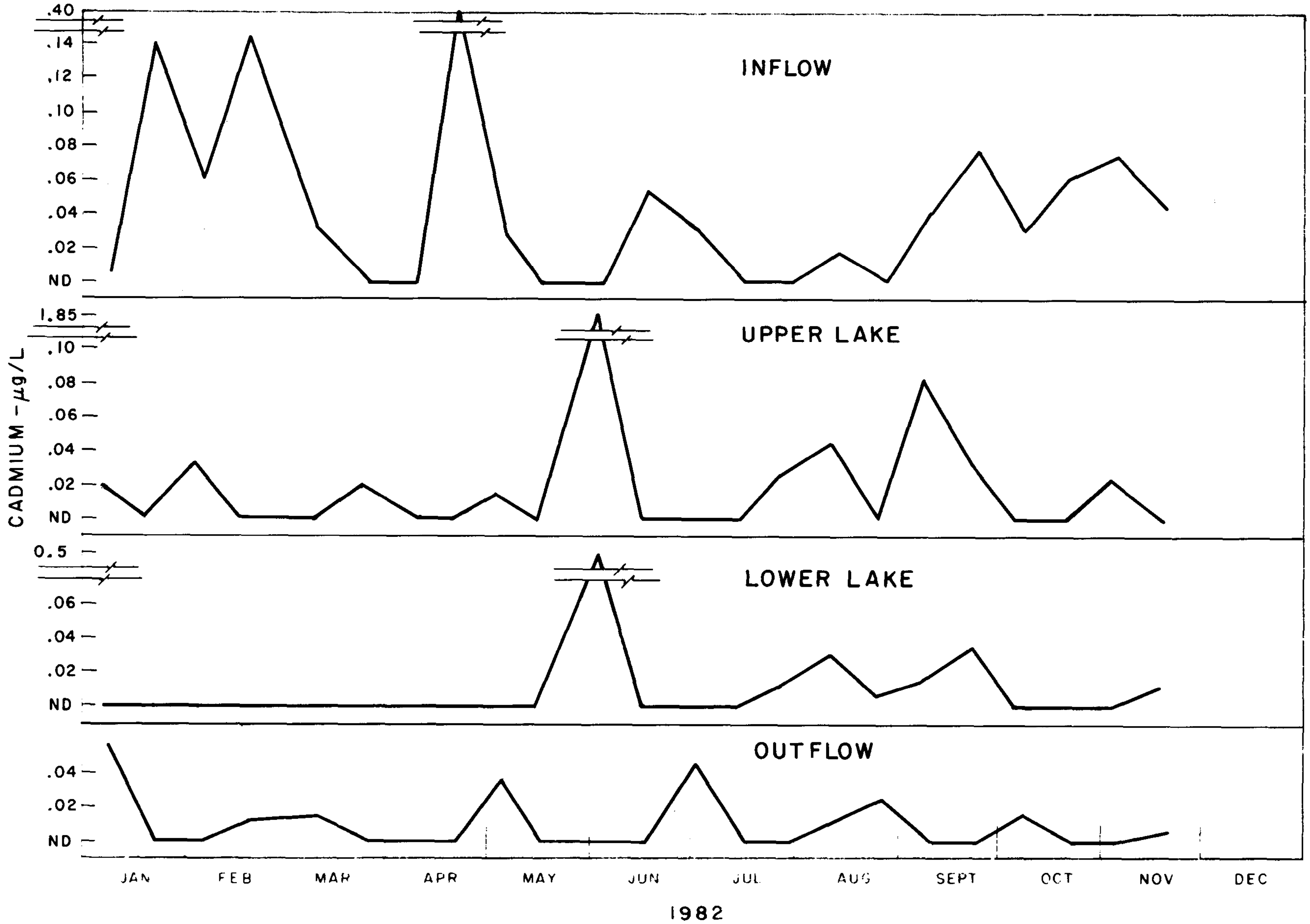


Figure 31. – Cadmium concentration in Twin Lakes and Lake Creek during 1982.

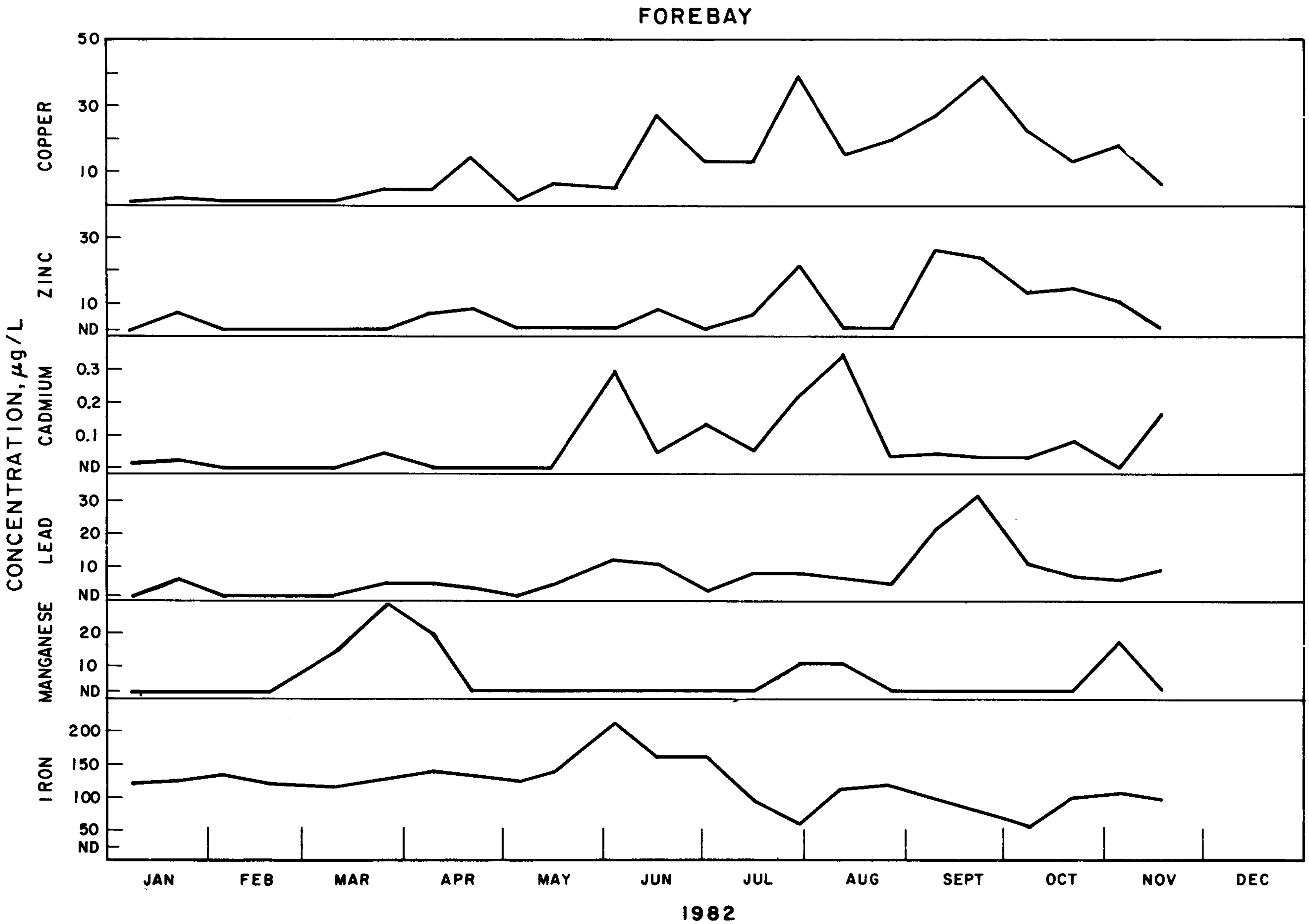


Figure 32. – Heavy metals concentrations in Mt. Elbert Forebay during 1982.

aquatic life in the forebay and certainly in the lower lake, as evidenced by the fish kills, results from this transfer of water. When and how these ecological conditions will stabilize is still unknown.

P-N Nutrients

Figures 33, 34, and 35 are plots of the phosphorus and nitrogen nutrient data collected at Twin Lakes during 1982. The arrangement of data on the graphs is upstream to downstream, top to bottom, and chronological, January through December, from left to right. Figure 36 includes histograms of average concentrations of nitrogen and phosphorus nutrients in samples collected from Twin Lakes, the Lake Creek inflow, and the outflow in 1982. Phosphorus continues to be limiting to biological productivity at Twin Lakes.

Orthophosphate phosphorus was only detectable (>1 μg/L) in 8 of 66 samples collected from the lower lake during 1982. All of the detectable samples were collected during the first half of the year. In three of the samples, concentration of the orthophosphate phosphorus was 2 μg/L, in the other five it was 1 μg/L. In 1982, no orthophosphate phosphorus was detected in the 66 samples collected from the upper lake or in the 44 samples from the outflow and inflow. Since orthophosphate phosphorus was detected so infrequently, plots of its concentration with time were not done.

Concentrations of total phosphorus in samples collected during 1982 from Twin Lakes, the Lake Creek inflow, and the outflow are plotted on figure 33. There is no apparent seasonal trend in these data; although higher concentrations were found in the lower lake during the first half of the year. For most of the sampling dates, total phosphorus was not found in detectable (>1 μg/L) concentrations in samples collected from the inflow or outflow. However, it was detected in 68 percent of the samples collected from the lower lake. Of interest is that total phosphorus was found in detectable concentrations on more than twice as many sampling dates in the lower lake (15) as in either the upper lake (7) or the Lake Creek inflow (7), and it was detected only 4 times in samples collected from the outflow. The average concentration of total phosphorus in 68 water samples from the upper and lower lakes during 1982 was 1.2 and 2.3 μg/L, respectively (fig. 36). The 25 samples collected from the Lake Creek inflow and the outflow contained, on the average, 1.9 and 0.8 μg/L total phosphorus, respectively (fig. 36). Lakes with total phosphorus concentrations below 5 μg/L are classified oligotrophic (Likens, 1975) [36]. Twin Lakes are phosphorus-poor, and this is reflected by the fact that the biota respond dramatically to any input of phosphorus at anytime of the year, see LaBounty, et al., 1980 [19] and LaBounty and Sartoris, 1981 [15].

Analysis for TKN (total Kjeldahl nitrogen) was performed on very few samples in 1982. However, even these limited data lead to the same conclusions as did previous years' data. That is, concentrations of TKN are greater in Twin Lakes than in the inflow and outflow, and average concentrations are similar from year to year.

Data plotted on figures 34 and 36 show that nitrate concentrations in the inflow were greatest and declined progressively downstream. This indicates that this inorganic nitrogen source, which is readily used in primary production, becomes tied up in biomass and is reflected in the TKN fraction. Note that where the concentrations of TKN were greatest (lower lake), the concentration of nitrate nitrogen was lowest, and where concentrations of TKN were lowest (inflow), the concentration of nitrate was highest. The final fate of this nitrogen in Twin Lakes is uptake of the nutrient by the fish. They may be caught and removed from the lake, or they may die and, along with much of the other biota, end up in the sediments. This same kind of transformation of various components of the nitrogen budget is described by Ashton (1981) [37] for an impoundment in South Africa.

The ammonia nitrogen component of the nitrogen budget of Twin Lakes is shown on figures 35 and 36. Concentrations of this component were greater in the lakes than in the inflow or outflow, and highest in the lower lake. Concentrations of ammonia were also greatest where and when the concentrations of biota were greatest; which seems reasonable because most ammonia nitrogen comes from the decomposition of organic matter and from excretion. The average concentrations shown on figure 36 are similar to those found during other years at Twin Lakes.

In summary, as with phosphorus, concentrations of nitrogen in water samples collected from Twin Lakes are generally low (<250μg/L), which place the lakes in the oligotrophic, or poorly productive, category (Likens, 1975) [36]. However, nitrogen is generally more abundant than phosphorus and does not seem to be the limiting nutrient that phosphorus is. Overall, there is much that is unknown about the chemistry of Twin Lakes. What is known is that because the waters are low in TDS and thus poorly buffered, elements and compounds are easily whisked around from one form to another. The entire ecology of these lakes is quite fragile and very responsive to these chemical reactions.

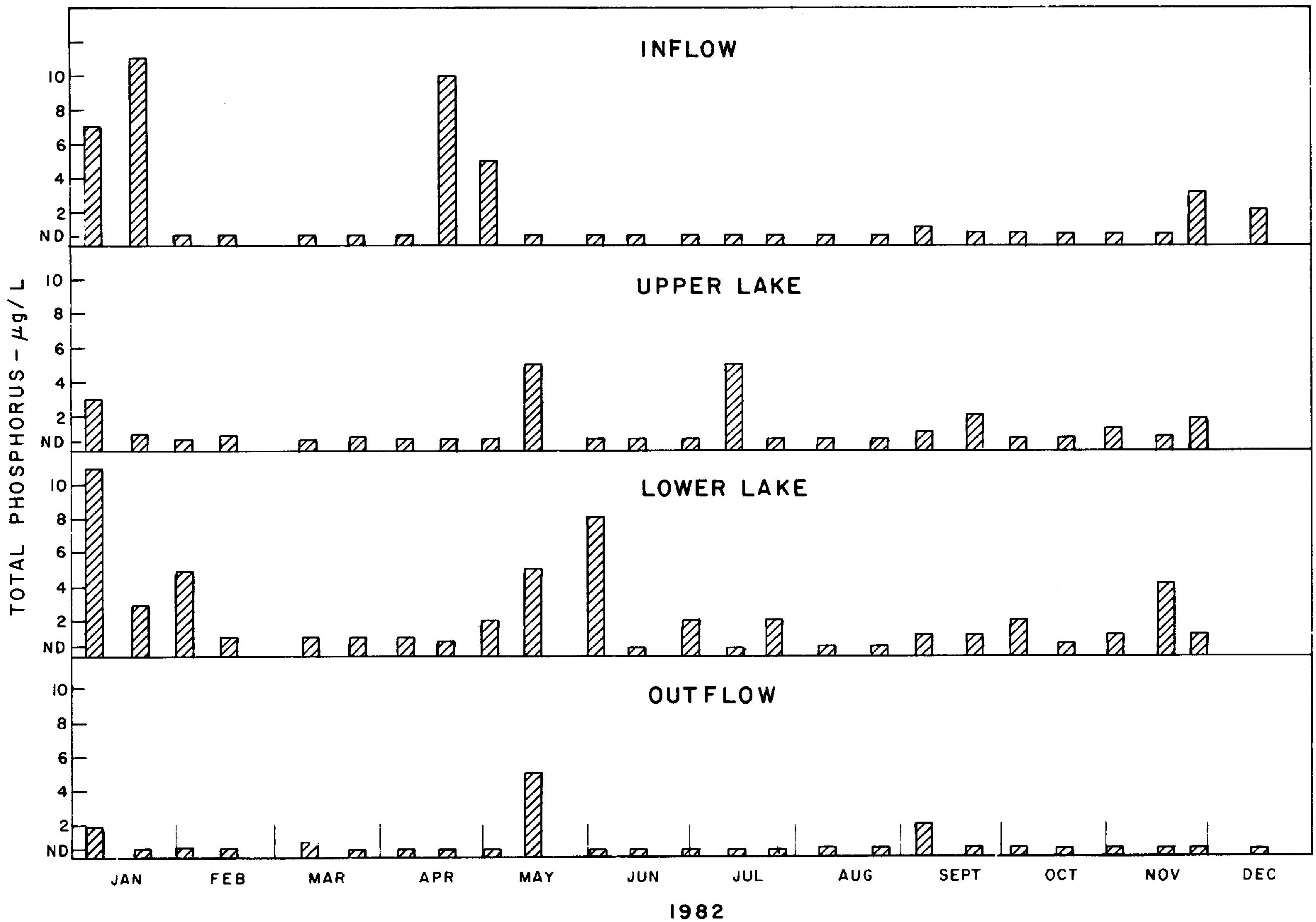


Figure 33. – Total phosphorus concentration in Twin Lakes and Lake Creek during 1982.

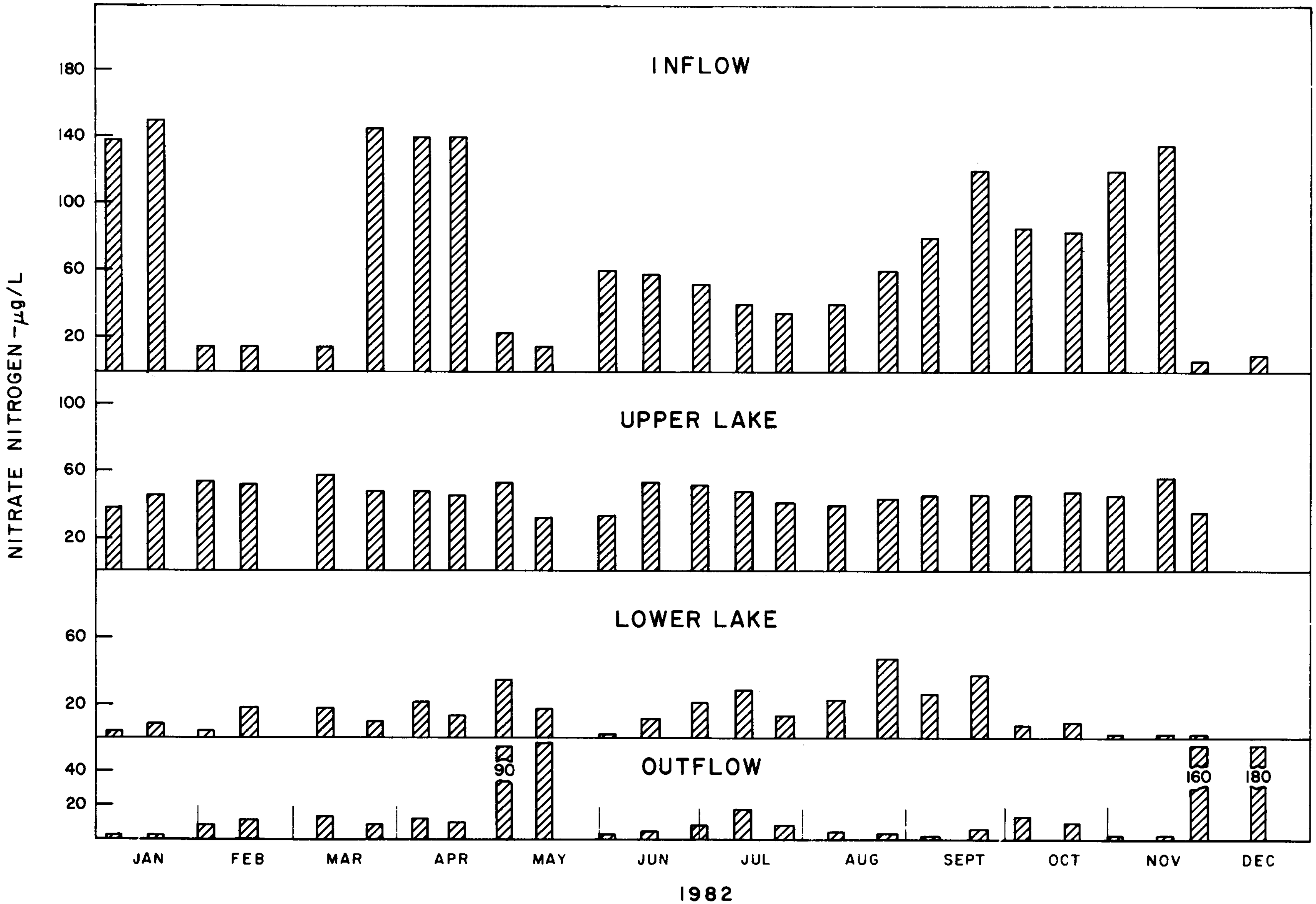


Figure 34. – Nitrate nitrogen concentration in Twin Lakes and Lake Creek during 1982.

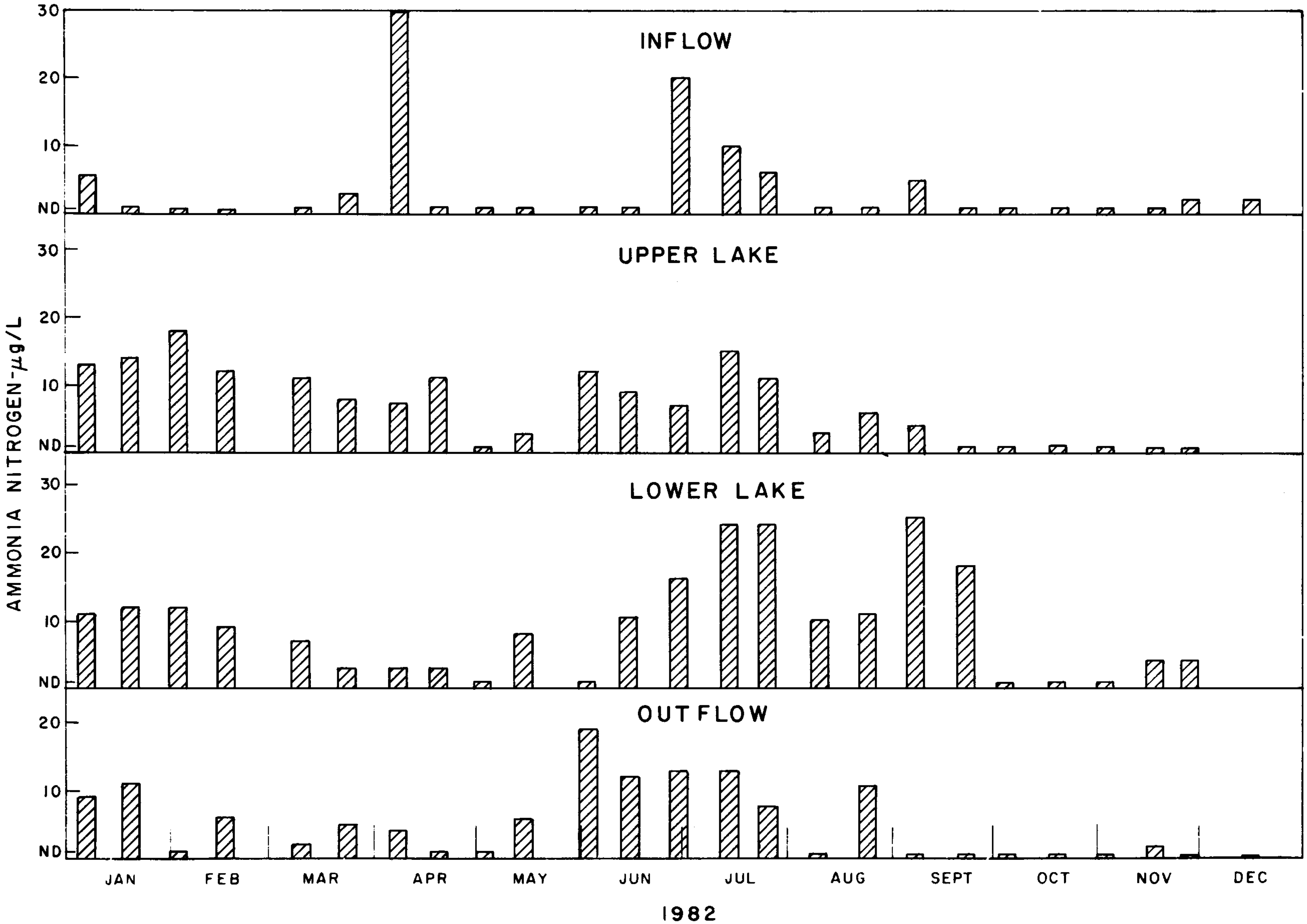


Figure 35. – Ammonia nitrogen concentration in Twin Lakes and Lake Creek during 1982.

