REC-ERC-80-7

STUDIES OF THE EFFECTS OF OPERATING THE MT. ELBERT PUMPED-STORAGE POWERPLANT ON TWIN LAKES, COLORADO: 1979 REPORT OF FINDINGS

Engineering and Research Center
Water and Power Resources Service

December 1980

MS-230 (3-78)
Water and Power

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
REC-ERC-80-7		

4. TITLE AND SUBTITLE

Studies of the Effects of Operating the Mt. Elbert Pumped-Storage Powerplant on Twin Lakes, Colorado: 1979 Report of Findings.

5. REPORT DATE

December 1980

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)

J. F. LaBounty, J. J. Sartoris, S. G. Campbell, J. R. Boehmke, and R. A. Roline

8. PERFORMING ORGANIZATION REPORT NO.

REC-ERC-80-7

9. PERFORMING ORGANIZATION NAME AND ADDRESS

Water and Power Resources Service
Engineering and Research Center
Denver, Colorado 80225

10. WORK UNIT NO.

11. CONTRACT OR GRANT NO.

13. TYPE OF REPORT AND PERIOD COVERED

12. SPONSORING AGENCY NAME AND ADDRESS

Same

14. SPONSORING AGENCY CODE

DIBR

15. SUPPLEMENTARY NOTES

Microfiche and/or hard copy available at the Engineering and Research Center, Denver, CO

Edited by BDM

16. ABSTRACT

A series of studies is being performed to qualify and quantify the changes that occur to the limnological features of Twin Lakes because of the Mt. Elbert Pumped-Storage Powerplant, scheduled to begin operation in 1981. Twin Lakes are a pair of dimictic, connected, montane, drainage lakes of glacial origin. This report presents the results of studies done during 1979. These results, along with those from other studies done since 1971 when the project began, are being used to define the preoperational limnology of Twin Lakes.

Maximum water temperature recorded at Twin Lakes during 1979 was 16.4 °C on the surface of the lower lake in August. The lowest dissolved oxygen concentration was 1.3 mg/L near the bottom of the lower lake in April. Hydrogen ion concentration (pH) ranged from 6.3 to 8.6, while conductivity levels were always between 42 and 122 μS/cm. Total phosphorus and nitrate-nitrogen concentrations averaged 1.8 and 46.0 μg/L, respectively. Primary productivity rates ranged from 99 to 21 696 μg carbon/($m^2 \cdot h$). Chlorophyll *a* concentrations averaged about 3 mg/m^3 for all depths and all sampling dates. The phytoplankton was predominantly *Dinobryon, Asterionella, Syndera,* and *Dictyosphaerium.* Besides being significantly lower in abundance, phytoplankton in the upper lake is dominated by *Asterionella* and *Synedra.*

The zooplankton population was dominated by two species of copepods, three species of rotifers, and mysis shrimp. Large pelagic cladocerons are notably absent from Twin Lakes. The benthos of Twin Lakes is dominated by chironomids, oligochaetes, and fingernail clams, averaging 2023, 524, and 132/m^2, respectively, in the lower lake, and, in the upper lake, 682, 1132, and 0/m^2, respectively. Fingernail clams are only rarely found in the upper 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/ lake currents/ meteorological factors/ wind/ surface currents/ fish/ lake trout/ spawning/

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

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

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (THIS REPORT)	21. NO. OF PAGES
Available from the National Technical Information Service, Operations Division, Springfield, Virginia 22161.	*UNCLASSIFIED*	66
(Microfiche and/or hard copy available from NTIS)	20. SECURITY CLASS (THIS PAGE) *UNCLASSIFIED*	22. PRICE

REC-ERC-80-7

STUDIES OF THE EFFECTS OF OPERATING THE MT. ELBERT PUMPED-STORAGE POWERPLANT ON TWIN LAKES, COLORADO: 1979 REPORT OF FINDINGS.

by

James F. LaBounty
James J. Sartoris
Sharon G. Campbell
John R. Boehmke
Richard A. Roline

December 1980

Applied Sciences Branch
Division of Research
Engineering and Research Center
Denver, Colorado

SI METRIC

UNITED STATES DEPARTMENT OF THE INTERIOR ★ WATER AND POWER RESOURCES SERVICE

ACKNOWLEDGMENTS

Funding for this project is provided by the Fryingpan-Arkansas Project, Lower Missouri Region, and the Division of Research (Proj. No. DR-331) of the Water and Power Resources Service. The study is a cooperative effort involving the Water and Power Resources Service, Colorado Division of Wildlife, and the Fish and Wildlife Service's Colorado Cooperative Fishery Research Unit at Colorado State University and is being performed under the supervision of N. E. Otto, Head, Environmental Sciences Section, and L. O. Timblin, Jr., Chief, Applied Sciences Branch. The Chemistry Laboratory of the Chemistry, Petrography, and Chemical Engineering Section performed the chemical analyses.

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island territories under U.S. administration.

On November 6, 1979, the Bureau of Reclamation was renamed the Water and Power Resources Service in the U.S. Department of the Interior. The new name more closely identifies the agency with its principal functions — supplying water and power.

CONTENTS

TABLES

FIGURES

CONTENTS

FIGURES — CONTINUED

INTRODUCTION

The present ecological studies of Twin Lakes began in 1971. The purpose of these studies is to document the effects of constructing and operating the Mt. Elbert Pumped-Storage Powerplant on the ecology of Twin Lakes, Colorado. Data from this project will be used to enhance the planning process of other projects. Initial operation of the power plant is planned for 1981.

Reports of the results of other activities, up to the date of this report, can be found in LaBounty (1975 and 1976) [15, 16][1], LaBounty and Sartoris (1976) [19], LaBounty et al. (1976) [17], Bergersen (1976) [3], Deason (1976) [6], Gregg (1976) [8], Griest (1977) [10], Sartoris, et al. (1977) [25], Walch (1979) [26], Krieger (1980) [14], Finnell (1980) [7], and LaBounty and Roline (1980) [18]. In addition, since 1976 quarterly activity reports have been prepared as Applied Sciences Referral Memorandums and are on file at the Water and Power Resources Service, Engineering and Research Center, Denver, Colorado. Sartoris, et al. (1977) [25], gave a comprehensive report on the physical and chemical limnology of Twin Lakes through 1976. Comprehensive reports on the biological limnology of Twin Lakes since 1971, excluding the fishery, are in preparation at the time of this report. The data presented here are almost exclusively from calendar year 1979. A progress report of work done in 1979 by the Colorado Cooperative Fishery Research Unit, under contract to the Water and Power Resources Service to provide information on the fishery of Twin Lakes, is included as an appendix.

Since the Mt. Elbert Pumped-Storage Powerplant is scheduled to begin operation in 1981, all the results thus far presented are of preoperation conditions. Following the commencement of powerplant operation, the same studies of Twin Lakes limnology will be repeated for a minimum of 3 years. In this manner, a comprehensive and relatively accurate analysis of the effects of operating the Mt. Elbert Pumped-Storage Powerplant on the aquatic ecology of Twin Lakes can be made. It is presently planned that the field studies at Twin Lakes will continue into 1984.

[1] Numbers in brackets refer to entries in bibliography.

APPLICATION

Results of this study will be combined with other preoperational data to describe the existing physical, chemical, and biological limnology of Twin Lakes. Those involved in predicting effects of planned powerplants will find data from these studies helpful; in fact, these data are already being used by the Water and Power Resources Service in preparing designs and plans of other pumped-storage facilities. Finally, results of these studies will be valuable to anyone involved in the study of lake ecosystems, especially those in mountainous regions.

GENERAL DESCRIPTION

Twin Lakes is located on Lake Creek at the eastern front 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 [4]). Twin Lakes probably originated with the morainal damming of Lake Creek (Sartoris, et al. 1977 [25]). Bottom topography and shoreline of Twin Lakes are shown on figure 2.

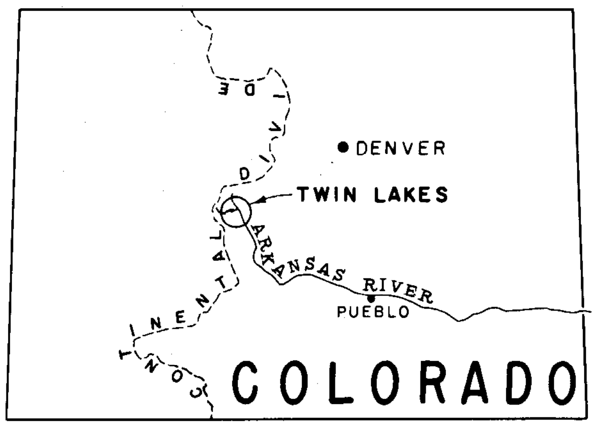


Figure 1.—General location map of Twin Lakes, Colorado.

Present maximum water surface areas are about 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 the State of Colorado (Pennak, 1966 [24]). Sartoris, et al. (1977) [25],

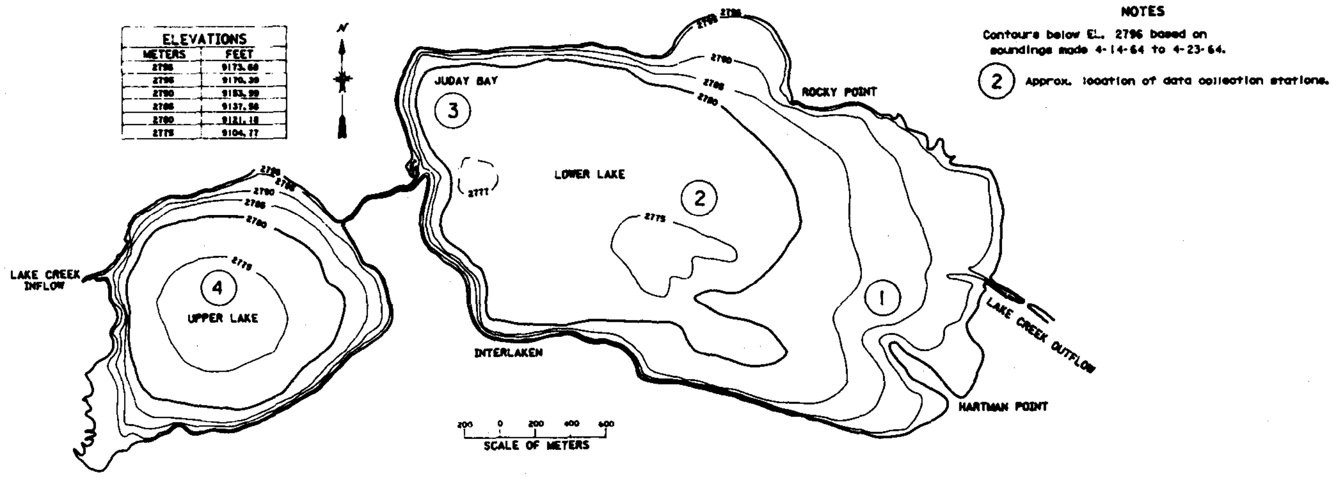


Figure 2.—Bottom topographic map of Twin Lakes, Colorado.

summarizes the literature reporting results of studies done from 1873-1977. Physical and biological changes made to Twin Lakes during the past 100 years are also discussed by Sartoris, et al. (1977) [25].

The installation of outlet control works, dredging of the channel between the two lakes, human activities in the area, introduction of rainbow trout *(Salmo gairdneri)*, lake trout *(Salvelinus namaycush)*, and mysis shrimp *(Mysis relicta)*, have resulted in the present-day status of the limnology of Twin Lakes. Further change in the lake's limnology is expected to occur when the Mt. Elbert Pumped-Storage Powerplant begins operation and the newly constructed Twin Lakes Dam allows the maximum storage capacity and mixing of the two lakes to increase. Quantification of these changes is the function of this project.

METHODS AND MATERIALS

Table 1 is a summary of the limnological field survey done during 1979 at Twin Lakes. During each of the surveys, data were collected in the same manner. Following is a brief description of the methods used to collect data for each of the series of activities listed in table 1.

Physical-Chemical Factors

Temperature, dissolved oxygen, conductivity, hydrogen-ion concentration (pH), and oxidation-reduction potential data were measured with a Hydrolab Corporation System 8000 multiparameter probe. Water samples were collected from surface, mid-depth, and bottom with a Van Dorn style water sampler. Samples were collected for the following analyses: complete cation-anion, trace metal (copper, zinc, iron, manganese, and lead), and plant nutrients (orthophosphate, total phosphate, total Kjeldahl nitrogen, nitrate-nitrogen, nitrite nitrogen, and ammonia). Samples for the trace metal analysis were preserved immediately after collection with 1 mL of concentrated nitric acid per 0.24 liter (½ pint or 8 fl. oz.). Samples for nutrient analysis were frozen immediately following collection. All samples were analyzed according to procedures in the "National Handbook of Recommended Methods for Water-Data Aquisition [1]). Light penetration was measured using both a standard Secchi disk and a limnophotometer. Light extinction coefficients were calculated from these measurements. A description of the limnophotometer and details on its use are presented in Otto (1975) [22].

Primary Productivity

The rate of net primary productivity using radioactive carbon (^{14}C) was done following the methods in Wood (1975) [29]. Measurements were always made during peak daylight hours. In August 1979 three separate surveys were made during the morning, noon, and afternoon hours. These surveys were done to determine the percent of activity occurring during these three separate segments of the daylight hours. Also in August, primary productivity rates were measured in a series of samples to which luxuriant

Table 1.—*Field surveys during 1979*

Date of survey	Activity performed						
	Physical factors	Chemical factors	Primary productivity	Chlorophyll	Phytoplankton	Zooplankton	Benthos
Jan. 10-12	x	x	x	x	x	x	x
Jan. 31-Feb. 1	x	x	x	x	x	x	x
Feb. 20-21	x	x		x	x	x	x
March 12-14	x	x	x	x	x	x	x
Apr. 4-6	x	x	x	x	x	x	x
Apr. 18-20	x	x		x	x	x	x
May 15-17	x	x	x	x	x	x	x
June 4-6	x	x	x	x	x	x	x
June 20-22	x	x	x	x	x	x	x
July 5-6	x	x		x	x	x	x
July 18-20	x	x	x	x	x	x	x
Aug. 2-3							
Aug. 13-17	x	x	x	x	x	x	x
Sept. 6-7	x	x		x	x	x	x
Sept. 14	x*	x*			x*	x*	
Sept. 19-21	x	x	x	x	x	x	x
Sept. 28	x*	x*				x*	
Oct. 5	x*	x*			x*	x*	
Oct. 10-12	x	x	x	x	x	x	x
Nov. 5-7	x	x	x	x	x	x	x
Nov. 28-30	x**	x**		x**	x**	x**	x**
Dec. 17-19	x	x	x	x	x	x	x

* Tailrace area (sampling station No. 3) of Lower Twin Lake and the Twin Lakes forebay sampled only.
** Only Lower Twin Lake was sampled (sampling station No. 2)

concentrations of phosphate, nitrate-nitrogen, and silica were added. Results of these studies will be presented in a separate report.

Chlorophyll

Samples for chlorophyll analysis were collected at 0.1, 1, 3, 5, 9, and 15 m depths from each lake. Following collection, 800 mL samples were filtered through millipore glass filter pads. Chlorophyll extraction and analyses were done according to methods outlined in Parsons and Strickland (1963) [23].

Phytoplankton and Zooplankton

Plankton were collected with a closing net having a No. 20 (mesh opening = 0.076 mm) silk net and bucket. Vertical hauls were made from 0 to 5, 5 to 10, 10 to 15, and 15 to 20 m. Samples were preserved with a 2-percent formalin solution for laboratory analysis. At times, plankton samples were collected by one or two other methods. A metered Clark-Bumpus plankton sampler with No. 10 (mesh opening = 0.158 mm) netting was towed horizontally at the surface, at depths of 1, 3, 5, 9, 15 m, and near the bottom (23 ± 3 m). Sampling was also done by collecting 10 liters of water from each of the above depths with a Van Dorn water sampler. These samples were then poured through a No. 20 silk student net. Laboratory methods follow those of Welch (1948) [27].

Benthos

Three samples of benthic muds were collected from each station using a Ponar dredge. These samples were filtered through a U.S. Standard series No. 30 sieve (opening = 0.589 mm) and then preserved in a 10-percent formalin solution for laboratory analysis. All specimens were identified according to type, and then counted and weighed. Both the wet and dry biomass were obtained by methods from APHA (1971) [1].

RESULTS

Physical-Chemical Factors

Physical-chemical results of 1979 limnological surveys at Twin Lakes are summarized in table 2 and on figures 3 through 8. A comparison of these results with those presented in the 1977 and

Table 2.—*Summary of 1979 basic physical-chemical data* *

Parameter	Upper Twin Lake			Lower Twin Lake		
	Maximum	Mean	Minimum	Maximum	Mean	Minimum
Temperature (°C)						
Surface	15.9	7.8	1.1	16.4	7.8	1.0
Bottom	6.3	4.7	3.2	8.6	5.5	2.2
Dissolved oxygen (mg/L)						
Surface	10.4	8.7	7.2	11.2	8.9	7.2
Bottom	9.7	6.1	1.4	9.9	5.8	1.3
pH						
Surface	8.0	7.5	7.1	8.6	7.8	7.2
Bottom	7.6	7.0	6.4	7.7	7.0	6.3
Conductivity (μS/cm)						
Surface	94	73	46	78	65	48
Bottom	122	76	42	85	70	54
Eh (mV)						
Surface	568	430	285	538	421	323
Bottom	595	441	270	568	447	350
Light extinction coefficient (m^{-1})	1.48	0.55	0.27	0.71	0.44	0.30

* Note: Dates of observation of surface, bottom, maximum, and minimum parameter values do not necessarily coincide.

1978 annual reports[2,3] reveals some general trends over the past 3 years. The basic mechanism underlying these trends appears to be the variation in winter precipitation over the Lake Creek watershed, both as it affects volume of spring runoff and winter conditions in the lakes themselves.

Table 3 shows annual Lake Creek runoff for water years 1972 through 1979 as a percentage of the long-term mean (calculated from data reported in U.S. Geological Survey Water Data Report CO-78-1).

These data show that over the last 3 years inflows to Twin Lakes have gone from less than 50 percent of normal during the drought year of 1977 to well over normal during the heavy snowpack years of 1978 and 1979. This variation in runoff and the associated variation in snow cover on the frozen lakes has had some important effects on the physical-chemical characteristics of Twin Lakes. These effects are discussed below with reference to the data summary presented in table 2 and on figures 3 through 8.

Surface water temperatures in the lower lake averaged about 3 °C lower in 1978 and 1979 as compared to 1977. Mean temperatures in both lakes were approximately equal in 1979, which is unusual since the lower lake has usually been about 2 °C warmer than the upper lake. This general decline in water temperature and the similarity of temperatures in both lakes in 1979 is probably due to increased inflows moving more

[2] Memorandum from Chief, Applied Sciences Branch, to Chief, Division of Research, dated March 17, 1979, "Assessment of the Effects of Mt. Elbert Pumped-Storage Powerplant Operation on the Ecology of Twin Lakes, Colorado — 1977 Annual Report," Applied Sciences Referral No. 78-2-6.

[3] Memorandum from Chief, Applied Sciences Branch, to Chief, Division of Research, dated March 12, 1979, "Assessment of the Effects of Mt. Elbert Pumped-Storage Powerplant Operation on the Ecology of Twin Lakes, Colorado — Quarterly Progress Reports No. 8 and 9 (time period July 1 to December 31, 1978) 1978 Annual Report — Fryingpan-Arkansas Project, "Applied Sciences Referral No. 79-2-10.

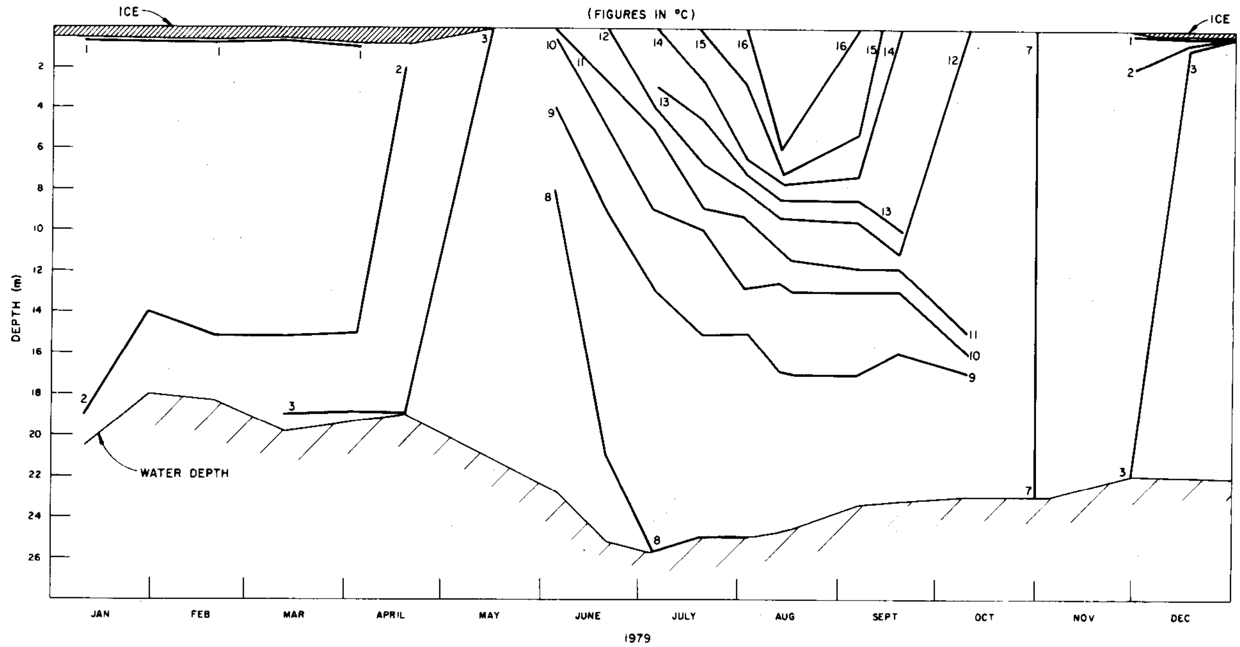


Figure 3.—Temperature isopleths for Lower Twin Lake during 1979(°C).

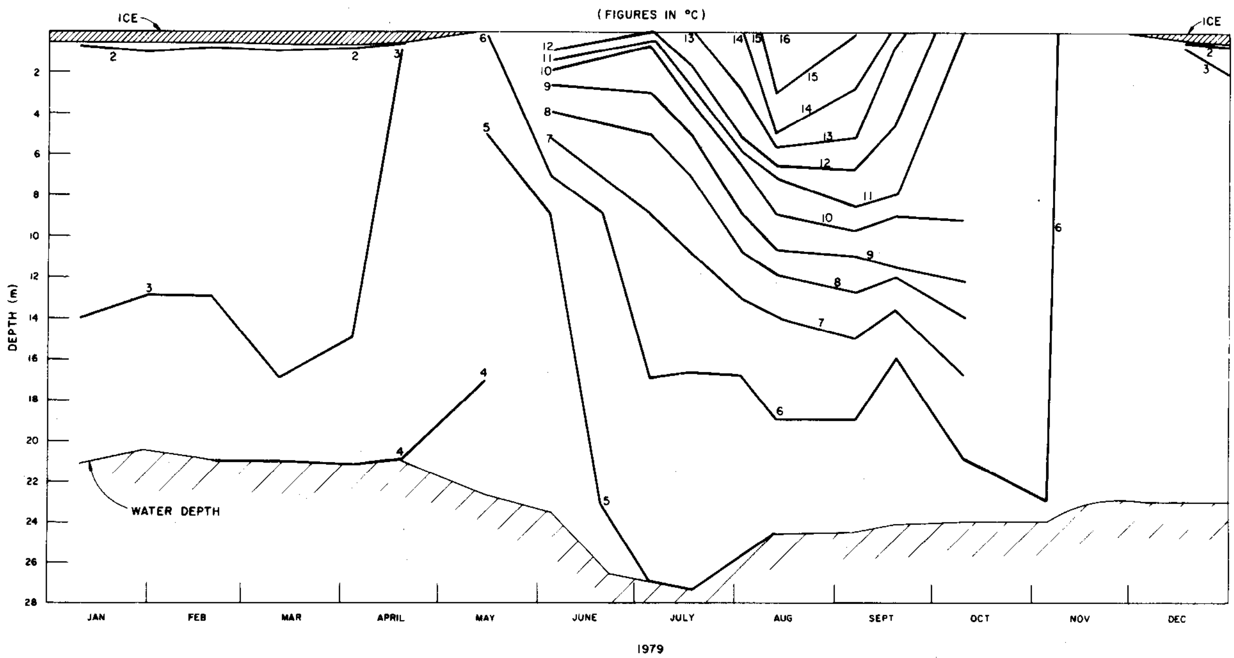


Figure 4.—Temperature isopleths for Upper Twin Lake during 1979(°C).

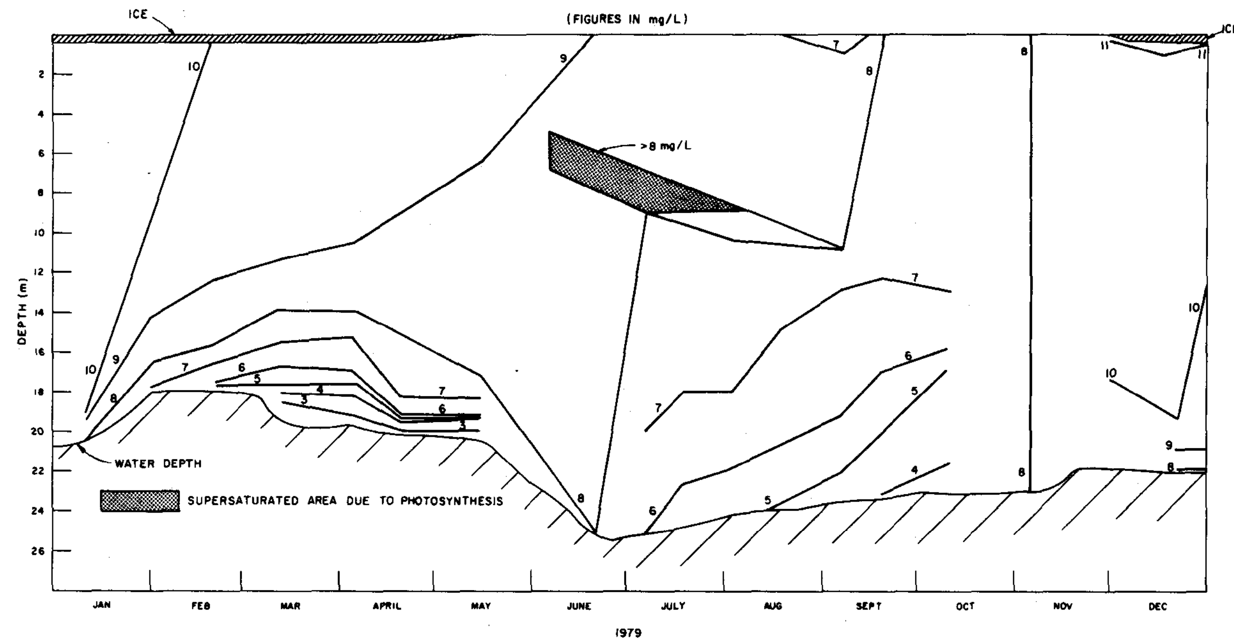


Figure 5.—Dissolved oxygen isopleths for Lower Twin Lake during 1979 (mg/L).

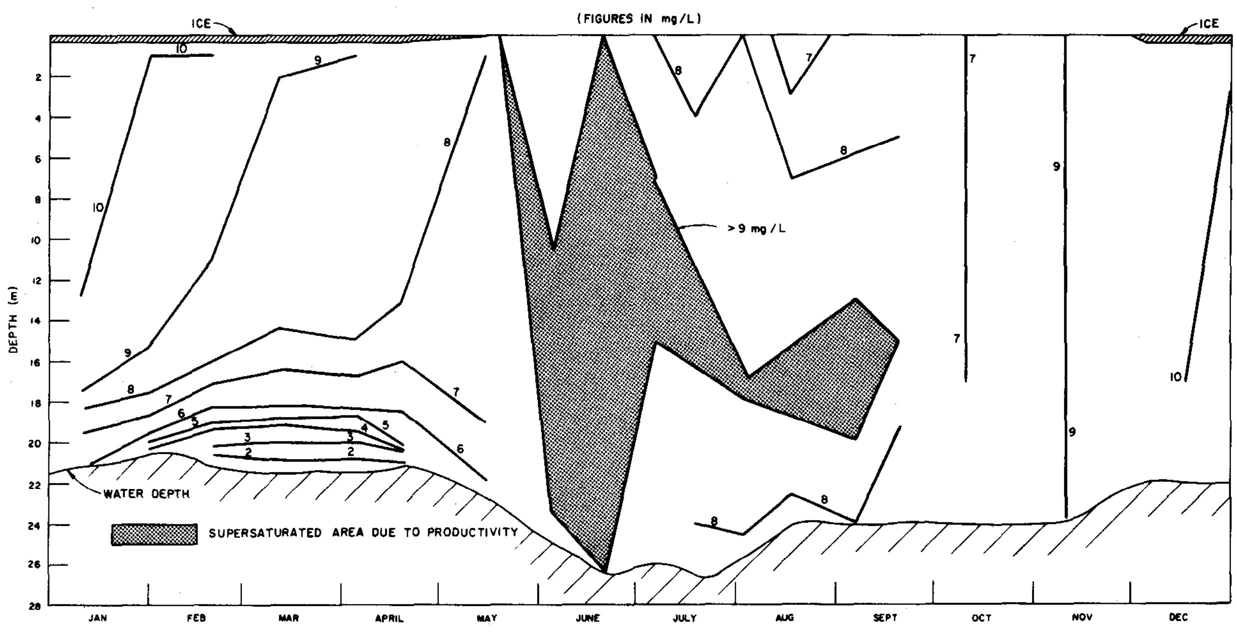


Figure 6.—Dissolved oxygen isopleths for Upper Twin Lake during 1979 (mg/L).