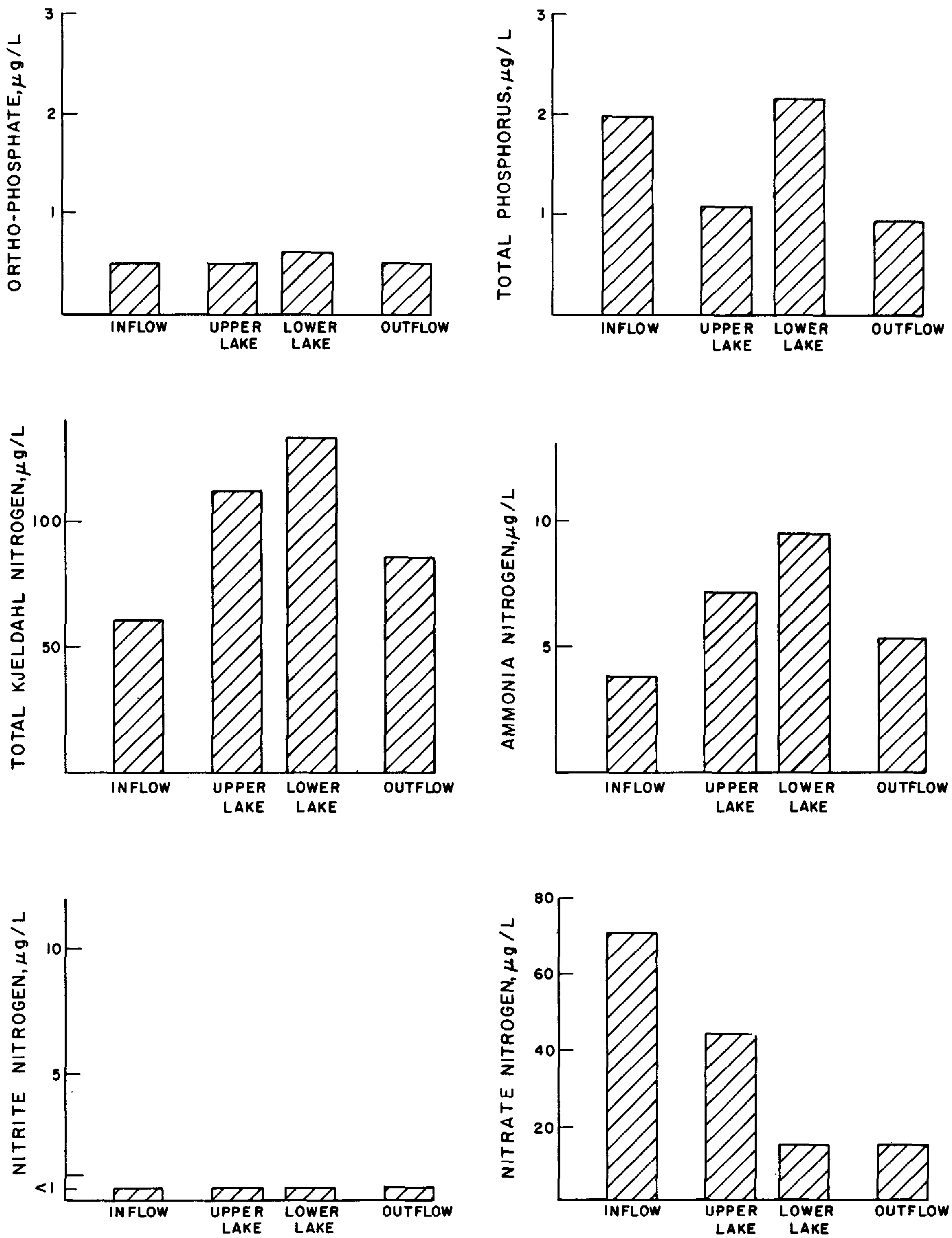


Figure 36. – Average concentrations of nitrogen and phosphorus nutrients in Twin Lakes and Lake Creek during 1982.

Biological Parameters

Primary Productivity. – The purpose of using the ^{14}C technique is to determine the primary productivity of Twin Lakes by measuring the instantaneous rate at which algae are fixing carbon during cellular development. This method was used on both lakes on 18 dates during 1982. Tables 13 and 14 present the maximum and areal primary productivity rates for the lower and upper lakes, respectively, on each of the sampling dates during 1982. Figure 37 contains profiles of these same data while figures 38 and 39 compare the 1982 areal rates with the 1973-82 average areal rates. Figures 40 and 41 are histograms of the annual areal rates of primary productivity from 1973 through 1982.

The lower lake, as is generally true, was more productive than the upper lake during 1982. Since runoff was greater during 1982, this difference was even greater. Primary productivity was lowest in the lower lake during the winter and lowest in the upper lake during June and July. The latter was due to the light limitation and rapid flushing that result from high runoff into the upper lake. When the ice cover melts for the season, the lakes turn over, circulating nutrients trapped at the bottom during winter stratification. Primary productivity is accelerated at this time. Nutrients (i.e., phosphorus and nitrate-nitrogen) become scarce during midsummer in the lower lake, resulting in depressed production rates. As fall turnover occurs and nutrients from the hypolimnion are once again circulated, the rate of primary productivity increases.In the fall, however, primary productivity is more restricted to the top 5 meters due to the shading effect of the greater abundance of plankton in the lakes; that is, the euphotic zone is reduced. All of the rates for the lower lake during 1982 (fig. 39) fall within one standard deviation of the 1973-82 mean. In fact, the rates generally are close to the monthly averages except in September when the 1982 rate was much higher. This was due to an earlier disruption of thermal stratification resulting in an earlier circulation of nutrients. The fall peak of production that normally occurs in October, occurred during September in 1982. Rates in the upper lake (fig. 38) fall within the expected range in 8 out of 12 months. Rates were somewhat greater than normal for the upper lake in January and March, and somewhat lower than normal in October and November. The lower than average rate for July 1982, although not more than one standard deviation from the mean, was due to the greater runoff, as previously discussed. In general, rates were low in the upper lake without displaying the degree of seasonal variability that rates in the lower lake displayed. When all primary productivity data from both lakes during 1982 are added together and compared to data from other years of this study (figs. 40 and 41), the rates for the upper lake are similar to the 10-year average, while those for the lower lake are greater. On the average, there is more primary productivity during the ice-free season. However, the upper lake differed from this generalization in that 50 percent occurred under the ice and 50 percent occurred during the ice-free season.

Table 13. – Primary production rates for lower lake during 1982.

Date, 1982	Maximum volumetric rate, mg C/(m³·h)	Areal rate, mg C/(m²·h)
Jan. 20	0.59	2.3
Feb. 18	0.46	2.3
Mar. 11	0.53	3.8
Apr. 8	0.32	0.5
May 4	1.26	9.4
May 20	1.28	11.2
June 3	1.37	10.3
June 16	1.23	6.1
July 1	1.65	8.4
July 15	0.93	5.4
July 29	0.84	5.6
Aug. 12	0.98	5.5
Sept. 9	1.49	9.6
Sept. 22	1.42	9.7
Oct. 7	1.60	10.9
Oct. 21	1.07	7.1
Nov. 4	1.45	7.8
Nov. 18	0.85	4.3

Table 14. – Primary production rates for upper lake during 1982.

Date, 1982	Maximum volumetric rate, mg C/(m³·h)	Areal rate, mg C/(m²·h)
Jan. 20	0.64	2.9
Feb. 18	.24	1.8
Mar. 11	.39	2.7
Apr. 8	.39	2.1
May 4	.56	5.1
May 20	.71	5.7
June 3	.71	3.4
June 16	.38	1.4
July 1	.14	0.3
July 15	.17	0.7
July 29	.14	0.7
Aug. 12	.61	3.6
Sept. 9	.75	5.2
Sept. 22	.38	2.8
Oct. 7	.55	3.8
Oct. 21	.28	1.8
Nov. 4	.35	2.2
Nov. 18	.24	1.8

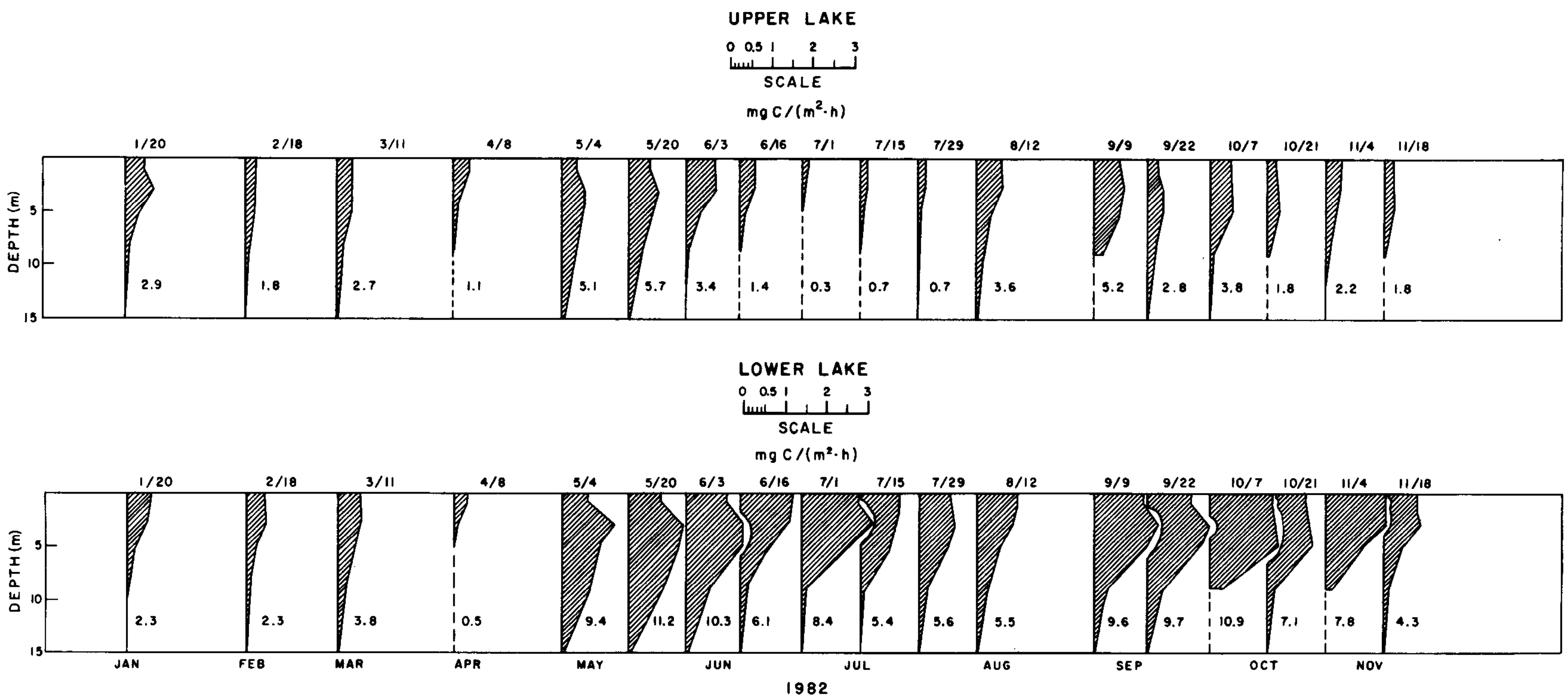


Figure 37. – Primary productivity profiles for Twin Lakes during 1982.

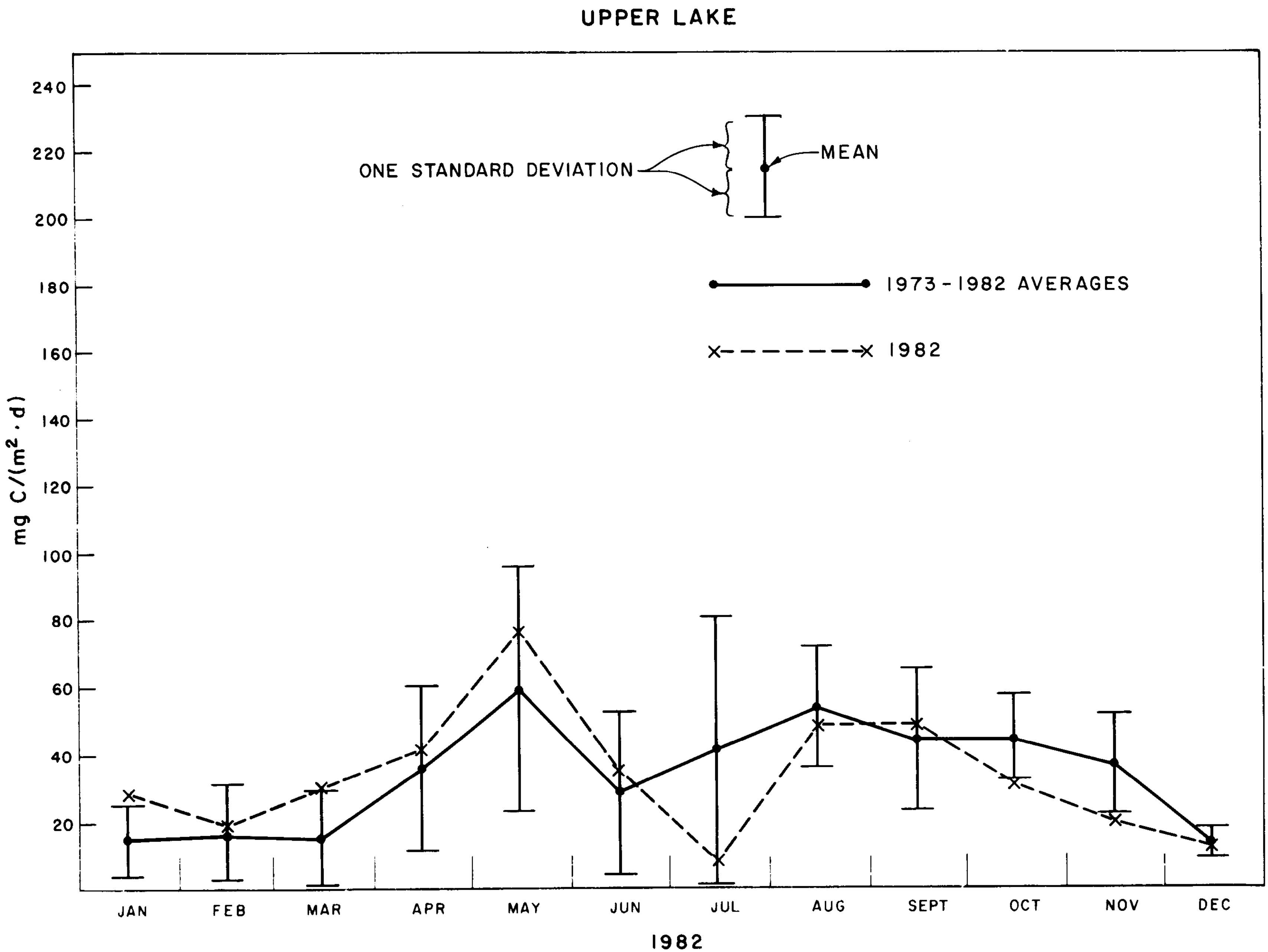


Figure 38. – Areal primary productivity rates for upper lake, 1982 values versus 1973-82 averages.

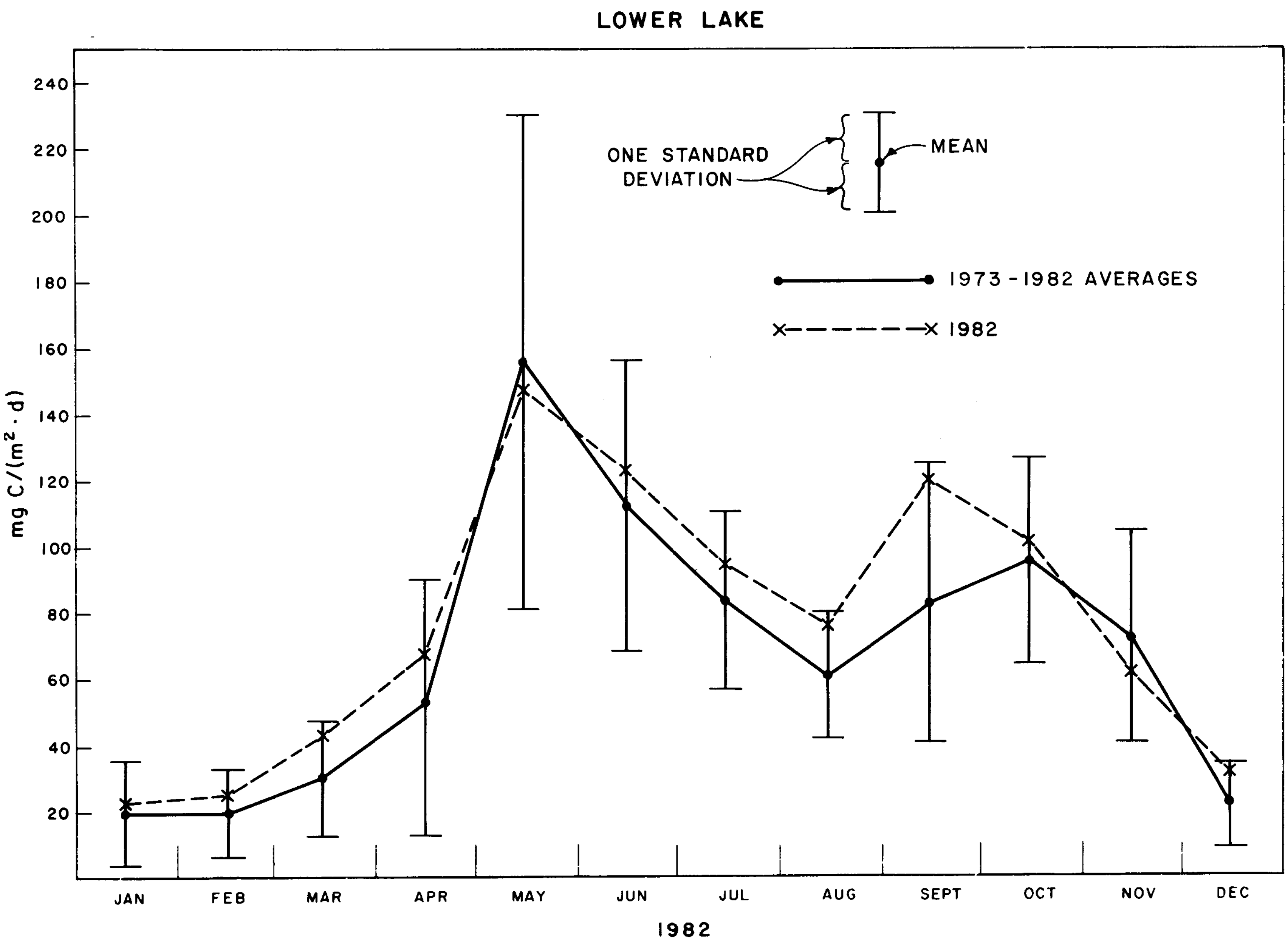


Figure 39. – Areal primary productivity rates for lower lake, 1982 values versus 1973-82 averages.

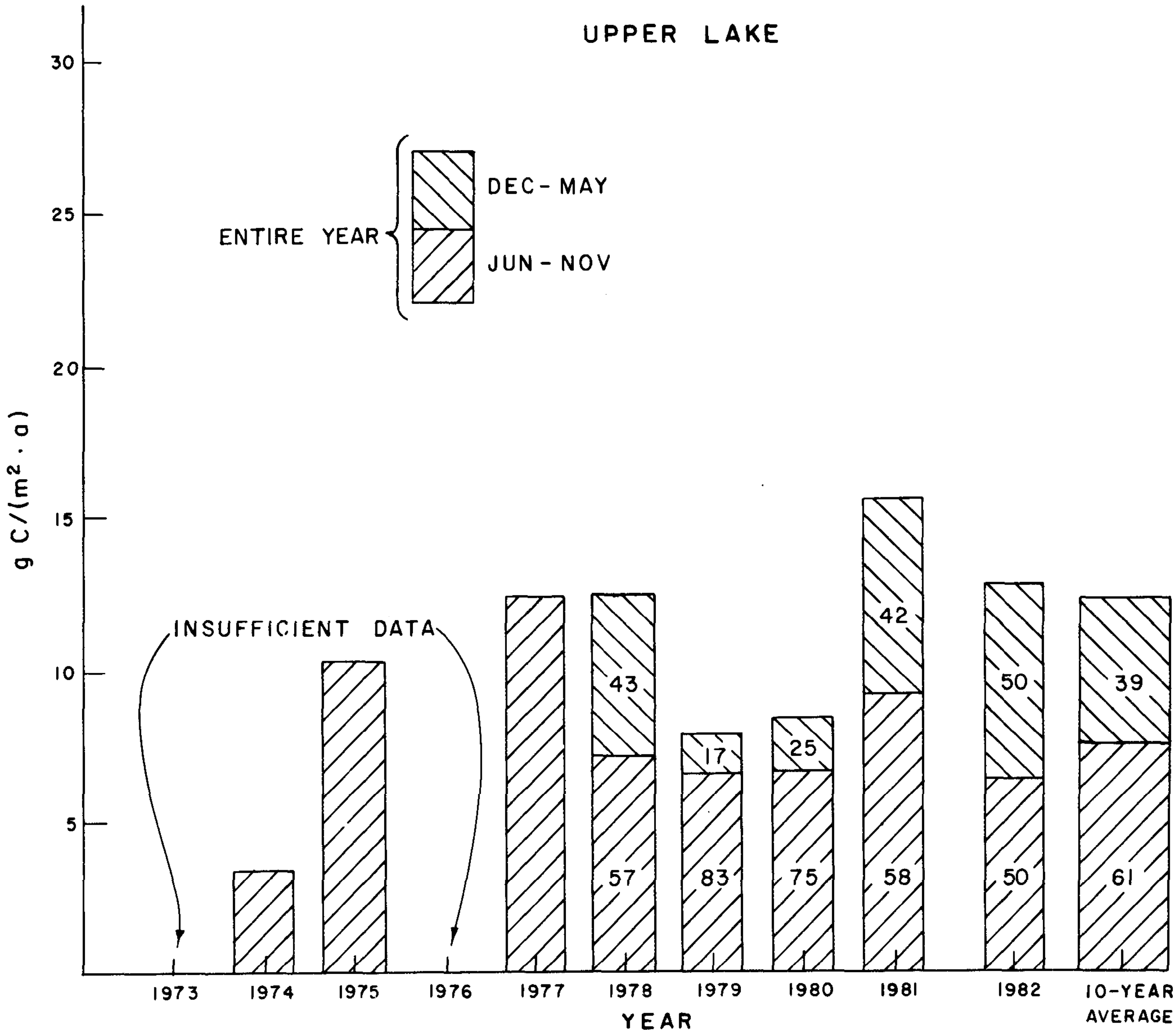


Figure 40. – Annual areal primary productivity rates for upper lake.

A greater percentage of primary productivity occurred during the winter in the upper lake than had been previously measured. The reason for this is not known at this time; however, it does not seem to be significant.

Chlorophyll a. – Tables 15 and 16 present results of chlorophyll *a* analyses from 24 sampling dates during 1982. The maximum and average volumetric and areal concentrations are presented. The profiles for each sampling date are shown on figure 42. These data indicate the abundance, or biomass, of phytoplankton in the water column from the surface to a depth of 15 meters. Figure 43 compares the areal chlorophyll *a* concentrations with hourly areal primary productivity rates.

Chlorophyll was generally more abundant in the lower lake than in the upper lake. As is typical with oligotrophic lakes, chlorophyll biomass was usually greatest somewhere below the surface (fig. 42), and usually near the top of the thermocline. The abundance curve for chlorophyll in the upper lake (fig. 43) generally followed the curve for the areal primary productivity rate. However, while the peak of primary productivity in the spring was somewhat greater than that in the fall, the peak of chlorophyll biomass in the spring was about half the fall peak. This is due to the flushing of peak spring runoff that placed most of the phytoplankton that were produced in the upper lake into the lower lake. Further evidence of this is seen by examination of the chlorophyll curve for the lower lake (fig. 43). That is, there is little or no depression

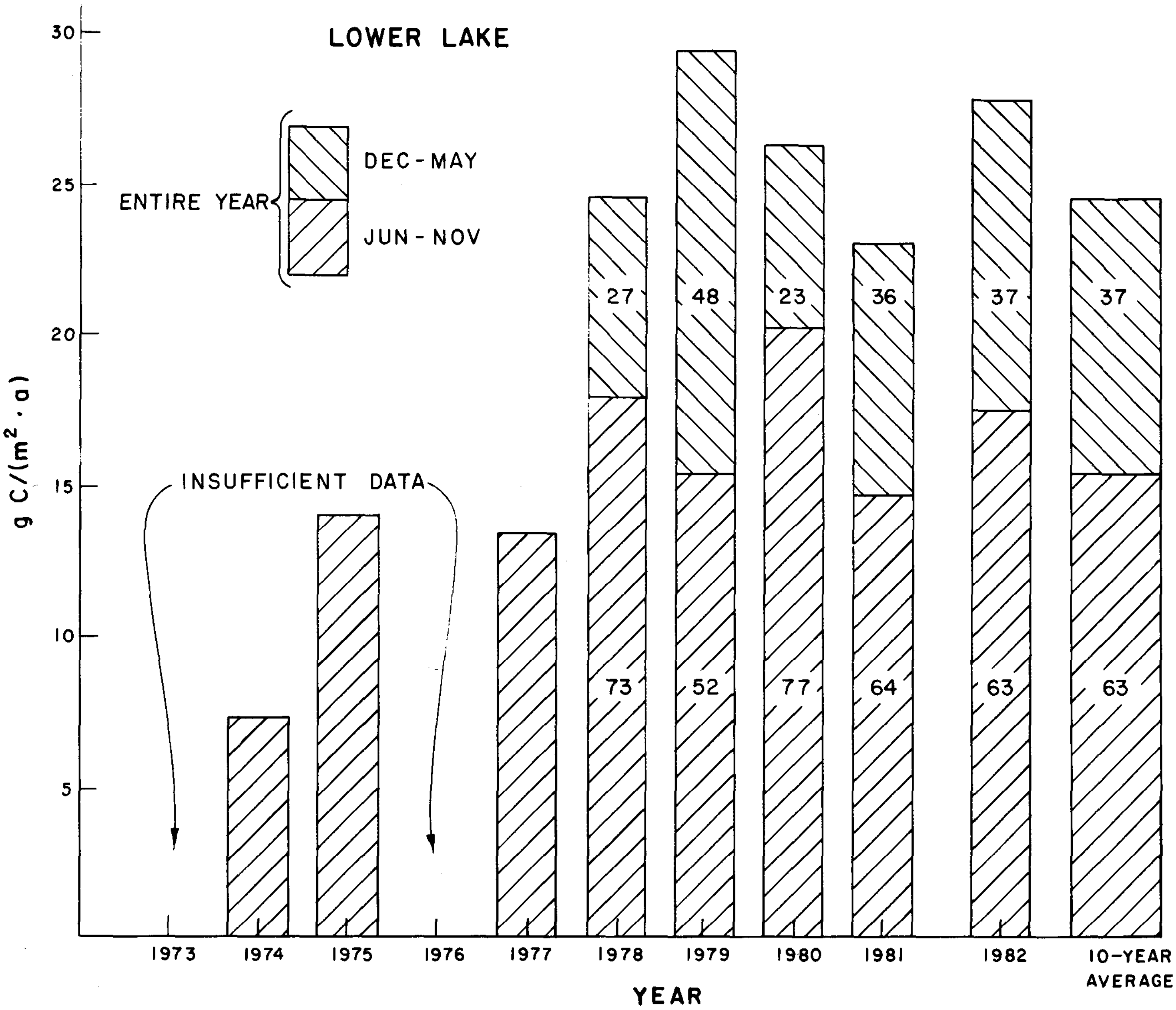


Figure 41. – Annual areal primary productivity rates for lower lake.

of chlorophyll biomass during midsummer. The fall peak of chlorophyll biomass does follow the peak of primary productivity rate by a couple of weeks, as it logically should. Therefore, the chlorophyll and primary productivity data from 1982 generally agree with each other. Previously, a good relationship between these two parameters has been difficult to show; improvement of methodology is partly responsible for this. In summary, the amount of chlorophyll *a* in the upper and lower lakes during 1982 was within the range of values previously observed during other years of these surveys.

Phytoplankton. – Figure 44 shows seasonal plankton patterns in the lower and upper lakes during 1982. Phytoplankton trends are similar in both lakes, with average densities peaking between April and July and again in the fall during October and November. During 1982, the lower lake was four times as productive of phytoplankton as the upper lake and showed a significant amplitude of seasonal change. A comparison of average yearly phytoplankton densities in Twin Lakes, table 17, shows the relative abundance of phytoplankton collected from the upper and lower lakes. Figure 45 graphically illustrates these data, with 1981 showing the greatest productivity of 6174 and 1965 per liter in the lower and upper lakes, respectively. The least productive year was 1982, with only 1185 (lower lake) and 304 (upper lake) per liter. Comparing 1981 and 1982, the upper lake was six and one-half times less productive during 1982, while the lower lake was five times less productive. A more dramatic observation of 1982 data is that the lower lake, with 1185 per liter, was even less productive than the upper lake in 1981 with 1965 per liter.

Table 15. – Chlorophyll *a* concentration in upper lake during 1982.

Date, 1982	Maximum concentration, mg/m³	Depth, m	Average concentration, mg/m³	Areal concentration, mg/m²
Jan. 6	3.55	3.0	2.79	39.10
Jan. 19	2.95	5.0	1.49	24.80
Feb. 4	3.46	5.0	2.29	35.07
Feb. 17	2.49	5.0	1.71	28.59
Mar. 10	2.33	3.0	2.15	31.94
Mar. 24	2.37	3.0	2.06	30.28
Apr. 7	2.56	9.0	2.19	35.79
Apr. 19	2.57	5.0	2.35	35.39
May 3	3.11	9.0	2.02	36.25
May 19	2.35	9.0	1.82	33.19
June 2	2.42	5.0	2.04	28.06
June 15	1.30	3.0	0.96	13.13
June 30	0.66	5.0	0.43	6.04
July 14	0.81	0.1	0.49	5.61
July 28	1.22	9.0	0.97	14.54
Aug. 11	3.00	9.0	1.34	25.03
Aug. 26	2.33	9.0	1.51	24.62
Sept. 8	2.55	9.0	1.70	28.14
Sept. 22	3.23	5.0	2.45	36.46
Oct. 6	3.25	5.0	2.63	40.28
Oct. 20	4.23	3.0	3.43	50.46
Nov. 4	4.24	5.0	4.14	62.21
Nov. 17	5.26	5.0	4.76	72.39
Nov. 30	5.55	1.0	5.26	77.59

Table 16. – Chlorophyll *a* concentration in lower lake during 1982.

Date, 1982	Maximum concentration, mg/m³	Depth, m	Average concentration, mg/m³	Areal concentration, mg/m²
Jan. 6	4.64	0.1	3.55	48.30
Jan. 19	3.05	3.0	2.41	40.02
Feb. 4	3.11	5.0	2.33	36.67
Feb. 17	3.04	3.0	2.37	36.71
Mar. 10	3.57	3.0	3.04	45.33
Mar. 24	2.66	1.0	2.05	30.05
Apr. 7	3.26	9.0	2.74	43.01
Apr. 19	2.95	9.0-15.0	2.77	42.28
May 3	4.71	9.0	3.73	63.03
May 19	3.36	15.0	3.24	48.53
June 2	3.47	15.0	2.66	41.59
June 15	3.36	5.0	3.07	47.06
June 30	3.48	3.0	2.93	45.56
July 14	3.03	9.0	2.57	38.71
July 28	3.56	9.0	2.95	45.97
Aug. 11	5.99	9.0	3.46	58.89
Aug. 26	3.87	5.0	3.03	47.52
Sept. 8	4.46	9.0	3.07	48.79
Sept. 22	4.94	9.0	4.03	61.32
Oct. 6	5.37	0.1	4.65	67.73
Oct. 20	5.90	5.0	5.61	85.84
Nov. 4	7.00	5.0	6.87	103.53
Nov. 17	7.32	15.0	6.71	102.12
Nov. 30	6.52	0.1	6.22	93.56

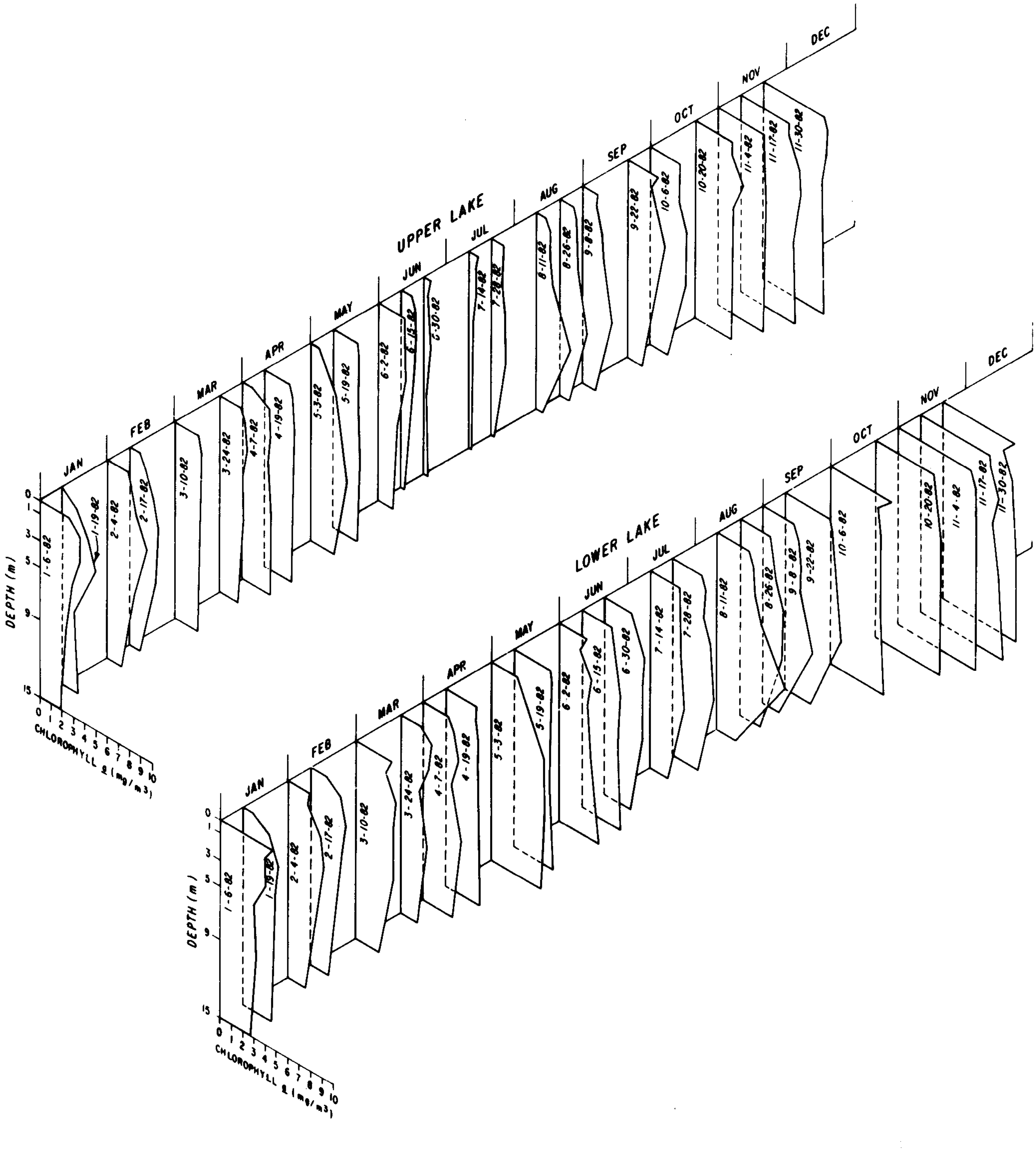


Figure 42. – Chlorophyll *a* profiles for Twin Lakes during 1982.

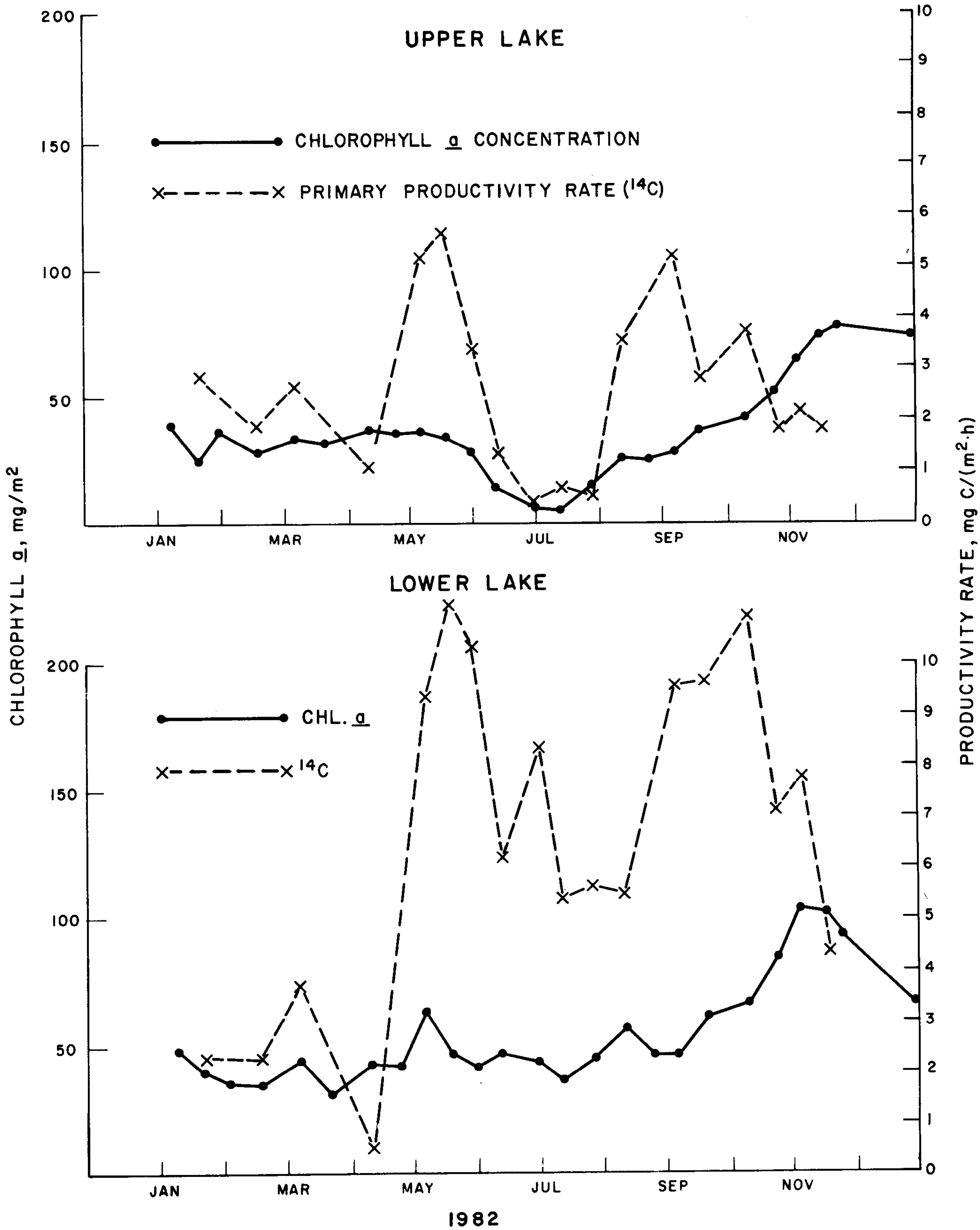


Figure 43. – Areal chlorophyll *a* concentration and primary productivity rates for Twin Lakes during 1982.

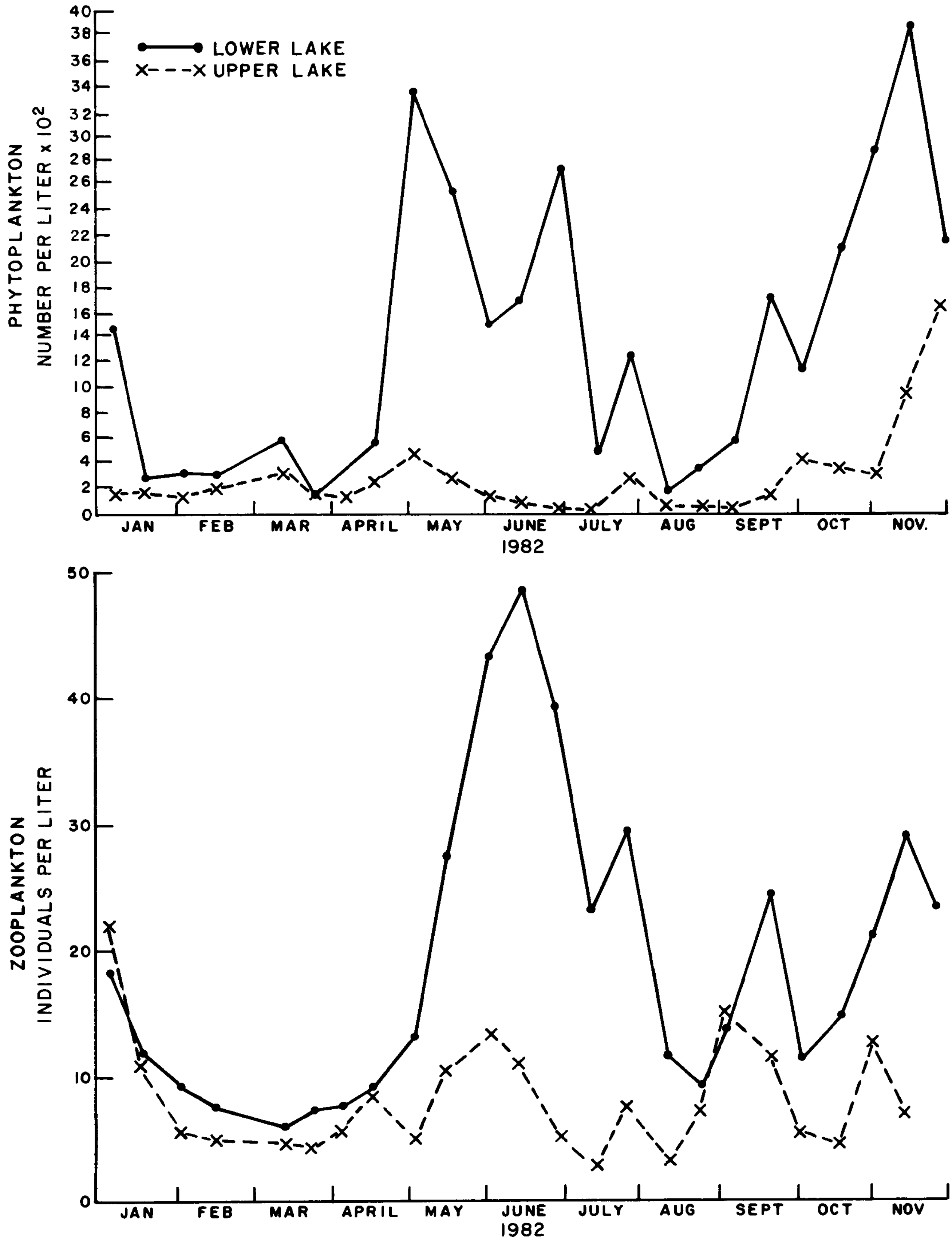


Figure 44. – Average plankton concentrations in Twin Lakes during 1982.

Table 17. – Comparison of average yearly phytoplankton densities, 1979-82.

Year	No. of sampling dates	Number per liter	
		Upper lake	Lower lake
1979	18	536	3694
1980	16	312	2712
1981	19	1965	6174
1982	22	304	1185

Figures 46 and 47, together, show average plankton concentrations for 1977-82. Figure 45 represents the overall yearly average for 1979-82, while figures 46 and 47 show the seasonal trends throughout the course of each year. The most significant observation between the upper and lower lakes is the striking difference in phytoplankton densities and their seasonal occurrence. The phytoplankton collected in the upper lake for the past 6 years usually reached a one-time peak during the fall months. An exception to this occurred during 1982, where the peaks fluctuated from March to September.

The year 1981 was a low run-off year, where flows did not cause a thorough flushing of the upper lake. A plankton population was able to develop through the summer because the population was supported by an adequate supply of nutrients, and was not affected by turbid waters. In contrast, 1982 was a high run-off year, with turbid inflow, a decrease in light, and flushing of much of the biota from the upper lake. The resulting phytoplankton population was low in numbers, with a visible increase in average density only from October to November.