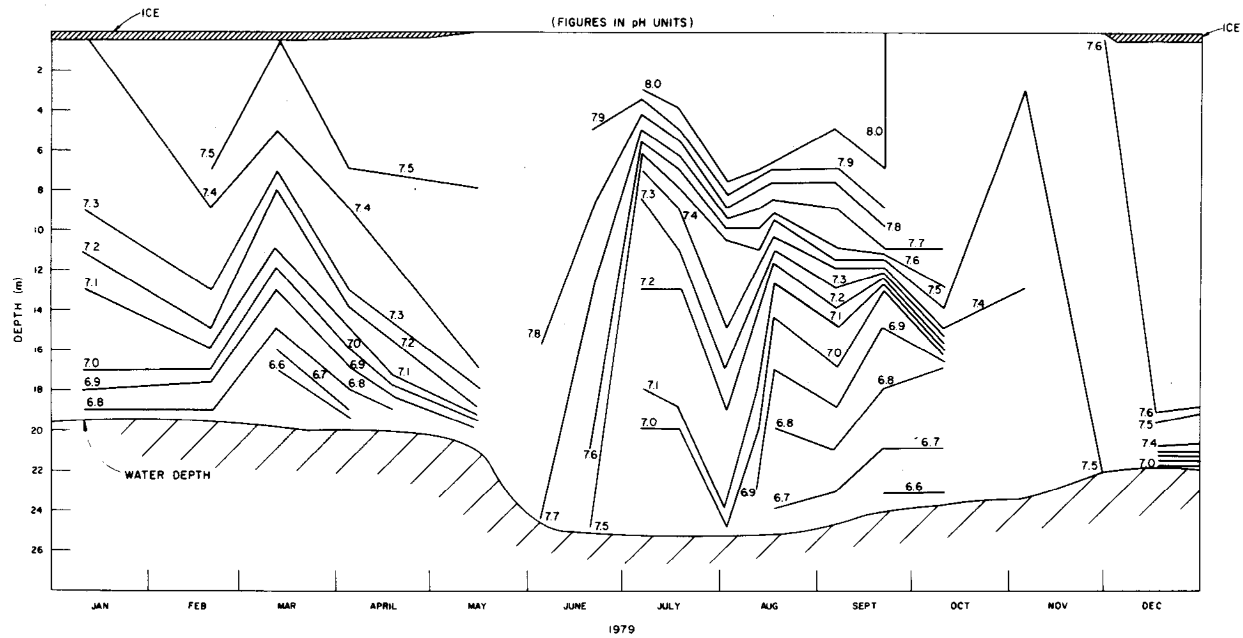


Figure 7.—pH Isopleths for Lower Twin Lake during 1979 (pH units).

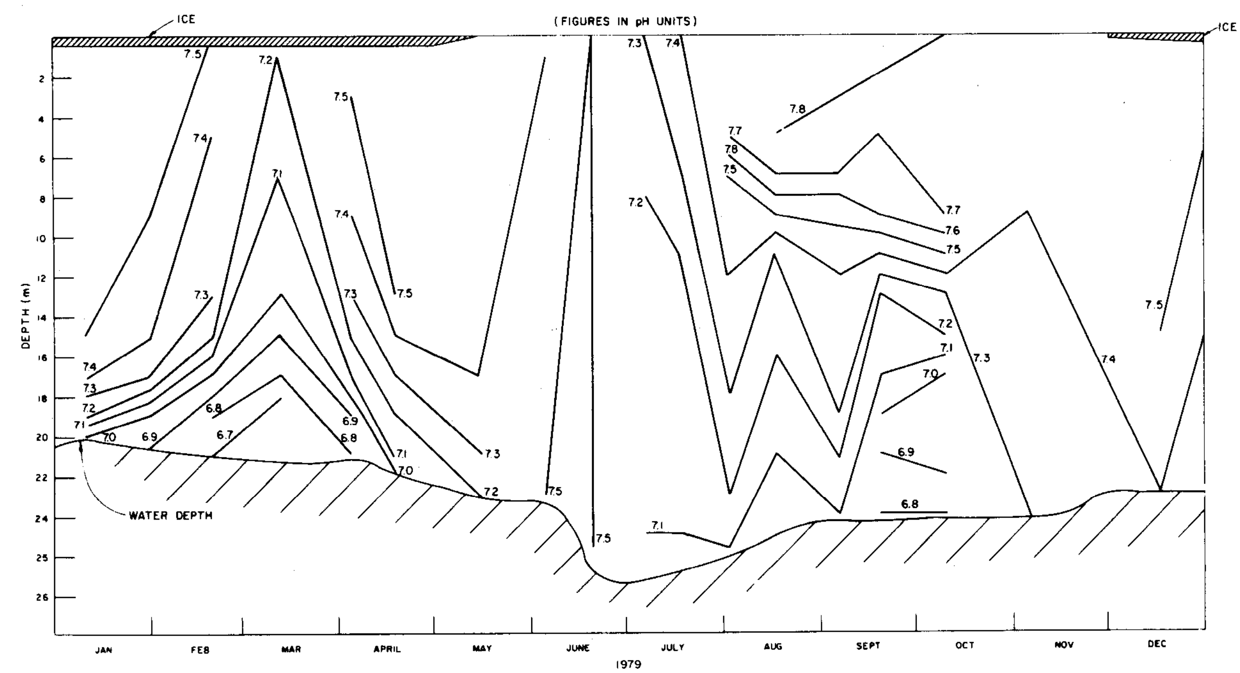


Figure 8.—pH Isopleths for Upper Twin Lake during 1979 (pH units).

rapidly through the lakes and thus lessening the "warming pond" effect the upper lake usually has during lower runoff years. Figures 3 and 4 show temperature isopleths for Lower and Upper Twin Lakes during 1979.

Table 3.—*Annual Lake Creek flows as percentages of 31-year mean*

Water year	Percent of mean annual flow
1972	110
1973	113
1974	82
1975	107
1976	82
1977	47
1978	124
1979	119

During the winter months of January through March 1979 the lower lake was about 1 °C colder under the ice. The 1 °C line was found immediately under the ice in the lower lake during January through March, whereas in the upper lake the water was 2 °C immediately under the ice during this same period. A temperature of 4 °C was not reached in the lower lake until after runoff. This is an indication of relatively high winds, supercooling, and resultant late ice formation that occurred during the fall of 1978. When ice forms early, as in the fall of 1979, and the lake has not cooled, the water under the ice is warmer during the entire winter season. This difference is displayed on figures 3 and 4 by the depth of the 2 and 3 °C lines in January and December. This difference could be as much as 3 °C during early winter, depending on the meteorological conditions delaying ice-on. Once the ice forms in late November or early December, the lakes begin to warm slowly from the bottom. As ice-off approaches, the warming accelerates. Following ice-off in late April to mid-May, the lakes begin to stratify. The amount and timing of runoff influences the rate of stratification and, as discussed, the average temperature of the lakes.

During the summer of 1979, however, the upper lake was cooler than the lower lake. This is typical and is due to the influence of runoff into the upper lake. During peak stratification in mid-August, the 16 °C line dipped to about 6 m in Lower Twin Lake but was only at the surface of Upper Twin Lake. By this same time the 8 °C line in the lower lake had disappeared, while in the upper lake it was at 12 m. Beginning in late August the lakes started cooling. By mid-October turnover was occurring in both lakes. This scenario is typical for both lakes every year. At this time of the year the major influence affecting the temperature structure of the lakes is the onset of autumn cooling. Ice-on occurred on November 29 and 30 for the upper and lower lakes, respectively. This was the earliest date ice had formed on Twin Lakes in at least 8 years. Because of this the high winds of late November and early December did not have a chance to supercool the lakes. Thus, as discussed above, the lakes began the ice-on season warmer than they did in 1978-79.

Dissolved oxygen (D.O.) concentrations in both lakes were about equal to those observed in 1978. Mean 1978-79 concentrations show a 1 to 2 mg/L increase over those recorded in 1977, which could be expected with higher inflows and lower water temperatures. Figures 5 and 6 present D.O. isopleths for Lower and Upper Twin Lakes during 1979. During the winter both lakes stagnated in the bottom 3 or 4 m. Concentrations of D.O. at the bottom of the upper lake had decreased to 2 mg/L by late February, while in the lower lake D.O. levels dropped to 3 mg/L in late March. By early to mid-April recharging of oxygen in the water column is indicated by the deepening of each of the isopleth lines. The recharge occurs when the increase in runoff intensity causes circulation within the water column. By late May, when ice goes off and Twin Lakes are circulating from top to bottom, the D.O. concentration at all depths is at or above saturation. During the summer, stagnation does occur in the hypolimnion to a certain degree. In addition, as indicated on figures 5 and 6, some supersaturation occurred in the water column due to photosynthetic activity of algae. As will be shown in the biological section of this report, primary production in Twin Lakes was relatively high during 1979. The shaded area of supersaturation for Upper Twin Lake was probably caused totally by turbid cold runoff until early July. After July photosynthesis by algae was the dominant influence. At fall turnover, circulation from wind action again supersaturated the entire water column. In addition, the colder the water, the more D.O. it will hold; therefore, greater concentrations are found during late fall, winter, and early spring. After ice formed in late November the D.O. concentrations under the ice were 10 to 11 mg/L, as in 1978. As winter progressed into January 1980, winter stagnation began.

Hydrogen ion concentrations (pH) have stayed about the same in both lakes over the last 3 years.

Figures 7 and 8 present pH isopleths for 1979. During the winter months of January through March, as stagnation progressed, pH values decreased into the acidic range. As circulation increased, due to runoff, pH values quickly rose above 7.5. By the end of June, pH values were above 8.0 in Lower Twin Lake, due to increased primary productivity. In Upper Twin Lake pH reached 7.8, but not until early August, when peak runoff was over. During summer stratification, stagnation near the bottom resulted in pH values of 6.6. As fall turnover approached and the thermocline sank, the volume of the lake having pH's below 7.5 decreased. At fall turnover, pH from top to bottom was again 7.5. Following ice-on, stratification of pH again occurred.

Mean conductivity in both lakes has also remained relatively constant since 1977. Maximum conductivity readings in the upper lake, however, were about 10 to 30 μS/cm higher in 1978 and 1979 as compared to 1977. These higher values were measured during the late winter in both years. They probably reflect chemical releases from the sediments during winter stagnation, as discussed in terms of oxidation-reduction potentials below.

Oxidation-reduction potentials (Eh) at the bottom of both lakes have declined steadily since 1977. A drop of 60 to 76 mV in mean Eh was noted between 1977 and 1978, while between 1978 and 1979 mean Eh fell another 80 to 99 mV. Both of these declines reflect the more severe winter conditions in 1978-79 compared to the mild winter of 1976-77. During the winter of 1976-77, the ice cover on the lakes remained generally clear of snow and lasted only 146 days, breaking up on April 28, 1977. The next winter (1977-78) the ice cover lasted only 147 days (ice-off on May 8, 1978), but there was enough snow on the ice to inhibit light penetration and contribute to lowered Eh values at the bottom of the lakes. As noted in the 1978 annual report, this led to some chemical release from the sediments in the upper lake as shown by higher late winter conductivity readings and the presence of small amounts of manganese and iron in the bottom waters. The winter of 1978-79 was the most severe noted at Twin Lakes since 1974-75, when anaerobic conditions in the upper lake led to a crash of the biota. Table 4 compares late winter conditions in Upper Twin Lake during 1975 and 1979.

Table 4 shows that by April 4, 1979, Upper Twin Lake had relatively large manganese and iron concentrations. By comparing data collected in 1975 when a severe winterkill occurred it appears as if the lake was on the verge of a similar situation. In some respects it could have been worse than that which occurred in 1975 except that dissolved oxygen levels remained adequate enough to prevent metals from going into solution. By the next survey on April 19, however, the weather had warmed to such an extent that the snow cover was reduced from about 38 cm to less than 2.5 cm, while the Lake Creek inflow had increased from 0.28 to 0.57 m^3/s. This sudden onset of warmer weather resulted in a rapid recharging of the upper lake. Redox potential (E_7) rose to 595 mV, the metals were reoxidized and precipitated out, and a winterkill like that of 1975 was averted. There was no evidence of decreased benthic populations which might have been expected if low redox potentials had lasted long enough for dissolved metals to build up to toxic concentrations.

Estimates of winterkill risk in Upper Twin Lake done by means of the method developed by Barcia and Mathias (1979) [2] indicate that this lake would probably suffer anaerobiosis during any winter in which a complete and continuous snow cover was maintained over the ice through the month of April. The experiences of 1975 and 1979 show further how critical the weather can be in this final month of winter: in 1975, continued cold weather and snow led to a winterkill in

Table 4.—*Comparison of late winter conditions in Upper Twin Lake in 1975 and 1979*

	1975	1979
Duration of ice cover	158 days	163 days
Minimum D.O. saturation	0 percent	14 percent
Minimum E_7*	157 mV	261 mV
Maximum Mn concentration	2.5 mg/L	2.60 mg/L
Maximum Fe concentration	1.7 mg/L	2.08 mg/L
Maximum Cu concentration	0.09 mg/L	0.02 mg/L
Maximum Zn concentration	0.07 mg/L	0.013 mg/L

* E_7 = Eh adjusted to a pH of 7.00.

the upper lake, while in 1979, a sudden warming trend averted a repeat occurrence.

Light extinction coefficients (table 2) also show the effect of the sudden onset of spring runoff in 1979. The value of the light extinction coefficient is inversely proportional to the clarity of the water, so the minimum values indicate clear conditions, while the maximum values reflect turbid conditions. In 1979, the minimum upper lake light extinction coefficients are not much different from those measured in 1977-78[4], but the maximum values for the upper lake, which were measured in June at the peak of the runoff, are much greater than those of the previous 2 years. These high maximum values reflect the greater turbidity of the runoff in 1979 compared to 1977-78. Although the total 1979 runoff was slightly less than that of 1978 (table 3), it began in a much more abrupt fashion, with 14 percent of the total runoff occurring in May 1979 as opposed to 7 percent of the total in May 1978. This sudden rush of water apparently entrained more suspended solids than the more gradual buildup of flows in 1978.

In addition, inflow has a significant influence on recharging oxygen in the hypolimnion of Upper Twin Lake. During winter, when inflow remains relatively low into April, the upper lake becomes nearly or partially anaerobic near the bottom. If inflow increases even by 0.3 to 0.9 m^3/s in April, the hypolimnion is recharged. During summer stratification, similar circumstances exist; however, the D.O. concentration near the bottom of Lower Twin Lake reflects to a greater degree any low volume of runoff during August and September.

Table 5 contains water chemistry data for the Lake Creek inflow, Upper Twin Lake, and Lower Twin Lake during the sampling dates when TDS (total dissolved solids) were at their maximum and minimum. Figure 9 presents graphically the percentage of each of the major anions and cations for the Lake Creek inflow and outflow, and for Lower and Upper Twin Lakes. The percent compositions are contrasted for dates when the

[4] Light extinction coefficient values during 1978 ranged from 0.27 to 0.61 m^{-1}, while those in 1977 ranged between 0.53 and 0.74 m^{-1}.

Table 5.—*Water chemistry of Twin Lakes during 1979 when TDS was maximum and minimum* (mg/L)

	Lake Creek inflow		Upper Twin Lake		Lower Twin Lake	
Element	Maximum Feb. 20	Minimum Aug. 2	Maximum Feb. 20	Minimum Aug. 2	Maximum Feb. 20	Minimum Aug. 2
Total dissolved solids	100	24	74	20	62	22
Calcium	17.60	9.00	10.80	8.00	8.00	9.00
Magnesium	2.93	1.59	1.71	0.98	2.44	0.61
Sodium	0.69	1.38	0.46	1.15	0.46	1.15
Potassium	2.35	0.78	1.56	0.78	1.56	0.78
Carbonate	0.0	0.0	0.0	0.0	0.0	0.0
Bicarbonate	29.30	23.80	26.80	20.70	24.40	19.50
Sulfate	34.10	10.10	14.40	8.64	10.60	10.10
Chloride	2.13	2.48	2.13	1.42	2.13	1.78
Copper	0.0110	0.0066	0.0050	0.0023	0.0130	0.0010
Iron	.1200	.2000	.5500	.0900	.0100	.0600
Lead	.0023	<.0005	.0017	.0005	.0089	.0005
Manganese	.0200	<.0100	.6500	.0100	.0100	.0100
Zinc	.0070	.0042	.0040	.0024	.0130	.0016
Ortho-PO_4	<.001	<.001	<.001	<.001	<.001	<.001
Total PO_4	<.001	<.001	<.001	<.001	.020	<.001
Organic N	.150	<.030	.150	.120	.180	.080
Nitrite	.002	<.001	<.001	<.001	<.001	<.001
Nitrate	<.001	.040	.054	.500	.014	.023
Ammonia	<.010	<.010	.010	.010	.010	.013

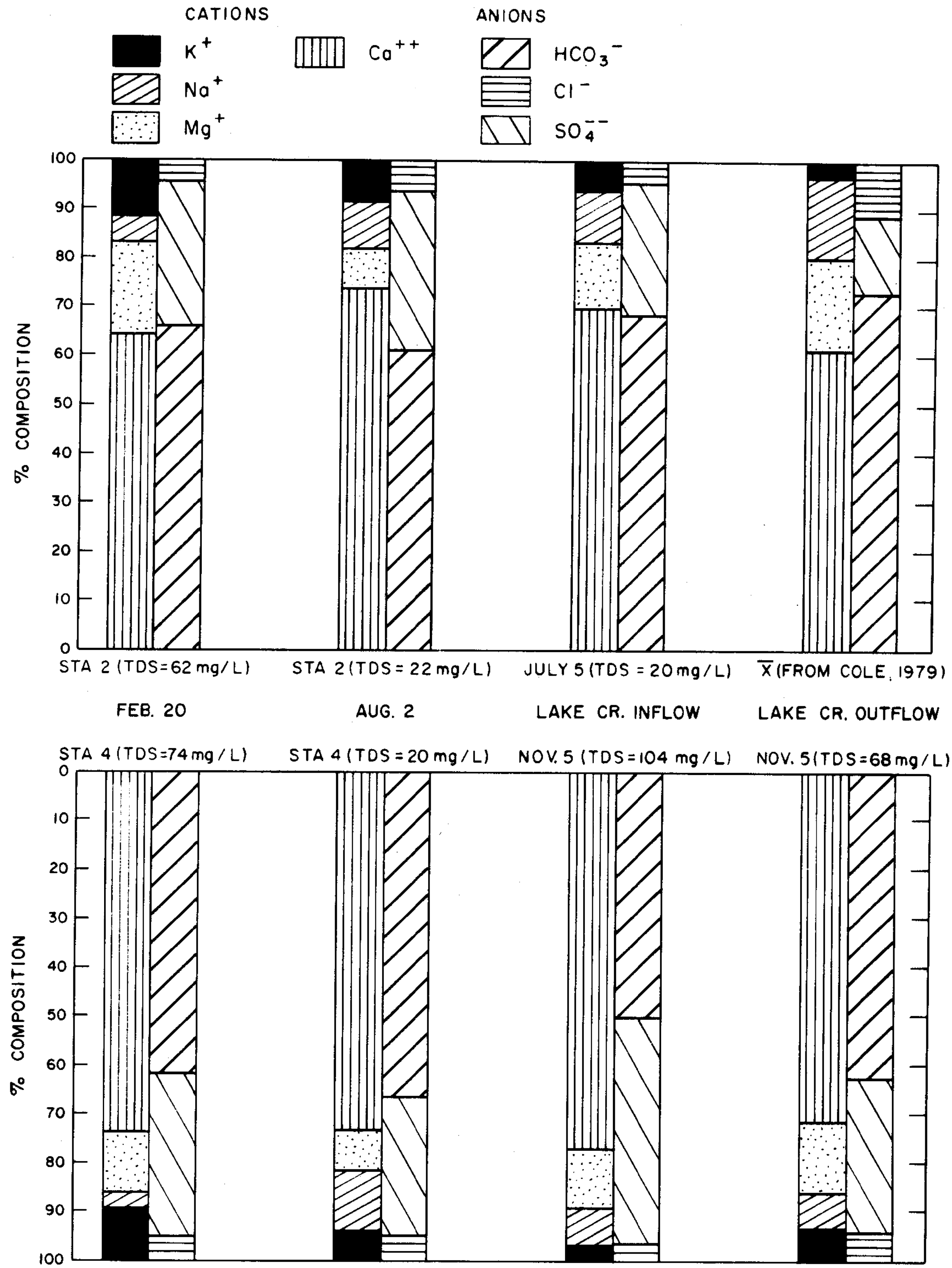


Figure 9.—Percent composition of cations and anions during 1979.

lowest and highest concentrations of total dissolved solids were measured. The upper right pair of bars are from Cole (1979) [5] and represent the average chemical compositions for the world's rivers. Calcium is always the dominant cation in Twin Lakes, composing between 64 and 73 percent of the cation mass. Cole reports the average for the world's rivers as 60.9 percent. Magnesium, sodium, and potassium compose the remaining cation mass in varying proportions.

In both lakes, magnesium and potassium decrease while sodium increases as TDS decreases. Bicarbonate and sulfate are the dominant anions. Bicarbonate composes between 50 and 68 percent and sulfate, between 27 and 46 percent of the anion mass in Twin Lakes. Cole (1979) [5] reports that alkalinity as carbonate (includes bicarbonate) makes up about 72.4 percent of the anion composition of the world's rivers and sulfate makes up 16.1 percent. Therefore, sulfate makes up a greater percentage of the anion content of Twin Lakes water than normal. In addition, since the pH of Twin Lakes is relatively neutral, carbonate is not common, and instead, bicarbonate is found. The chloride composition of Twin Lakes water ranges between 4 and 6 percent. Therefore, waters of Twin Lakes and its tributary consist dominantly of calcium bicarbonate and/or calcium sulfate. Sartoris, LaBounty, and Newkirk (1977) [25] discuss in greater detail the anions and cations of Twin Lakes. In general, water in Twin Lakes can be referred to as extremely soft.

Figure 10 presents the variability of TDS in the Lake Creek inflow and in the upper and lower lakes. Figure 11 presents the rate of flow in Lake Creek on the sampling dates during 1979. Two conclusions can be made from the data presented on figures 10 and 11. First, the TDS concentration of both lakes reflects that of the inflow. As concentrations of the inflow increase, they follow suit in both lakes, and vice versa. This illustrates how much the lakes are influenced by the quantity and quality of inflow waters. That is, when inflow contributes significant nutrients and/or trace elements, the biota of the lakes reflect these conditions. Conversely, when inflow is lacking, nutrient and/or trace element concentrations are low (LaBounty & Sartoris, 1980 [19]). The biota will reflect these conditions also. Therefore, allochthonous (external) sources are the controlling factor.

Thus, as data in this report and others (see LaBounty and Sartoris, 1980 [20]) show, the flow characteristics have significant impact on Twin Lakes, both chemically and biologically. This conclusion is important in considering what effect powerplant operation and interbasin water transfers will have on the ecology of Twin Lakes, or any body of water for that matter.

A second conclusion drawn from figure 10 is that TDS concentrations are decreased by as much as 80 percent during peak runoff (June and July, see fig. 11). However, yield during this period is as high or higher. Following peak runoff, TDS again increases to about 100 mg/L in inflow samples, and between 60 and 80 mg/L in samples from the two lakes. TDS remain high throughout the winter in samples from Twin Lakes but fluctuate somewhat depending on the volume of inflow both from Lake Creek and snowmelt around and on the lakes. Most of the year the TDS concentration of the lower lake was somewhat lower than that of the upper lake. Concentrations in both lakes were mostly lower than those of the inflow; the only exception is during peak runoff (June, July, and August, see fig. 11). Thus, when water flows through the lakes, solids settle out. In areas where evaporation rates are higher (i.e., deserts and plains), the reverse is the case; that is, as one progresses downstream the TDS content increases.

The range of TDS concentration that Twin Lakes falls into is between 20 and 200 mg/L. Cole (1979) [5] reported 120 mg/L as the average TDS for the world's rivers. Hart, et al. (1945) [11] reported that among inland waters in the United States supporting a good mixed fish fauna, about 5 percent have dissolved solids concentration under 72 mg/L, and about 50 percent under 169 mg/L. Lieth and Whittaker (1975) [21] categorized lakes with total inorganic solids between 2 and 15 mg/L as ultra-oligotrophic and those between 10 and 200 mg/L as oligo-mesotrophic. Therefore, based on their classification using TDS, Twin Lakes are oligotrophic (=relatively low production). It should be noted that Twin Lakes fall in the oligotrophic category for most parameters. The concentration of dissolved solids is important to a lake's ecology, because they may influence the toxicity of heavy metals and organic compounds to fish and other aquatic life, primarily because increased hardness results in an increase in the oxidation of metals; that is, the metals are prevented from existing in a toxic ionic state. Since the TDS concentration of Twin Lakes is relatively low, the effect of any heavy metal input, whether it be from allochthonous or

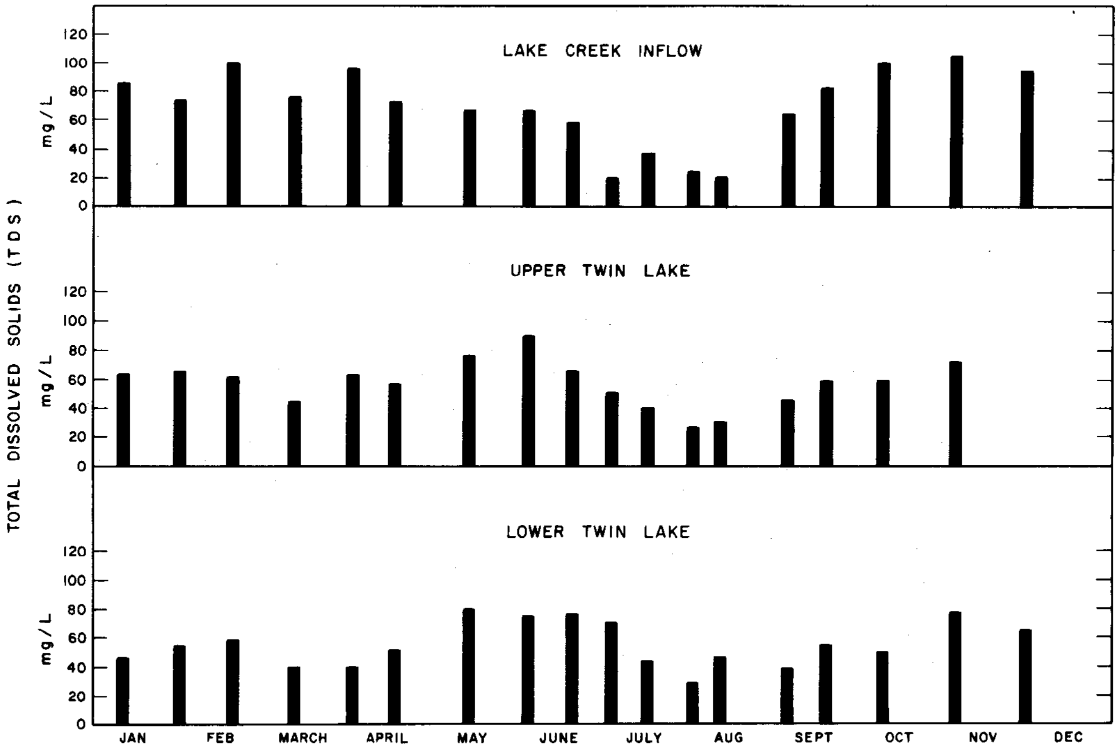


Figure 10.—Total dissolved solids, 1979.

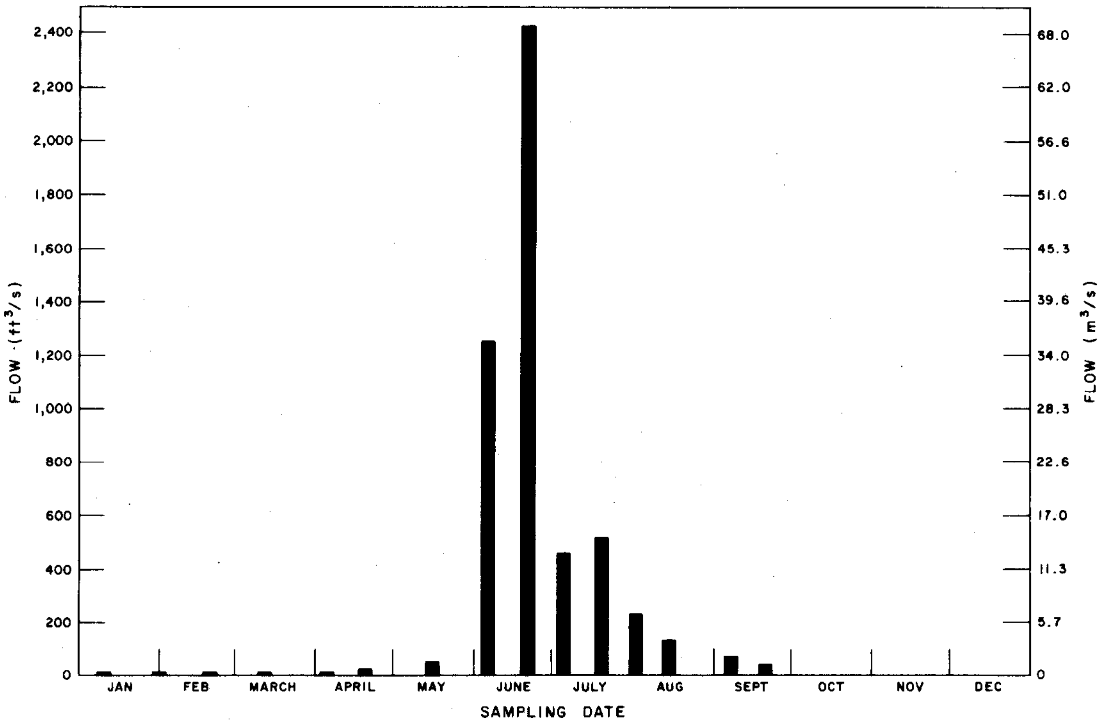


Figure 11.—Flow into Twin Lakes from Lake Creek during 1979 sampling dates.

autochthonous (internal) sources, is relatively high. Sartoris, et al. (1977) [25] discussed these relationships for Twin Lakes in detail.

Figures 12 through 15 include the total phosphorus, nitrate, total Kjeldahl nitrogen, and ammonia concentrations in water samples collected from Twin Lakes and the Lake Creek inflow during 1979. Orthophosphate and nitrite were measured but were not graphed. Generally, the trends in concentrations of phosphorus and nitrogen nutrients found in the lakes reflect those found in the inflow. Orthophosphate was only detected (>1.0 μg/L) once during 1976 in 116 samples. Furthermore, total phosphorus was detectable (>1.0 μg/L) less than 30 percent of the time (fig. 12), with the greatest amount measured being 12 μg/L in Lake Creek during initial runoff in May and again in November in the lower lake just at ice-on. No trend in total phosphorus availability is apparent. From 2 to 4 μg/L was found in the lower lake during January and February. During mid-August, from 2 to 5 μg/L was found throughout the system. At this same time, intermittent heavy rains for at least a week were observed by research field personnel. Significant nutrient concentrations were contributed by local runoff due to these storms. Hutchinson (1957) [12] reported the mean total phosphorus from several lake districts was about 21 μg/L. Lieth and Whittaker (1975) [21] presented a table of some general characteristics of lakes of various trophic status. In that table lakes with from less than 1 to 5 μg/L total phosphorus are categorized as ultra-oligotrophic and those with total phosphorus of from 5 to 10 μg/L as oligo-mesotrophic. The average total phosphorus concentration of Twin Lakes in 1979 was 1.8 μg/L, placing it then in the low end of the oligotrophic category.

Figure 13 contains a graphic display of the nitrate concentration in the Lake Creek inflow and the upper and lower lakes during 1979. There is a marked decrease in nitrate concentration going downstream. The highest concentrations (>170 μg/L) occurred in the Lake Creek inflow during the winter when the flow rate is lowest (<0.3 m^3/s). When flow rates increased above 3 to 5 m^3/s, nitrate concentrations in the Lake Creek inflow dropped below 100 μg/L. The nitrate concentration in the upper lake remained mostly between 50 and 80 μg/L throughout 1979. At the beginning of heavy runoff in mid-May, 120 μg/L nitrate was measured in the upper lake. Nitrate concentrations in the lower lake ranged from below the detectable limits (<10 μg/L) mostly during the winter to a high of 60 μg/L in September. Most detectable concentrations were between 20 and 40 μg/L. The average nitrate concentrations during 1979 were 108 μg/L for the Lake Creek inflow and 46 μg/L for Twin Lakes (67 μg/L for the upper lake and 25 μg/L for the lower lake). Thus, in moving from the inflow to the upper lake there is about a 40-percent reduction in nitrate and from the upper to the lower lake, an additional 40-percent reduction. Nitrate is used both in biological processes and retained in sediments and used in future biological production.

Total Kjeldahl nitrogen concentrations in Twin Lakes during 1979 are found on figure 14. No distinct pattern of occurrence is obvious except that both lakes always had detectable levels, while 50 percent of the time no detectable amounts were found in samples of the Lake Creek inflow. However, during the summer months some relatively high concentrations (360 and 480 μg/L) were found in the inflow. Both lakes had an average total Kjeldahl nitrogen concentration during 1979 of 106 μg/L, while the average for the inflow was 96 μg/L. Lieth and Whittaker (1975) [21], in their table of general characteristics of lakes of various trophic status, categorize lakes less than 1 to 250 μg/L total Kjeldahl nitrogen as ultra-oligotrophic, and lakes with from 10 to 200 μg/L as oligo-mesotrophic. Based on total Kjeldahl nitrogen concentration, Twin Lakes fall into the oligotrophic category presented by Lieth and Whittaker.

Ammonia-nitrogen concentration in Twin Lakes and the Lake Creek inflow during 1979 are graphed on figure 15. Most of the ammonia-nitrogen is generated by heterotrophic bacteria as the primary end product of decomposition of organic matter (Wetzel, 1975 [28]). Therefore, the greatest concentration would be expected during the winter and early spring, when many life cycles are completed. Figure 15 shows this to be the case for Twin Lakes. The Lake Creek inflow contained an average concentration of ammonia of less than 10 μg/L. Ammonia-nitrogen was detectable in the Lake Creek inflow less than 20 percent of the time during 1979. The average ammonia-nitrogen concentration for the upper lake during 1979 was 24 μg/L and for the lower lake, 16 μg/L. The difference in ammonia-nitrogen concentrations between Twin Lakes and its inflow reflects the difference in their biotas. Reasons for the seasonal difference in ammonia-nitrogen concentrations between the lower and upper lakes are unclear. The lower lake has a far greater abun-

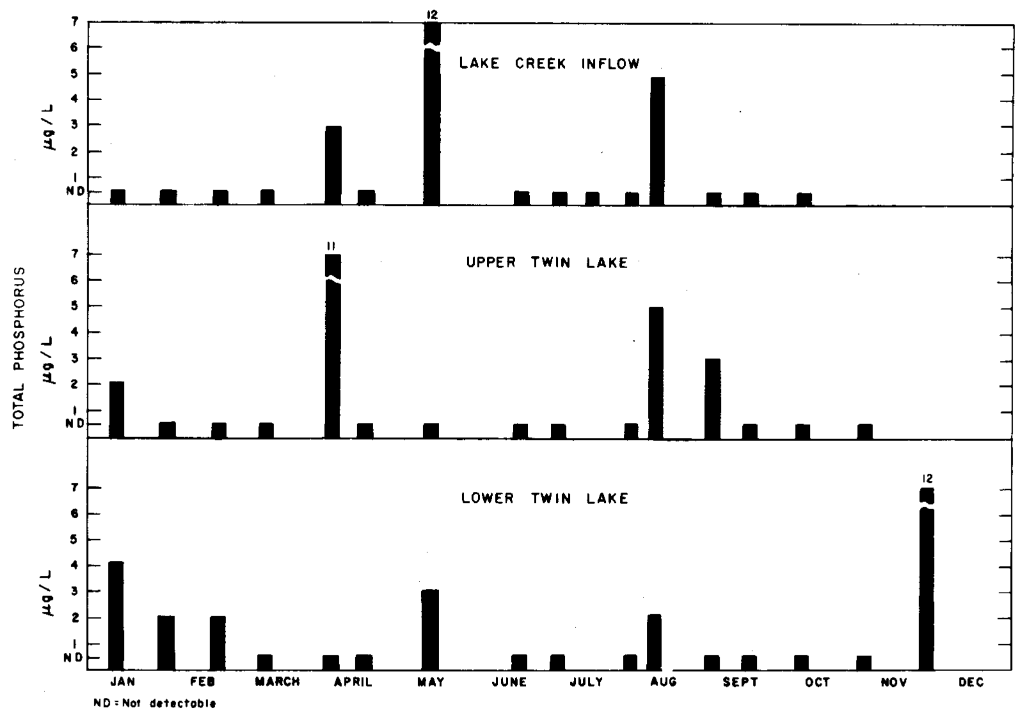


Figure 12.—Total phosphorus concentrations, 1979.

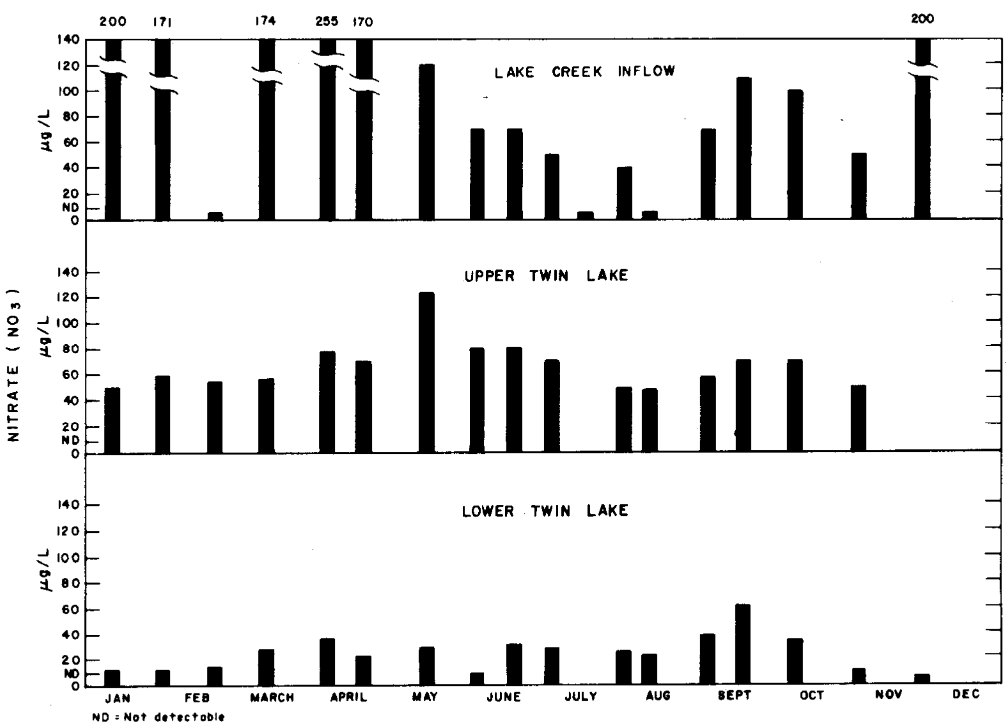


Figure 13.—Nitrate concentrations, 1979.

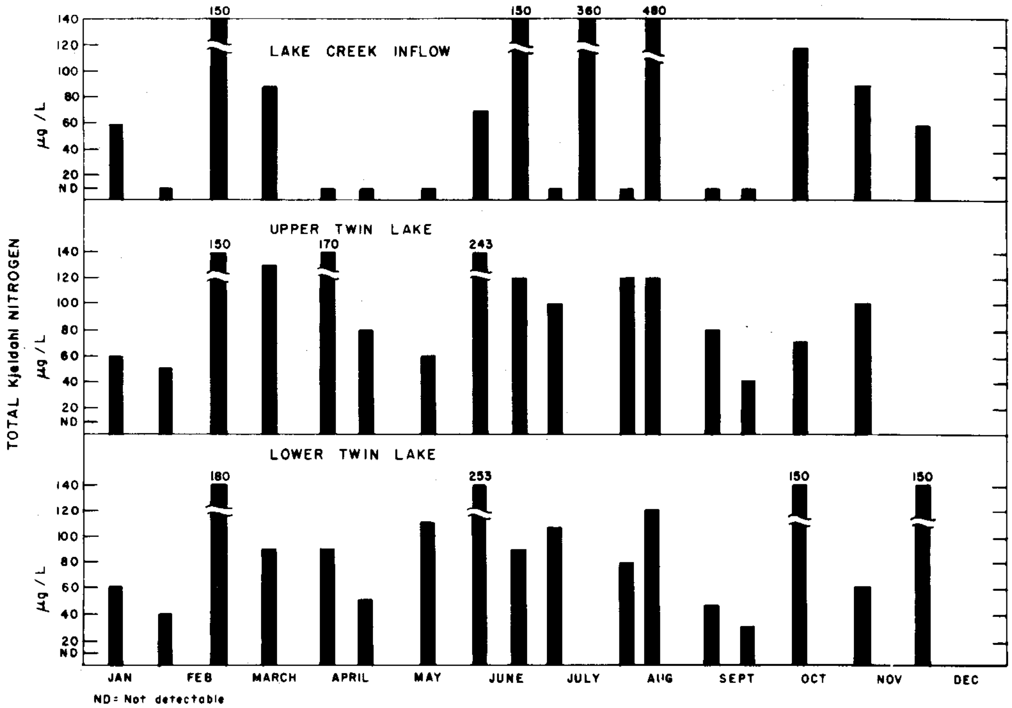


Figure 14.—Total Kjeldahl nitrogen concentrations, 1979.

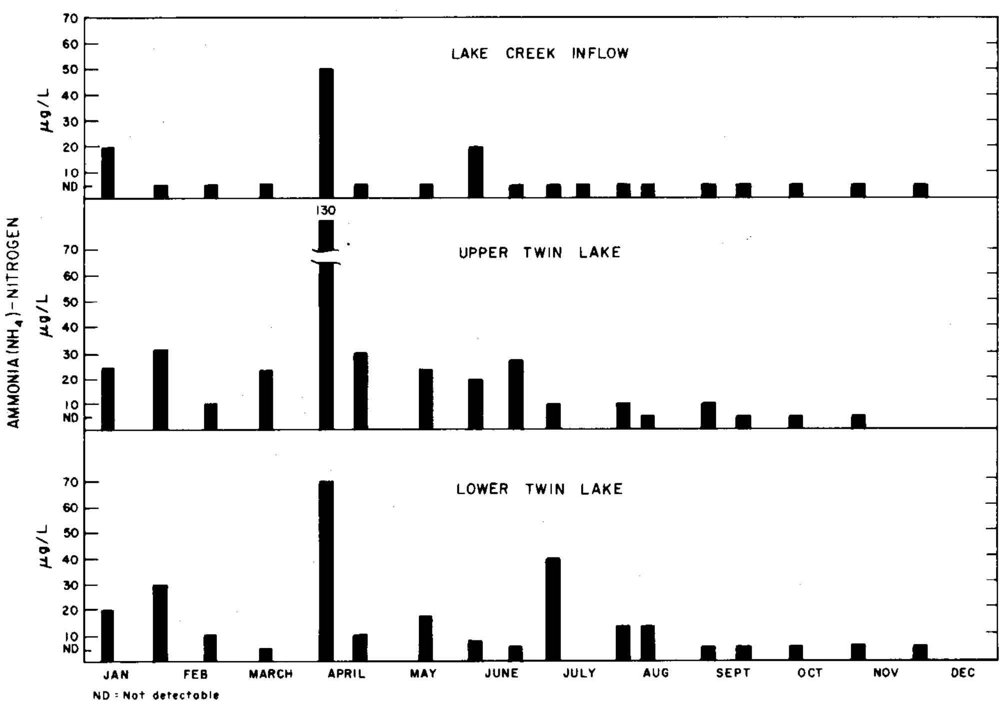


Figure 15.—Ammonia concentrations, 1979.

dance of biota, but ammonia-nitrogen concentrations were, on the average, lower. Perhaps during the period April through June 1979, the relatively higher ammonia concentrations of the upper lake reflected a significant die-off of biota in that lake due to toxicity from trace metals. As discussed earlier, concentrations of some trace elements were notably higher during May and June of 1979 than in previous years. Biological data to be presented in the next section further substantiate this hypothesis.

Biological Factors

Primary Productivity. — Primary productivity using the ^{14}C technique is a method of measuring the instantaneous rate at which algae is fixing carbon in cellular development. Figures 16 and 17 present the carbon assimilation rates measured in Twin Lakes during 1979. Figure 16 graphs the areal rates in micrograms of carbon assimilated per square meter per hour of maximum daylight. The measured rates for both lakes are included.

The rates for the lower lake, with one exception (August), were always greater during 1979 than those of the upper lake. The plotted curve connecting the measured rates for the lower lake is distinctly bimodal, with the peaks occurring just after spring and autumn turnovers. The spring peak doubled that of the fall. The lower rates measured during winter and summer did not differ much from each other. The lowest rates in the lower lake were measured during the maximum stratification of winter (January-February) and of summer (August-September). The availability of nutrients in the euphotic zone causes the differences in primary productivity rates through the season.

The measured trend in 1979 for the upper lake is quite different. Negligible production rates were measured from January through June 1979. During mid-June, the rate was nearly zero. These depressed rates during the first half of 1979 were due to two factors. One, the presence of trace metals during the late ice-on season may have caused not only a depression in production because of the "scrubbing effect," but also, somewhat of a die-off of algae. Second, the flow rate via Lake Creek exceeded 68 m^3/s during mid-June, resulting in a relatively high flushing rate. That is, at the rate of inflow of 68 m^3/s, it would take exactly 7 days for the upper lake to completely flush once. At that rate, production would be expected to be low. Add to this the fact that turbidity during this time inhibits light penetration beyond a few feet. As the inflow rate became reduced and light penetration increased (late July and August), the rate of primary productivity in the upper lake increased. From this point, the trend in primary productivity for the two lakes was similar. During September, the upper lake became stratified and the biological response was similar to that of the lower lake: the production rate was low. As turnover occurred, the rate of primary productivity for Upper Twin Lake was at its greatest. When winter set in, the rates for both lakes again became relatively low.

Figure 17 graphs in profile the primary productivity rates for both lakes during 1979. Notable from this graph is the difference between the lower lake profile in May and the profiles for the rest of the season. During May (just after the ice-off), substantial production was measured even at 15 m. The next survey done in June shows production to be more restricted — to between 5 and 9 m and above. This was due to the effect of shading from both silt and the algae that was produced just after ice-off. This phenomenon continued throughout the remainder of the season in the lower lake, but, as July approached, it was due more to the shading of algae. The upper lake shows a somewhat similar pattern later in the year. However, as discussed above, production was very limited during early season. These low values are especially obvious in figure 17.

The following discussion relates the rates of primary productivity measured in Twin Lakes to those from other lakes. First, it should be pointed out that the pattern described above for 1979 may or may not be typical for Twin Lakes. It certainly is no duplication of patterns found in any other year since 1974. This subject will be discussed in detail in future reports. However, in summary, the rate of primary productivity over the season depends on numerous factors, including nutrient availability, intensity of winter stratification, and the quantity and quality of runoff. Also, there is a wide range of variability in the rates from season to season and year to year. Primary productivity rates using the ^{14}C technique have been measured at Twin Lakes since 1974. The levels measured on May 19, 1979, for the lower lake were the highest ever measured at Twin Lakes. To put this in perspective, data are presented in table 6.

Lieth and Whittaker (1975) [21] reported a primary productivity range of 4100 to 25 000

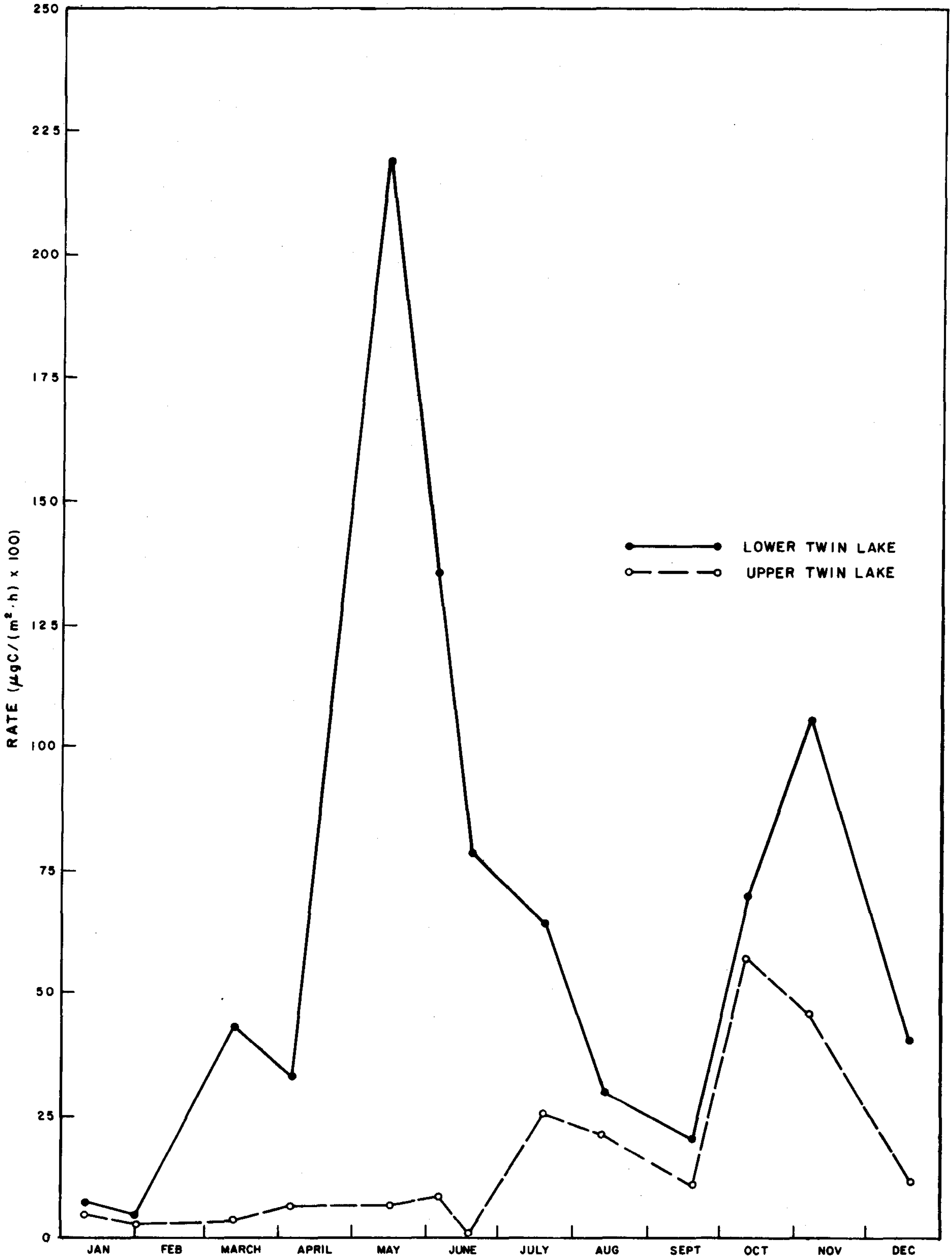


Figure 16.—Carbon assimilation rates (areal) in Twin Lakes during 1979.

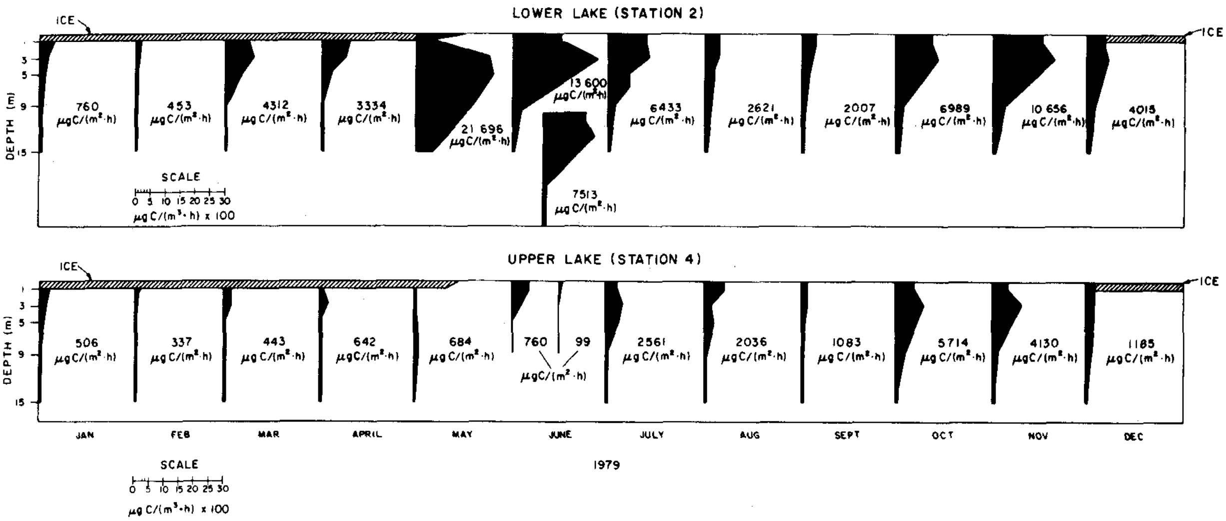


Figure 17.—Carbon assimilation rates (profile) in Twin Lakes during 1979.

Table 6.—*The extreme values of primary productivity measured at Twin Lakes, Colorado, from August 1973 through December 1979*

Sampling location	Lowest value, µgC/(m² · h)	Date measured	Highest value, µgC/(m² · h)	Date measured
Upper lake (station 4)	99*	6-19-79	9 683	7-12-77
Lower lake (station 2)	453	2-1-79	21 696**	5-19-79

* Previous low rate was 213 µgC/(m² · h) measured on June 13, 1974.
** Previous high rate was 14 444 µgC/(m² · h) measured October 5, 1978.

µgC (m² · h) for oligotrophic lakes of the world. Most values obtained at Twin Lakes during the ice-free season fall within this range. The high values in table 6 for the lower lake is near the upper limit of Lieth and Whittaker's range, but nevertheless in the range. The highest rate measured for the upper lake is in the lower 50 percent of this range. This, then, shows how relatively unproductive the upper lake remains. The low values in the table 6 for both lakes are well below the range reported by Lieth and Whittaker. However, these rates were both measured during the winter when snow and ice inhibit light penetration and, in the case of the upper lake, during times when runoff was heavy. When runoff is heavy, the upper lake acts as a settling basin for the lower lake. Partly because of this, the upper lake is nearly nonproductive in May and June. When runoff is low, as in 1977, production in the upper lake seems to be relatively undisturbed. The high value measured on July 12, 1977, may substantiate this idea.

Chlorophyll* a *Concentration.—Chlorophyll *a* is an estimate of the phytoplankton biomass. Chlorophyll *b* and *c* were also estimated but are not reported here. A future report will discuss them. Figure 18 displays the trends for chlorophyll *a* concentrations in both lakes during 1979. Data in this figure are presented in profile; that is, the abundance of chlorophyll *a* is presented from the surface to a depth of 15 m (19 sampling dates for the lower lake and 17 dates for the upper lake). Three conclusions can be derived from these data. First, there is a seasonal trend for chlorophyll in both lakes, with low concentrations before and during spring and fall turnover periods. The maximum values occurred in August for both lakes. Following fall turnover, chlorophyll *a* concentrations increased. There seems to be no initial

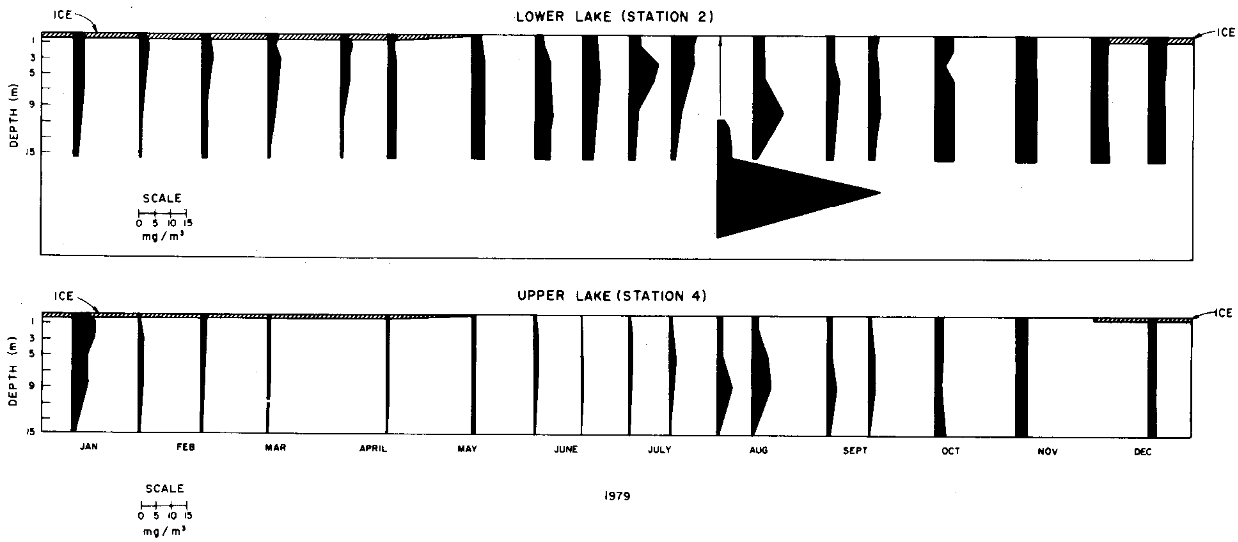


Figure 18.—Chlorophyll *a* concentrations during 1979 (mg Chl. *a*/m³).

impact of ice formation on chlorophyll *a* concentrations. However, in February, when winter stratification was at its maximum, and the lakes were in the stagnation phase, chlorophyll *a* concentrations dropped significantly.