The lower lake, from 1977-82 (figs. 46 and 47), shows variable seasonal cycles with low densities occurring during the winter months and high densities in either spring, summer, or fall. For example during 1980, phytoplankton populations peaked in the summer (Aug.) at 13 000 per liter, while during 1981, they peaked in the spring (early March) at 18 000 per liter and then decreased during the summer months. In 1982, phytoplankton reached a low density during March of 113 per liter and peaked in late fall (Nov.) to 3823 per liter. Even after fall turnover, when the lake had a chance to mix and stir up nutrients from the lake floor, the peak density reached only one-fifth of the peak density of 1981. During a high run-off year, as was 1982, nutrients and plankton are flushed through the lakes and, as a result, nutrient loading that had a favorable effect on the phytoplankton in 1981 did not take place in 1982. The variable plankton cycles are a result of spring runoff, volume of inflow, and the mixing of the lakes during spring and fall turnover. The overall effect of these three factors are responsible for the smaller or greater abundance of phytoplankton and the season in which the greatest densities occur (e.g., summer, 1980; spring, 1981; fall, 1982).

The species composition of phytoplankton is graphically illustrated on figure 48. There are 14 commonly occurring limnetic phytoplankters that have been collected in Twin Lakes since 1974 (Lieberman, 1983) [20]. The diatoms (Bacillariophyta) were the dominant phytoplankters in both lakes during 1982.

The upper and lower lakes are typically dominated by the diatoms, *Asterionella formosa* Hassall, *Synedra amphicephala* Kuetz, *S. delicatessima* W. Sm., *S.* radians Kuetz, and *S. ulna* var. *Danica* (Kuetz) vh. The yellow brown alga *Dinobryon cylindricum* Imhof has been a dominant species in the upper lake in past years but, in 1982, it appeared only in the fall. The percentages of each species are based on the total number of phytoplankton collected per liter.

In the lower lake, *Asterionella* sp. and *Synedra* spp. were codominant species throughout the year. Peak density of *Asterionella* sp. occurred in November with 1548 per liter. *Synedra* spp. reached highs in June with 1892 per liter. *Dinobryon* sp. shows a peak density in November of 203 per liter. In 1981, the lower lake was dominated by *Synedra* spp., *Asterionella* sp., and *Dinobryon* sp. Also present were the green algae, *Dictyosphaerium pulchellum* wood and *Sphaerocystis schroeteri* Chodat. During 1982, the diatoms, *Tabellaria flocculosa* (Roth) Kuetz and *Fragilaria crotonensis* Kitton, and the green algae *Staurastrum longiradiatum* W. and W., added to the phytoplankton population density but were not collected in abundance. These three species comprised only from 1 to 10 percent of the phytoplankton population in the lower lake.

The upper lake was dominated by *Asterionella* sp. from January through June, *Synedra* spp. from July through mid-September, and *Dinobryon* sp. from mid-September through November. The species comprising from 1 to 35 percent of the total include *Dictyosphaerium* sp., *Tabellaria* sp., *Fragilaria* sp., the yellow-green algae *Mallomonas elongata* Rever and *M. pseudocoronata* Prescott, and the blue-green algae *Oscillatoria amphibia* C.A. Agardh, and *O. tenius* C.A. Ogardh.

The diatom, *Tabellaria* sp. was collected from both lakes and the forebay, especially during the fall months. *Tabellaria* sp., may have been transported from Turquoise Lake into Mt. Elbert Forebay and then released into the lower lake. Nesler (1981) [24] predicted the transfer of *Tabellaria* sp. from Turquoise Lake into Twin Lakes.

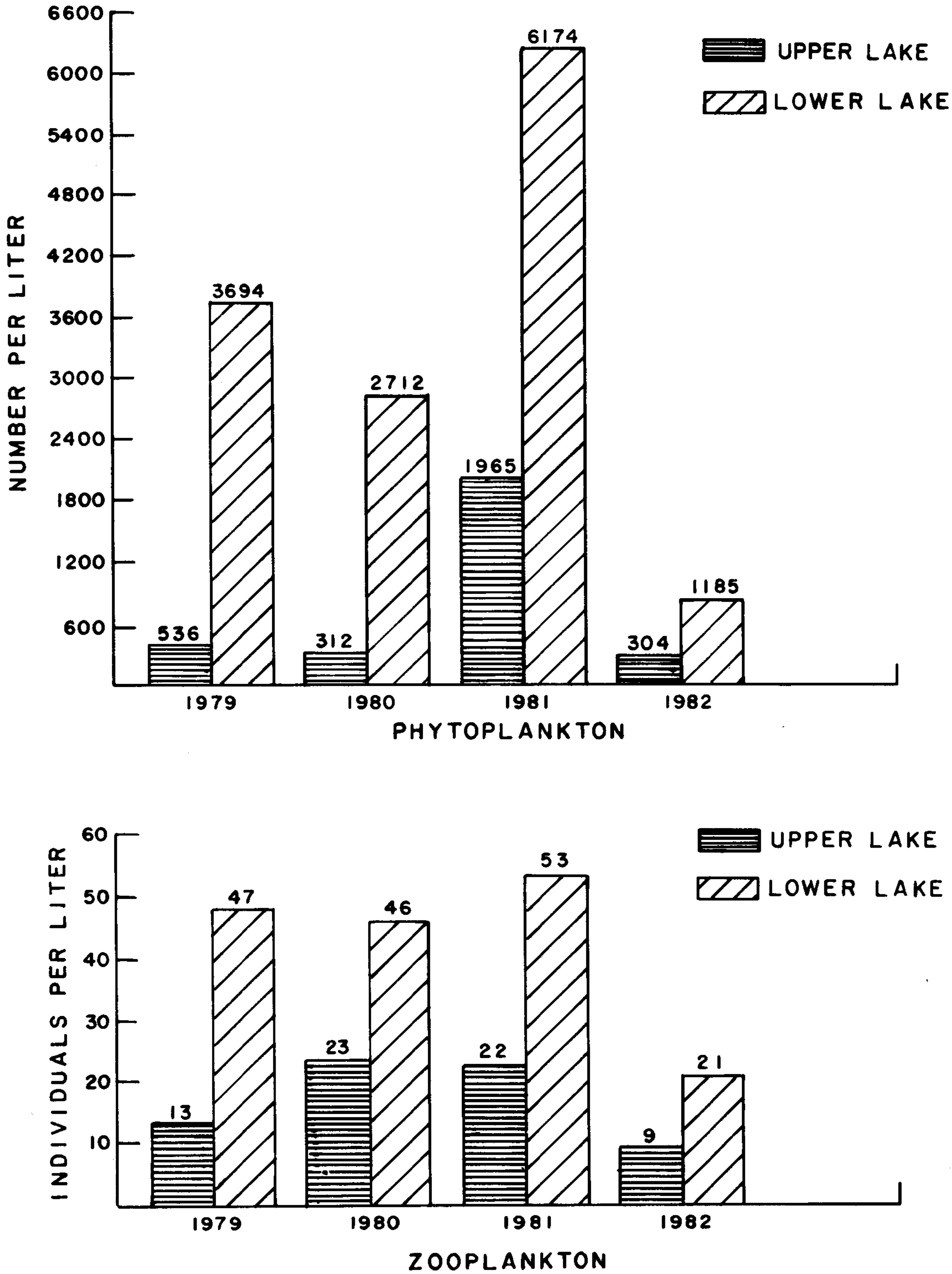


Figure 45. – Comparison of average plankton densities, 1979-82.

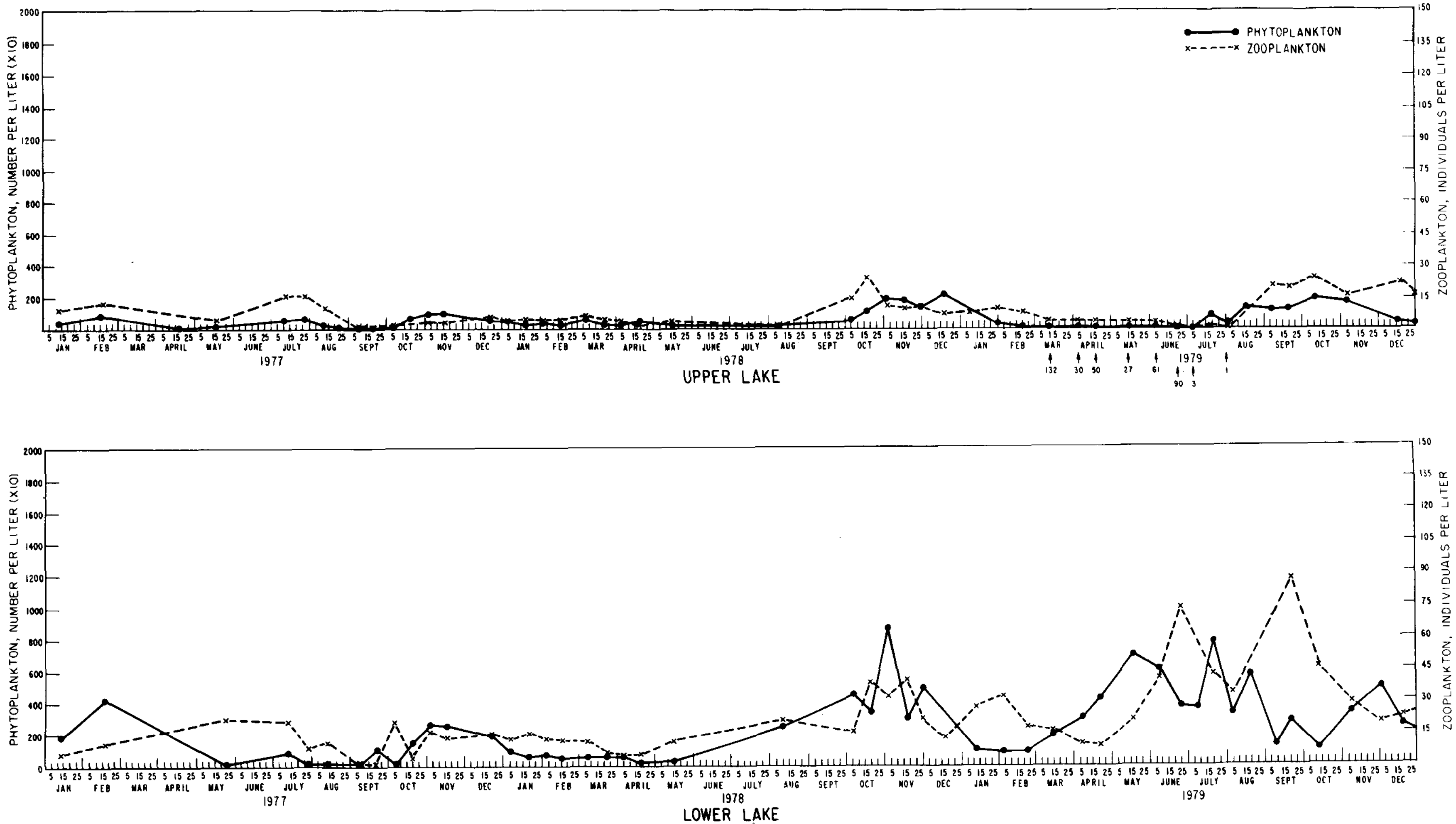


Figure 46. – Average plankton concentrations in Twin Lakes, 1977-79.

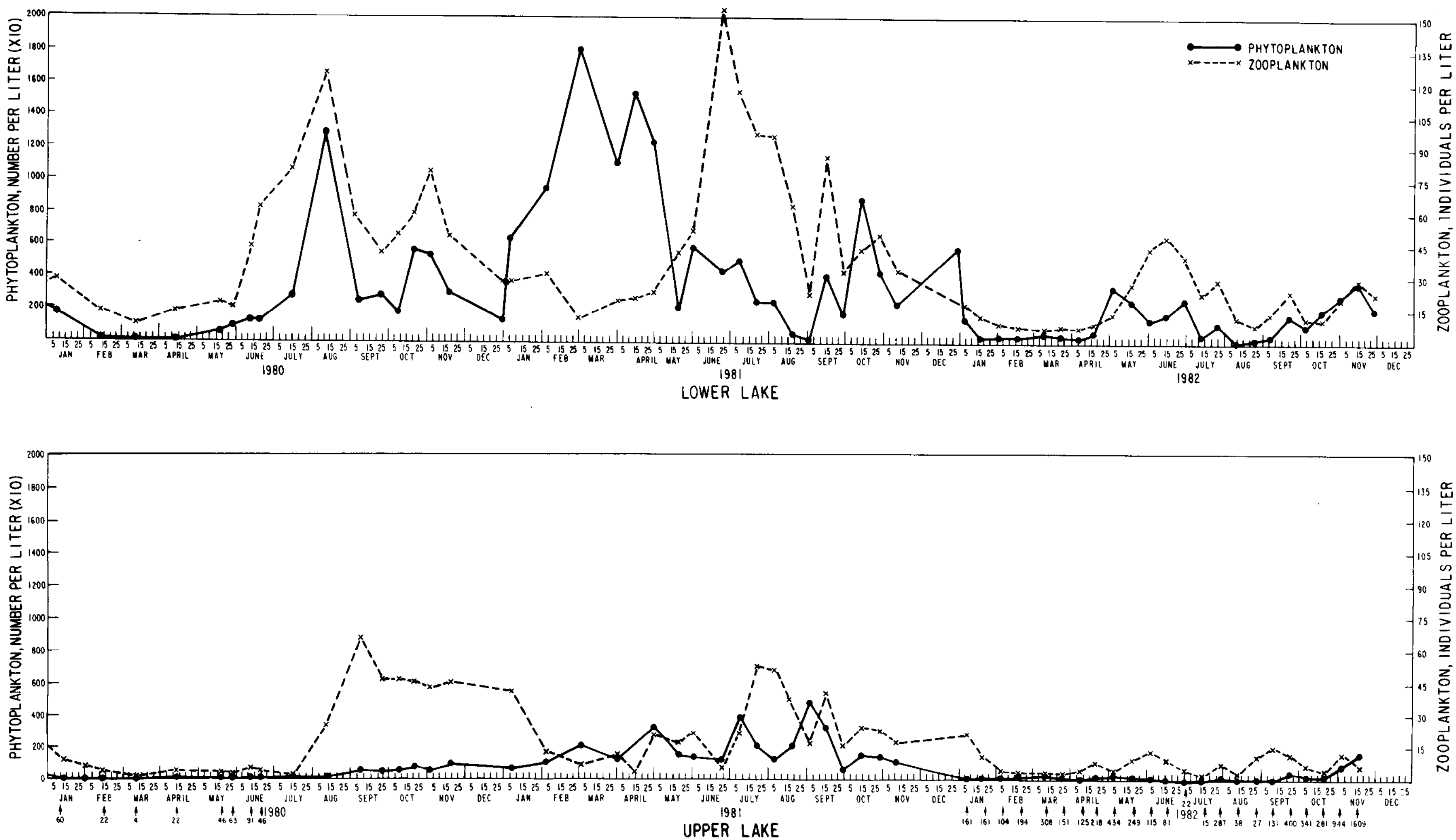


Figure 47. – Average plankton concentrations in Twin Lakes, 1980-82.

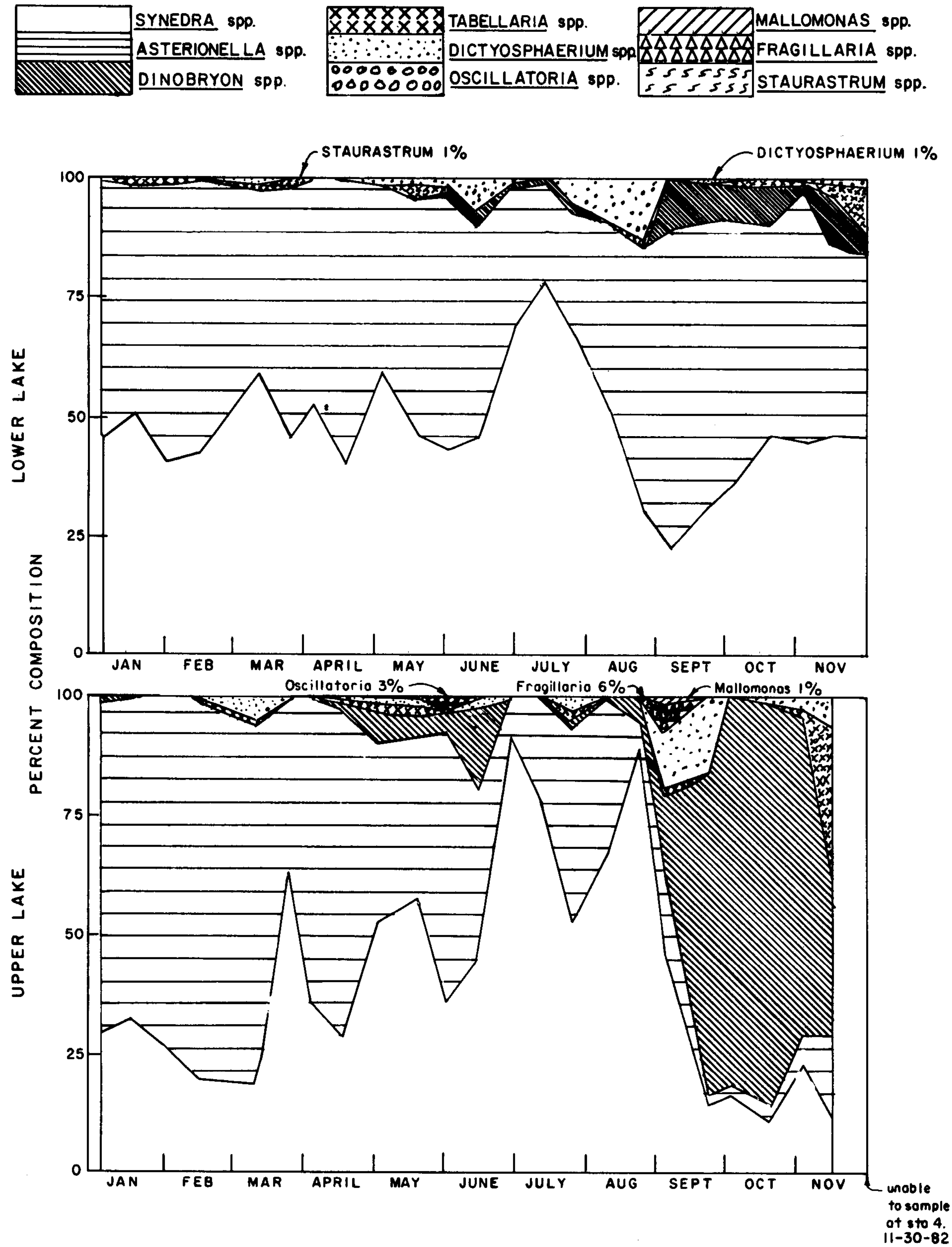


Figure 48. – Species composition of phytoplankton population in Twin Lakes during 1982.

In summation, the dominant phytoplankton species in Twin Lakes were, as in other years, the diatoms, *Asterionella* sp., and *Synedra* spp. The yellow-brown algae *Dinobryon* sp. comprised the greatest percentage of algae in the upper lake during the fall months. The phytoplankton does not appear to follow yearly or even definite seasonal successional trends. The abundance and occurrence of each species must depend on the amount of inflow from spring runoff, nutrients, light, temperature, and predation.

Zooplankton. – During 1982, the average zooplankton concentrations (fig. 44) show low densities in the spring and high densities in the summer. The lower lake had the highest density in mid-June of 49 individuals per liter and the lowest density in mid-March of 6 individuals per liter. The upper lake had an average of 2.3 times less zooplankton than the lower lake. The highest density in the upper lake was in early January with 22 individuals per liter and the lowest density was in July with about 3 individuals per liter. Table 18 compares average yearly densities from 1979 through 1982. Average densities from 1979, 1980, and 1981 were similar for the lower lake and somewhat similar for the upper lake.

Figure 45 illustrates the comparison between zooplankton densities. In contrast to the last 3 years, 1982 shows a reduction of more than 50 percent. The upper lake had a yearly average of only 9 individuals per liter as compared to 1981 with 22 individuals per liter, and the lower lake had a yearly average of 21 individuals per liter for 1982 as compared to 53 individuals per liter for 1981. Not only does this show that the total numbers were down for 1982, but also that concentrations of zooplankton were much greater in the lower lake than in the upper lake.

Figures 46 and 47 compare average zooplankton densities in the upper and lower lakes for 1977-82. The highest density for the upper lake was in September 1980 with 65.9 individuals per liter, while the highest in the lower lake was 153.1 individuals per liter, recorded in June 1981. In 1982, there was an increase in concentrations in early summer and again in the fall, but the zooplankton never reached the 1981 average. This situation parallels that of the phytoplankton discussed earlier, and probably reflects the same influences.

Table 18. – Comparison of average yearly zooplankton densities, 1979-82.

Year	No. of sampling dates	Individuals per liter	
		Upper lake	Lower lake
1979	18	13	47
1980	16	23	46
1981	19	22	53
1982	21	9	21

The 1982 zooplankton species composition is illustrated on figure 49. Rotifers, mysids, copepods, and cladocera were collected from the lakes. Rotifers were the most abundant group, followed by copepods and an occasional cladoceran. The opossum shrimp, *Mysis relicta* Loven, is considered to be both a zooplankter and a benthic species. This species will be discussed further in the benthic section of this report. Since 1974, 11 different species of zooplankton have been collected from Twin Lakes. The dominant copepod, *Cyclops biscupidatus thomasi* Forbes was collected throughout the year, and reached a peak density of 9.6 individuals per liter during July 1982 in the lower lake. The other two copepods, *Diaptomus judayi* Marsh and *Diaptomus connexus* Light reached their peak of 3.2 individuals per liter in August. The nauplii population was abundant from May through November, comprising from 35 to 75 percent of the total zooplankton population. The peak nauplii density of 11.8 individuals per liter occurred in November.

The rotifer population was most abundant in the month of June, comprising 63 percent of the total zooplankton population and had a peak density of 28.6 individuals per liter. The dominant and most abundant rotifer was *Keratella cohlearis* Bry de St. Vincent, followed by *Kellicottia longispina* Ohlstrom, *Polyarthra* sp., and *Brachionus* sp., which was only 1 percent of the total zooplankton population in September. The cladocera, *Bosmina longirostris* (Mueller), *Daphnia pulex* Leydig, and *Daphnia rosea* Sars are rarely collected in the lower lake. In July and September 1982, cladocera comprised only 1 percent of the total zooplankton population. Juday (1906) [38] reported that cladocera made up from 20 to 45 percent of the adult zooplankton population of Twin Lakes during 1902 and 1903. The disappearance of the cladocera is attributed to several factors, including predation by mysis shrimp, which LaBounty and Sartoris (1983) [18] describe in detail.

The upper lake has a similar species composition to the lower lake. There is an absence of the rotifera, *Brachionus* sp. and the cladoceran, *Daphnia* spp. In 1982, copepods and nauplii, comprised more of the total zooplankton population than in 1981 because of a definite decline in the rotifera population.