The second conclusion from data in figure 18 is the radical difference in chlorophyll *a* concentration between the lower and upper lakes. The concentrations in the lower lake were always greater than those in the upper lake, especially during the summer months. While concentrations of chlorophyll *a* were increasing in the lower lake (May-July), they were at their lowest in the upper lake. These depressed concentrations in the upper lake during May through July were due to flushing; turbidity, which decreases light penetration; and a release of toxic levels of heavy metals during March and April. These factors are discussed in greater detail in earlier sections of this report. By late July when the peak runoff had subsided, chlorophyll *a* concentrations in the upper lake began to increase. However, stratification during September and its effect in limiting nutrient circulation in the water column depressed production; thus, chlorophyll *a* concentrations were somewhat lower. Following fall turnover and the recirculation of nutrients, chlorophyll *a* concentrations in Upper Twin Lake again increased.

The third conclusion gleaned from data in figure 18 is the effect that thermal stratification has on chlorophyll *a* concentrations. During the periods when the lakes are isothermal (April-June and October-December), chlorophyll *a* concentrations are nearly equal at all depths. Factors responsible for this are circulation by turbulence from the inflow and wind action, and clarity of lake water (later in the season). During periods of stratification, phytoplankton are concentrated at the thermocline. As the thermocline sinks, so does the stratum for maximum chlorophyll *a* concentration. On August 2, 1979, just before Twin Lakes were at their peak thermal stratification (mid-August), chlorophyll *a* concentration at 9 m was over 51 mg/m³. However, on this same date the concentrations were less than 5 mg/m³ at 5 m and less than 2 mg/m³ at 15 m. Therefore, the chlorophyll *a* was very concentrated at the thermocline. The average chlorophyll *a* concentrations for Lower and Upper Twin Lakes during 1979 were 3.84 mg/m³ and 1.49 mg/m³, respectively. Lieth and Whittaker (1975) [21] categorized lakes with chlorophyll *a* concentrations between 0.3 and 3.0 mg/m³ as oligotrophic and those with chlorophyll *a* concentrations between 2 and 15 mg/m³ as mesotrophic. Based on these classifications of lakes by chlorophyll concentration, Upper Twin Lake falls neatly in the oligotrophic category while Lower Twin Lake falls in the lower end of the mesotrophic (= mildly productive) category.

Phytoplankton Abundance.—Figures 19 and 20 present data on the trends and composition of the phytoplankton flora in the lower and upper lakes, respectively. By contrasting the two figures, the relative abundances of the two lakes can be seen. Density of phytoplankton was always greatest in

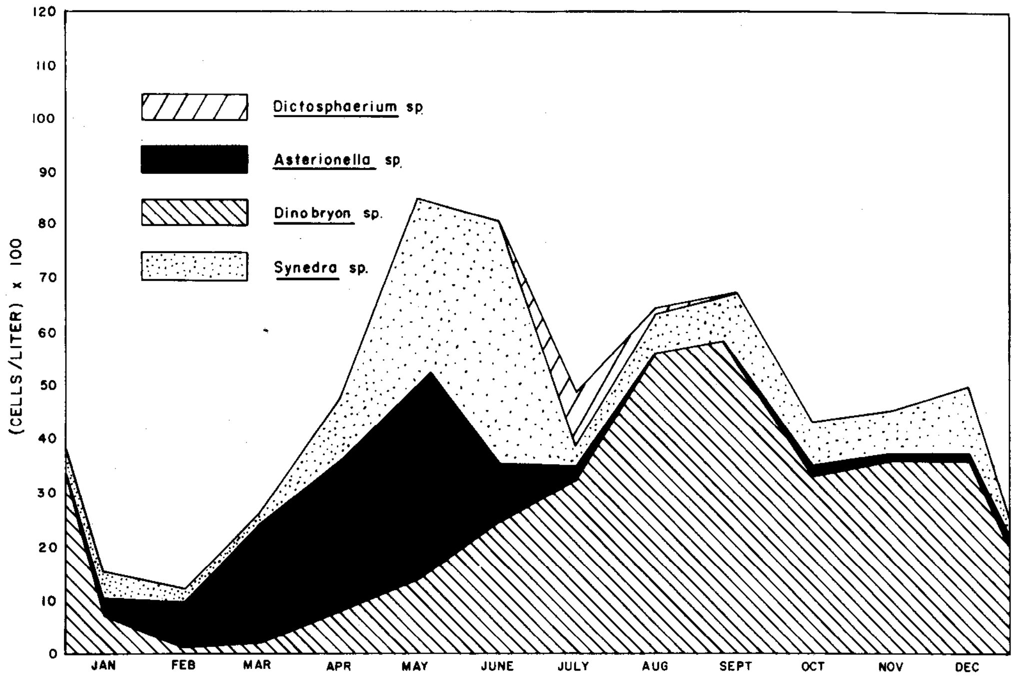


Figure 19.—Average phytoplankton abundance — Lower Twin Lake, 1979.

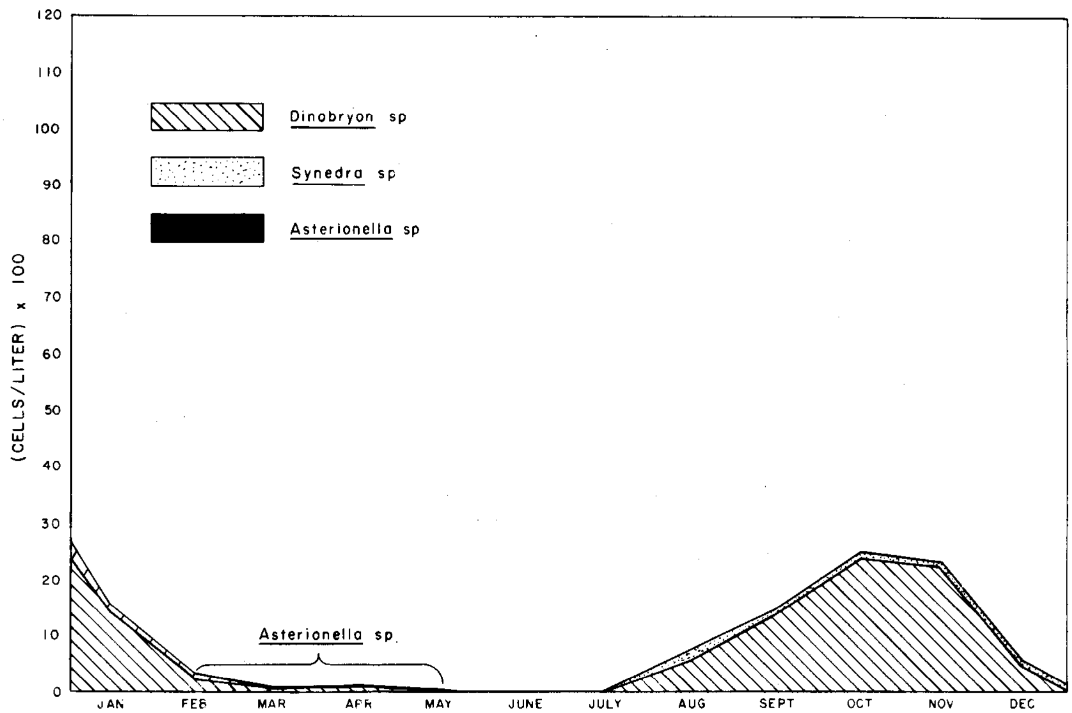


Figure 20.—Average phytoplankton abundance — Upper Twin Lake, 1979.

the lower lake. The average total phytoplankton density during 1979 was 4800 cells per liter and 1000 cells per liter for the lower and upper lakes, respectively. Thus, the abundance in the lower lake averaged about five times greater than that in the upper lake. The greatest density of phytoplankton in the lower lake (May-June) was from 8100 to 8500 cells per liter compared to under 100 cells per liter in the upper lake during this same time. These data compare very well with those for chlorophyll *a* and primary productivity rate. The reasons for this difference between the two lakes were discussed above. The peak density of phytoplankton (2500 cells per liter) in Upper Twin Lake occurred when the runoff had subsided and fall turnover had occurred (October-November). At this same time, the density of phytoplankton in the lower lake was still almost twice as great as that in the upper lake.

The two lakes also differ markedly in phytoplankton species composition. While both lakes are dominated during later summer and early fall by the yellow-brown algae *Dinobryon* sp., the phytoplankton flora in the lower lake was always more diverse. Diatoms of the closely related genera *Asterionella* sp. and *Synedra* sp. dominated the phytoplankton flora of the lower lake from January to July. These two species also occurred in the upper lake but, as in other years, they were never abundant. During 1979, in the lower lake, the green algae species *Dictyosphaerium* sp. made up about 20 percent of the phytoplankton flora during late June and July. *Dictyosphaerium* also occurred sparsely at this same time in the upper lake.

Other species which occurred in Twin Lakes in densities too small to show up on the figures were the following: the diatom *Tabellaria* sp. frequently occurred in the lower lake during November and December and in the upper lake one time in December; the golden-brown species *Mallomonas* sp. occurred frequently in the lower lake and very infrequently in the upper lake from January through June; and the blue-green species *Oscillatoria* sp. occurred in Lower Twin Lake only, on one date in June and frequently in November. The presence of *Oscillatoria* indicates that the lower lake was mildly enriched following fall turnover. During the years when spring runoff is low and the biota in Twin Lakes is relatively low in density, *Oscillatoria, Mallomonas, Tabellaria,* and *Dictysphaerium* are either not found or found very sparsely. During years of greater runoff, these species occur in varying, but always greater, densities. In addition, many other species of algae occur in Twin Lakes, but always in very small densities and mostly in restricted areas of the lakes.

The lakes, then, are typically dominated by *Dinobryon, Asterionella,* and *Synedra. Asterionella* and *Synedra* occur during winter and spring, mostly in the lower lake, and are replaced during summer and fall by *Dinobryon,* which occurs in both lakes. The sparse occurrence of *Asterionella* and *Synedra* in Upper Twin Lake may be related to their relative sensitivity to the greater concentrations of heavy metals which are found during late winter. Lower concentrations of trace metals are found in Lower Twin Lake. These conditions perhaps favor the growth of *Asterionella* and *Synedra* there. Hutchinson (1957) [12] suggested that *Asterionella* was an indicator of phosphorus-poor water. During late winter the phosphorus concentrations of the lower lake are indeed low, conceivably then favoring *Asterionella.* Later in the season, as runoff from both Lake Creek and around the lakes increases, phosphorus is more plentiful. At this time *Dinobryon* and other species of algae increase in abundance, while *Asterionella* and the closely related species of *Synedra* decrease in abundance.

Zooplankton Abundance.—Four kinds of zooplankters are commonly found in the plankton of Twin Lakes: mysis shrimp, cladocerans or water fleas, copepods, and rotifers. Mysids copepods, and rotifers are by far the most abundant kinds found, with cladocerans occurring only during years of relatively greater abundance of biota in Twin Lakes. Juday (1906) [13] reported that cladocerans (*Daphnia* spp.) made up from 20 to 45 percent of the adult zooplankton faunas of Upper and Lower Twin Lakes during 1902 and 1903. During the last 6 years (1974-79) of study at Twin Lakes, cladocerans have never made up as much as 1 percent of the adult zooplankton fauna. The only cladoceran found in any significant abundance in Twin Lakes is the relatively small-bodied *Bosmina*. Only an occasional specimen of *Daphnia* is ever collected. Figures 21 and 22 contain data on the abundance and species composition of the zooplankton fauna at Twin Lakes during 1979. The density of zooplankton was always far greater in the lower lake than in the upper. The average total zooplankton densities during 1979 were 47 and 13 per liter for Lower and Upper Twin Lakes, respectively; that is, the density of zooplankton

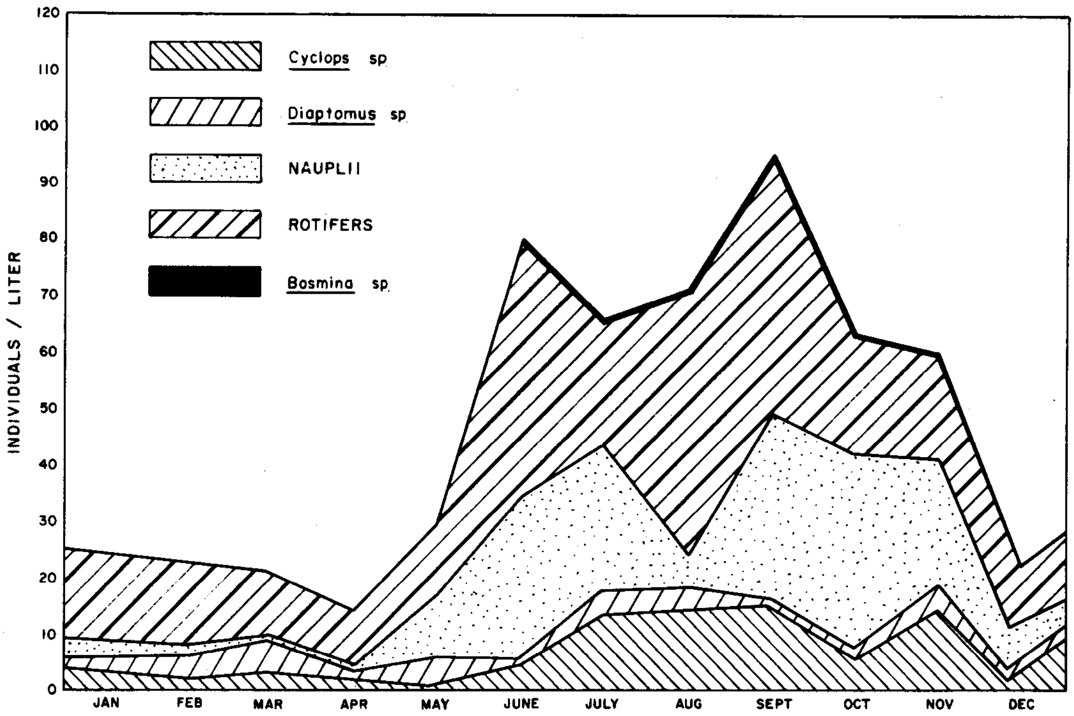


Figure 21.—Average zooplankton abundance — Lower Twin Lake, 1979.

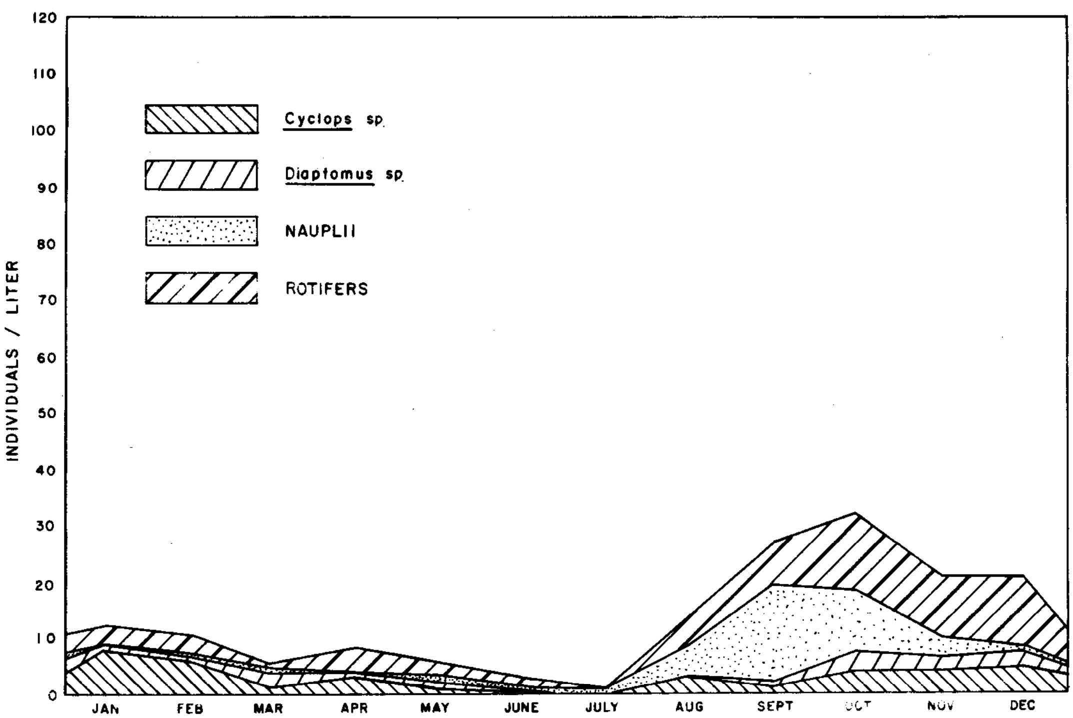


Figure 22.—Average zooplankton abundance — Upper Twin Lake, 1979.

was on the average over three times greater in the lower lake. During July, the zooplankton density in the lower lake was 65 times greater than that of the upper lake. This was probably a result of the flushing by runoff. During mid-June, when runoff was greatest, it took about 7 days to replace the entire volume of the upper lake.

Rotifers and copepods made up over 99 percent of the Twin Lakes zooplankton fauna during 1979. Three species of rotifers dominated: *Kellicotia* sp., *Keratella* sp., and *Polyarthra* sp. *Kellicotia* and *Keratella* are the most abundant of these three. Two species of copepods are found in Twin Lakes: *Diaptomus shoshone* and *Cyclops longispinius*. *Cyclops* is the dominant of the two during June through January. From February to June, *Diaptomus* dominates slightly. This may indicate that the *Cyclops* in Twin Lakes hatch during the early season and the *Diaptomus* hatch during late season. It is not possible to distinguish between the different species of nauplii or immature copepods. As seen on figures 21 and 22, nauplii begin to increase in density during April in Lower Twin Lake and in July (following runoff) in Upper Twin Lake. From then on throughout the ice-free season, there seemed to be a constant replenishment of nauplii, with perhaps a low during mid-August. There are two possible explanations for this replenishment: both species may constantly reproduce themselves during the ice-free season or each of the species may be univoltine for a specific time of the year. Nonetheless, the adult population of copepods increases at a constant rate following the increase in nauplii density. The introduced[5] freshwater shrimp, *Mysis relicta,* is very abundant in Twin Lakes. *Mysis* are habitually nocturnal, and since the zooplankton in figures 21 and 22 were collected exclusively during daylight hours, *Mysis* do not show up. Gregg (1976) [8] reports on the densities of *Mysis relicta,* in Twin Lakes.

Due to the fact that rotifers, some copepods, and *Mysis* are especially carnivorous, the abundance of nauplii is not reflected equally by the abundance of adults. Predation on the nauplii from various species of zooplankton probably results in the loss of a significant number.

The greater abundance of rotifers and the near absence of cladocerans during at least the last 10 years versus what was reported by Juday (1906) [13] for 1902 and 1903 is especially curious. The subject will be discussed in greater detail in a report being prepared on the results of 6 years of collecting zooplankton from Twin Lakes. However, it seems quite likely that the introduced freshwater shrimp, *Mysis relicta,* may be the main cause of the change in the composition of the Twin Lakes zooplankton fauna between 1903 and 1974. Goldman, et al. (1979) [9] described a similar alteration in the composition of the zooplankton fauna following the introduction of *Mysis relicta* into Lake Tahoe. However, in the case of Twin Lakes, other species introductions (rainbow trout, brown trout, lake trout, and brook trout), physical changes in the lakes (lowered outlet works, dredging of channel, blasting of Lake Creek waterfalls), hydrological changes (augmentation of inflow, controlled outlow, fluctuating water levels), and human settlement of the area (mining, road construction etc.) could also be reasons for changes in the species composition of zooplankton in Twin Lakes. Since the ecology of Twin Lakes seems to be very sensitive to any change, all of the above possibilities must be considered. However, when the newly constructed dam and the Mt. Elbert Pumped-Storage Powerplant begin operation, further change in the composition of the zooplankton fauna will probably occur.

Benthos. —The 1979 benthic data brought out several relationships between the upper and lower lakes. The chironomid population of the lower lake (station 2) was larger than that of the upper lake (station 4). In terms of abundance, the lower lake was found to contain three times as many chironomids as the upper lake, while the grams dry weight per square meter was 2½ times greater (figs. 23 and 24). Although the upper lake contained fewer chironomids, the average weight per individual was found to be 24 percent higher.

Fluctuations during the year showed slight depressions in the chironomid populations during the summer months in both lakes. The chironomid biomass remained fairly constant in the upper lake (fig. 25), but showed a dramatic increase (four times) between March and December in the lower lake (fig. 26).

Oligochaetae populations in Twin Lakes showed almost exactly the opposite trends during 1979 (figs. 27 and 28). The upper lake was found to contain twice the abundance and weight of oligochaetae in comparison with the lower lake, but

[5] *Mysis relicta* was introduced in 1958 from Clearwater Lake in Minnesota by the Colorado Division of Wildlife.

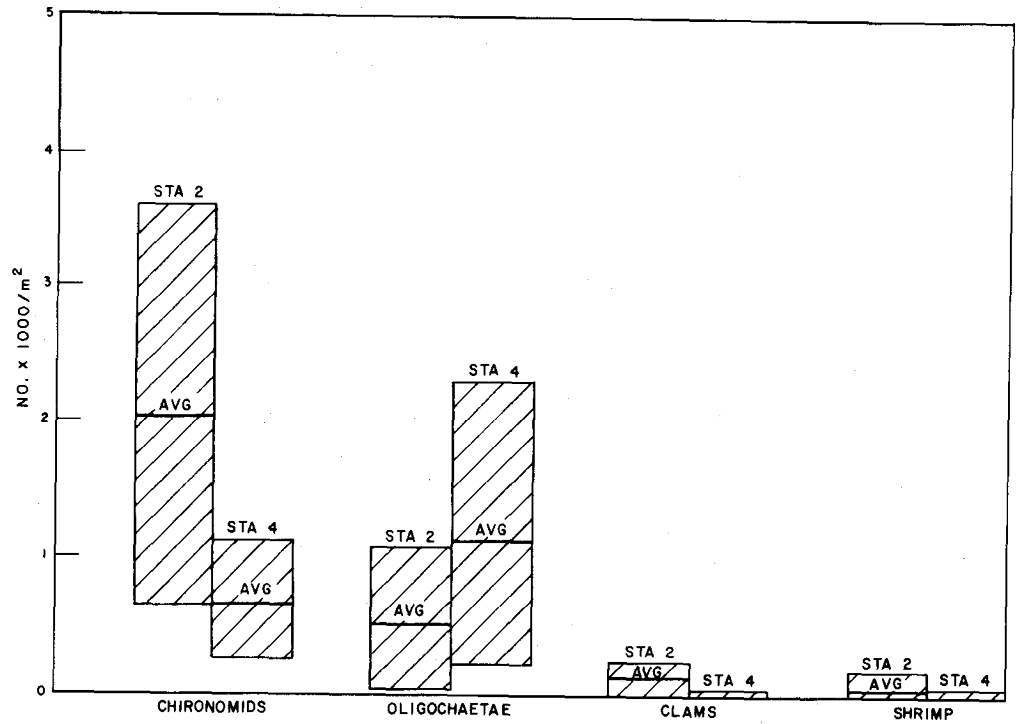


Figure 23.—Benthic abundance ranges, 1979.

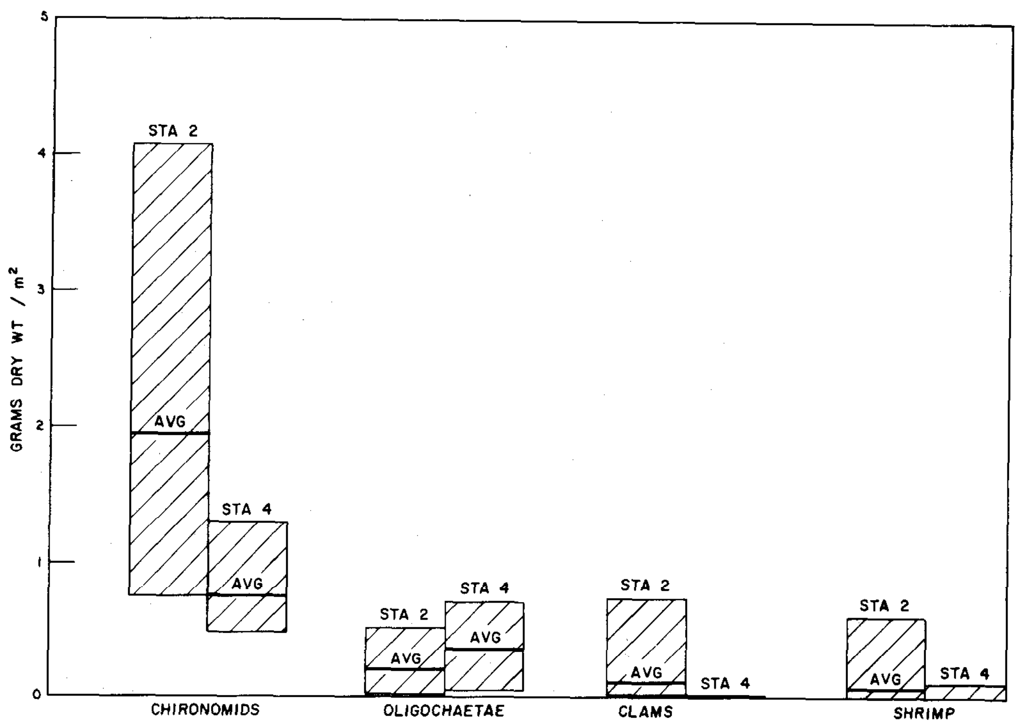


Figure 24.—Benthic biomass ranges, 1979.

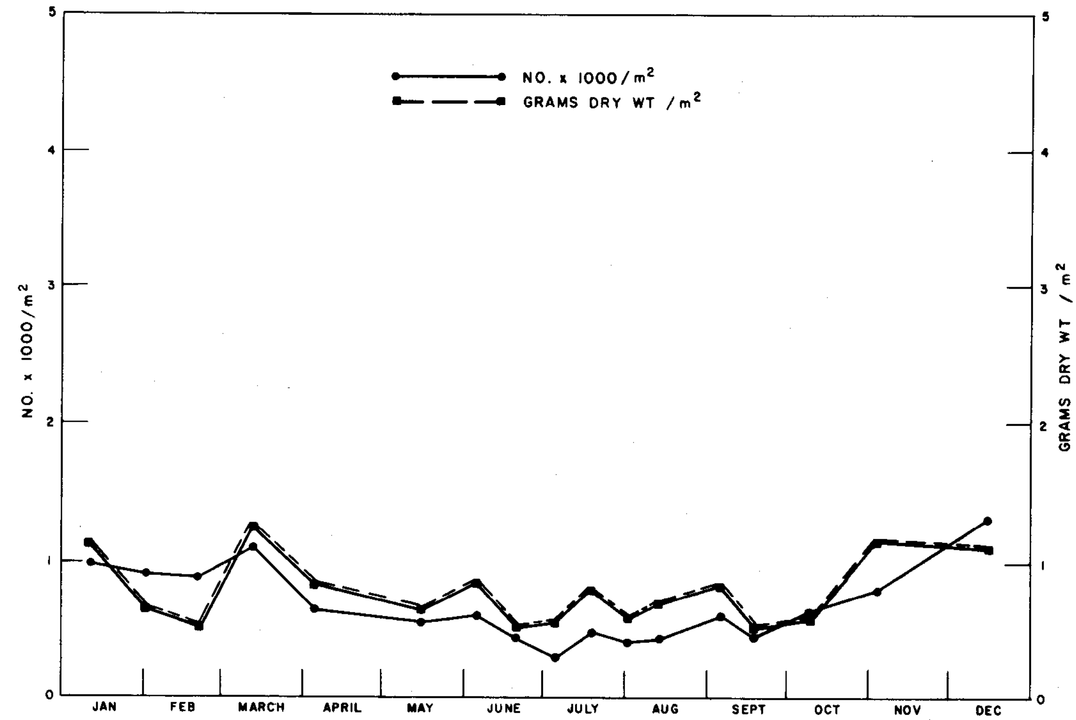


Figure 25.—Chironomids — Upper Twin Lake, 1979.

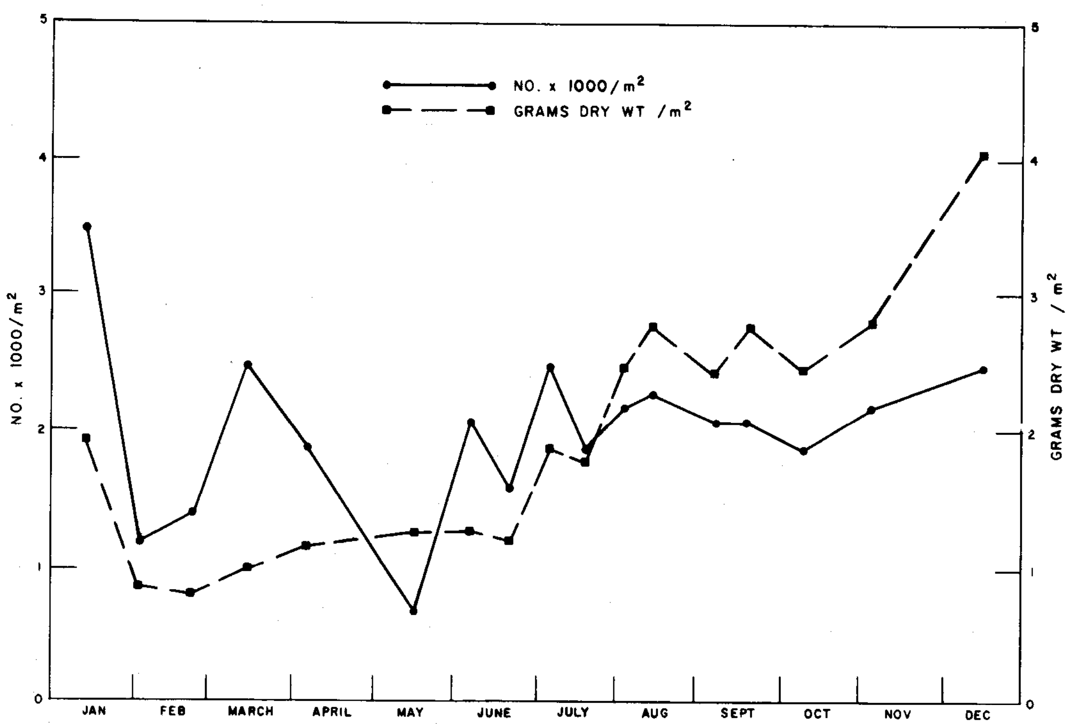


Figure 26.—Chironomids — Lower Twin Lake, 1979.

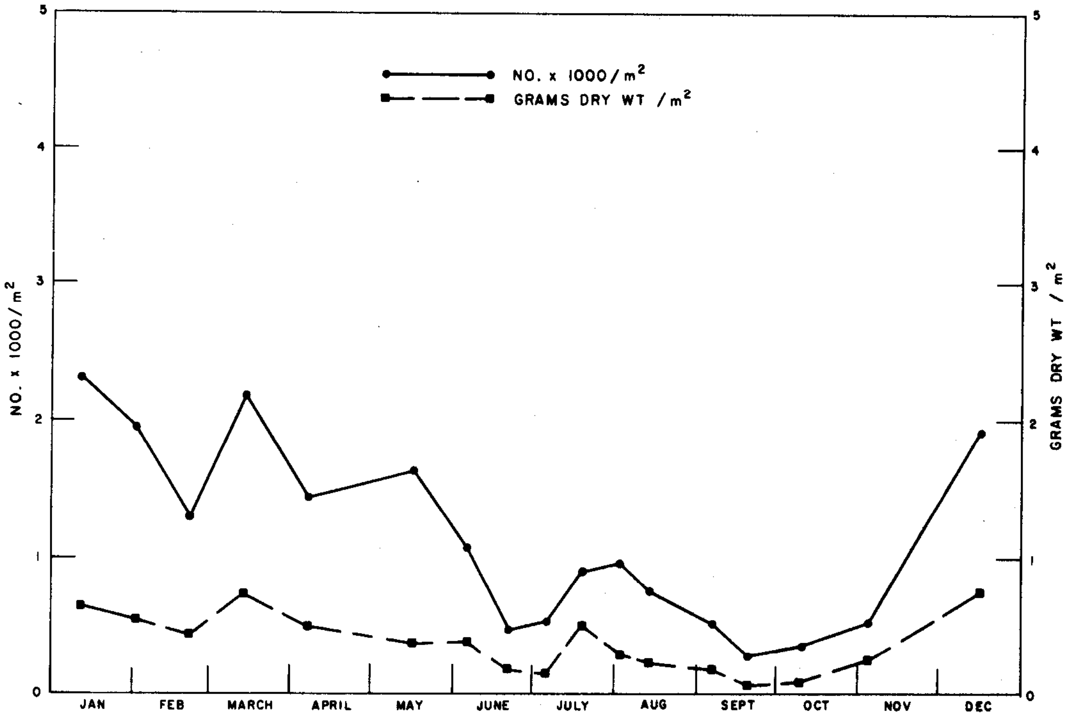


Figure 27.—Oligochaetae — Upper Twin Lake, 1979.

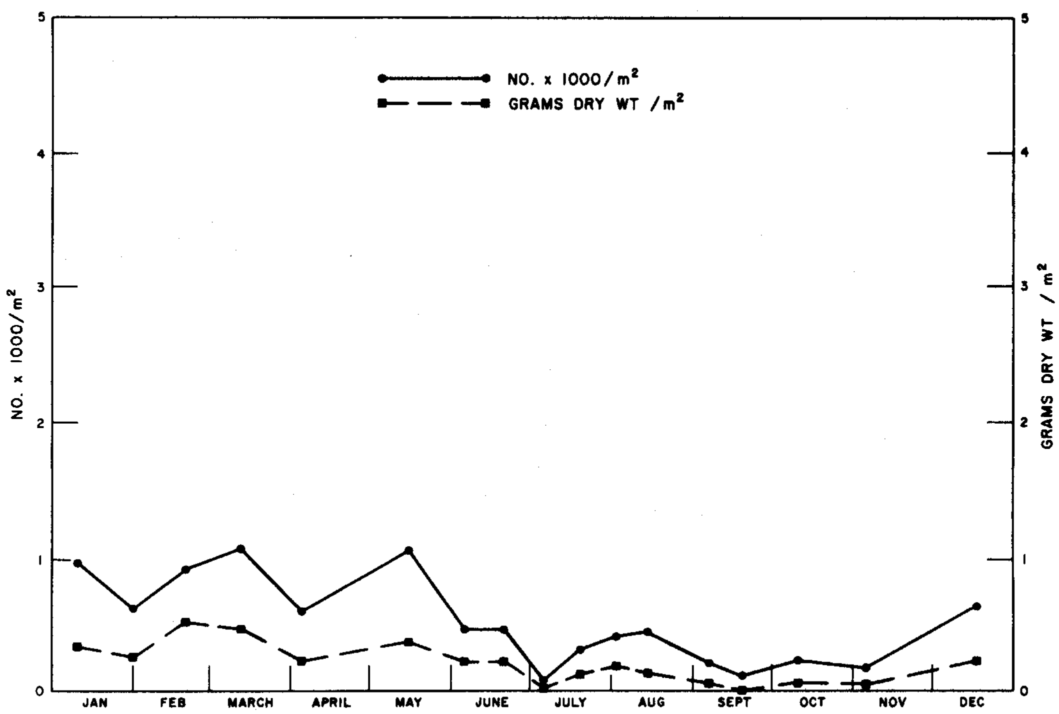


Figure 28.—Oligochaetae — Lower Twin Lake, 1979.

the lower lake's individual weight was greater by 15 percent (figs. 23 and 24).

Neither clams nor *Mysis* shrimp played a large part in the makeup of the benthos (figs. 23 and 24). The lower lake's samples consistently contained fingernail clams. The abundance of clams in Lower Twin Lake during 1979 was 132 per square meter, while the upper lake samples contained clams on only one date, December 17, 1979 (table 7).

Mysis shrimp, rarely found in our benthic samples, showed up in substantial (up to 172 /m²) numbers from July to November in the lower lake. This fall peak corresponds with the mysis trawl data collected by the Colorado Department of Wildlife (Mr. Tom Nessler, personal communication). As with the clams, the abundance of shrimp in the upper lake was also lower than that of the lower lake. Mysids were found on only two occasions in the upper lake (table 7).

The average total benthic biomass (chironomids, oligochaetes, clams, and shrimp) for the lower lake was twice that of the upper lake during 1979. In previous years this difference has been both greater (1975-76) and less (1977-78). Severity of the depletion of dissolved oxygen during the winter stagnation and the volume of runoff into Twin Lakes probably influence the type and abundance of benthic populations.

DISCUSSION

The Twin Lakes ecological study includes 6 years of limnological data (1974 through 1979). The data collected from 1974 through 1978 left many unanswered questions regarding the limnological characterization of the lakes. The data collected during 1979 helped answer many of those questions. The following is a summary of the events that have affected the lakes since 1974 and our interpretation of their impact on the lake's limnology.

The winter of 1974-75 was relatively severe. It was a prolonged winter, with a heavy snowpack on Twin Lakes. A mild spell from early to mid-March caused runoff down Lake Creek to flow over the top of the ice. The weather then turned cold and the lakes remained frozen and snow covered into early May. By mid-April, the upper lake was anaerobic at the bottom, with pH values below 7.0. The result was that some of the trace metals in the sediments underlying this anaerobic layer became dissolved. This heavy-metal-laden anaerobic layer probably remained for the 2-week period. Spring turnover caused it to dissipate. The benthos in Upper Twin Lake was almost totally destroyed by the toxic concentrations of these metals. The population of benthos in the upper lake did not recover for at least 3 years and even now the population of clams may not have completely recovered. When spring turnover occurred, toxic concentrations of dissolved metals (copper, zinc) dissipated into the water column and were even carried by flow into the lower lake. Zooplankton and phytoplankton were killed before these metals reformed in soluble salts with available anions. Since Twin Lakes water is poorly buffered and has a total dissolved solid concentration of as low as 20 mg/L in spring, these unassociated ions may persist in solution long enough to cause toxicity to at least algae and zooplankton. It was not until late August that chlorophyll *a* was again detected in Upper Twin Lake.

Table 7.—*Twin Lakes benthos summary, 1979*

Station	Organism	Avg. No./m²	Avg. dry wt (g/m²)	Avg. dry wt (g/m²)
2	Chironomids	2023	1.9550	0.00100
2	Oligochaetae	524	0.2100	.00038
2	Clams	132	.1225	.00079
2	Shrimp	31	.0658	.00114
4	Chironomids	682	.7846	.00124
4	Oligochaetae	1132	.3691	.00033
4	Clams	N/A	N/A	N/A
4	Shrimp	N/A	N/A	N/A
2	Total biomass		2.3533	
4	Total biomass		1.1537	

A winter of the severity of 1974-75 has not occurred since. The winter of 1978-79 came closest, but runoff began relatively early because of mild weather at the end of March. The winters of 1975-76 and 1976-77 were extremely mild, with relatively low runoff. If runoff had been average or above during these mild winters, zooplankton and phytoplankton populations would have shown a faster recovery than they did from the effects of metals pollution during the spring of 1975. As it happened, drought conditions severely limited nutrient input, thus restricting productivity through the entire food chain. No significant snow cover was maintained during the winter of 1977. Field investigators had to wear crampons to avoid slipping on the bare ice. Also, the mountain peaks surrounding Twin Lakes remained clear of snow during the entire winter. During the winter of 1977-78, conditions were different. Snowpack was at or above what is considered normal. Runoff following the winter of 1978-79 was significantly above normal. However, these two "wet" winters were still not as severe as that of 1974-75 in terms of depth and duration of snow cover on the lakes. Therefore, toxicity from metals pollution was not a problem.

The above-normal runoff during years since 1977 have brought above-normal input of phosphorus and nitrogen nutrients. These available nutrients have caused a far greater algal production than had been measured in 1975, 1976, or 1977. This greater abundance of phytoplankton is being reflected throughout the entire food chain. LaBounty and Sartoris (1980) [20] discussed in detail the effects of the drought versus wet years on the limnology of Twin Lakes. The limnological data indicate that 1979 was a culmination of recovery both from the effects of metals pollution and the drought. The data further indicate that 1979 conditions reflect above-normal inputs of nutrients and the results of having both lakes maintained at high water levels. Figure 29 contains data on the abundance of zooplankton in Lower Twin Lake during August from 1974 through 1979. These data provide a good summary of conditions in Twin Lakes during the past 6 years. In August 1974, the zooplankton population was relatively high. Also, the greatest density of zooplankton and the thermocline occurred below 10 m at that time. Since zooplankton accumulate at the thermocline, the density below 10 m was greatest. In August 1975, the densities were perhaps 15 to 20 percent of what they had been in August 1974. These low densities were a result of toxicity from the heavy metals release at spring turnover. In August 1976 densities were even lower. The low densities found in 1975 were sustained in August 1976 because of low nutrient input.

The drought was most severe during the winter of 1976-77; however, during February 1977, the primary productivity rates under the ice were higher than we had ever measured in Twin Lakes until that time. These high rates were due to lack of snow cover and were probably influenced by a nutrient change from some source. However, we do not have data to substantiate the latter. Nevertheless, production rates were high and it does seem that these conditions plus the lack of a severe winter during 1976-77 provided the foundation for the recovery of Twin Lakes noted in the dramatically increased densities found in August 1977. Data in figure 29 show these beginnings of the recovery from the two conditions. Data from other months of 1977 substantiate this and the data from August 1978 show further recovery. Finally, the densities in 1979 far exceeded any previously measured at Twin Lakes. The greatest densities occurred in the top 10 meters, above the thermocline. Increased nutrient input during the previous 2 years resulting in greater than normal primary production, plus the lack of any severe winter conditions, contributed to the increased densities of zooplankton in 1979. The result of this increase in primary and secondary productivity should eventually be reflected in the biomass of fish found in Twin Lakes. Data collected during the next few years will prove or disprove this hypothesis. Finally, it is not yet clear whether or not Twin Lakes has reached its maximum level of productivity. Data from 1980, to be reported in a subsequent publication, should help answer this question.

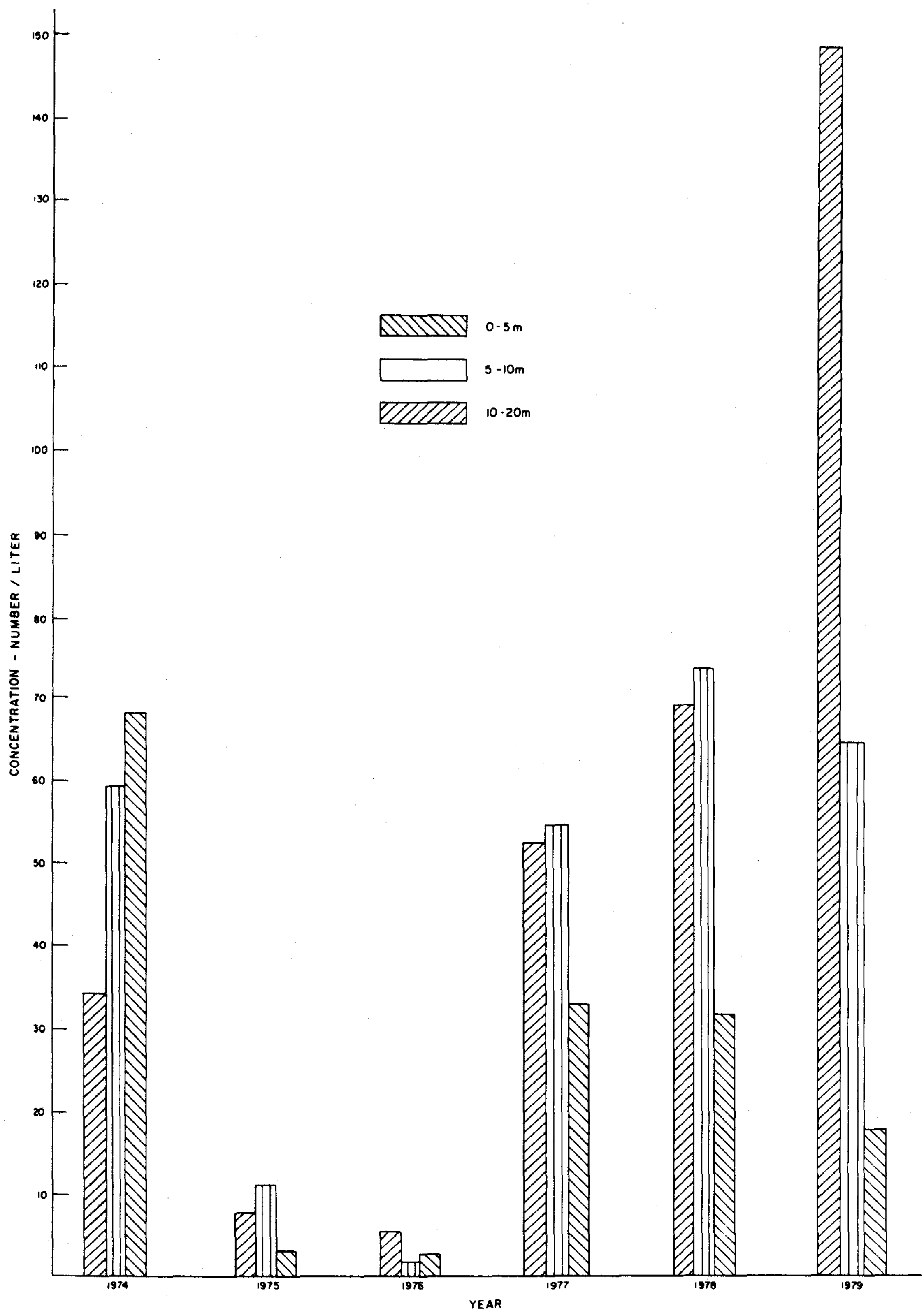


Figure 29.—Zooplankton abundance during August in Lower Twin Lake.

BIBLIOGRAPHY

[1] U.S. Geological Survey, *National Handbook of Recommended Methods for Water-Data Acquisition,* Reston, Virginia, 1977.

[2] Barcia, J., and J. A. Mathias, "Oxygen Depletion and Winterkill Risk in Small Prairie Lakes under Extended Ice Cover," *J. Fish. Res. Board Can.,* vol. 36, pp. 980-986, 1979.

[3] Bergersen, E. P., "Aging and Evaluation of Twin Lakes Sediments," pp. 29-40 *In:* LaBounty, J. F., (ed.) *Studies of the Benthic Environment of Twin Lakes, Colorado,* Bureau of Reclamation Report No. REC-ERC-76-12, 47 pp., Denver, Colo., 1976.

[4] Buckles, W. G., *Archeological Salvage for the Fryingpan-Arkansas Project in Lake, Chaffee, and Pitkin Counties, Colorado, in 1972,* National Park Service Contract No. 2-929-P-20073, 157 pp., Anthropology Laboratory, Southern Colorado State College, Pueblo, 1973.

[5] Cole, G. A., *Textbook of Limnology,* The C. V. Mosby Company, 426 pp., St. Louis, Mo., 1979.

[6] Deason, W. D., "Bacteriological Survey of Twin Lakes, Colorado," *In:* LaBounty, J. F. (ed.) *Studies of the Benthic Environment of Twin Lakes, Colorado,* Bureau of Reclamation Report No. REC-ERC-76-12, pp. 42-47, Denver, Colo, 1976.

[7] Finnell, L. M., *Results of Fishery Investigations at Twin Lakes, Colorado: 1974-76,* Water and Power Resources Service Report No. REC-ERC-80-5, Denver, Colo., (in press).

[8] Gregg, R. E., *Ecology of* Mysis relicta *in Twin Lakes, Colorado,* Bureau of Reclamation Report No. REC-ERC-76-14, 70 pp., Denver, Colo., 1976.

[9] Goldman, C. R., M. D. Morgan, S. T. Threlkeld, and N. Angeli, "A Population Dynamics Analysis of Cladoceran Disappearance from Lake Tahoe, California-Nevada," *Limnology and Oceanography,* vol. 24, No. 2, pp. 298-297, 1979.

[10] Griest, J. R., *The Lake Trout of Twin Lakes, Colorado,* Bureau of Reclamation Report No. REC-ERC-77-4, 29 pp., Denver, Colo., 1977.

[11] Hart, W. B., P. Doudoroff, and J. Greenbank, *Evaluation of Toxicity of Industrial Wastes, Chemicals, and Other Substances to Freshwater Fishes,* Water Control Laboratory, Atlantic Refining Company, Philadelphia, Pa., 1945.

[12] Hutchinson, G. E., *Treatise on Limnology,* Volume I, 1,115 pp., John Wiley and Sons, Inc., New York, N.Y., 1957.

[13] Juday, C., *A Study of Twin Lakes, Colorado, with Aspectual Consideration of the Food of the Trouts,* Bureau of the Fisheries, Document No. 616, pp. 148-178, 1906.

[14] Krieger, D. A., *Life Histories of Catostomids in Twin Lakes, Colorado, in Relation to a Pumped-Storage Powerplant,* Water and Power Resources Service Report No. REC-ERC-80-2, Denver, Colo., (in press).

[15] LaBounty, J. F., *Second Workshop on Ecology of Pumped Storage Research at Twin Lakes, Colorado,* Bureau of Reclamation, Engineering and Research Center, 48 pp., Denver, Colo., 1975.

[16] LaBounty, J. F., *Third Workshop on Ecology of Pumped-Storage Research at Twin Lakes, Colorado, and Other Localities,* Bureau of Reclamation, Engineering and Research Center, 107 pp., Denver, Colo., 1976.

[17] LaBounty, J. F., R. A. Crysdale, and D. W. Eller, *Dive Studies at Twin Lakes, Colorado, 1974-75,* Bureau of Reclamation Report No. REC-ERC-76-15, 23 pp., Denver, Colo., 1976.

[18] LaBounty, J. F., and R. A. Roline, "Studies of the Effects of Operating the Mt. Elbert Pumped-Storage Powerplant," *In:* Clugston, J. (ed.), *Proceedings of the Clemson Workshop on the Environmental Effects of Pumped Storage Hydroelectric Operations,* U.S. Fish and Wildlife Service Report No. FWS/OBS-80/28, pp. 54-56, Clemson, S. C., 1980.

Foreword

This report describes the ongoing research efforts of the Colorado Cooperative Fishery Research Unit at Twin Lakes, Colorado, during 1979. Because of the continuing nature of our work at Twin Lakes, preliminary conclusions stated in this report should be considered tentative.

APPENDIX CONTENTS

TABLES

FIGURES

APPENDIX CONTENTS

FIGURES — CONTINUED

INTRODUCTION

The objectives of the Colorado Cooperative Fishery Research Unit's efforts at Twin Lakes in 1979 were to fill in gaps in our knowledge of the two-lake system and to develop environmental monitoring techniques suitable for use during post-construction operating periods of the Mt. Elbert Pumped-Storage Powerplant. All progress to date on various segments of the research is described. Also included in this report is a brief discussion of planning and development efforts specifically related to our proposed activities in 1980.

LAKE CURRENTS

Introduction

The currents in Twin Lakes are one part of the physical limnology of this two-lake system which has not previously been studied. The completion of the Mt. Elbert Powerplant along with a new dam on Lower Twin Lake will undoubtedly change the lake's currents. Monitoring these current changes will further our understanding of changes in the physical, chemical, and biological parameters of these lakes.

Upon completion of the dam and subsequent enlargement of the lake, the increased fetch of the wind may increase the velocity of the lake currents. If this occurs, several components of the food chain in the lake will be impacted. Additional wind-induced currents could affect the *Mysis relicta* population, which is known to be sensitive to turbulence (Gregg & Bergersen 1980). Bottom sediments could be disturbed. Larval fish could become dislodged from the protection of some shores and become concentrated on less sheltered shorelines.

The powerplant will increase lake currents in the vicinity of the tailrace. These currents are also likely to affect the *Mysis* population, bottom sediments, and/or larval fish. Furthermore, these currents will add a new dimension to the situation in that they will continue throughout the winter. This could have two effects. Changes may become apparent in the ice sheet (erosion, pitting, etc.), making parts of the lake dangerous for recreational uses (ice fishing, jeep and snowmobile races, etc.) Also, under-ice currents could be sufficiently strong to keep sediments suspended during the period of time when they normally settle to the bottom. This would result in increased turbidity and a subsequent change in the energy budget of the lake.

Our efforts in 1979 were directed toward documenting seasonal patterns in surface and bottom currents in the two-lake system.

Materials and Methods.

Wind Vane.—Wind data were gathered with a recording wind vane made by placing a Minolta time lapse movie camera over a conventional wind vane. The intervalometer on the camera was set to take one frame every 12 to 15 minutes. In this manner, one roll of movie film recorded a whole month's wind directions. The vane and camera were placed on the roof of the garage next to the field office. A street light 5 m away provide light for nighttime exposures.

Wind Roses.—Wind roses were used to describe the wind direction from the 16 compass points. Each day was divided into fourths, and one wind rose drawn for that quarter. Wind direction was recorded at approximately 12 to 15 minute intervals by the wind vane camera. Each "arm" segment of the wind rose radiating from the center represents one reading of the wind vane. The orientation of the wind rose arms indicate the direction from which the wind was blowing. Complete calm was seldom, if ever, recorded at the lake.

Surface Currents.—Surface current measurements were based on movements of submerged drogues. Two types were fabricated (figs. 1A and 2A): one for use during the day, the other for nighttime use. Drogues were made so that they would passively move with the surface currents and be affected only minimally by the wind.

The electronics of the strobe drogue were designed and built by John Haase at the Colorado State University's electronics lab. His strobe design (fig. 3A) greatly extended battery life.

Surface currents were measured monthly. Nine to 21 drogues were set on transect lines and followed for varying lengths of time. Surface drogues were set between 7:00 and 8:00 a.m. and were monitored until sunset. Periodically the position of each drogue was recorded by triangulating on known shore positions with a sextant. Drogue positions were then plotted on maps. The velocities of surface currents were calculated by measuring the map distances traveled and multiplying by the scale of the map, then dividing by the time interval between sightings.

Bottom Currents.—The development of equipment to study bottom currents took place between May and July 1979. The ultimate purpose of this effort was to develop a current meter capable of determining the direction and velocity of bottom currents in Twin Lakes. The first step was to procure or develop equipment capable of measuring these parameters. Most conventional current meters have problems in this regard because of their inability to accurately measure slow currents (<15 cm/sec), difficulty in operating at depths of 20 m or more, and their high cost. To surmount these problems we modified the leaning tube current indicator originally developed by Carruthers (1958).

Design of the Current Indicator.—The basis of the design of leaning tube indicators is the simple fact that a bottle suspended in a current will lean or tilt in the direction of the current. If the bottle is partially filled with liquid gelatine which will solidify when cooled by the surrounding water, the angle of the surface of the gelatine from vertical can be correlated with the velocity of the current. A bar magnet suspended in the gelatine becomes locked into its north-pointing direction as the gelatine cools, thus indicating the direction of the current. This type of current indicator has several advantages: (1) it can operate at any depth, (2) it is inexpensive ($3-$5 per unit), (3) all components are easily assembled and readily available, (4) it is quick and easy to use, (5) it is reusable, and (6) it is independent of any drift associated with the research vessel used to position it.

Since Carruthers "Pisa" indicators were designed for deep oceanic use and were unnecessarily large for our purposes, we designed a considerably smaller indicator which operated on the same principle.

The physical properties of a 3-percent (by weight) gelatine solution were studied before the initial testing of the indicators. It was found that gelatine, initially heated to 55 °C, would solidify in 0.5 hours when the indicators were immersed in water below 10 °C. The time for the gelatine to solidify varied little when water temperatures were between 0 and 10 °C. Hardening time was longer when the bottles were not immersed in water, but allowed to cool in air. At 2 and 13 °C ambient air temperatures, the gelatine would harden in 2 and 5 hours, respectively.

Initial calibration of the current indicators at the Water and Power Resources Service Hydraulics Laboratory was unsuccessful. The 3-percent gelatine solution would not harden in the 17 °C water available in the laboratory test flumes. Various concentrations of gelatine and agar were tested to find a suitable media which would harden at or above 21 °C. Results of the testing (table 1A) indicated a 10-percent (by weight) gelatine solution would be satisfactory. Agar was found to harden too quickly and to need high temperatures to remelt once solidified.

Table 1A.—*Results of testing various concentrations of agar and gelatine*

Media	*Hardening time, min.	Approximate temp. at hardening, °C
0.5% Agar	20	24
0.75% Agar	20	26
1.0% Agar	20	25
5% Gelatine	40	20
7% Gelatine	33	22
10% Gelatine	30	23

*Both media were heated to approximately 60 °C, then cooled in a 20 °C water bath.

Indicator Calibration.—An inclinometer was built to measure the angle of the surface of the gelatine (fig. 4A). To measure the angle, the bottle is placed flush against the side of the inclinometer and the line etched in the triangle is then raised or lowered until parallel with the surface of the gelatine. The degrees from vertical are then read directly from the protractor.

Indicators containing a 10-percent gelatine solution were tested at the Water and Power Hydraulics Laboratory; however, tests were not entirely successful. Upon being placed in the flume, the cooling effect of the water caused a partial vacuum to form inside some of the indicators, thereby drawing water into the bottles and causing them to sink. Those that did function properly were found to be insensitive to slow currents due to their large mass. Indicators were redesigned to eliminate the leakage problem and to make them more sensitive to slower currents. These modifications (fig. 5A) included filling the air space above the gelatine with liquid vegetable oil to eliminate the vacuum problem and a reduction in cross sectional profile. The new design was tested on June 15, 1979 and proved to be suitable for our purposes. The results of the flume tests are shown on figure 6A. A list of all materials used in construction of the current meter and its rigging is given in table 2A.