Forebay Plankton. – Figure 50 shows the Mt. Elbert Forebay average plankton concentrations during 1982, and table 19 shows these concentrations for

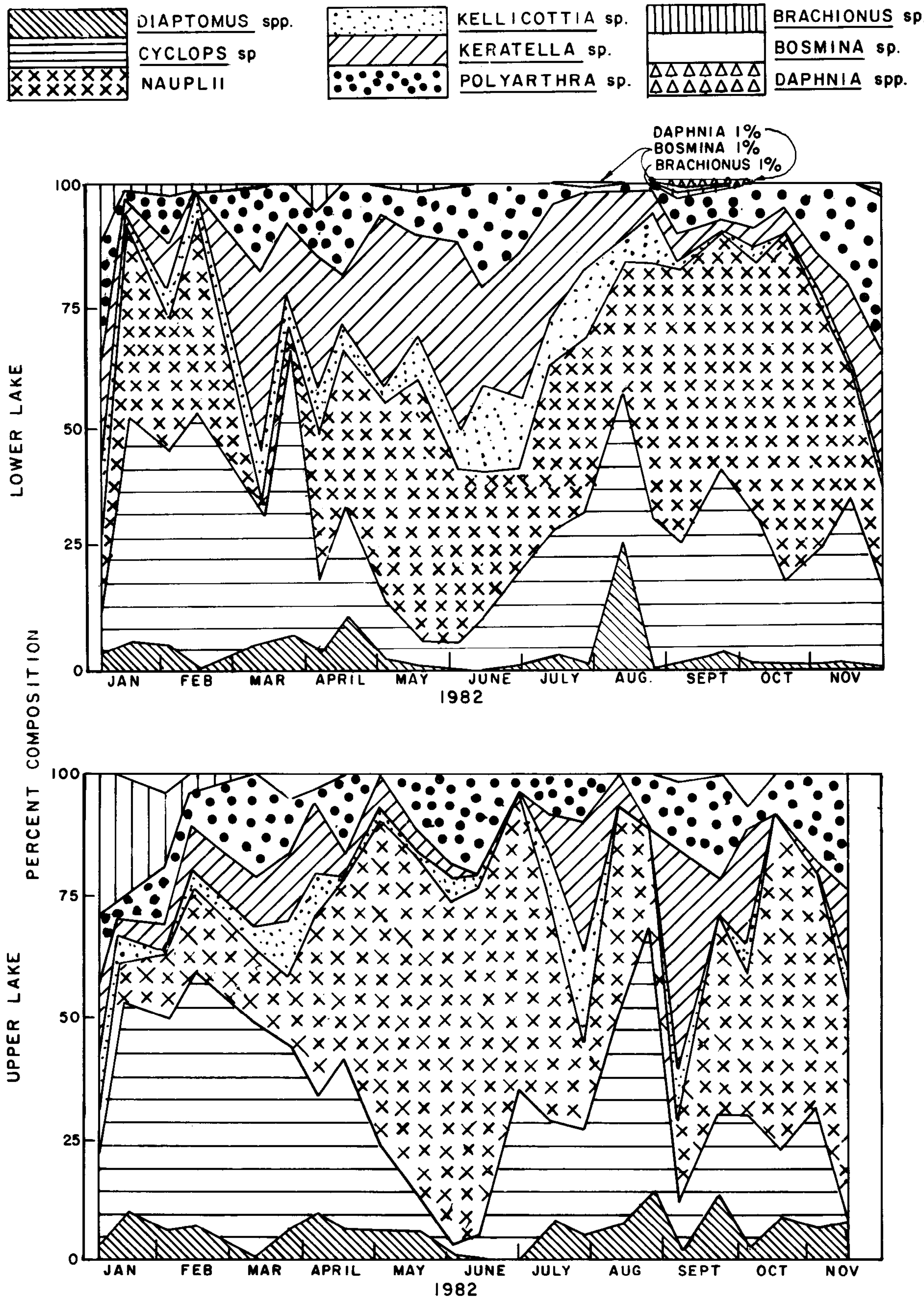


Figure 49. – Species composition of zooplankton population in Twin Lakes during 1982.

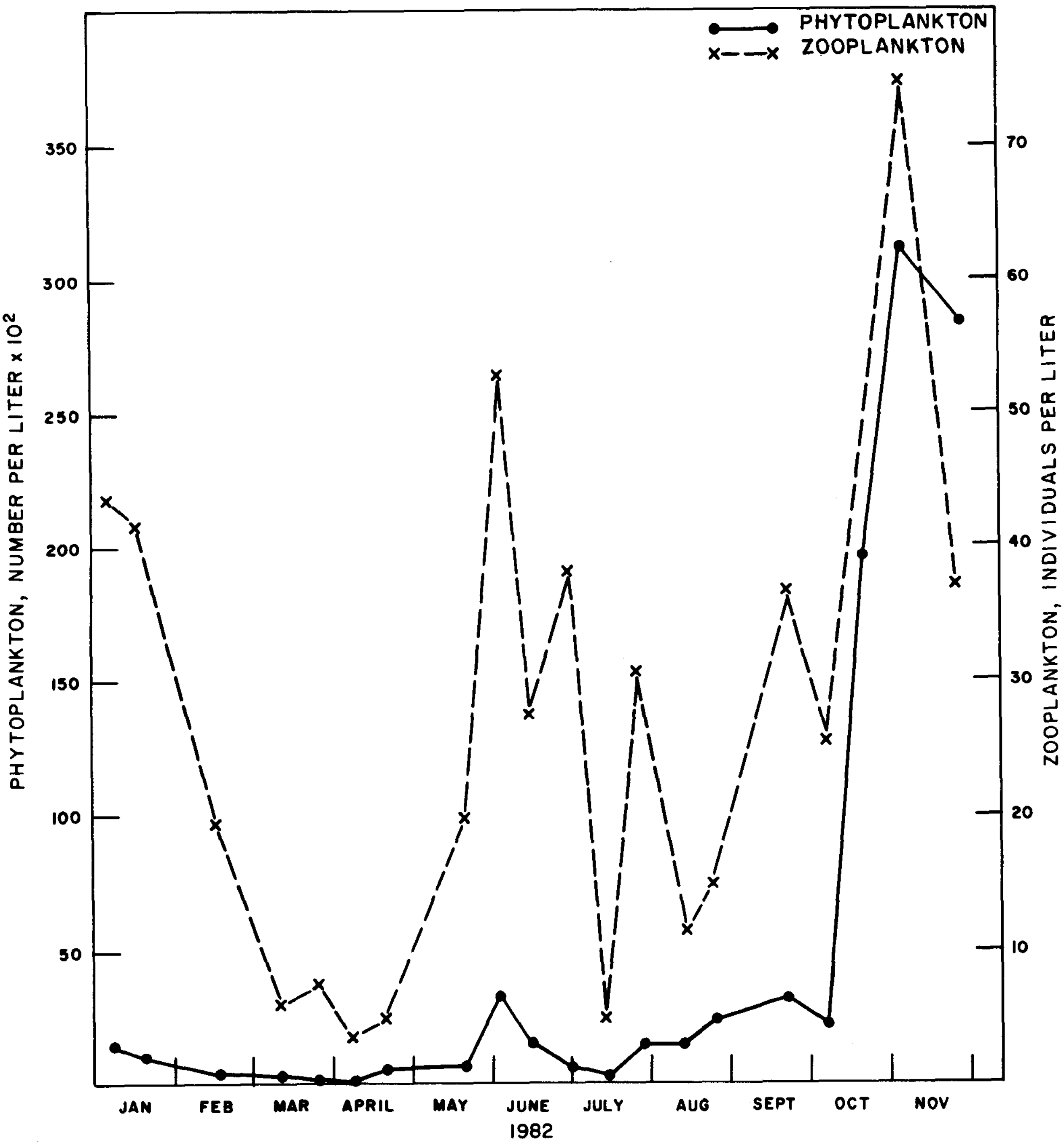


Figure 50. – Average plankton concentrations in Mt. Elbert Forebay during 1982.

specific sampling dates. A low phytoplankton density of 157 per liter was reached in early April, and a high density of 31 142 per liter in early November. From May through June, there was an increase in phytoplankton density, followed by a decline during July. The population again increased in August and September and began to peak in mid-October and early November. There was an increase of almost 10 percent from October 6 to 20. This increase is attributed to the large contribution of *Tabellaria* sp. via Turquoise Reservoir. *Tabellaria* sp., collected from the forebay in significant numbers beginning in late August (fig. 51), filtered into the lower lake from the forebay and was first collected from the lower lake in late September (fig. 48).

The phytoplankton population of Mt. Elbert Forebay is comprised of the diatoms, *Asterionella* sp., *Synedra* sp., and *Tabellaria* sp.; yellow-brown alga, *Dinobryon* sp.; the desmid, *Staurastrum* sp., and the green alga *Dictyosphaerium* sp. (fig. 51). The dominant species are *Synedra* spp. and *Asterionella* sp.; the latter comprising over 50 percent of the phytoplankton population most of the year, except in July when it drastically declines to zero. During July, *Synedra* sp. comprises 100 percent of the total population. The remaining species comprise from 1 to 43 percent of the population throughout the year. Significantly, *Tabellaria* sp. makes up 41 percent of the total phytoplankton population during the fall months.

Table 19. – Mt. Elbert Forebay average plankton concentrations during 1982.

Sampling dates, 1982	Concentrations	
	Phytoplankton, number per liter	Zooplankton, individuals per liter
Jan. 7	1 365	43.9
Jan. 19	990	42.0
Feb. 18	457	18.7
Mar. 11	277	6.1
Mar. 25	215	7.6
Apr. 8	157	3.7
Apr. 20	508	5.1
May 20	777	7.0
June 2	3 165	51.3
June 15	1 533	27.7
June 30	514	38.4
July 14	39	5.0
July 27	1 442	30.7
Aug. 11	1 526	11.8
Aug. 26	2 550	14.7
Sept. 22	3 042	36.5
Oct. 6	2 272	25.8
Oct. 20	19 650	46.0
Nov. 5	31 142	74.5
Nov. 17	28 498	37.6

The average zooplankton concentration in the forebay is also presented on figure 50. The zooplankton population declines rapidly from February through mid-April, increases in late spring and early summer, and builds to a peak of 74 individuals per liter in early November (table 19). The high density of zooplankton in October and November correlates with phytoplankton during this time.

The forebay zooplankton population is made up of copepods, rotifers, and a single species of cladoceran (fig. 52). Copepods are predominately *Cyclops* sp., which were collected throughout the year. *Diaptomus* was abundant in February and March and showed slight peaks in June, September, and November. Nauplii were also collected in samples throughout the year and comprised 60 percent of the total zooplankton population in January. The rotifer population increased in abundance in June and comprised 82 percent of the total population. The rotifer population is dominated by *Kellicottia* sp., followed by *Keratella* sp. and *Polyarthra* sp. *Brachionus* sp. was collected only from January to February and, at the most, made up 5 percent of the total population. The cladoceran, *Bosmina* sp., showed a slight peak in March, July, and October, and in June was 6 percent of the total population. *Daphnia* sp. were commonly collected in previous years from the forebay, but in 1982, this was not the case. They disappeared the same time as the pumps brought mysis to the forebay. Cladocera now make up an insignificant proportion of the total zooplankton population in the lakes or forebay.

The forebay shows as diverse a plankton population as the lakes do. A portion of this population will certainly find its way into the lower lake as was seen with *Tabellaria* sp. during the fall months. It will be interesting to see how plankton populations imported from Turquoise Reservoir will affect the forebay and Twin Lakes.

Benthos. – Benthic fauna are important to the overall ecology of a lake because they are decomposers of organic material and also a valuable food source for fish (LaBounty and Sartoris, 1976) [14]. There are four bottom-dwelling benthic organisms commonly collected from Twin Lakes: chironomids (nonbiting midges), oligochaetes (aquatic earthworms), fingernail clams, and the opossum shrimp.

Chironomids belong to the order of flies, Diptera, and the family, Chironomidae. Chironomids live on the bottom of all types of freshwater bodies where they burrow into the lake sediments. Chironomid larvae are chiefly herbivorous and feed on algae, higher aquatic plants, and organic detritus (Pennak, 1978) [39].

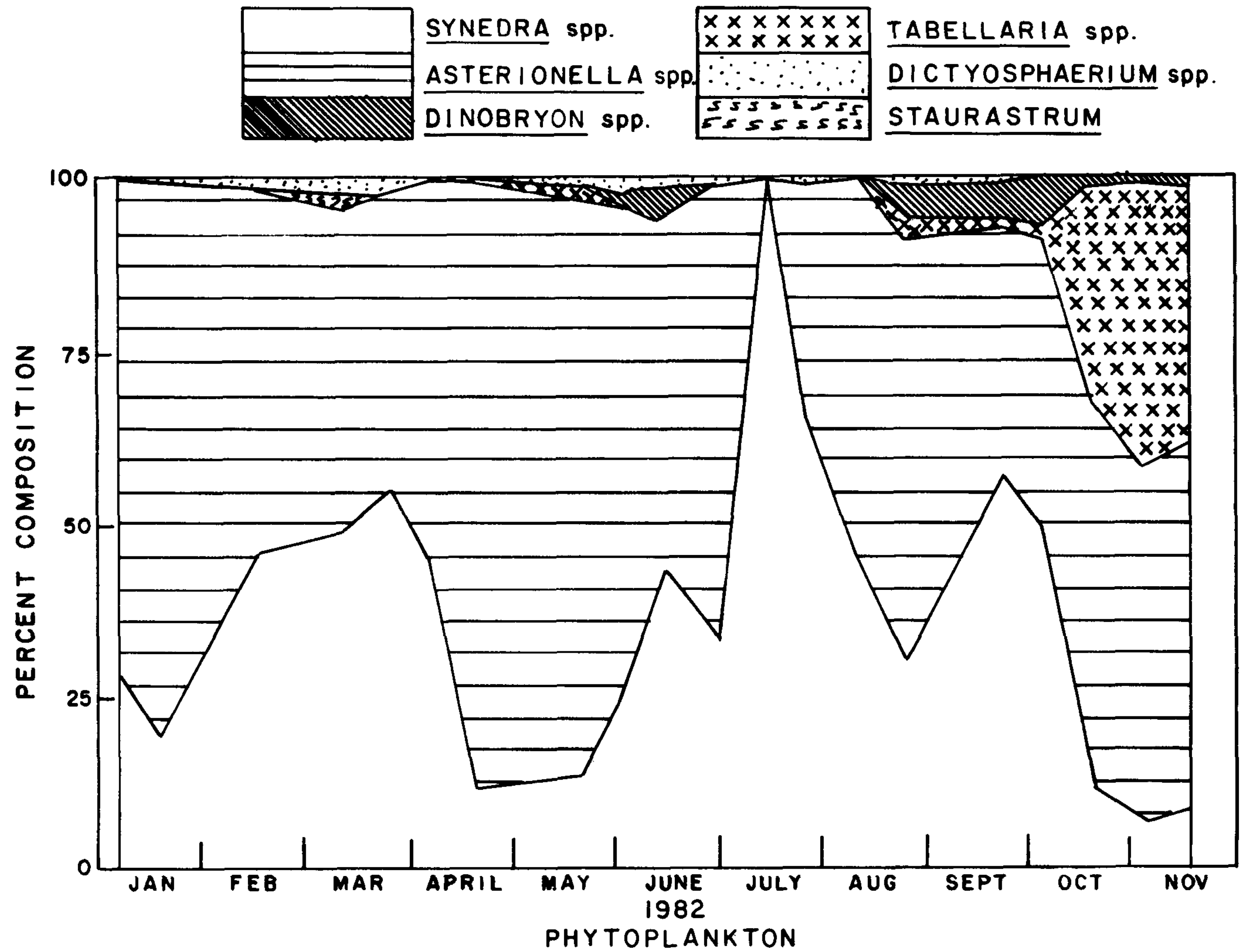


Figure 51. – Species composition of phytoplankton population in Mt. Elbert Forebay during 1982.

Oligochaetes belong to the order of aquatic earthworms, Annelida, and to the family, Oligochaeta. Oligochaetes also burrow into the bottom sediments and feed on bacteria and organic material in the bottom mud.

Fingernail clams are tiny bivalved freshwater mollusks belonging to the order, Pelecypoda; family, Sphaeriidae; and genus, Pisidium. The bivalve clam is found on all types of lake bottoms except clay and rock, and favor substrates composed of sand mixed with other materials (Pennak, 1978) [39]. The two species of fingernail clams found in Twin Lakes are the *Pisidium casertanum* (Poli) and *P. pauperculum* Sterki (LaBounty and Sartoris, 1976) [14].

The opossum shrimp belong to the order Mysidacea, and the genus, Mysid. The species collected at Twin Lakes, *Mysis relicta* Loven is one of only three species that have adapted to freshwater in the United States. Of all the freshwater Crustacea known to exhibit daily vertical migrations, *Mysis relicta* has the most extensive and rapid migrations. *Mysis relicta* remain near the bottom during the day and at dusk migrate to the surface. Downward movements begin at dawn (Pennak, 1978) [39]. Mysids are an important food source for fish, and were introduced into Twin Lakes in 1957 to support the introduced lake trout, *Salvelinus namaycush* Walbaum (Klein, 1957) [40]. Today, the mysids are an important part of the fauna in Twin Lakes, but are only rarely collected in benthic dredge samples.

A comparison of the average number and dry mass of the benthic fauna collected during 1982 is presented in table 20. The lower lake is dominated by chironomids, with an average of 762 individuals per square meter. The fingernail clam, *Pisidium* spp., shows an average of 651 individuals per square meter. Benthos data from 1981 shows *Pisidium* spp. as being the most abundant fauna with 702 individuals per square meter.

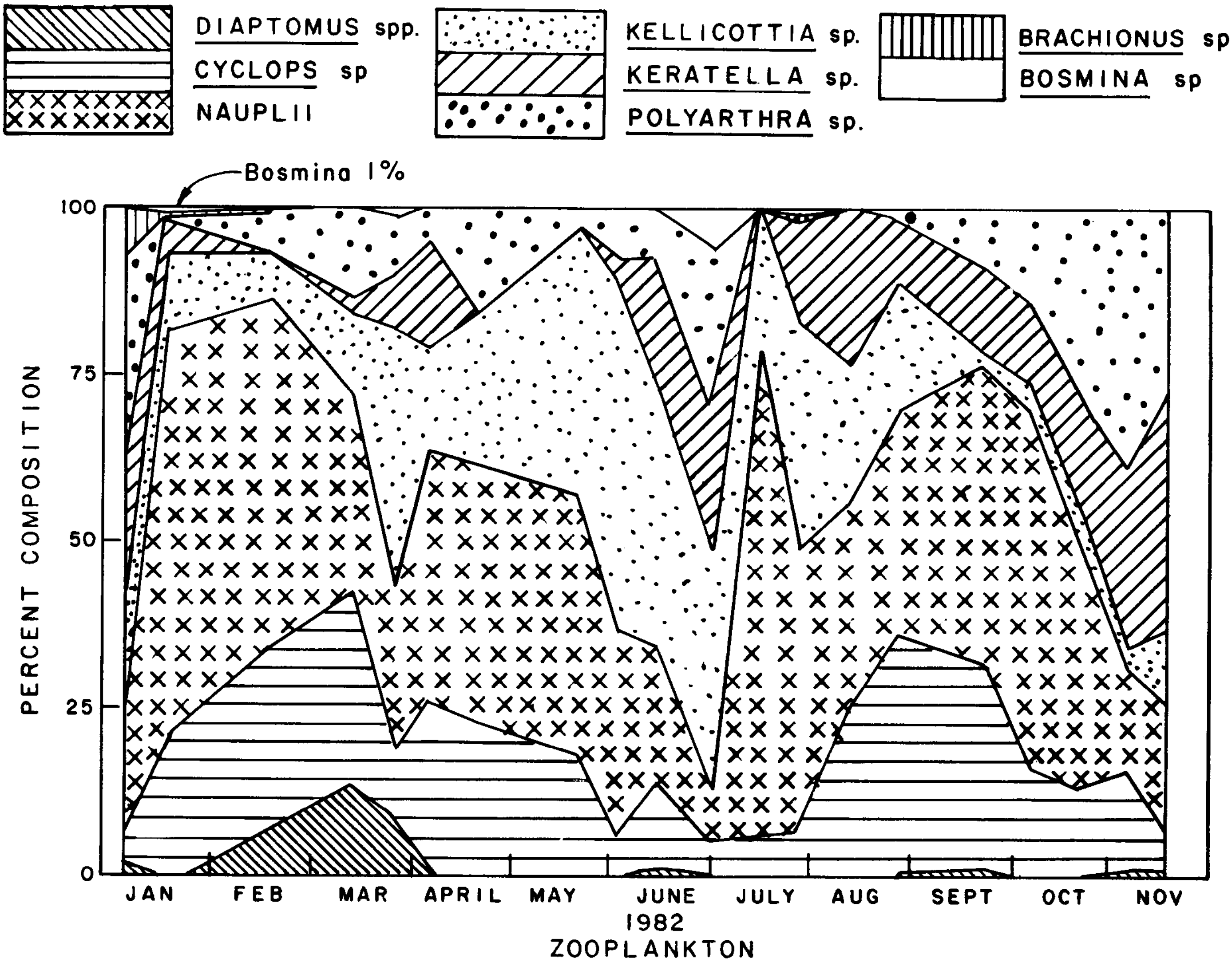


Figure 52. – Species composition of zooplankton population in Mt. Elbert Forebay during 1982.

During 1982, the upper lake was dominated by oligochaetes with 1585 individuals per square meter, followed by a chironomid population of 270 individuals per square meter. The upper lake has a much smaller chironomid population than the lower lake and a much larger oligochaete population. During 1981, more chironomids were collected in the upper lake, 617 individuals per square meter, than in the lower lake, 578 individuals per square meter. The difference in numbers in the chironomid population may be explained by the increase in inflow during the high runoff year of 1982, as compared to the dry year of 1981. This has happened in other years of this study. Wetzel (1975) [41] presented the idea that a general reduction in the number of chironomids and other benthic animals and a concurrent increase in oligochaete worms occurs when a lake becomes more productive. The upper lake also collects a lot of leaf and wood litter as well as heavy metal-laden sediment, especially during early summer when runoff is greatest.

During the fall, it was observed on the field sampling date of October 8, 1982, that the benthic dredge samples contained sand and silt. Sand smothers the chironomid larvae, resulting in a die-off of the maturing larvae and a decrease in the chironomid population. The fluctuation in the benthic population and the decrease in density may also be related to powerplant operation which began in September 1981. All of these factors could cause a shift in population from year to year. Table 21 compares the past 5 years (1978-82) of benthic fauna abundance (excluding the fingernail clam and opossum shrimp) in Twin Lakes. The upper lake has fluctuated in average concentrations from year to year, decreasing to a low in 1979. The lower lake seems to have fluctuated even more, with a drastic decrease in population in 1981 and an increase in 1982.

Table 20. – Summary of benthos data from Twin Lakes during 1982.