The current meter was rigged (fig. 7A) so it could be released over the side of the research vessel and sink to the bottom without sinking into bottom sediments. Bottom currents were measured monthly along three transects in the upper lake and five in the lower lake. Eight to 10 indicators were set along each transect. The position of set was triangulated by sextant and the depth was recorded. Current indicators were set in the mornings on the day of measurement. At least 30 minutes after setting, indicators were retrieved and degree tilt of gelatine surface from horizontal was measured with the inclinometer. The direction of the current was determined by comparing the direction of tilt of the bottle to the north-south orientation of the bar magnet which was firmly held in the solidified gelatine. Position of sets were recorded on maps and the direction and velocity indicated.

Results

Surface and bottom currents in the upper and lower lakes were plotted for the months of August, September, October, and November. Surface currents and wind directions for the upper lake are shown on figures 8A through 15A. Surface currents and their respective wind directions for the lower lake are shown on figures 16A through 23A. Bottom currents and wind directions for the upper and lower lakes are given on figures 24A through 43A. The velocity of surface currents is given in centimeters per second and was calculated using the straight line distance between the points and, therefore, represents the minimum velocity estimate. The velocity of bottom currents is also given in centimeters per second but could only be measured down to 3 cm/s due to limitations of the sampling device.

The maximum surface current measured on the upper lake was 14 cm/s and the lower lake's maximum was 13.7 cm/s. Maximum observed bottom currents for the upper and lower lakes were 9.0 and 15.2 cm/s, respectively. The maximum bottom velocity in the lower lake was measured near the inflow.

Discussion

Surface Currents - Upper Lake.—A strong dependence exists between wind surface currents in the upper lake. For example, figures 8A, 9A, 14A, and 15A show that when the wind is out of the southwest, surface currents move strongly to the northeast. The reverse is also true. Winds out of the east-southeast drive currents to the west-northwest (figs. 10A and 11A). In the upper lake,

Table 2A.—*Specific materials used in improved flow indicator*

Material	Size
1. Evenflo clear plastic nursers	240 mL
2. Hollow brass tube	9.8 cm x 0.16 cm
3. Nylon thread	11.5 cm
4. Baby bar magnet	2.2 cm
5. Silicone rubber sealant	0.1 mL
6. Grayslake unflavored gelatine	14 gr.
7. Red food coloring	2 drops
8. Crisco vegetable oil	150 mL
9. Plastic bead	5 mm x 2 mm
10. Water	130 mL
11. Brass screw eye	1.3 cm
12. Rubber washer	3 cm
13. Monofilament (40 lb test)	41 cm
14. Treated masonite	30 cm x 60 cm
15. Snap swivel	2.2 cm
16. Plastic float	10 cm x 5 cm
17. One hole button	1 cm

then, with it's relatively low shoreline development, open exposure to winds, and smaller size, currents move nearly straight downwind. When the downwind shore is reached, currents move along shore and their velocity decreases.

Surface Currents - Lower Lake.—Surface currents on the lower lake are more variable. This is probably due to more variable wind patterns over the lake. The north bay, Mackinaw Point, and the raised land south of the channel (fig. 44A) tend to shelter areas of the lake from direct exposure to the wind. For example, Mackinaw Point's east side (fig. 22A) is protected from west winds (fig. 23A). The lee side becomes an area of eddying.

The raised land with tree cover south of the channel also protects its lee side (fig. 16A). West winds drive the surface currents strongly downwind on the north side of the lake. Currents then tend to travel back upwind in the protected area in front of Interlaken.

Some aspects of the circulation of Lower Twin Lake have yet to be explained. September's circulation pattern (fig. 18A) shows major currents moving to opposite ends of the lake. Further studies should clarify such unusual patterns.

Bottom Currents - Upper Lake.—Bottom currents of Upper Twin Lake were variable. Obvious circulation patterns, however, existed in August (fig. 24A) and November (fig. 31A). At the time currents were measured, winds were predominantly out of the southeast (figs. 25A, 26A, and 32A). Mountains on the south side of the lake blocked or slowed the wind in this area. The wind hitting the north side of the lake was relatively stronger, which caused counterclockwise currents to occur.

Worthy of closer study are the currents along the southeast shore of the upper lake. It was found that bottom currents in this area tended to be relatively strong (figs. 24A and 29A). Currents in this area appear to be sufficiently strong to remove silt from the rock bottom and provide what appears to be highly suitable lake trout spawning habitats.

Bottom Currents - Lower Lake.—In August, strong currents entered the lower lake through the channel (fig. 34A). Currents were directed to the northeast. Because of the temperature profile of the channel and lake, the inflow water did not continue along the bottom, but flowed into the epilimnion at some distance off the bottom. These were the strongest currents recorded in the two-lake system.

Bottom currents proved to be quite variable. No clear pattern could be established for the lake as a whole. Walch (1979) located probable spawning areas in the lower lake. These areas included North Bay, Rocky Point, Mackinaw Point, the south shoreline, and Hartman Point. Interestingly, some of these areas also were found to have strong currents. Currents from 10 to 11 cm/s were recorded on Rocky Point in September (fig. 35A) and November (fig. 41A). Hartman Point was found to have currents of 7 cm/s converging on its tip (fig. 38A). In September (fig. 35A) and October (fig. 38A), currents were measured off Rocky Point as high as 10.7 and 7.0 cm/s, respectively. Currents in these areas are likely to keep sediments flushed out of rocks, providing good spawning substrate. Also, Rocky Point and Mackinaw Point commonly received high fishing pressure which attests to the fact that lake trout congregate here at times other than the spawning season. The currents, presence of rocks, or both, are likely to be factors attracting the lake trout.

No clearcut relationship is yet apparent between wind and bottom currents in the lower lake.

PHOTO TRAWL

Introduction

Through the summer and fall of 1979 attempts were made to develop methods of estimating *Mysis relicta* numbers photographically. If suitable photographic methods could be developed, considerable amounts of time and manpower could be saved since the shrimp would not need to be removed from the net, preserved, and then individually counted. Accuracy of density estimates could be increased in several ways. First, the speed of the research vessel no longer becomes critical. In the present method, errors in boat speed lead to errors in distance covered and thus error in density estimates. With photographs, the area covered by each frame could be accurately measured. Second, should the trawl lift off the bottom undetected, fewer shrimp are caught. With phototrawling, the position of the trawl can be seen in the photograph. Third, mysids have been shown to exhibit a clumped distribution on the bottom. Small areas of high densities of mysids are undetectable by trawling, yet would be readily apparent in photographs. Finally, and probably most importantly, passive and active avoidance of nets by mysis may be high, thus reducing estimates of their numbers. This problem could be avoided by using a phototrawl.

Materials and Methods

An alumninum-frame trawl with outrigger skids was used in this study. It was equipped with brackets to hold a Canon F-1 35 mm camera in an underwater housing and an MK Subsea 150 underwater strobe light. The camera was positioned to be 45 cm off the lake bottom. Thus positioned, it takes a picture covering 2700 cm^2 of bottom directly in front of the trawl. The strobe was positioned over the mouth of the trawl at a 45° angle to the lake bottom. This position would accentuate the shrimp's shadows, thus increasing ease of detection and counting.

Various types of films were tested. These included both slide and print films having ASA speeds of 25, 35, 64, 100, 160, 200, and 400. Daylight as well as tungsten films were tested. Various f stops, shutter speeds, and strobe light intensities were tried with each film and a yellow filter was used in an attempt to increase contrast. Pictures were taken with the strobe 15, 30, 45, and 60 cm from the lake bottom. A total of 280 exposures were taken in this study.

Results and Discussion

Various problems have plagued this project. The strobe light was found to leak at shallow depths. A new "O" ring was purchased, the front lens was sealed with silicone, and a plexiglass bracket which enabled the two halves of the strobe to be tightened against the "O" ring seals was built. The leakage problem was eliminated.

Many pictures were underexposed, as if the strobe hadn't fired. Yet, the camera and strobe worked flawlessly above water. To confuse matters further, some pictures taken at the same setting would be underexposed or overexposed intermittently. Synchronization of camera and strobe were checked at the Lake County Camera Shop and CSU's photography lab. Synchronization was correct. A new battery was tried in the strobe. In shallow water, test pictures were good. Testing in 10 m of water with 100 ASA film and low f stops produced good exposures but with low depth of field. A higher ASA film was tried. Photographs were completely black. The strobe was returned to Subsea Products Incorporated for repair, and three internal parts were replaced (SCR, resistor, and photo cell). Further tests will be conducted at ice-out in 1980.

DOCUMENTATION OF SHALLOW SPAWNING BY LAKE TROUT

Introduction

Because of the fluctuating lake levels which will occur during the pumping-generating cycle, it is likely that any fish eggs deposited in less than 1 to 1.5 m of water will be exposed daily to the air and resulting extremes of environmental conditions which will not be favorable to their survival. Walch (1979) reported catching ripe lake trout in as little as 1.5 m of water. It was not known, however, whether these fish would have spawned this shallow. The objective of this phase of the Twin Lakes study was to determine if lake trout do spawn in water 1 m or less. The presence of live trout eggs in shallow water would be prima facie evidence of spawning in this area.

Materials and Methods

A 0.45 by 1 m frame was built to hang over the side of our work boat. It was made so the frame could be detached quickly for cleaning. The bottom of the frame was covered with 3 by 3 mm mesh hardware cloth. A Briggs and Stratton gasoline engine pump was used to pump water from the lake through the screened frame.

This equipment was taken to two known spawning areas (the east side of Mackinaw Point and the west side of Rocky Point). Both areas had suitable substrate for spawning. Two hundred and fifty meters of suspected shoreline spawning habitat was vacuumed with this pump apparatus.

Results and Discussion

Small suckers, opossum shrimp, and amphipods were found in the shallow shoreline areas but no lake trout eggs were collected. Since these shorelines were assumed to be two of the best for spawning, the preliminary conclusion would be that lake trout do not spawn in less than 1 m of water.

With ice cover exceeding 0.6 m in Twin Lakes, eggs shallower than this depth would likely freeze or be crushed by ice movements during freezing and thawing. During operation of the powerplant, the ice cover in the lake will rise and fall an additional 1 to 1.5 m. Thus, the critical depth for eggs would be as deep as 2 m. This study will continue during the fall of 1980, with depths to 2 m being checked for trout eggs.

TROUT DECOMPOSITION RATES

Introduction

A preliminary experiment was conducted to determine if any noticeable differences in decomposition rate of fish carcasses would occur if carcasses were exposed to macroscavengers or were kept isolated from them during the decomposition process. Our intent was to exclude mysis shrimp from the decomposing fish in one case and allow them free access to it in the other. Through this experiment we hoped to gain some insight into the energy contribution of dead rainbows to the *Mysis* food chain.

Materials and Methods

Rainbow trout of similar weight were placed into two baskets connected back-to-back. A weight was placed on the bottom of the baskets to sink them, and a float was placed on the top of the baskets to keep them out of the bottom sediments (fig. 45A). Mesh sizes for the baskets were 1 by 1 mm and 6.4 by 6.4 mm.

The paired baskets were lowered into 23 m of water at the center of the lower lake (Station 2). Periodically, the baskets were raised and the trout weighed on a triple-beam balance.

Results and Discussion

The weight changes that occurred in the two trout are shown on figure 46A. It is apparent that the fish exposed to larger scavengers did decompose at a slightly faster rate, at least during the second week of exposure, than the fish in the protective cover. We feel the results of this experiment are inconclusive since the experiment was not replicated. Handling differences as well as intrinsic variability could account for differences in decomposition rates. The experiment did indicate, however, that trout do decompose in a relatively short time period, even at the relatively cold temperatures encountered at 23 m. We may refine this experiment and increase replicates during 1980 if time permits.

DEVELOPMENT ACTIVITIES

Considerable time was spent during the winter of 1979-80 developing new equipment for use in the Twin Lakes studies. A prototype of a sonic release device (Ziebell, et al. 1968) has been built. A battery charger for the device was also built. Both devices were constructed by John Haase, CSU electronics lab. Testing of the release device in Rocky Ridge Reservoir, Fort Collins, Colorado, showed the device had limited sensitivity. Efforts are underway to rectify this problem.

When completed, this release device will enable us to place sediment traps (also being built) or other sampling devices on the lake bottom where they will remain undisturbed yet can be retrieved on demand without the use of surface-float attachment lines.

LITERATURE CITED

Carruthers, J. N., "A Leaning-Tube Current Indicator ("Pisa")," *Bulletin De L'Institut Oceanographique,* No. 1126, Monaco, Sept. 15, 1958.

Gregg, R. E. and E. P. Bergersen, "*Mysis relicta:* Effects of Turbidity and Turbulence on Short Term Survival," *Trans. Am. Fish. Soc.,* Vol. 109, pp. 207-212, 1980.

Walch, Leonard A., *Movements of Lake Trout in Twin Lakes, Colorado, in Relation to a Pumped-Storage Powerplant,* Water and Power Resources Service Report No. REC-ERC-79-17, July 1980.

Ziebell, C. D., W. J. McConnell, and H. A. Baldwin, "A Sonic Remote Recovery Device for Submerged Equipment," *Limnology and Oceanography* Vol. 13, No. 1, pp. 198-200, 1968.

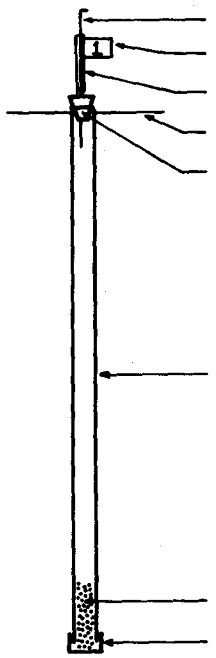


Figure 1A.—Drogue used to measure lake surface currents during daylight hours at Twin Lakes, Colorado.

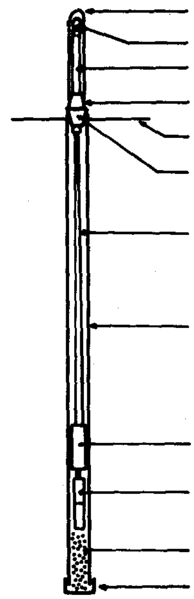
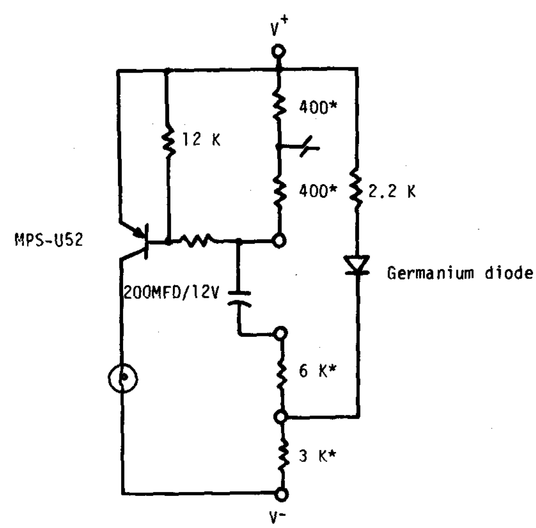


Figure 2A.—Strobe-lighted drogue for measuring nighttime lake surface currents at Twin Lakes, Colorado.



*Specified connections are contained in LM3909.

Figure 3A.—Electronics of strobe drogue used in nighttime studies of lake surface currents at Twin Lakes, Colorado.

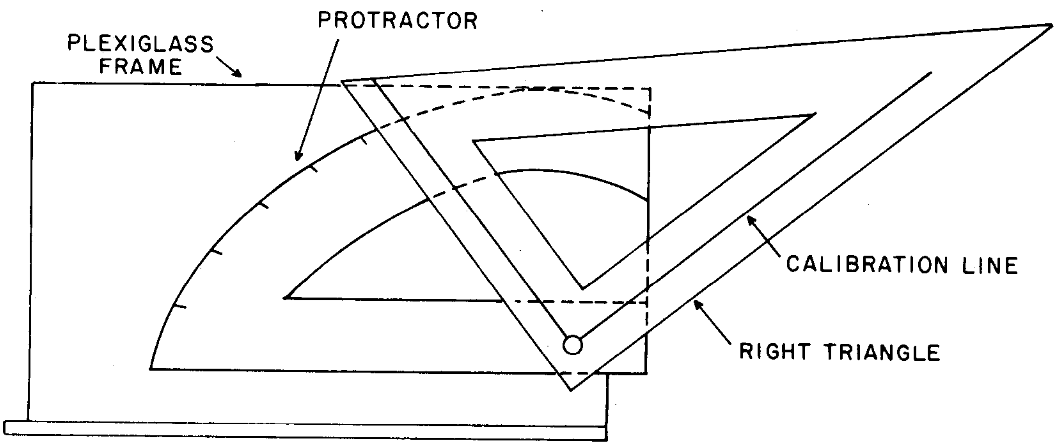


Figure 4A.—Inclinometer built to measure surface angle of the gelatine in the flow indicators.

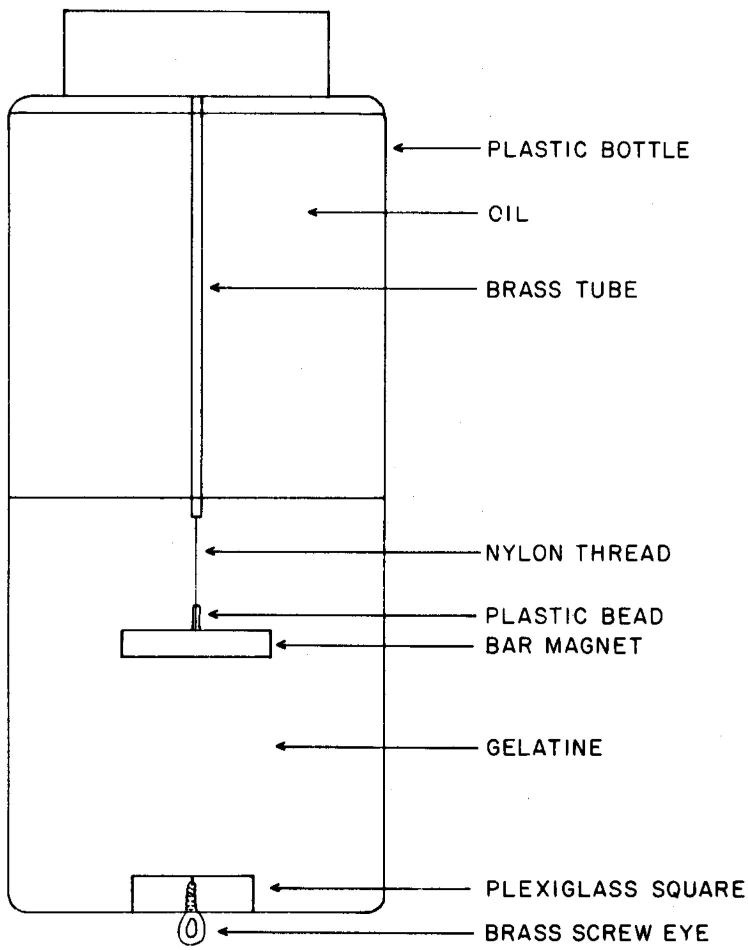


Figure 5A.—Improved design of flow indicator.

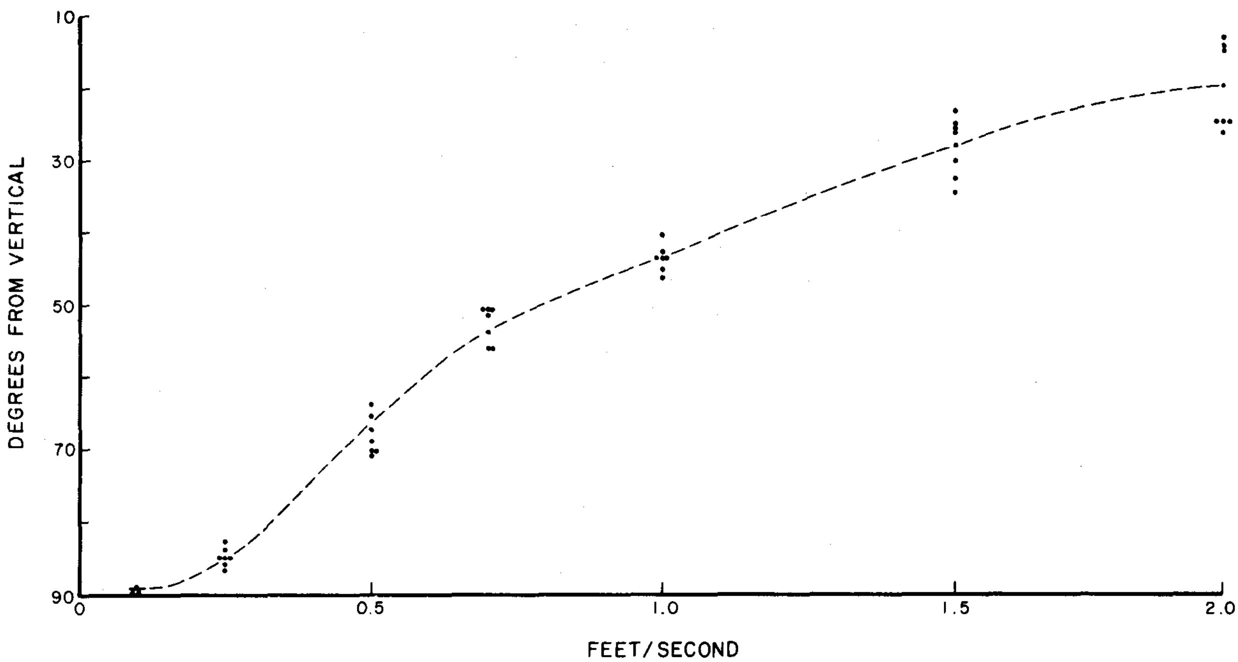


Figure 6A.—Calibration curve for 10-percent-gelatine current meter.

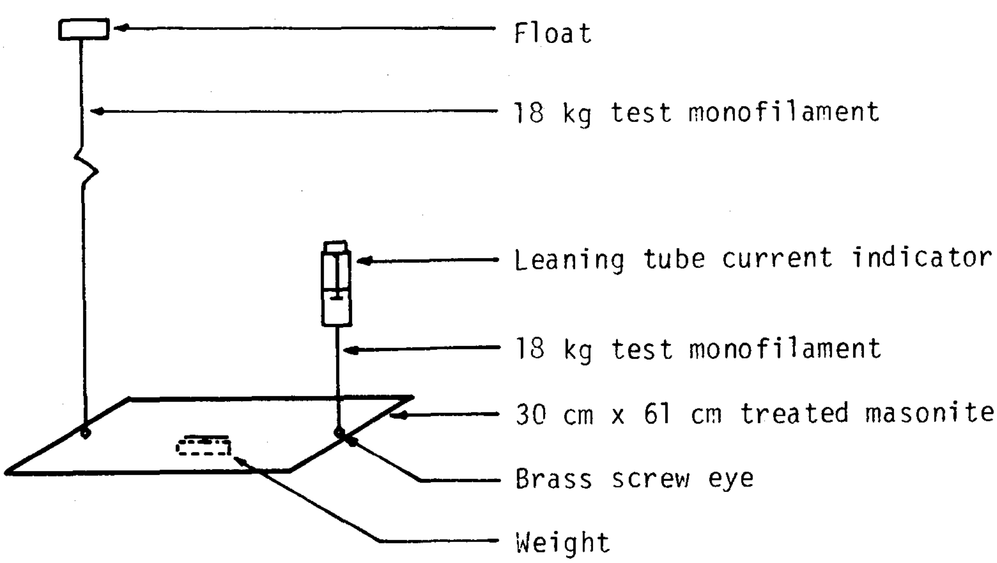


Figure 7A.—Rigging of leaning-tube current indicator for measuring bottom currents of Twin Lakes, Colorado.

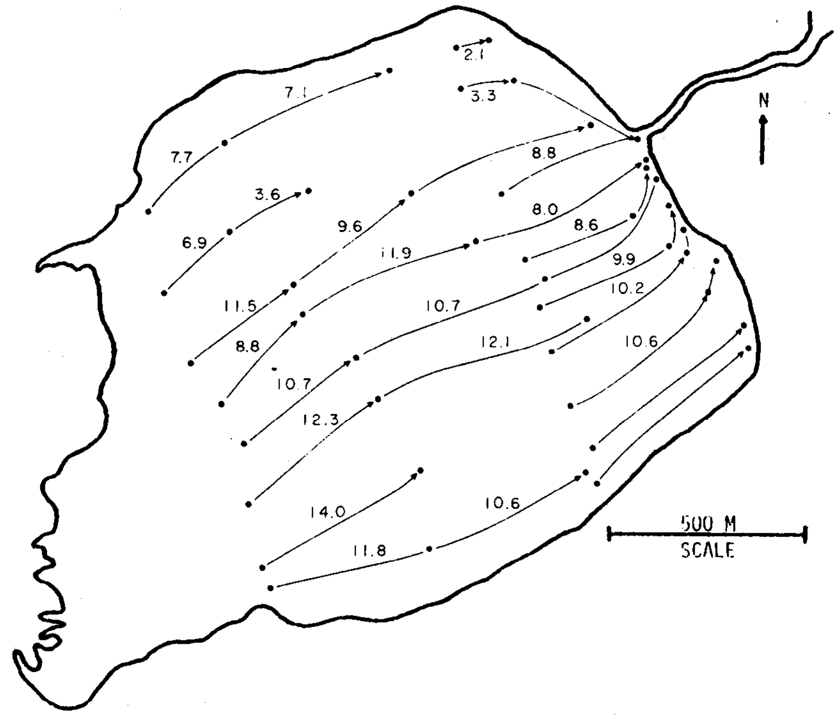


Figure 8A.—Surface currents measured on Upper Twin Lake August 31, 1979. Velocities between drogue sitings are given in cm per second.

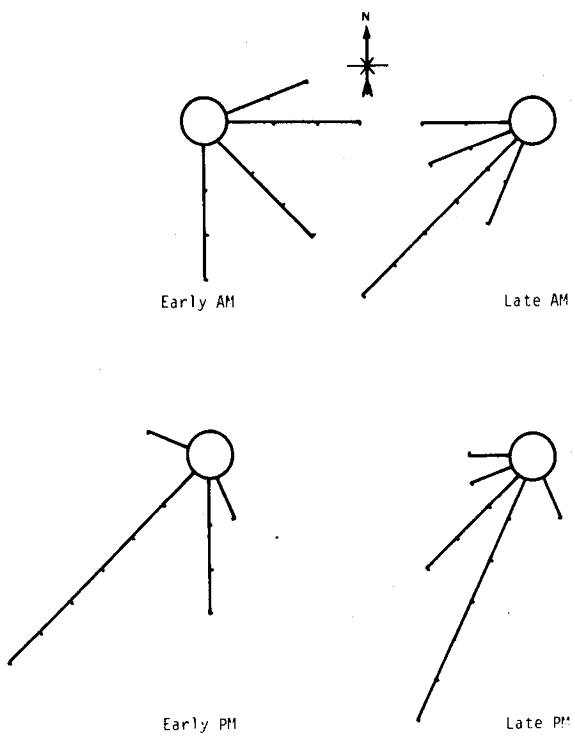


Figure 9A.—Wind roses for August 31, 1979.

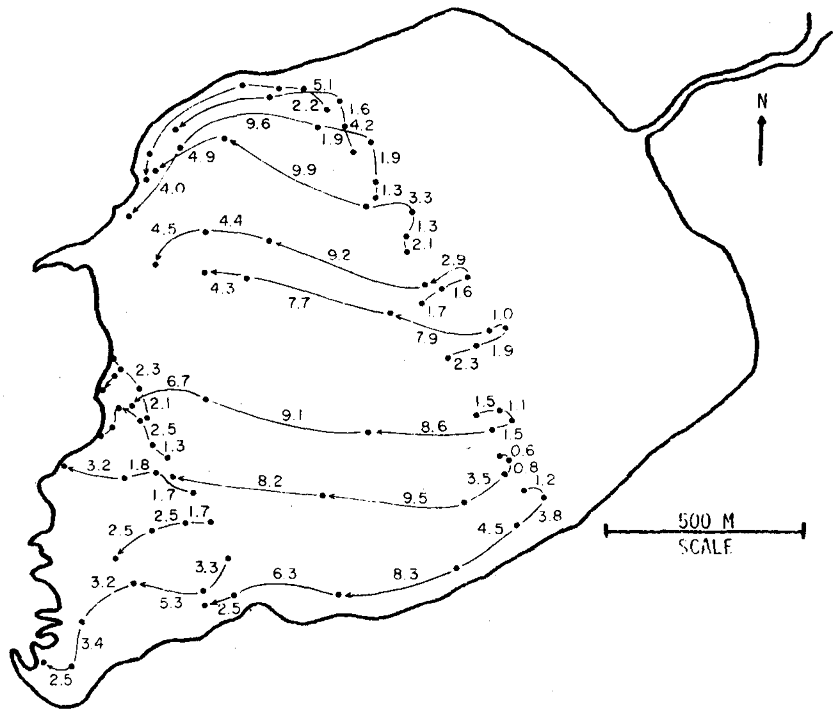


Figure 10A.—Surface currents of Upper Twin Lake September 17, 1979. Velocities between drogue sitings are given in cm per second.