Location	Organism	Avg. no. per square meter (23 samples)	Avg. dry mass, g/m² (23 samples)
Lower lake	Chironomids	762	0.85
	Oligochaetes	536	.11
	Pisidium spp.	651	.64
	Mysis relicta	37	.05
Upper lake	Chironomids	270	.50
	Oligochaetes	1585	.33
	Pisidium spp.	54	.03
	Mysis relicta	6	.01

Figures 53 through 56 show the trends in chironomid, oligochaete, clam, and shrimp populations, respectively. The measured density of chironomid larvae in the lower lake fluctuates from May to August; this could be a result of population patchiness. The chironomid larvae are more abundant and have a greater dry mass in the summer months. The upper lake contains a smaller population. The average dry mass of the larvae increased from January to June, as the larvae matured, before the emergence of the adult midge flies. From mid-June to September, the density of larvae decreased and began to increase again in the fall due to recruitment of smaller larvae. The decline in population in the upper lake during the summer was a result of heavy inflows and the increase of silt in the water. Decrease in densities also occurred after ice-off in mid-May, due to maturation of larvae and emergence of terrestrial adult midge flies.

Figure 54 shows the oligochaete concentration and dry mass in both lakes. The greatest abundance in the upper lake occurred during January and February with a decline in population from June to September. The lower lake developed a fluctuating population and a much lower abundance than the upper lake.

The fingernail clam population (fig. 55) fluctuates from year to year. From 1973 to 1976, there were no clams collected from the upper lake. In 1982, a greater abundance of clams were collected from the lower lake than from the upper lake. The lower lake must have a more favorable habitat for the *Pisidium* spp. than the upper lake.

Table 21. – Comparison of average abundances of benthic fauna (excluding mollusks and shrimp), 1978-82.

Location	Average abundances (number per square meter) 1978 (N=28)	1979 (N=34)	1980 (N=28)	1981 (N=38)	1982 (N=23)
Lower lake	1375	2453	2203	986	1298
Upper lake	2114	1814	2740	2243	1855

Note: N indicates number of samples taken.

The shrimp, *Mysis relicta*, is collected infrequently in our benthic dredge samples. Figure 56 shows the relatively few opossum shrimp collected using this method. Mailoie and Bergersen (1983) [21] have developed an accurate method for estimating shrimp densities using a phototrawl, and Nesler (1981) [22] presents an analysis of the relative abundance of mysids in Twin Lakes based on data obtained using a benthic trawl.

Figures 57 through 60 present the mean, standard deviation, and range data of the average abundance and dry mass for benthic fauna from 1979 to 1982. A comparison of the four groups of benthic organisms for the lower lake (figs. 57 and 58), illustrate the relative abundance of the chironomid population. The average chironomid dry mass decreased slightly in 1982. The average abundance and dry mass of the oligochaetes has remained almost stable for the past 4 years. Clam dry mass increased in 1982, but abundance of this mollusk has remained stable from 1980 to 1982.

The most abundant benthic organism collected from the upper lake is the oligochaete (figs. 59 and 60). From 1980 to 1982, oligochaete abundance has remained stable, but dry mass has slightly declined. The chironomid population has been decreasing in abundance for the past 3 years, and dry mass has been decreasing since 1981. Clams comprise only a small portion of the upper lake benthos and seem to be more adapted to living in the substrate of the lower lake. There is only limited value in the shrimp data because of the collection methods used.

For the past 3 years, stable benthic populations seem to have been established for the oligochaetes and

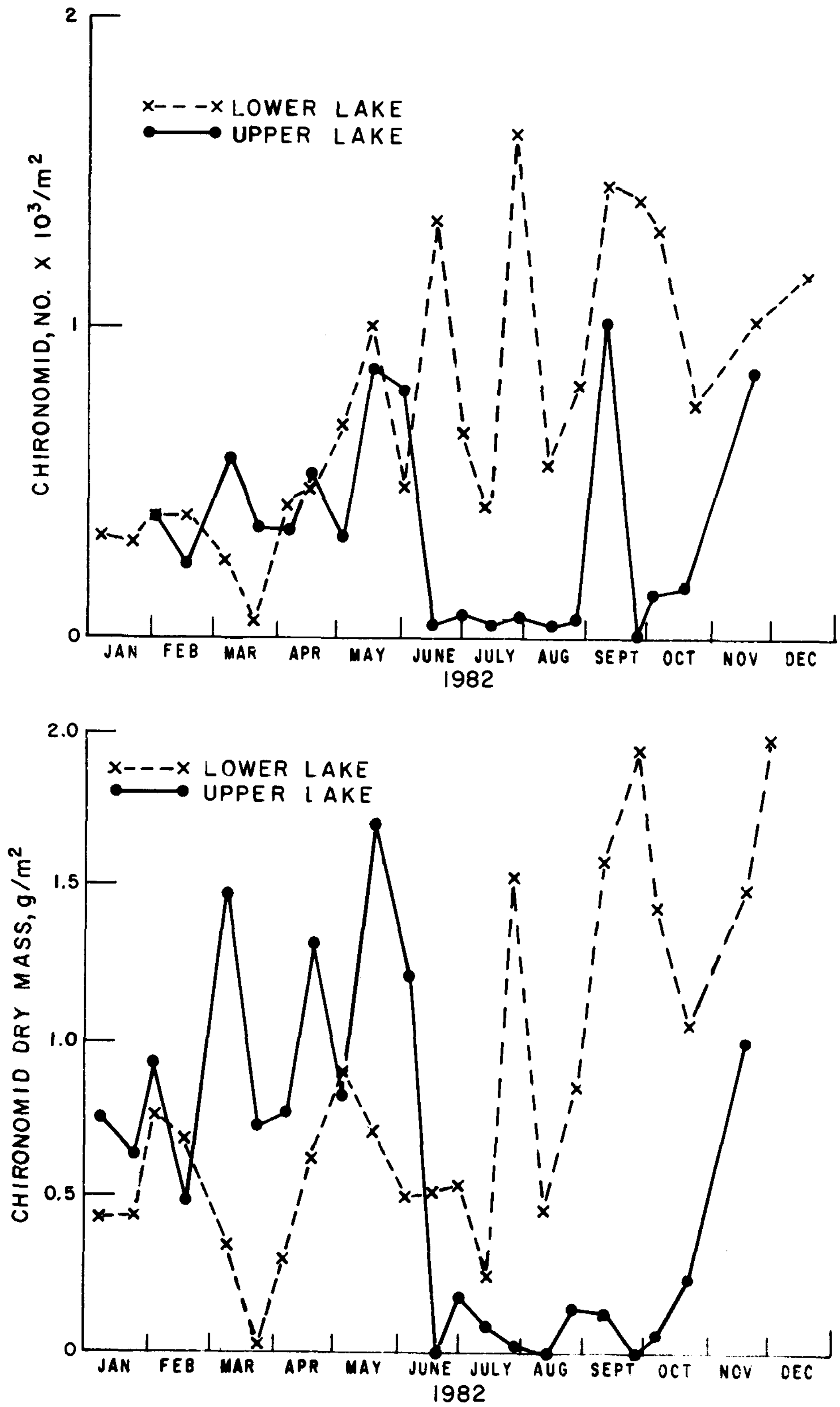


Figure 53. – Abundance and dry mass of chironomids in Twin Lakes during 1982.

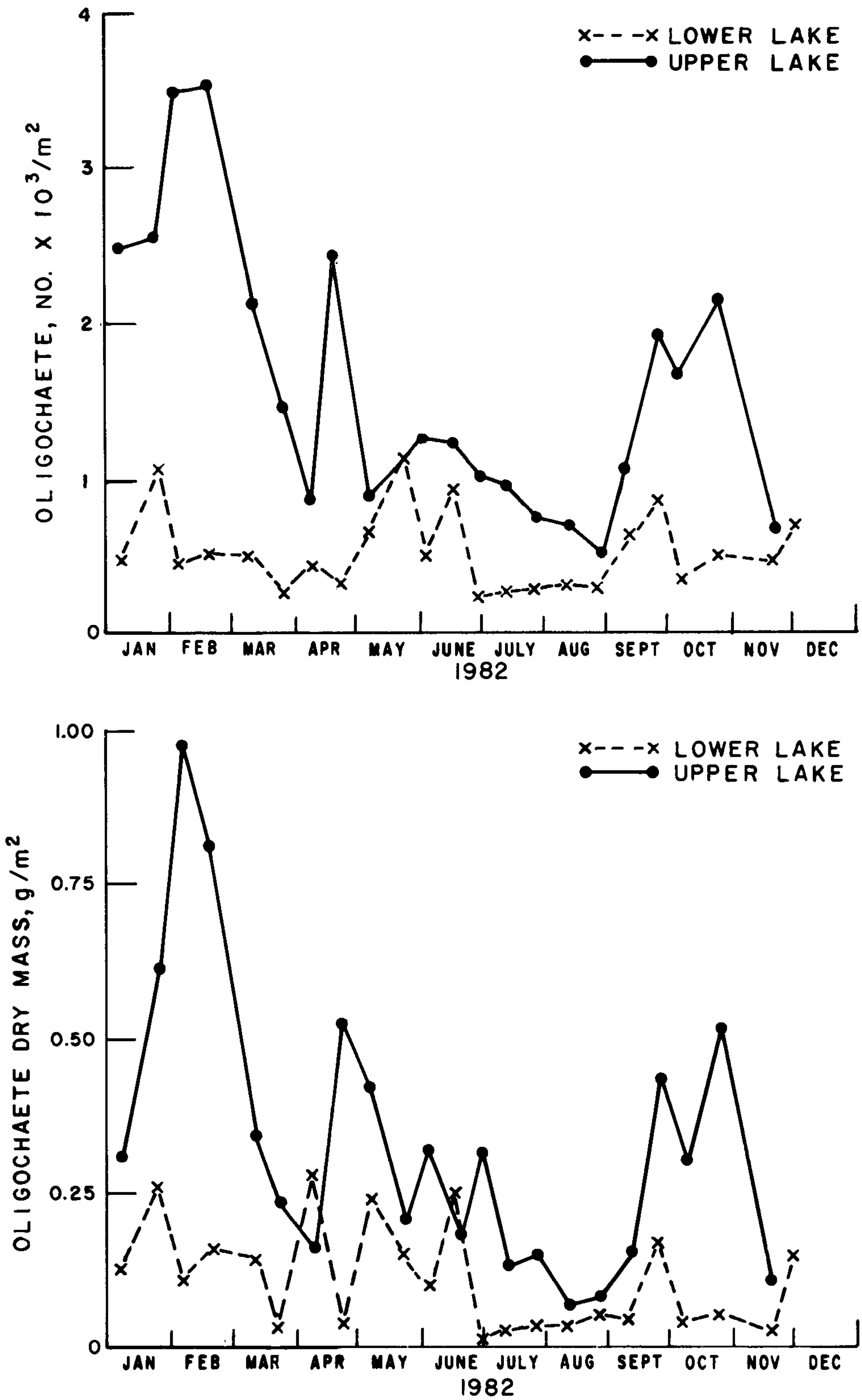


Figure 54. – Abundance and dry mass of oligochaetes in Twin Lakes during 1982.

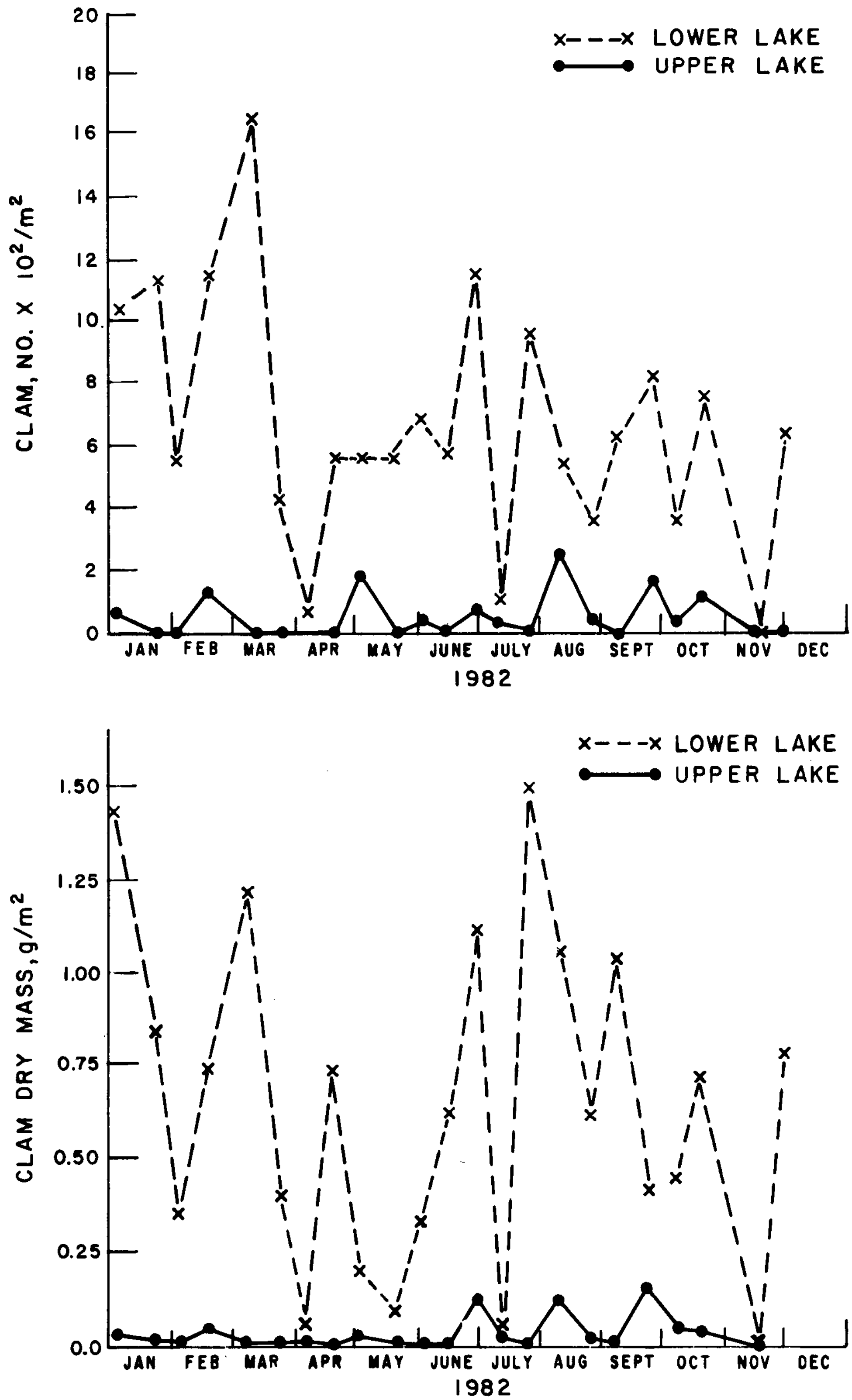


Figure 55. – Abundance and dry mass of clams in Twin Lakes during 1982.

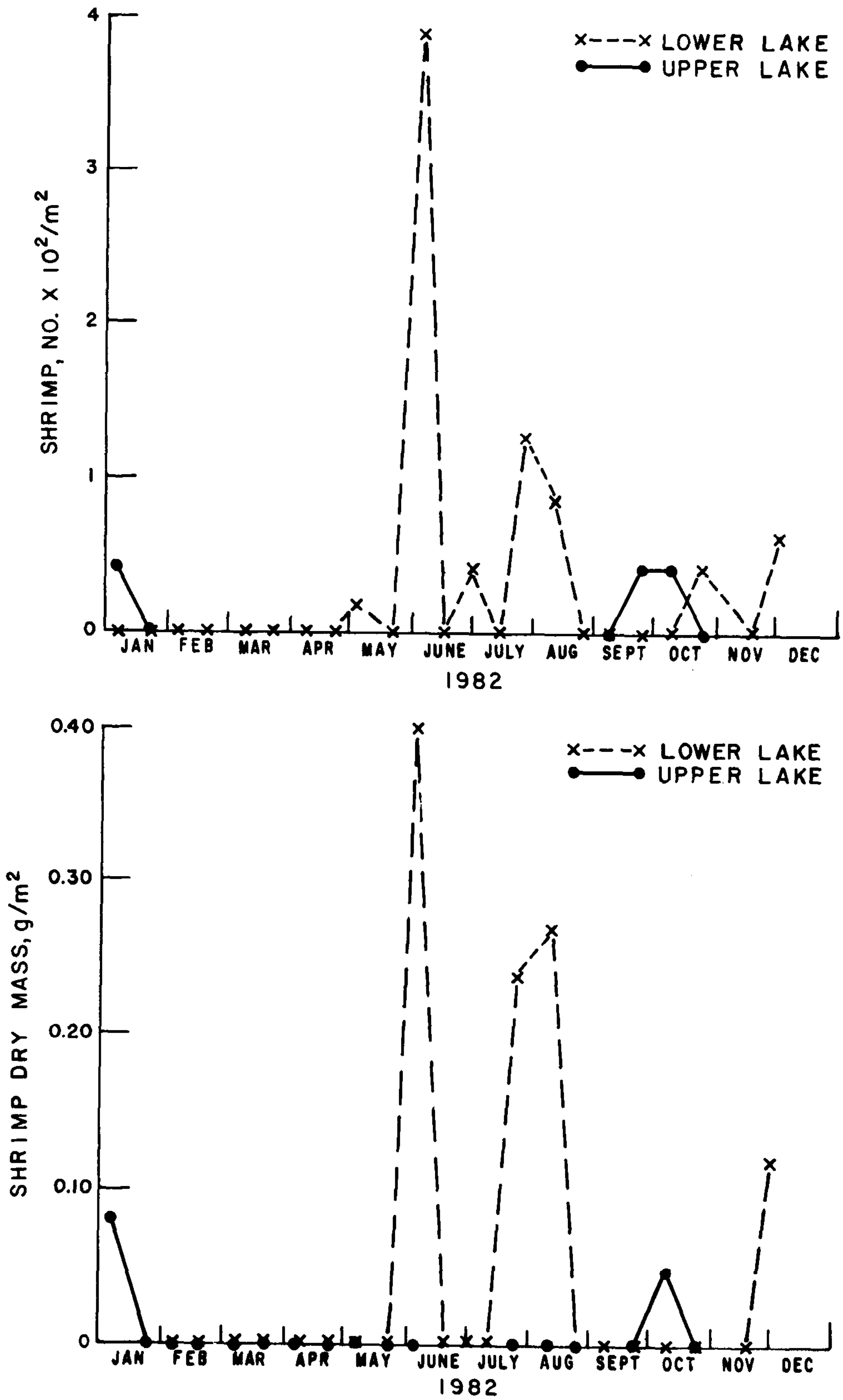


Figure 56. – Abundance and dry mass of shrimp in Twin Lakes during 1982.

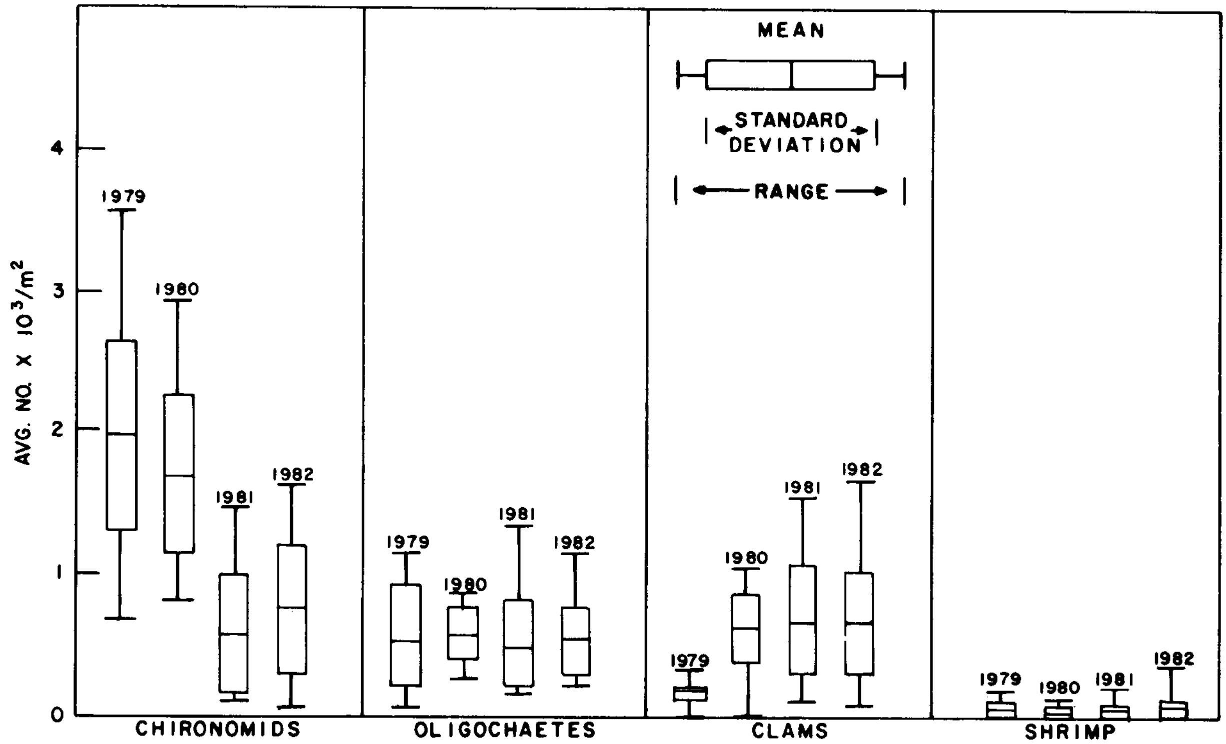


Figure 57. – Average abundance of four types of benthic organisms in lower lake, 1979-82.

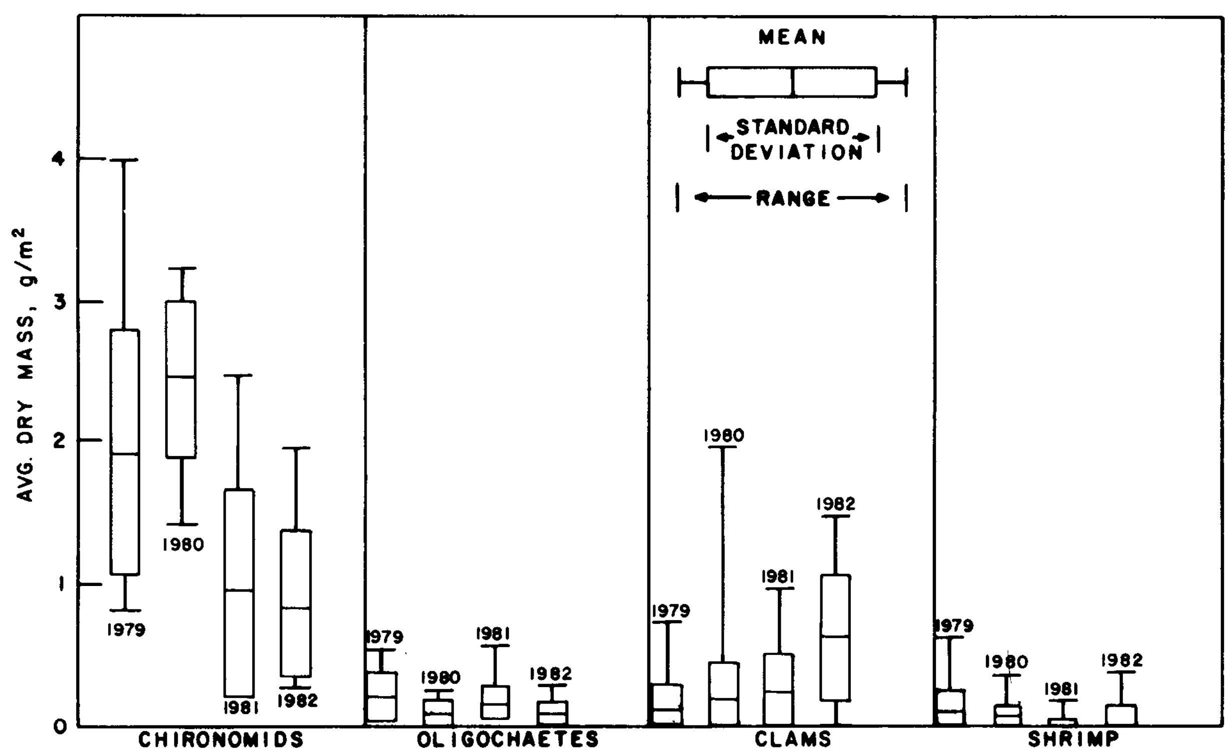


Figure 58. – Average dry mass of four types of benthic organisms in lower lake, 1979-82.