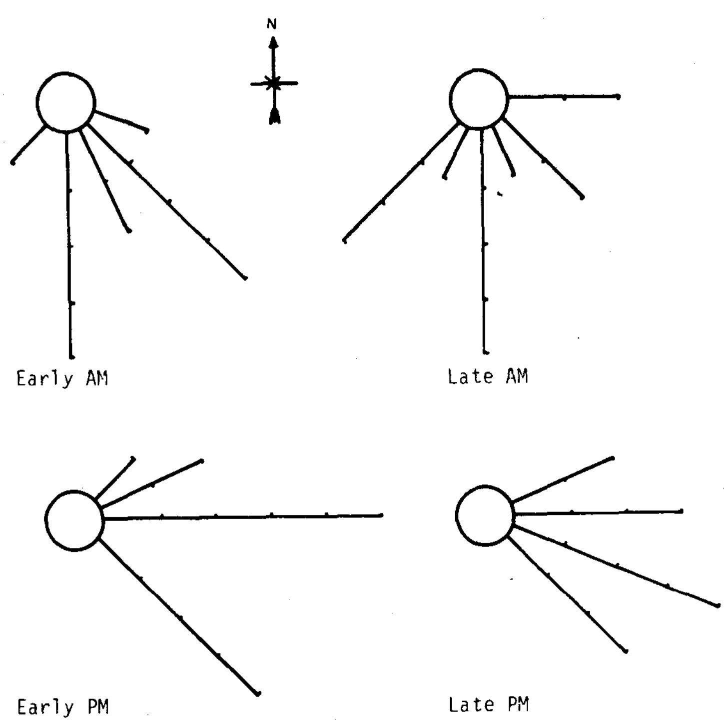


Figure 11A.—Wind roses for September 17, 1979.

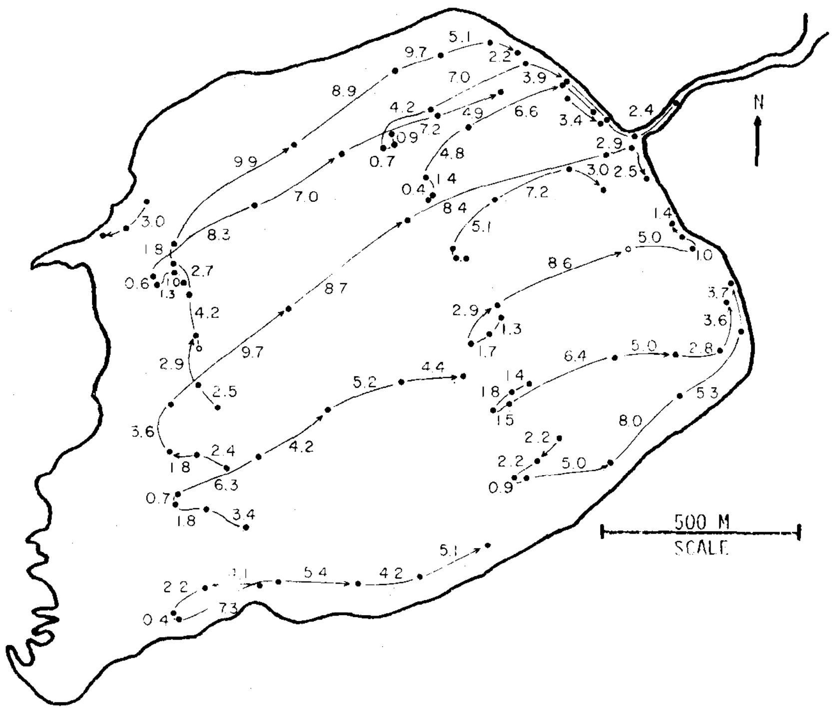


Figure 12A.—Surface currents of Upper Twin Lake October 8, 1979. Velocities between drogue sitings are given in cm per second.

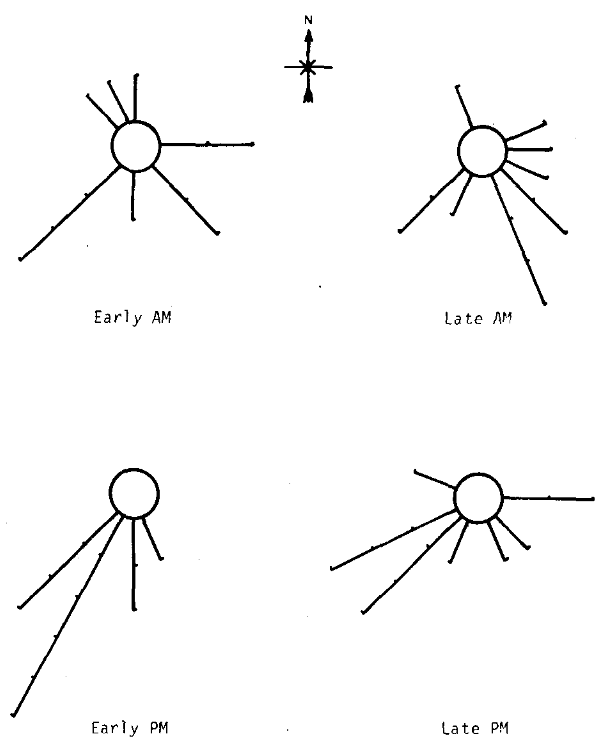


Figure 13A.—Wind roses for October 8, 1979.

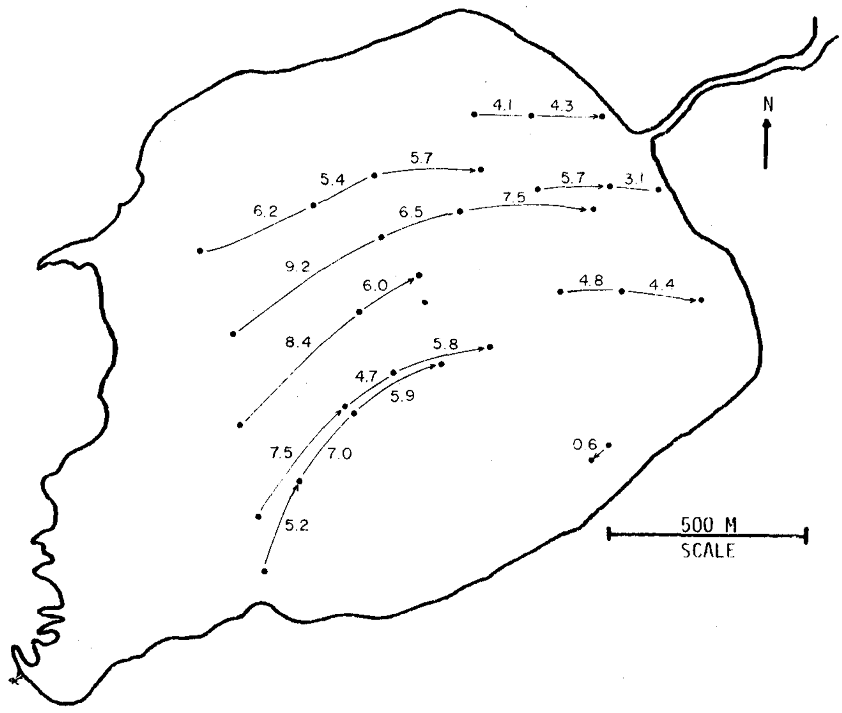


Figure 14A.—Surface currents of Upper Twin Lake November 13, 1979. Velocities between drogue sitings are given in cm per second.

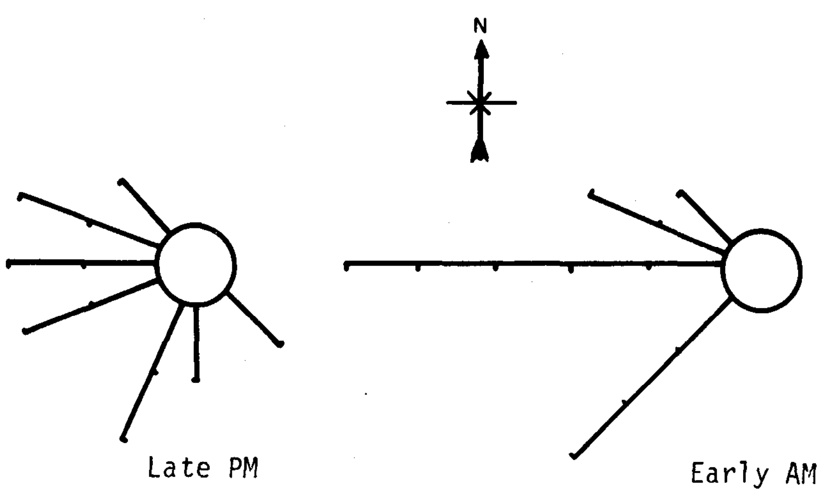


Figure 15A.—Wind roses for the night of November 13, 1979, during the time surface currents were measured.

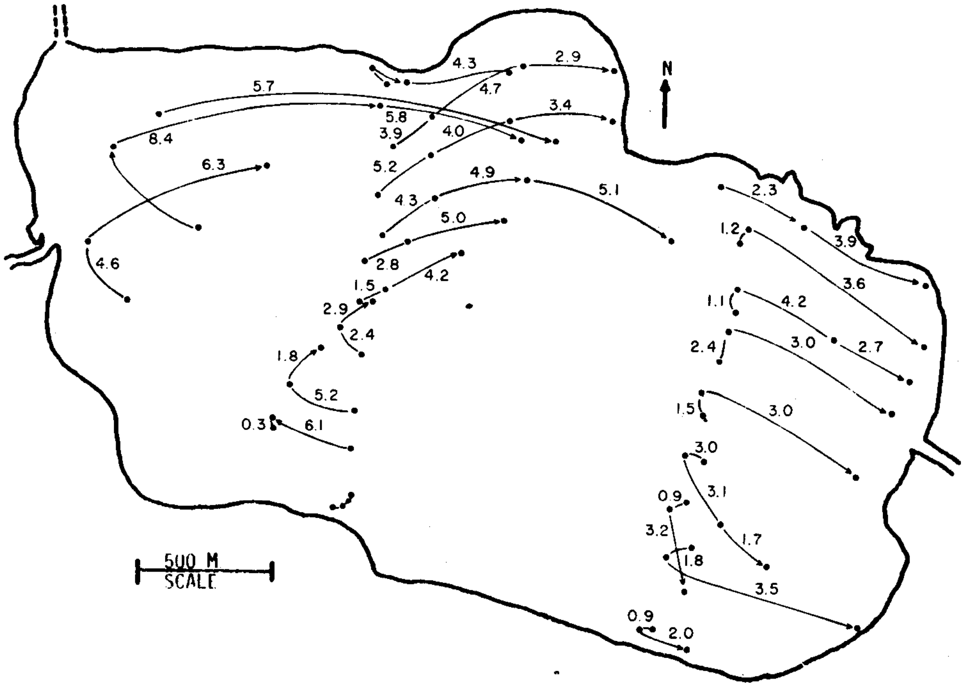


Figure 16A.—Surface currents of Lower Twin Lake August 29, 1979. Velocities between drogue sitings are given in cm per second.

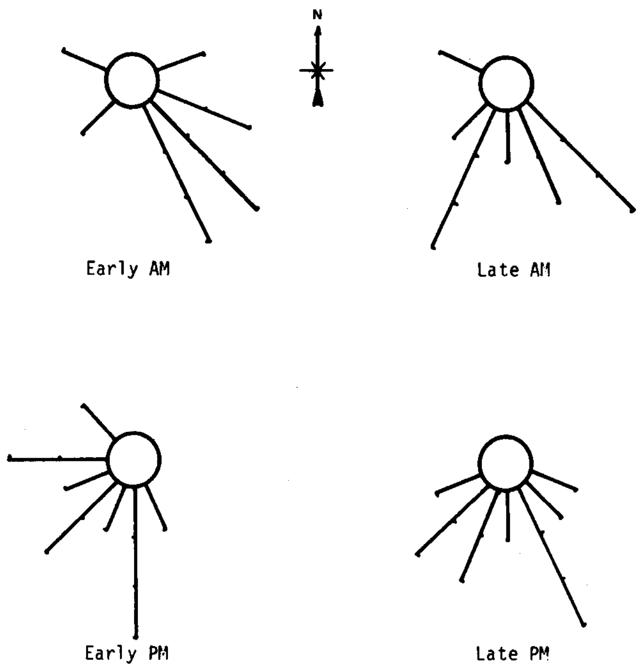


Figure 17A.—Wind roses for August 29, 1979.

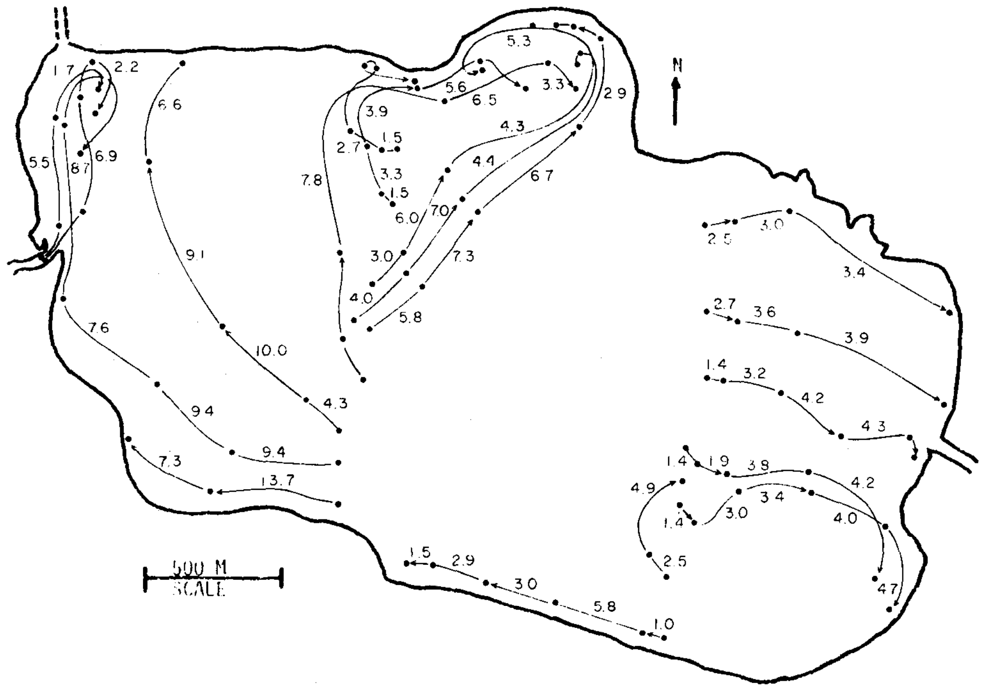


Figure 18A.—Surface currents of Lower Twin Lake September 7, 1979. Velocities between drogue sitings are given in cm per second.

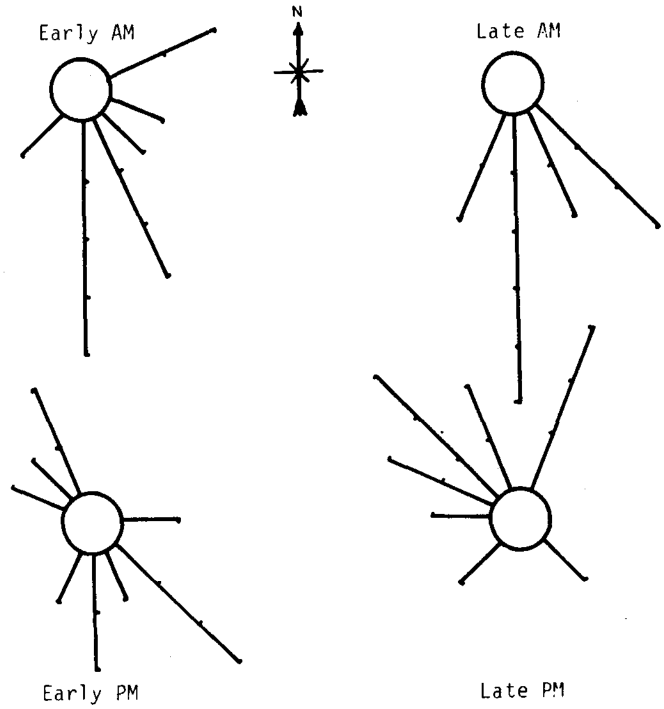


Figure 19A.—Wind roses for September 7, 1979.

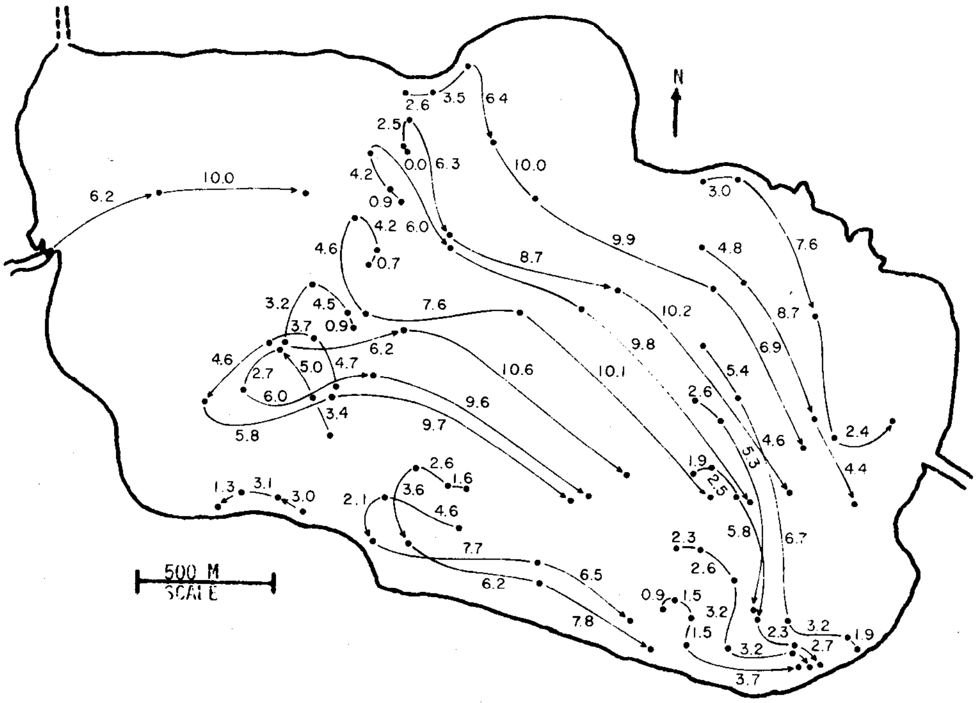


Figure 20A.—Surface currents of Lower Twin Lake October 1, 1979. Velocities between drogue sitings are given in cm per second.

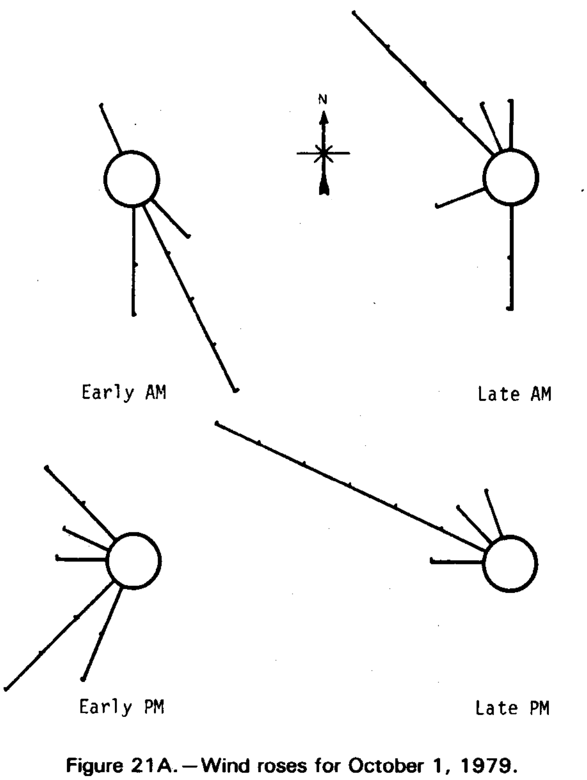


Figure 21A.—Wind roses for October 1, 1979.

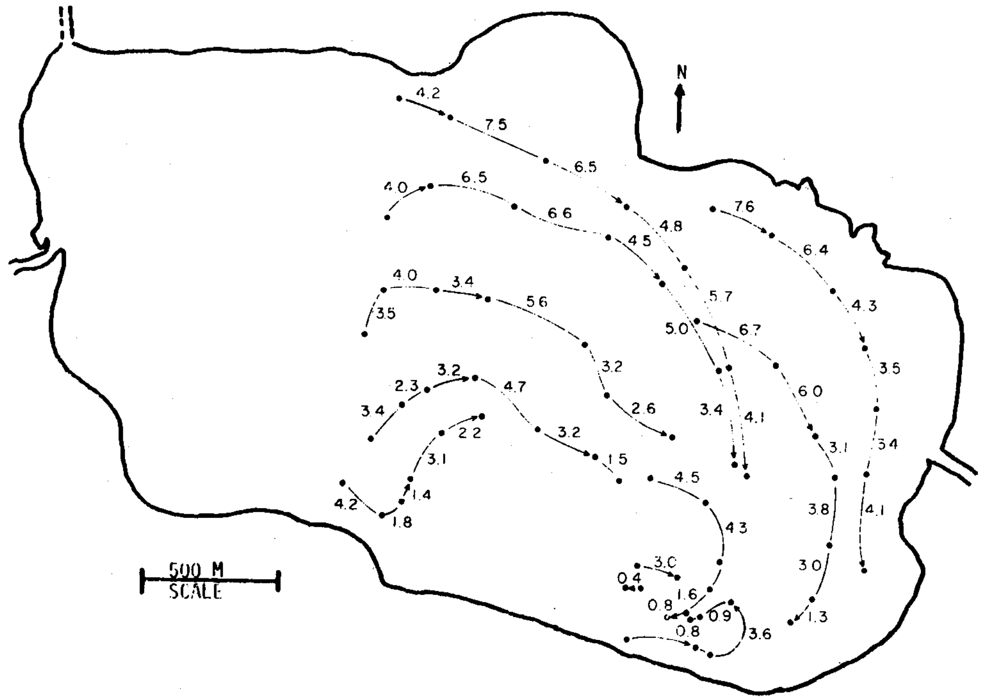


Figure 22A.—Surface currents of Lower Twin Lake October 14, 1979. Velocities between drogue sitings are given in cm per second.

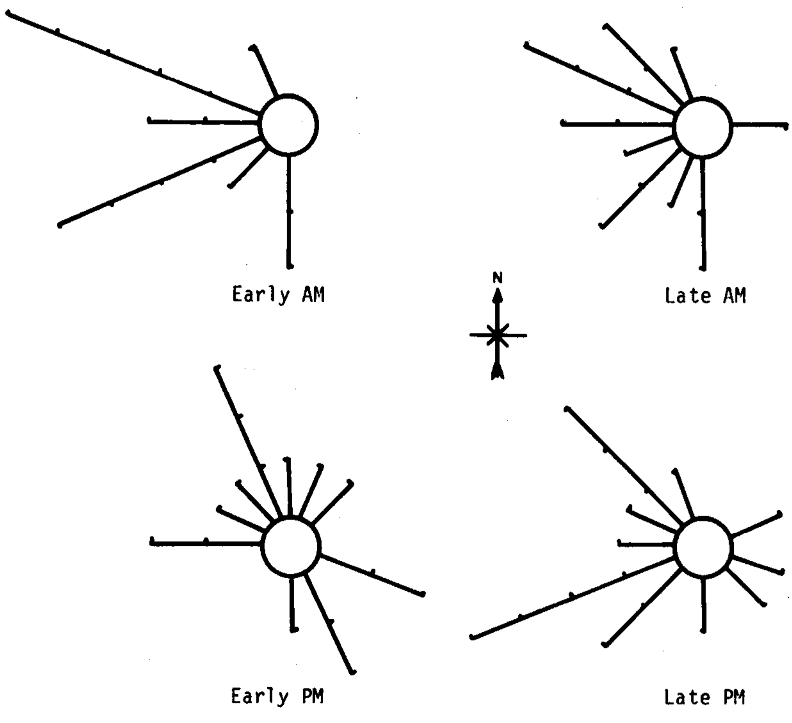


Figure 23A.—Wind roses for October 14, 1979.

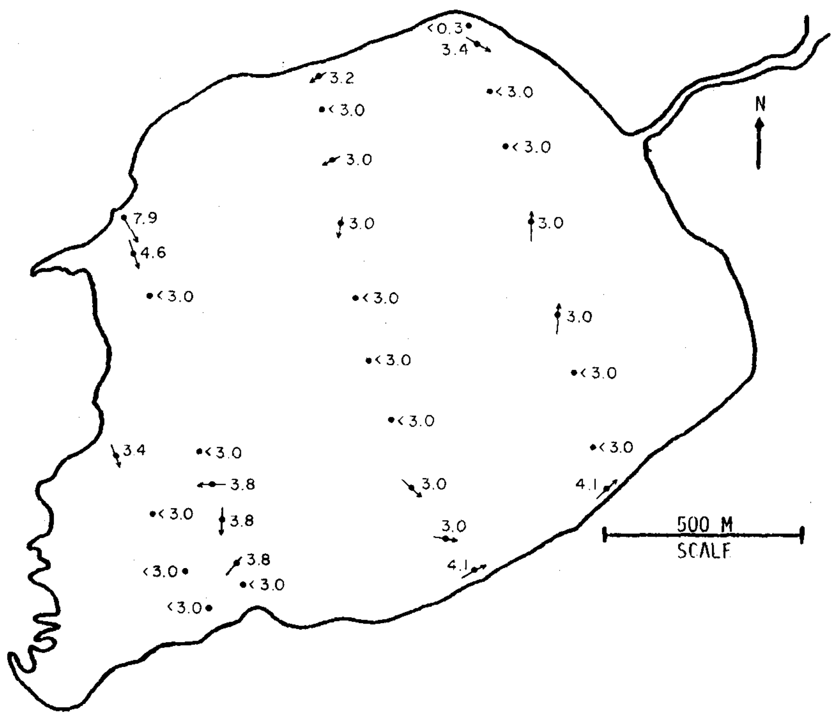


Figure 24A.—Bottom currents of Upper Twin Lake August 15 and 17, 1979. Current velocities are shown in cm per second. Direction of current is indicated by arrows.

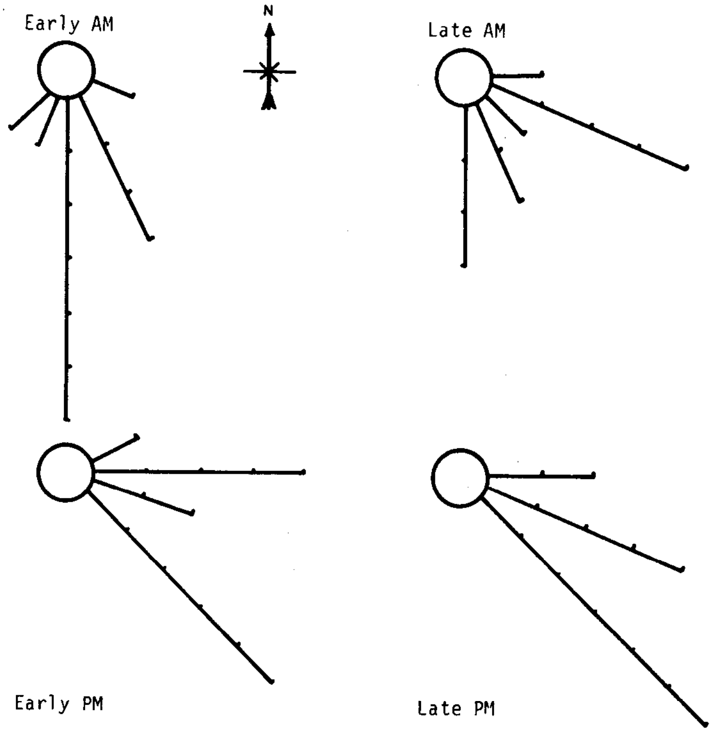


Figure 25A.—Wind roses for August 15, 1979.

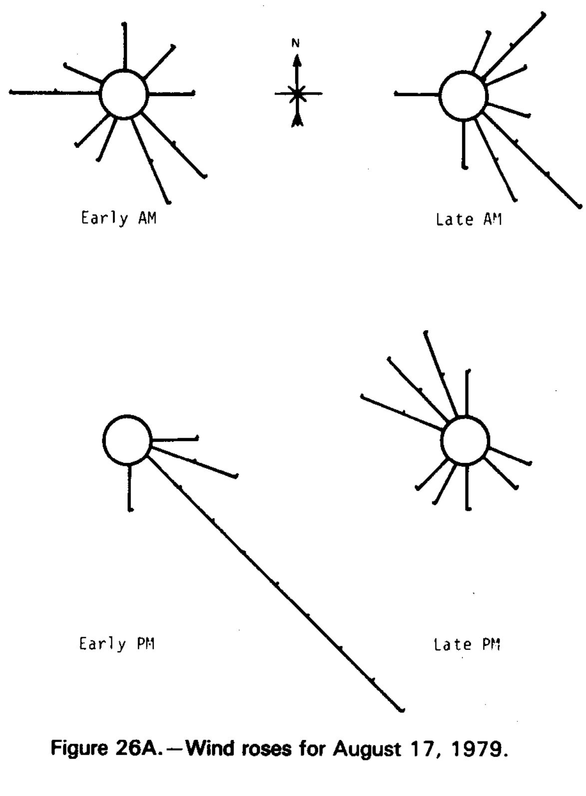


Figure 26A.—Wind roses for August 17, 1979.