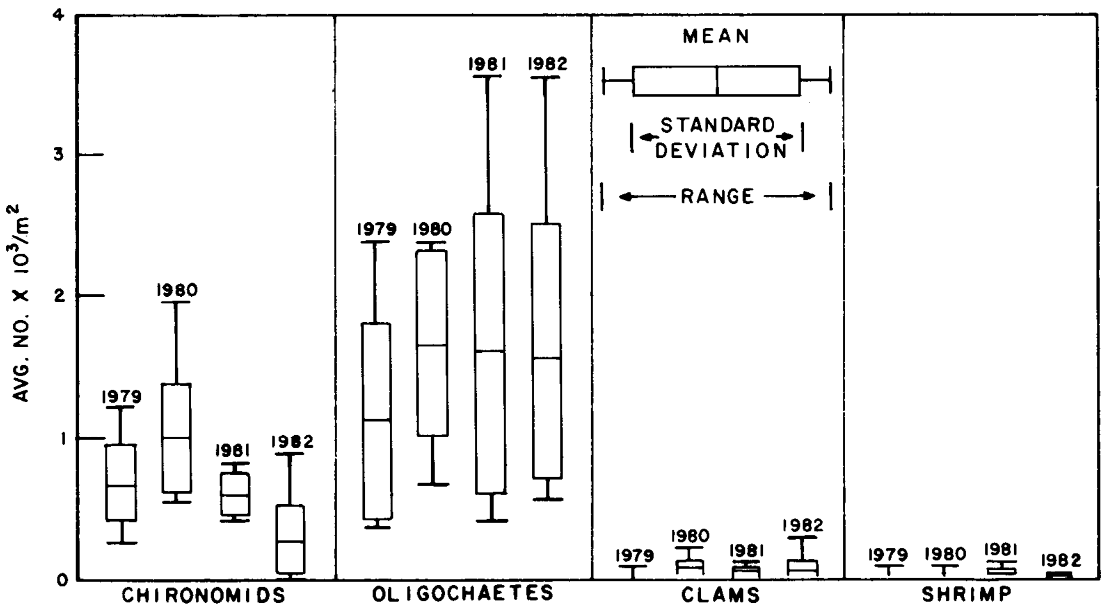


Figure 59. – Average abundance of four types of benthic organisms in upper lake, 1979-82.

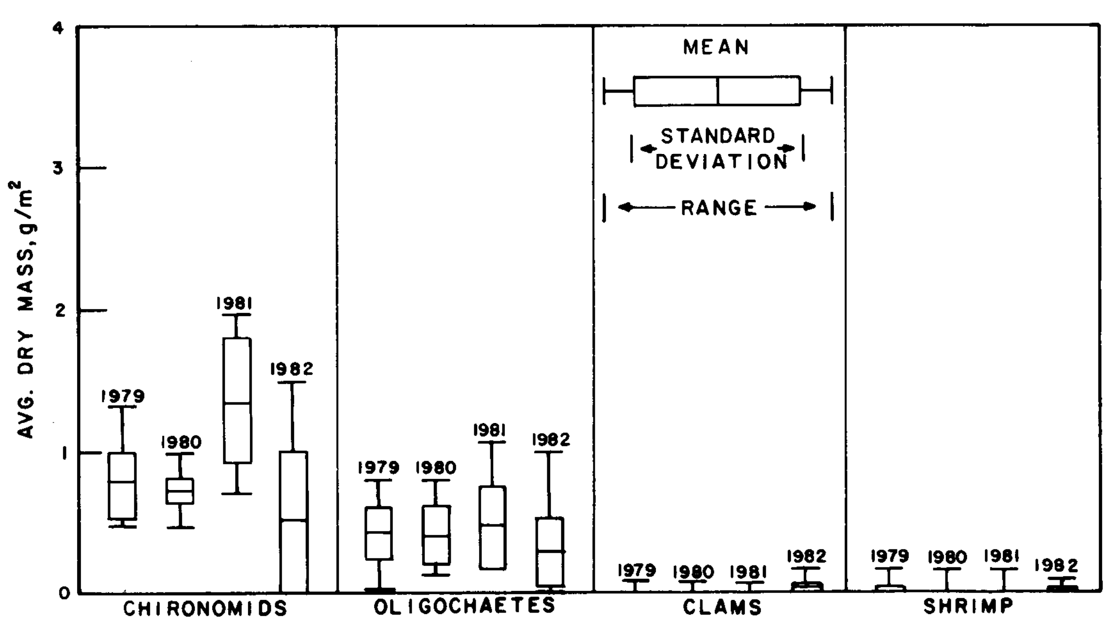


Figure 60. – Average dry mass of four types of benthic organisms in upper lake, 1979-82.

fingernail clams. The chironomid population has decreased in the past 2 years in both lakes. Factors causing the observed decline in chironomid populations could include development of larvae to adult midge flies, heavy inflows, siltation, turbid water, and stirring of bottom sediments by the powerplant, while patchiness could adversely affect population estimates.

Table 22 compares the average abundance of benthos (excluding mollusks) of Twin Lakes with those of other locations selected from the literature. The 1974-79 averages, when compared to the 1980-82 averages, show that the upper lake has become four times more productive than the lower lake in recent years. For 1974-76, the data show that the abundance of benthos in the upper lake was very low due to bottom anaerobic conditions in the hypolimnion. This caused metals to be reduced and toxic concentrations to collect in the bottom waters (LaBounty and Sartoris, 1976) [14]. Benthos in the lower lake has decreased in density by 1.5 times during the last 3 years. In summary, the upper lake has recently established a more productive benthic population than the lower lake because of the overall decline in chironomid populations.

SUMMARY

Tables 23 and 24 show extreme values for some of the key limnological parameters observed at Twin Lakes during 1982. Similar summaries were prepared for the 1980 and 1981 data and are reported in references [15] and [18], respectively.

Comparing the 1981 [18] values with 1982 (table 23) for the lower lake leads to seven major observations:

1. Lower lake was cooler and less stratified in 1982.
2. Conductivity was generally lower in 1982.
3. Light extinction coefficients were higher overall in 1982.
4. Concentrations of nitrogen and phosphorus nutrients were less in 1982.

Table 22. – Comparison of abundances of benthic fauna at Twin Lakes with other selected locations.

Location	Number per square meter	Reference
Twin Lakes, upper lake (1974-79 average)	548	Keefe, 1980 [8]
Twin Lakes, upper lake (1980-82 average)	2279	
Twin Lakes, lower lake (1974-79 average)	2337	
Twin Lakes, lower lake (1980-82 average)	1495	
Great Slave Lake, Canada	1603	Rawson, 1953 [42]
Seminoe Reservoir, Wyoming (4-year average)	1518	Sartoris, et al., 1981 [43]
Alcova Reservoir, Wyoming (3-year average)	4175	Sartoris, el at., 1981 [43]
Waterton Lake, Canada	370	Rawson, 1942 [44]
Loch Levan, Scotland	2027	Maitland, et al., 1970 [45]
Lake Pocasse, S. Dakota	0 to 5220	Roline and LaBounty, 1980 [46]
Candlewood Lake, Conn.	5500	Deevey, 1941 [47]
Lake Cayuga, New York	6000	Henson, 1954 [48]

Table 23. – Extreme readings on selected limnological data from lower lake during 1982.

Parameter	Units	Maximum	Month measured	Minimum	Month measured
Ambient light[1]	g-cal/(cm^2•h)	47.10	Aug.	2.75	Sept.
Wind[1]	km/h	45.0	Oct.	0.3	May
Air temp.[1]	°C	16.7	July	−15.0	Dec.
Water temp.[1] (1-m depth)	°C	16.7	July	1.2	Dec.
Water temp.	°C	16.4	Aug.	0.3	Feb.
Stratification temp. difference	°C	6.8	Aug.	−0.1	Apr.
Water temp. (monthly mean)	°C	12.2	Aug.	1.6	Jan., Feb.
Dissolved oxygen	mg/L	10.8	Mar.	2.0	Sept.
pH	—	8.0	Sept.	6.4	Feb.
Conductivity	μS/cm	73	Feb., Mar.	47	May
Bottom redox potential (E_7)	mV	452	Oct.	261	May
Light extinction coefficient	m^{-1}	0.70	Apr.	0.35	May
Alkalinity	mg/L	19	June	12	Feb.
Mean nitrate nitrogen	μg/L	49	Aug.	<1	Nov.
Mean ammonia nitrogen	μg/L	25	Sept.	<1	Oct.
Mean orthophosphate phosphorus	μg/L	1	Jan., Mar., June	<1	Feb., Apr.-May, July-Dec.
Mean total phosphorus	μg/L	11	Jan.	<1	Aug.
Primary productivity (areal)	mg C/(m^2•d)	134.4	May	6.0	Apr.
Mean chlorophyll concentration	mg/m^3	6.9	Nov.	2.0	Mar.
Avg. phytoplankton concentration	No./L	3823	Nov.	113	Mar.
Avg. zooplankton concentration	No./L	49	June	6	Mar.
Density of chironomid larvae	No./m^2	1623	July	66	Mar.
Density of oligochaetes	No./m^2	1154	May	240	June
Density of pea clams	No./m^2	1645	Mar.	0	Nov.

[1] Daily average from continuous monitoring system at station 3.

5. Plankton concentrations were less in 1982.
6. Primary production rates and cholrophyll concentrations were similar for 1981 and 1982.
7. Benthos densities were similar in 1981 and 1982.

The main change in the regime of the lower lake from 1981 to 1982 was the operation of Mt. Elbert Powerplant, which began in September 1981. Most of the seven observations noted above can be explained in terms of the hydrodynamic effects of pump generation and the dilutional effect of importing water from Turquoise Reservoir and Halfmoon Creek. Observations (5) and (6) would seem to indicate a shift to sub-net-sized phytoplankton in 1981.

The following observations were based on a comparison of 1981 [18] and 1982 (table 24) data for the upper lake:

1. Upper lake was cooler in 1982.
2. Lake Creek inflow was much greater in 1982 (a 69 percent increase in peak inflow volume over 1981).
3. Light extinction coefficients were somewhat greater in 1982.
4. Concentrations of nitrogen and phosphorus nutrients were lower in 1982.
5. Plankton concentrations were less in 1982.
6. Primary production rates and chlorophyll concentrations were lower in 1982.

Table 24. – Extreme readings on selected limnological data from upper lake during 1982.

Parameter	Units	Maximum	Month measured	Minimum	Month measured
Water temp.	°C	14.8	July	0.3	Feb.
Stratification temp. difference	°C	8.9	July	0.1	Nov.
Water temp. (monthly mean)	°C	9.2	Aug.	2.2	Jan., Feb.
Dissolved oxygen	mg/L	11.0	Feb.	2.4	Mar.
pH	—	8.0	Oct.	6.3	Mar.
Conductivity	μS/cm	103	Mar.	53	June, July, Aug.
Bottom redox potential (E_7)	mV	477	Oct.	298	May
Lake Creek inflow volume (monthly total)	$m^3 \times 10^7$	7.54	June	0.13	Feb.
Light extinction coefficient	m^{-1}	0.89	June	0.29	Mar.
Alkalinity	mg/L	27	Jan.	14	Feb., July
Mean nitrate nitrogen	μg/L	57	Mar., Nov.	33	May
Mean ammonia nitrogen	μg/L	18	Feb.	<1	Oct., Nov.
Mean orthophosphate phosphorus	μg/L	<1	All year	<1	All year
Mean total phosphorus	μg/L	5	July	<1	Feb.-Apr., June, Aug., Oct.
Primary productivity (areal)	mg C/($m^2 \cdot$d)	68.4	May	3.6	July
Mean chlorophyll concentration	mg/m^3	5.2	Nov.	0.4	June, July
Avg. phytoplankton concentration	No./L	1667	Nov.	33	July
Avg. zooplankton concentration	No./L	22	Jan.	3	July
Density of chironomid larvae	No./m^2	1016	Sept.	16	Sept.
Density of oligochaetes	No./m^2	3550	Feb.	540	Aug.
Density of pea clams	No./m^2	249	Aug.	0	Mar., Apr., Nov.

7. Among the benthic populations, the densities of clams and chironomids were greater in 1982.

Observation (2), on the increase in inflow, has a high influence on the other six observations.

In general, 1982 was notable for the high volume of inflow into the upper lake, and because of the first full year of powerplant operation. Both events had the overall effect of flushing and diluting the lakes.

Table 25 compares the 1982 data with criteria proposed by Likens [36] for the trophic classification of lakes. The results of this comparison are summarized in table 26. Once again, the Twin Lakes fall definitely within the oligotrophic category.

Table 25. – Selected limnological characteristics of Twin Lakes compared to parameters by Likens (1975) [36] to categorize trophic status.

Lake	Mean primary productivity, mg C/(m²·d)	Total organic carbon, mg/L	Chlorophyll *a*, mg/m³	Dominant phytoplankton	Light extinction coeff., m^{-1}	Total P, µg/L	Total N, µg/L
Lower lake (1981)	80.1	[1]1.6-2.1	2.0-6.9	Bacillariophyceae,	0.35-0.70	<1-11	[2]81-180
Upper lake (1981)	32.0	[1]1.4-1.7	0.4-5.2	Bacillariophyceae, chrysophyceae	0.29-0.89	<1-15	[2]135-177
Ultra-oligotrophic	<50		0.1-0.5	Chrysophyceae, cryptophyceae	0.03-0.8	<1-5	<1-250
Oligotrophic	50-300	<1-3	0.03-3	Dinophyceae, Bacillariophyceae	0.05-1.0		
Oligo-mesotrophic						5-10	250-600
Mesotrophic	250-1000	<1-5	2-15		0.1-2.0		
Mesoeutrophic						10-30	500-1100
Eutrophic	>1000	5-30	10-500		0.5-4.0		

[1] As measured in 1975
[2] Total N measured only in Nov.

Table 26. – Categorization of trophic status of Twin Lakes based on data in table 25.

Parameter	Upper lake	Lower lake
Primary productivity	Ultra-oligotrophic	Oligotrophic
Chlorophyll *a*	Ultra-oligotrophic-mesotrophic	Oligotrophic-mesotrophic
Dominant phytoplankton	Ultra-oligotrophic-oligotrophic	Oligotrophic
Light extinction coefficient	Ultra-oligotrophic-oligotrophic	Ultra-oligotrophic-oligotrophic
Total organic carbon	Oligotrophic	Oligotrophic
Total P	Ultra-oligotrophic	Oligotrophic-mesoeutrophic
Total N	Ultra-oligotrophic	Ultra-oligotrophic

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Note: From Nov. 1979 to May 1981, the Bureau of Reclamation was known as the Water and Power Resources Service; consider the names synonymous in the Bibliography.

APPENDIX

Preliminary Investigations of the Macroinvertebrate Populations in Lake Creek, Colorado, Above and Below Twin Lakes, Colorado.

OPTIONAL FORM NO. 10
JULY 1973 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

Memorandum

Denver, Colorado

TO : Chief, Applied Sciences Branch

DATE: December 9, 1982

FROM : Head, Environmental Sciences Section

SUBJECT: Preliminary Investigations of the Macroinvertebrate Populations in Lake Creek, Colorado, above and below Twin Lakes Colorado

Applied Sciences Referral No. 83-2-8

Investigations by: S. G. Campbell

INTRODUCTION

A study of macroinvertebrate populations in Lake Creek, Colorado, was conducted from April through September 1981. Lake Creek is the principal source of inflow to Twin Lakes, Colorado. As part of the ongoing assessment of pumped-storage powerplant operation on the limnology of Twin Lakes (DR-331), two related studies on Lake Creek have already been performed. Water quality sampling from 1975-76 identified the South Fork of Lake Creek as the source of heavy metals entering Twin Lakes (Sartoris, et al., 1977). An algal growth potential test performed on waters collected along Lake Creek in August 1979 indicated that inhibition of algal growth can occur in waters of the south fork of Lake Creek (Campbell, 1980). With these two factors in mind, it was decided to investigate macroinvertebrate populations at sites above and below Twin Lakes in order to further elucidate the factors influencing biological productivity in Lake Creek.

METHODS AND MATERIALS

Physical-chemical parameters, including water temperature (°C), hydrogen ion concentration (pH), dissolved oxygen concentration (mg/L), and conductivity (µS/cm), were measured in situ with a Hydrolab 1/ multiparameter probe and samples for analyses of major ions, phosphorus and nitrogen compounds, and heavy metal concentrations were collected. Samples for phosphorus and nitrogen compound analysis were frozen immediately after collection. Samples

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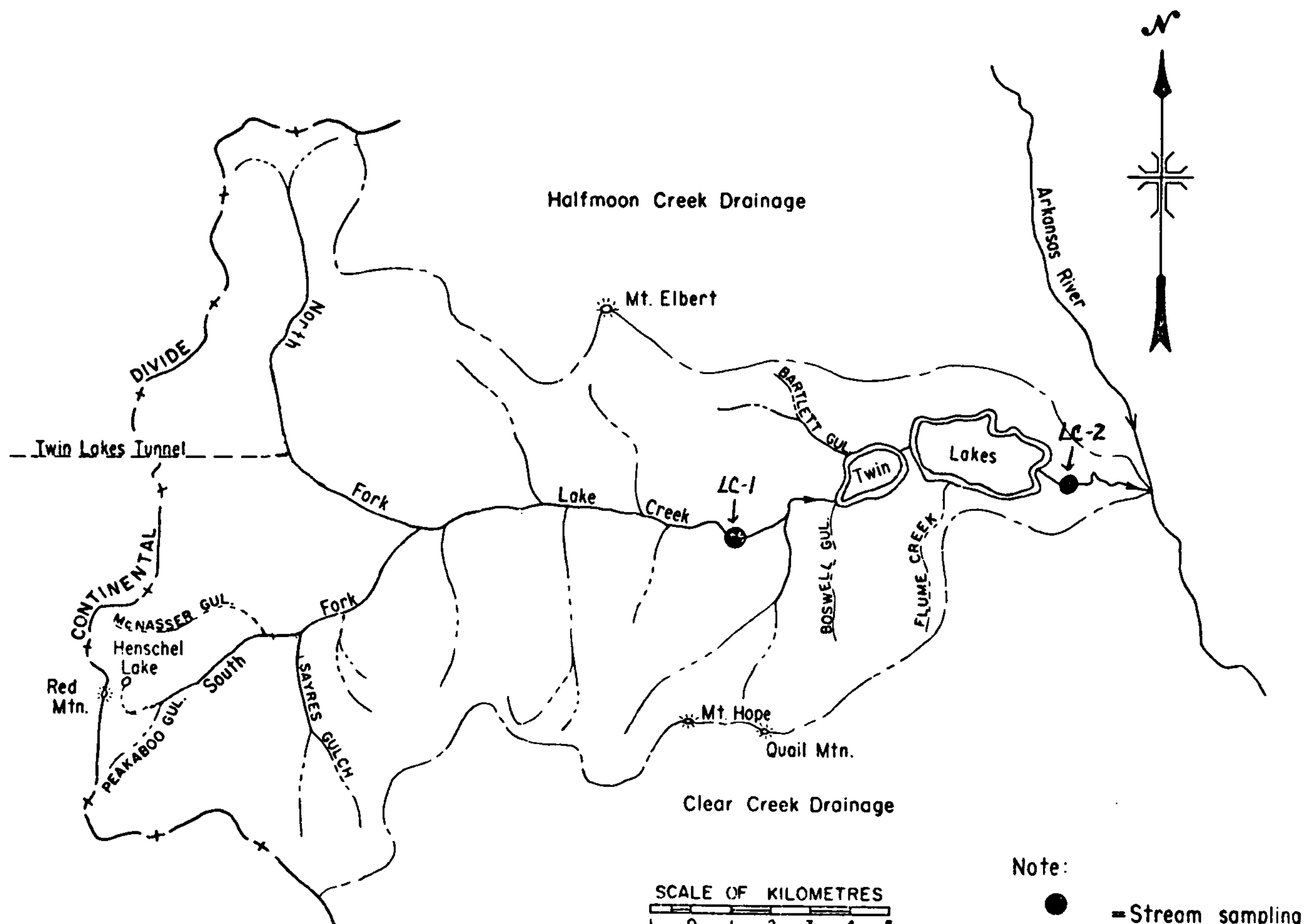


(Adapted from U.S.F.S. map of San Isabel Nat'l Forest, Colo.)

FIGURE 1

for heavy metal analysis were preserved with 1-mL concentrated nitric acid per 240-mL water immediately after collection. Major ion analysis was performed as outlined by Ellis (1981). Analysis for phosphorus and nitrogen compounds and heavy metals was performed as described in "Standard Methods," APHA, (1976).

Benthic invertebrates were sampled using two types of samplers: a Surber sampler and barbecue basket artificial substrate samplers. The Surber sampler is widely used and consists of scrubbing and/or stirring the substrate within a 30-cm square frame lying on the stream bottom (Surber, 1937). By orienting the sampler with the current flowing toward the net, dislodged organisms are carried into the net bag and retained. After three replicate samples were obtained and combined, the net bag was emptied into a white porcelain tray. Large pieces of debris or rocks were removed, and the organisms were preserved in 10 percent formalin for later enumeration and identification.

Barbecue basket artificial substrate samplers were used at both stations. Each basket was filled with redwood bark chips (Bergersen and Galat, 1975). Baskets were in place at each sampling site for approximately 4-week intervals from April through September. Processing of bark contents consisted of scrubbing each chip with a stiff bristle brush to remove adhering organisms and hand picking to separate organisms from debris. Organisms were preserved in 10 percent formalin for later enumeration and identification.

Statistical analysis of benthic data consisted of calculation of mean diversity ($\bar{d}$) and equitability (e). Mean diversity was calculated using the Shannon-Weaver equation reported in Wilhm and Dorris (1968) as follows:

$$\bar{d} = \sum_{i=1}^{S} \frac{N_i}{N} \log_2 \frac{N_i}{N}$$

Where: S = total number of genera in the sample
N_i = number of organisms in the i^{th} genus
N = total number of organisms in the sample

Equitability was determined from the relationship reported in Lloyd and Gehlardi (1964) as follows:

$$e = \frac{S'}{S}$$

Where: S = total number of genera in the sample
S' = the number of genera expected from a community that conforms to the MacArthur "broken stick" model of species distribution (tabulated values)

RESULTS AND DISCUSSION

Lake Creek flows generally east through Twin Lakes into the Arkansas River (fig. 1). Flows in the North Fork of Lake Creek are increased by releases from Grizzly Lake in the Roaring Fork drainage through the Twin Lakes Tunnel above the confluence with the South Fork of Lake Creek. Lake Creek then flows into Upper Twin Lake, through Lower Twin Lake, and a short distance below Twin Lakes, into the Arkansas River. Two streamsites were selected for evaluation of macroinvertebrate populations:

LC-1 - Lake Creek above Twin Lakes, used for water quality sampling since 1972

LC-2 - Lake Creek below Twin Lakes, used for water quality sampling since 1979

Sampling, which included water quality, benthos, air and water temperatures, and occasional physical-chemical measurements with a multiparameter probe, occurred at approximately monthly intervals.

Physical-chemical Parameters

Waters in Lake Creek were generally clear and cold. Mean water temperature averaged 9.3 °C with a range between 2 and 17 °C for the study period April-September 1981. Conductivity averaged 90 μS/cm with a slight increase in conductivity observed below Twin Lakes. Dissolved oxygen concentrations averaged 9.05 mg/L in Lake Creek throughout the study and were always near 100 percent saturation. Dissolved oxygen was always above the 5-mg/L minimum concentration recommended by the EPA (Environmental Protection Agency) (1976) for freshwater aquatic life. Mean hydrogen ion concentration (pH) at both stations was 7.45, well within the range of 6.5 to 9.0 recommended by the EPA (1976) for protection of freshwater fish and bottom-dwelling invertebrates.

Major Ion Analysis Data

A comparison of mean major ion concentrations in Lake Creek with water quality criteria recommended by EPA (1976) and McKee and Wolf (1963) is shown in table 1.

Table 1. - A comparison of mean major ion concentrations in Lake Creek to those listed in two water quality criteria references

Major ions	Concentration (mg/L) LC-1	LC-2	Concentration (mg/L) in EPA (1976) or McKee and Wolf (1963)
TDS (total dissolved solids)	57.0	42.0	250
Calcium	11.9	9.6	None
Magnesium	1.9	1.6	14.0
Sodium + potassium	1.2	0.9	85.0
Bicarbonate alkalinity	26.2	25.0	*20.0
Sulfate	14.8	10.7	90.0
Chloride	1.8	1.8	170.0

* A minimum value - 95 percent of good fisheries have 20 mg/L or more.

All major ion concentrations were below or within tolerances recommended for the protection of aquatic life by the EPA (1976) or those listed in McKee and Wolf (1963) below which 95 percent of United States waters having good fisheries are found.

Nitrogen and Phosphorus compounds Analysis Data

A comparison of mean nitrogen and phosphorus compound concentrations in Lake Creek to those recommended by EPA (1976) for the protection of aquatic life indicates that nutrients needed for primary productivity are quite low (table 2).

Table 2. - A comparison of nitrogen and phosphorus compound concentrations found in Lake Creek during 1981 to those listed in EPA (1976) for the protection of aquatic life

Nitrogen or phosphorus compound	LC-1	LC-2	EPA
Ammonia, un-ionized NH_3 (mg/L)	0.012	0.006	0.02
Nitrite, NO_2 (mg/L)	0.018	0.002	1.00
Nitrate, NO_3 (mg/L)	0.049	0.019	10.00
Phosphate, PO_4 (mg/L)	0.005	0.004	0.05

Table 3. - Annual mean heavy metal concentrations (mg/L) in Lake Creek from 1975-1981

Station	Date	Copper	Lead	Iron	Manganese	Zinc
LC-1	1975	0.019	0.0013	0.28	0.011	0.012
	Range	(0.005-0.07)	(0.0005-0.008)	(0.05-0.7)	(0.005-0.02)	(0.005-0.02)
	1978	0.009	0.0013	0.27	0.018	0.006
	Range	(0.005-0.015)	(0.0005-0.003)	(0.05-0.55)	(0.005-0.025)	(0.005-0.02)
	1979	0.014	0.005	0.44	0.015	0.011
	Range	(0.005-0.034)	(0.0005-0.044)	(0.12-1.36)	(0.005-0.025)	(0.003-0.03)
	1980	0.016	0.0015	0.58	0.013	0.008
	Range	(0.998-0.031)	(0.0005-0.006)	(0.05-3.54)	(0.005-0.053)	(0.005-0.02)
	1981	0.019	0.0008	0.47	0.017	0.006
	Range	(0.007-0.028)	(0.00005-0.002)	(0.23-1.22)	(0.01-0.04)	(0.005-0.01)
LC-2	1979	0.004	0.0019	0.28	0.013	0.009
	Range	(0.003-0.004)	(0.0005-0.005)	(0.05-0.77)	(0.01-0.02)	(0.005-0.01)
	1980	0.002	0.0007	0.026	0.007	0.005
	Range	(0.0005-0.003)	(0.0005-0.003)	(0.05-1.34)	(0.002-0.02)	(0.005-0.01)
	1981	0.003	0.0007	0.06	0.011	0.009
	Range	(0.005-0.0044)	(0.00005-0.002)	(0.05-0.08)	(0.005-0.02)	(0.005-0.03)
Detection limit		0.001	0.001	0.10	0.01	1/ 0.01

1/ When concentration was below detection limit, one-half that value was used to calculate the mean.

Twin Lakes, the impoundments between the two Lake Creek stations, are generally described as nutrient, particularly phosphorus, limited (LaBounty and Sartoris, 1981). Data collected for the Lake Creek study show that concentrations of nitrogen and phosphorus compounds coming into Twin Lakes are low, with minor increases observed during spring runoff.

Heavy Metal Concentration Analysis Data

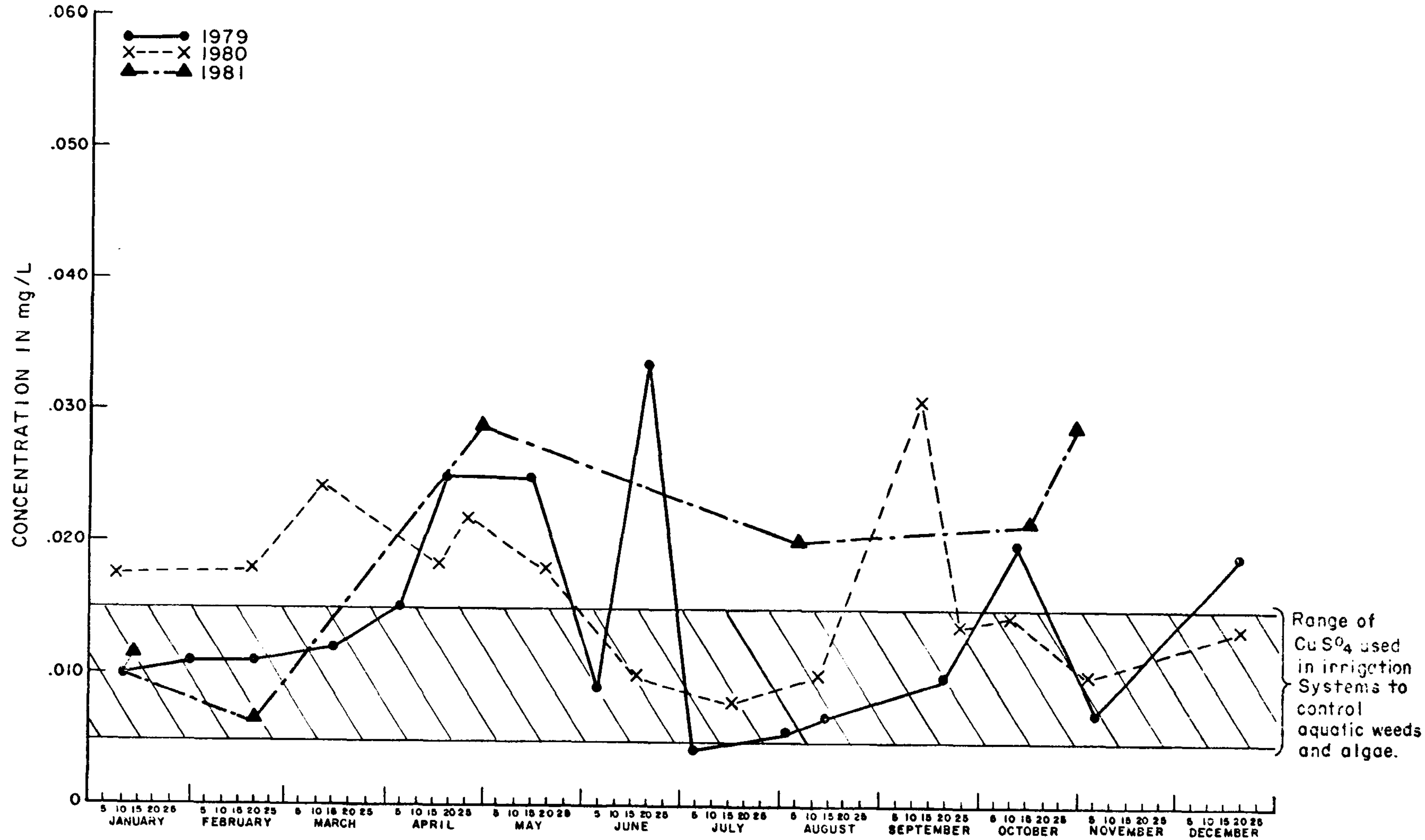
Concentrations of heavy metals in Lake Creek are summarized in table 3. A comparison of mean heavy metal concentrations in Lake Creek to those recommended by EPA (1976) or Davies and Goettl (1976) for the protection of aquatic life is shown in table 4.

Table 4. - A comparison of mean heavy metal concentrations in Lake Creek during 1981 to those recommended by EPA (1975) or Davies and Goettl (1976) for the protection of aquatic life

Metal	LC-1	LC-2	Davies and Goettl and EPA ( )
Copper (mg/L)	0.019	0.002	0.01 (1.0)
Lead (mg/L)	0.0008	0.0007	0.004 (0.005)
Iron (mg/L)	0.47	0.06	0.5 (1.0)
Manganese (mg/L)	0.017	0.011	1.0 (0.05)
Zinc (mg/L)	0.006	0.009	0.05 (5.0)

Concentrations of zinc, manganese, and lead were always below levels shown to be toxic to benthic invertebrates (Warnick and Bell, 1969; Wooldridge and Wooldridge, 1969). Iron, which is considered to be nontoxic in concentrations up to 1.0 mg/L (EPA, 1975), sometimes exceeds this level for short periods of time during spring runoff. Warnick and Bell (1969) showed iron to be acutely toxic to a coleopteran at 0.32 mg/L. Concentrations of copper in samples from LC-1, however, are usually above or at the limit (0.01 mg/L) recommended by Davies and Goettl (1976) for the protection of aquatic life.

In addition, copper concentrations in Lake Creek above Twin Lakes are usually (97 percent of all sampling dates) within or above the range, 0.005-0.01 mg/L, listed by Bartley (1976) used to control algae in irrigation systems. Figure 2 is a plot of copper concentrations at LC-1 with the range of copper necessary to control algae superimposed. Although an abundance of algae was observed in Lake Creek below Twin Lakes, no algae was observed in Lake Creek above Twin Lakes where copper concentrations are in this range. High concentrations of copper naturally occurring in Lake Creek above Twin Lakes may prevent growth of algae which are food and habitat for macroinvertebrates.



CONCENTRATION OF COPPER IN LAKE CREEK INFLOW TO TWIN LAKES, COLORADO

FIGURE 2

Copper concentrations may also be high enough to inhibit bacterial and fungal growth above Twin Lakes. Solutions of copper in the form of Bordeaux's solution have been used extensively to control fungus diseases of agricultural crops (Walker, 1969). Aquatic insects prefer to utilize leaf litter in streams which have been "conditioned" by bacterial and fungal action (Peckarsky, 1980). Leaf litter observed in the streambed above Twin Lakes from surrounding willows and aspen did not appear to be utilized as food by aquatic insects. Concentrations of copper in Lake Creek high enough to prevent algal growth may also inhibit growth of bacteria and fungi necessary to condition leaf litter, thus eliminating two sources of food and habitat for macroinvertebrates.

Macroinvertebrate Data

Station LC-1, above Twin Lakes, has been used for regular water quality sampling since 1972. The substrate consists of very compacted boulders and cobbles 1/. Available habitat for macroinvertebrates is limited by the compaction and large particle size of the substrate. Both of the factors, as they increase, tend to reduce the amount of interstitial space available for occupancy by macroinvertebrates. Streambank vegetation is a mixture of willows and aspen, and considerable amounts of leaf litter were observed in the stream prior to runoff and again in early fall.

Station LC-2, below Twin Lakes, has been used for water quality sampling since 1979. The substrate is moderately compacted to uncompacted gravel with a few boulders. Streambank vegetation is mostly willows with a few alder trees across the stream from the sampling site. An abundance of algae was observed growing on rocks in the streambed, and leaf litter was abundant in early spring and fall.

Habitat at LC-2, compared to LC-1, is preferable for macroinvertebrate habitation. LC-2 substrate is less compacted and smaller in particle size than LC-1, which tends to increase the available space for macroinvertebrates. Periphyton in the streambed at LC-2 improves habitat quality since it provides food and living space for invertebrates.

Organisms found in samples of macroinvertebrates from Lake Creek were in four general groups: caddisflies, mayflies, stoneflies, and dipterans. Numerically, most caddisflies were in the genus *Hydropsyche*. Most mayflies were in the genera *Ephemerella* and *Baetis*, and stoneflies were primarily in the genus *Leuctra*. Organisms found in the order Diptera include *Simulium*, *Chironomidae*, *Limnophora*, *Atherix*, *Agabina*, and *Tipula*. A complete list of macroinvertebrate data can be found in table 1, appendix A.

1/ Substrate size was determined using the Unified Soil Classifications system as follows:

Sand	- particles pea size or less (0.074-4.76 mm)
Gravel	- pea size to tennis ball size (4.76-76 mm)
Cobbles	- tennis ball to volley ball size (76-276 mm)
Boulders	- volley ball size or larger (276 mm)

Macroinvertebrates in samples taken at LC-1 were collectors or shredders of organic debris (Merritt and Cummins, 1978). No filter feeding species such as Simulium or net spinning caddisflies such as Hydropsyche, common below Twin Lakes, were seen in samples from LC-1.

Results of Surber Sampling

A summary of macroinvertebrate data in Lake Creek Surber samples is shown in table 5.

Table 5. - Summary of macroinvertebrate population data in Lake Creek Surber samples during 1981

Station	Date 1981	Abundance	$\bar{d}$	e	No. of taxa
LC-1	4-2	22	0	- *	1
	8-20	3	0.92	- *	2
	9-25	4	0	- *	1
LC-2	4-3	402	1.55	0.62	6
	8-20	679	1.76	0.62	7
	9-25	327	0.81	0.25	8

* Not calculated.

Abundance at LC-1 ranged from 3 to 22 organisms per sample, while at LC-2 abundance ranged from 327 to 679 organisms per sample. Abundance at LC-1, with a mean of 10 organisms, was considerably less than the mean abundance of 469 organisms observed at LC-2.

Diversity values ($\bar{d}$) also followed the pattern seen in abundance data (table 5). LC-1 had an average $\bar{d}$ of 0.3 for the three sampling dates. LC-2 had an average $\bar{d}$ of 1.37 for the same three sampling dates. Diversity and abundance in Surber samples of macroinvertebrates were much greater below Twin Lakes than above Twin Lakes.

Equitability values (e) are a way of describing how closely a population conforms to an ideal model for distribution among a number of species within a total population (Wilhm and Dorris, 1968). The model represents the theoretical distribution among species in a mature, stable population. Generally, the closer the equitability value is to 1, the more closely an observed population approximates the model. However, this is true only if sample size is equal to or greater than 100 organisms. Sample size less than 100 organisms invalidates the model comparison. Therefore, e values were not calculated for data from LC-1.

Equitability values for data from LC-2 range from 0.25 to 0.62 with an average e of 0.5. Populations which are subjected to fluctuations in environmental parameters or pollution are usually less stable and less diverse. The location of LC-2 below a reservoir with a highly fluctuating flow from April through October makes this a likely explanation for the low e values calculated for samples taken at LC-2.

Results of Barbecue Basket Sampling

A summary of macroinvertebrate data in Lake Creek barbecue basket samples is shown in table 6.

Table 6. - Summary of macroinvertebrate population data in Lake Creek barbecue basket samples during 1981

Station	Date 1981	Abundance	$\bar{d}$	e	No. of taxa
LC-1	5-21	4	1.0	- *	2
	9-25	33	1.03	- *	5
LC-2	5-21	182	0.92	0.45	5
	9-25	2,725	0.74	0.32	6

* Not calculated.

Abundance in barbecue basket samples from LC-1 and LC-2 averaged 18.5 organisms and 1,450 organisms, respectively. The pattern of decreased abundance above Twin Lakes compared with below Twin Lakes observed in Surber samples was similar to the abundance pattern observed at the two stations in barbecue basket samples.

Diversity values did not follow the same pattern seen in results from Surber samples. Diversity values were slightly higher at LC-1 in the barbecue basket samples with an average $\bar{d}$ value of 1.02 compared to an average $\bar{d}$ value of 0.83 at LC-2. This is somewhat misleading since the diversity values at LC-1 are based on a small number of organisms distributed into a small number of taxa.

Equitability values again were not calculated for samples at LC-1. Average e value for station LC-2 was 0.44, very similar to the average e value of 0.5 observed in Surber samples.

A trend in abundance of organisms was seen in both Surber and barbecue basket macroinvertebrate samples from Lake Creek. LC-1 had much fewer organisms per sample in both types of samplers than LC-2. LC-1 also had consistently fewer taxa represented on each sampling date than did LC-2, although a direct comparison of $\bar{d}$ values between the two stations is impossible because the limited number of organisms at LC-1 tends to bias the index.

SUMMARY

Waters in Lake Creek are clear, cold, and soft ($CaCO_3$ less than 100 mg/L). Concentrations of major ions and nitrogen and phosphorus compounds are all within criteria recommended by EPA (1976) or McKee and Wolf (1963) for the protection of aquatic life. Concentrations of heavy metals at LC-1, particularly copper, do occasionally exceed criteria recommended by Davies and Goettl (1976) for the protection of aquatic life. Copper concentrations at LC-1 are consistently high enough to be within the range recommended by Bartley (1976) of 0.005 to 0.01 mg/L to control algae in irrigation systems.

Benthic populations in Lake Creek above and below Twin Lakes, Colorado, are quite different in abundance and species of organism. LC-1, above Twin Lakes, had a lower abundance than LC-2, below Twin Lakes. Species of net spinning caddisflies and filter feeding blackflies, common in samples of macroinvertebrates from LC-2, were not found in LC-1.

Interacting factors such as food availability, habitat quality, and high concentrations of heavy metals seem to affect populations of macroinvertebrates in Lake Creek. Concentrations of copper occurring naturally in Lake Creek above Twin Lakes exceeded recommended levels for protection of aquatic life and may inhibit the growth of algae, bacteria, and fungi which are important as food, leaf conditioners, and habitat for macroinvertebrates.

The source of heavy metals has previously been identified as the South Fork of Lake Creek. While dilution from the North Fork and the Twin Lakes tunnel seems to mitigate the influence of flows from the South Fork, enough metals may be present to adversely affect the water quality in Lake Creek below the confluence of the South Fork.

This combination of relatively high sustained concentrations of copper, occasional high concentrations of iron, poor quality (very compacted, large particle size) substrate, and lack of algae or suitable leaf litter for food, seem to be responsible for the low abundance of macroinvertebrates observed in Lake Creek above Twin Lakes.

Attachment

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APPENDIX A

Table 1. - Identification and enumeration data from samples obtained in Lake Creek, Colorado, during 1981

	Date of collection: 4-2-81 Sampler: S 1/	
Taxa	LC-1	LC-2
Heptagenia	22	
Ephemerella		150
Baetis		209
Hydropsyche		
Brachycentrus		
Ryacophila		
Glossosoma		
Isoperla		
Alloperla		12
Leuctra		
Allocapnia		
Acroneuriinae		
Limnophora		
Atherix		1
Agabina		
Tipula		
Simulium		15
Chironomidae		15
Oligochaeta		
Total Number	22	402

1/ S = Surber.

APPENDIX A

Table 1. - Identification and enumeration data from samples obtained in Lake Creek, Colorado, during 1981

Date of collection: 8-20-81
Sampler: S

Taxa	LC-1	LC-2
Heptagenia	1	
Ephemerella	2	
Baetis		73
Hydropsyche		343
Brachycentrus		3
Ryacophila		
Glossosoma		
Isoperla		
Alloperla		
Leuctra		
Allocapnia		
Acroneuriinae		
Limnophora		1
Atherix		
Agabina		
Tipula		
Simulium		64
Chironomidae		192
Oligochaeta		3
Total Number	3	679

APPENDIX A

Table 1. - Identification and enumeration data from samples obtained in Lake Creek, Colorado, during 1981

	Date of collection: 9-25-81 Sampler: S	
Taxa	LC-1	LC-2
Heptagenia		
Ephemerella	4	
Baetis		23
Hydropsyche		285
Brachycentrus		2
Ryacophila		
Glossosoma		
Isoperla		
Alloperla		
Leuctra		5
Allocapnia		
Acroneuriinae		3
Limnophora		
Atherix		1
Agabina		
Tipula		
Simulium		7
Chironomidae		
Oligochaeta		
Total Number	4	327

APPENDIX A

Table 1. - Identification and enumeration data from samples obtained in Lake Creek, Colorado, during 1981

Date of collection: 5-21-81
Sampler: BBQ 1/

Genus	LC-1	LC-2
Heptagenia		154
Ephemerella		
Baetis		
Hydropsyche		8
Brachycentrus		
Ryacophila		
Glossosoma		
Isoperla		
Alloperla	2	11
Leuctra		
Allocapnia		
Acroneuriinae		
Limnophora		
Atherix		
Agabina		
Tipula		
Simulium		2
Chironomidae	2	8
Oligochaeta		
Total Number	4	183

1/ BBQ = barbeque basket.

APPENDIX A

Table 1. - Identification and enumeration data from samples obtained in Lake Creek, Colorado, during 1981

	Date of collection: 9-25-81 Sampler: BBQ	
Genus	LC-1	LC-2
Heptagenia		
Ephemerella	1	
Baetis		42
Hydropsyche		348
Brachycentrus		
Ryacophila		2
Glossosoma		
Isoperla		
Alloperla		
Leuctra	27	42
Allocapnia		
Acroneuriinae		1
Limnophora		
Atherix		1
Agabina		
Tipula		
Simulium	1	2,292
Chironomidae	2	24
Oligochaeta		
Total Number	33	2,725

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REC-ERC-

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