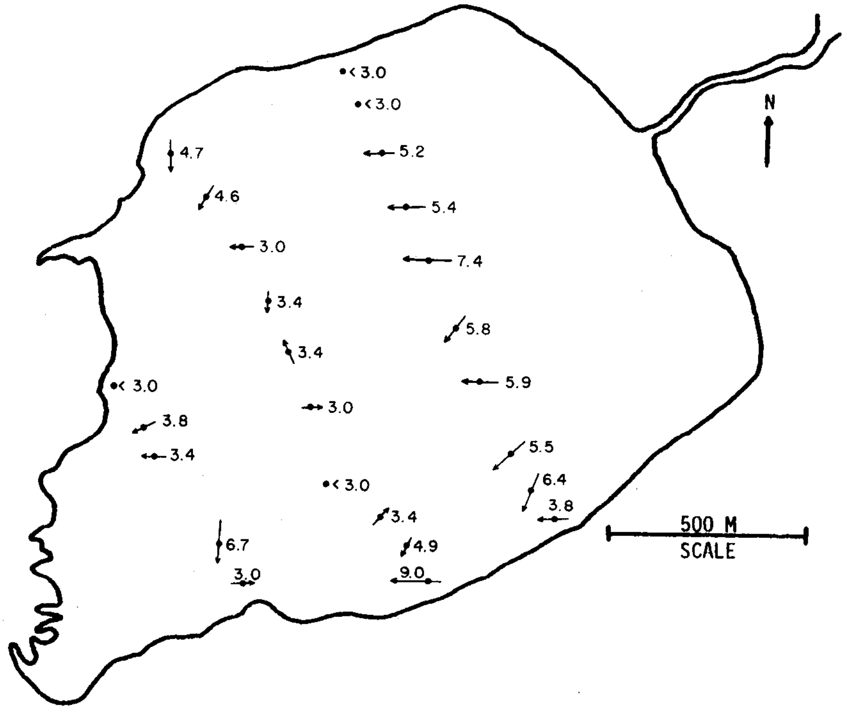


Figure 27A.—Bottom currents of Upper Twin Lake September 13, 1979. Current velocities are shown in cm per second. Direction of current is indicated by arrows.

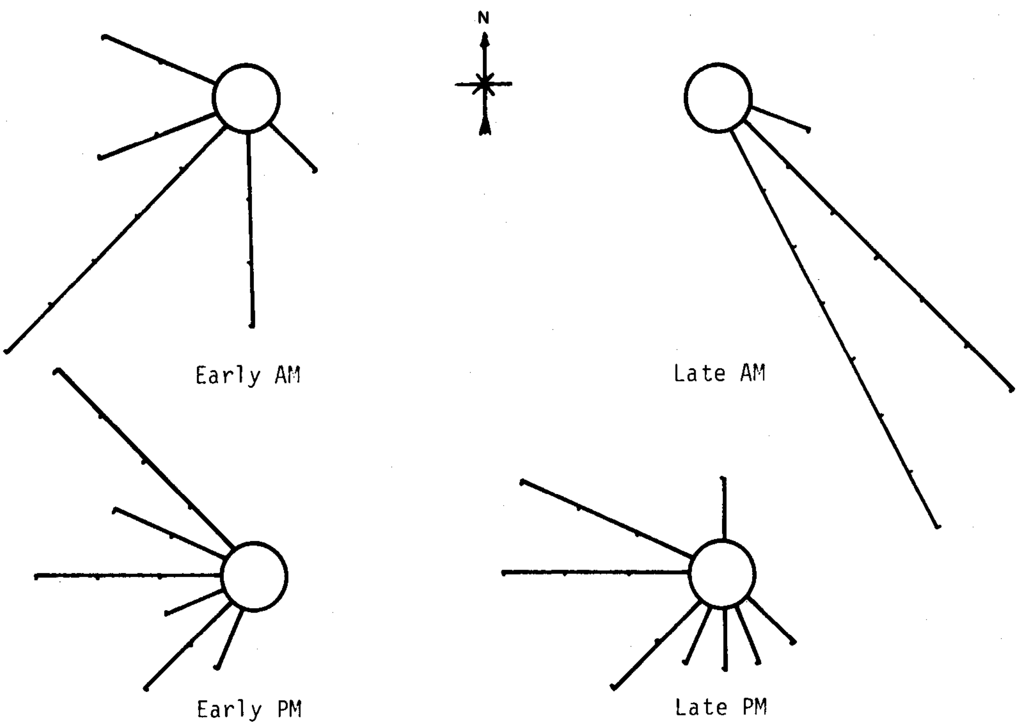


Figure 28A.—Wind roses for September 13, 1979.

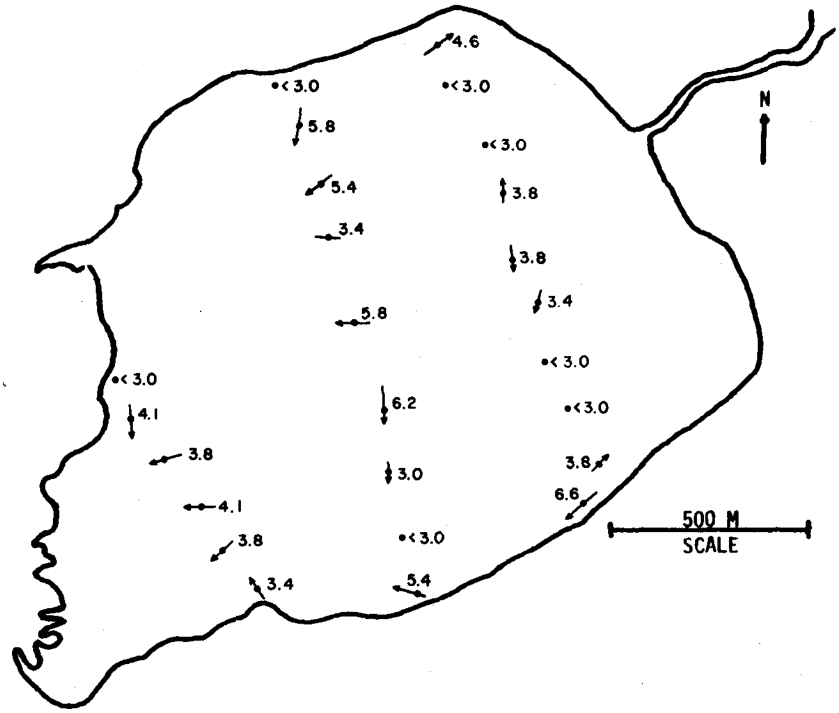


Figure 29A.—Bottom currents of Upper Twin Lake October 5, 1979. Current velocities are shown in cm per second. Direction of current is indicated by arrows.

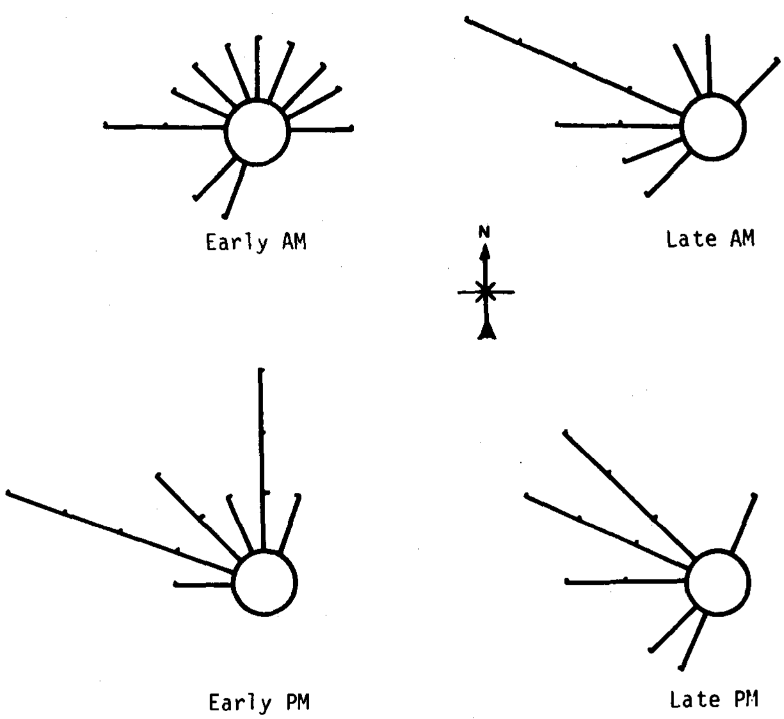


Figure 30A.—Wind roses for October 5, 1979.

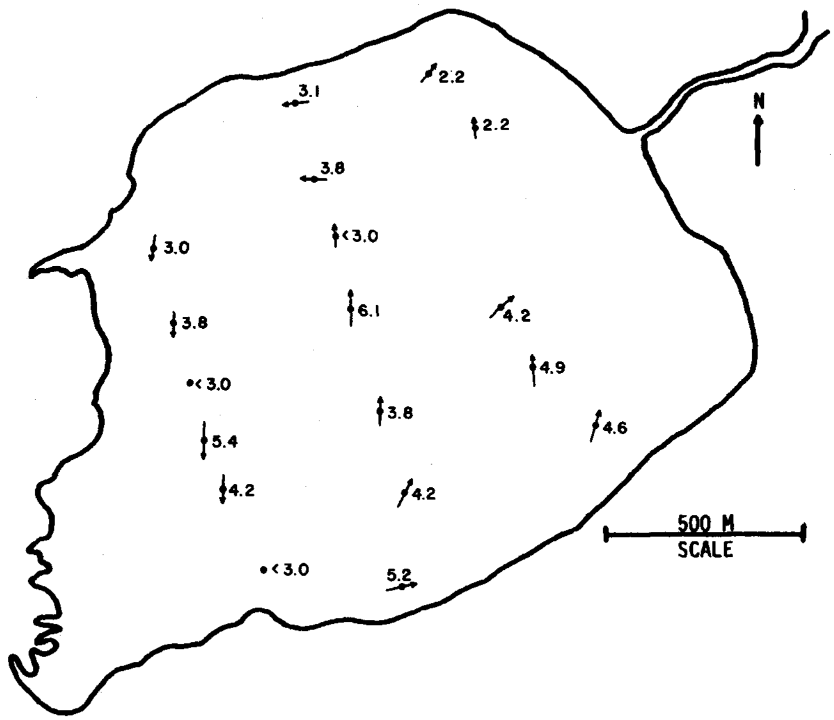


Figure 31A.—Bottom currents of Upper Twin Lake November 26, 1979. Current velocities are shown in cm per second. Direction of current is indicated by arrows.

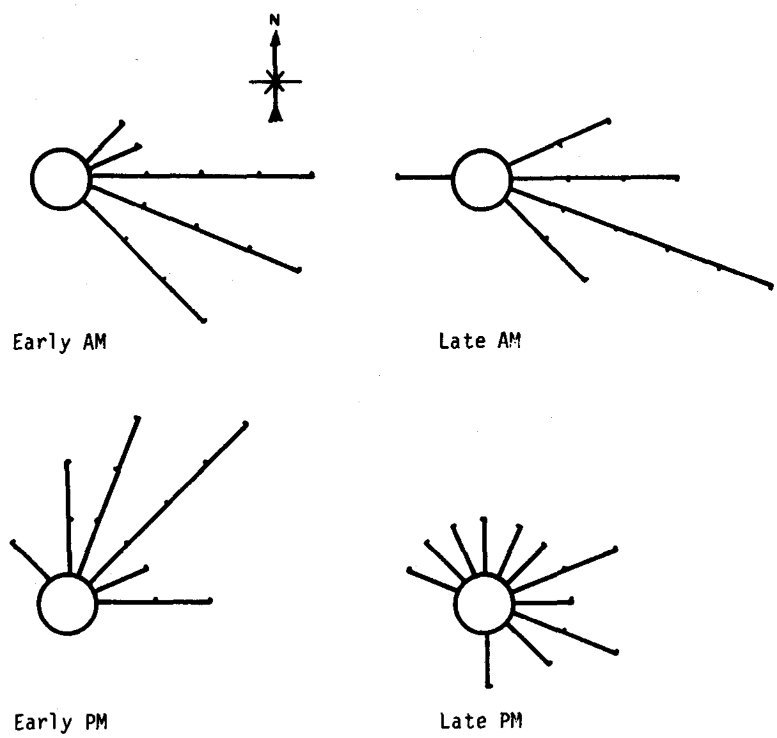


Figure 32A.—Wind roses for November 26, 1979.

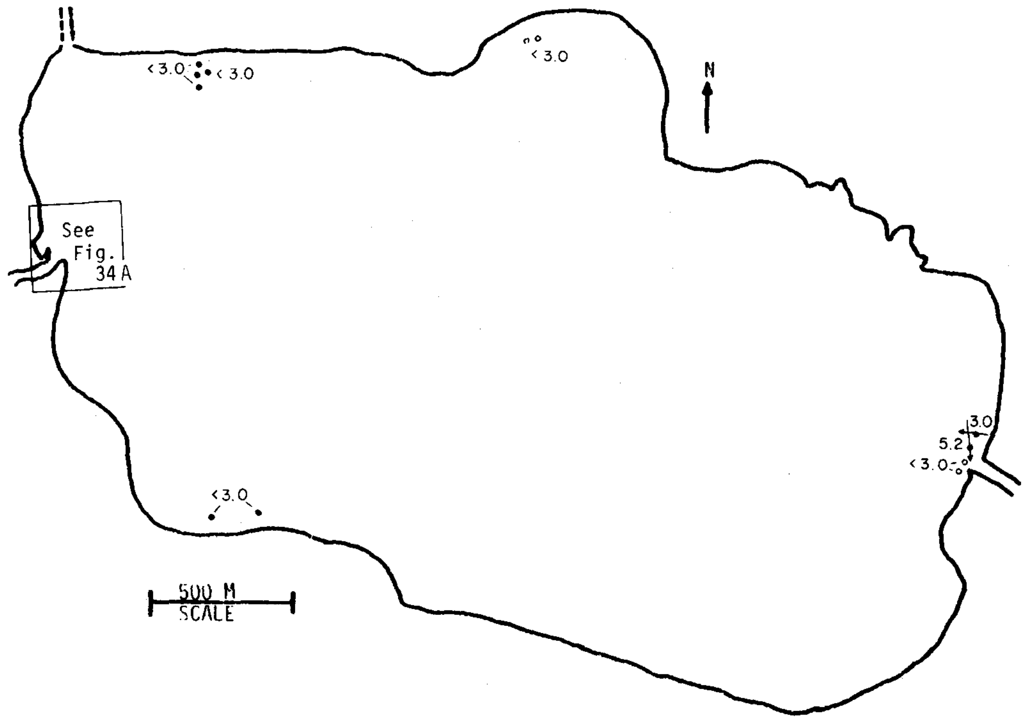


Figure 33A.—Bottom currents of Lower Twin Lake August 1, 1979. Current velocities are shown in cm per second. Direction of current is indicated by arrows.

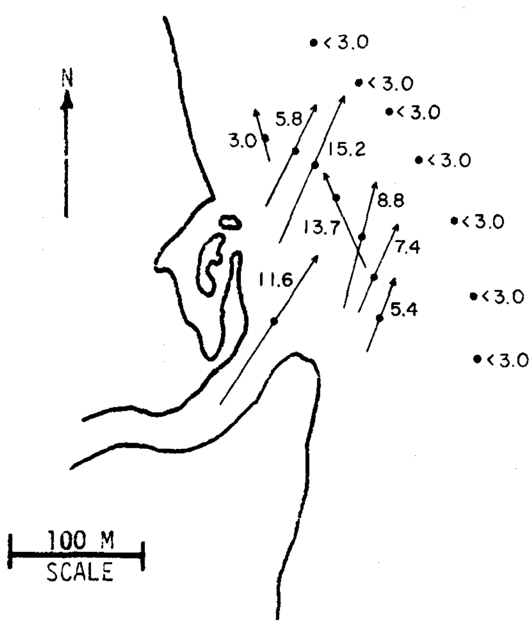


Figure 34A.—Bottom currents at inflow to Lower Twin Lake measured August 1, 1979.

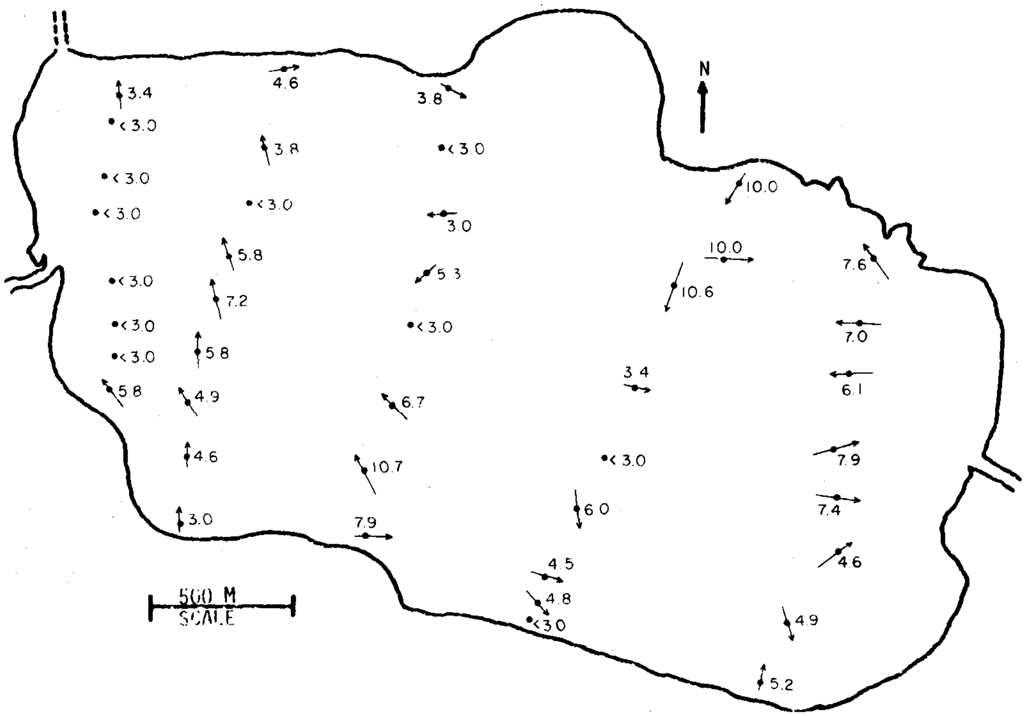


Figure 35A.—Bottom currents of Lower Twin Lake September 11 and 12, 1979. Current velocities are shown in cm per second. Direction of current is indicated by arrows.

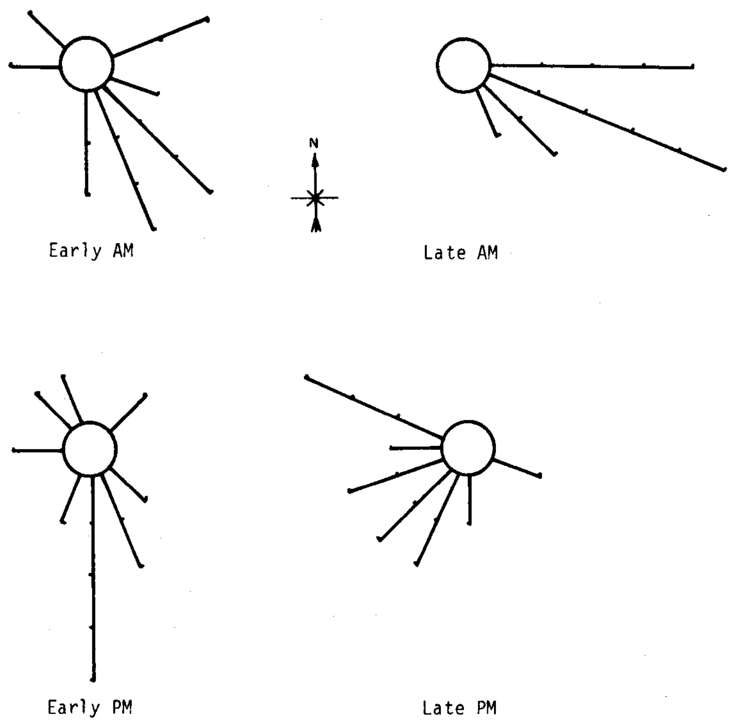


Figure 36A.—Wind roses for September 11, 1979.

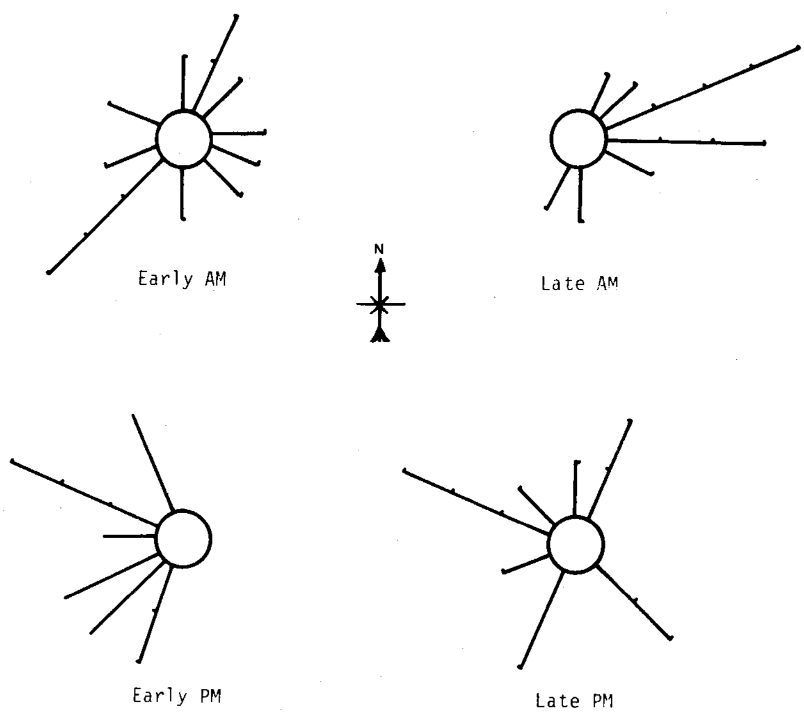


Figure 37A.—Wind roses for September 12, 1979.

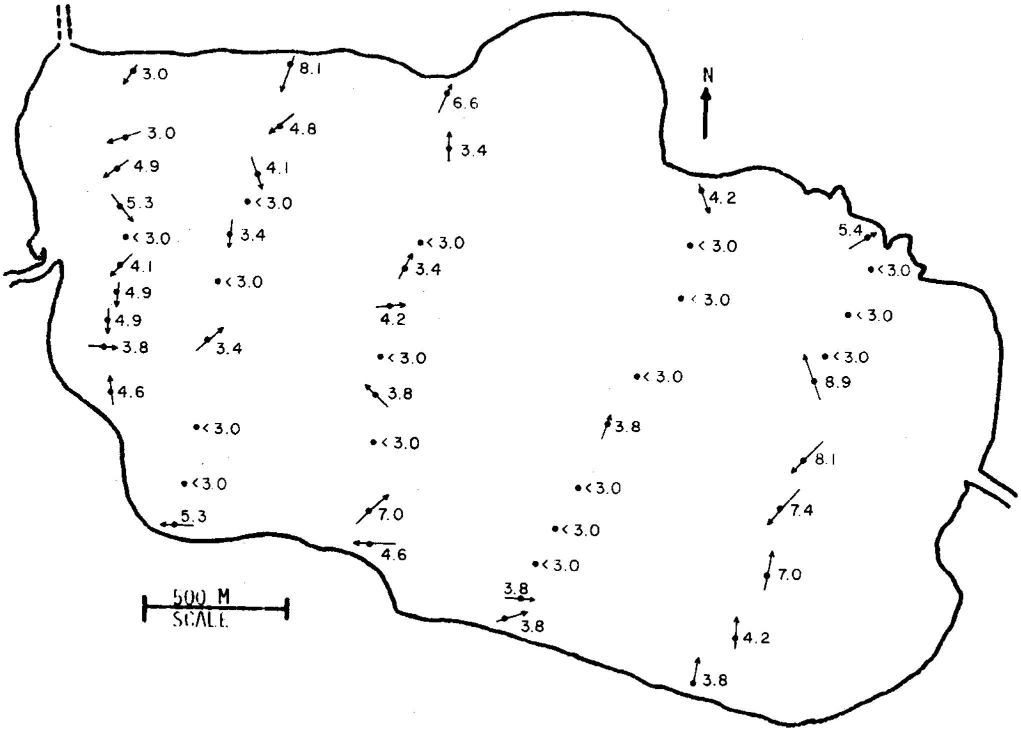


Figure 38A.—Bottom currents of Lower Twin Lake October 2, 3, and 4, 1979. Current velocities are shown in cm per second. Direction of current is indicated by arrows.

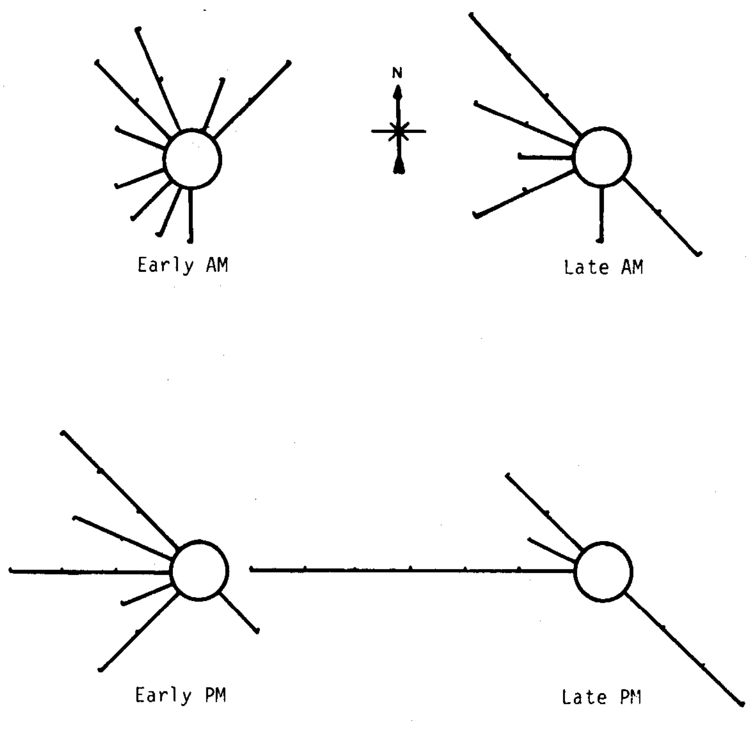


Figure 39A.—Wind roses for October 2, 1979.

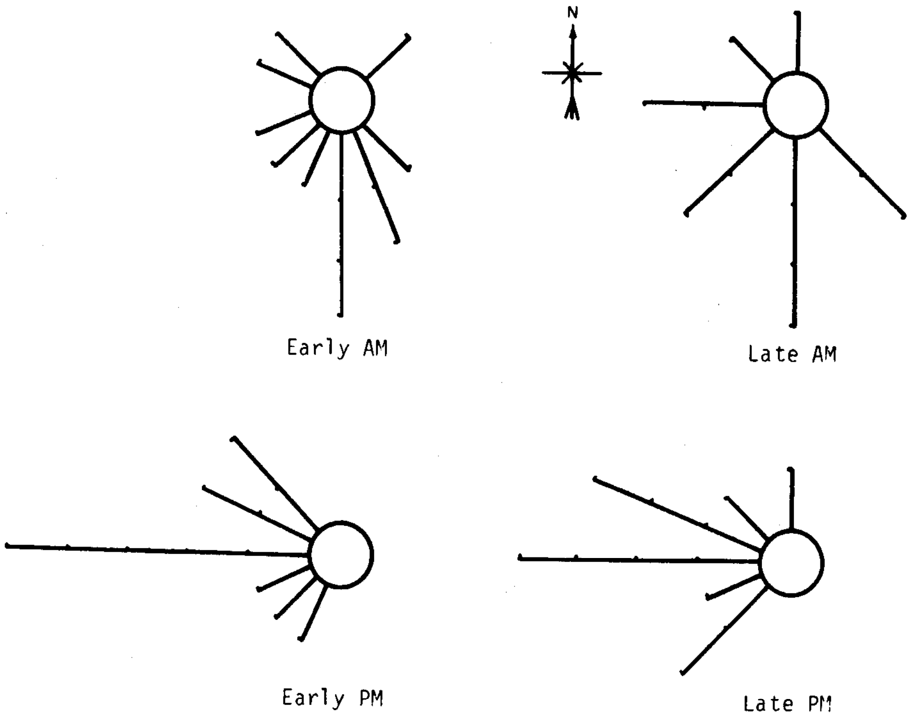


Figure 40A.—Wind roses for October 3, 1979.

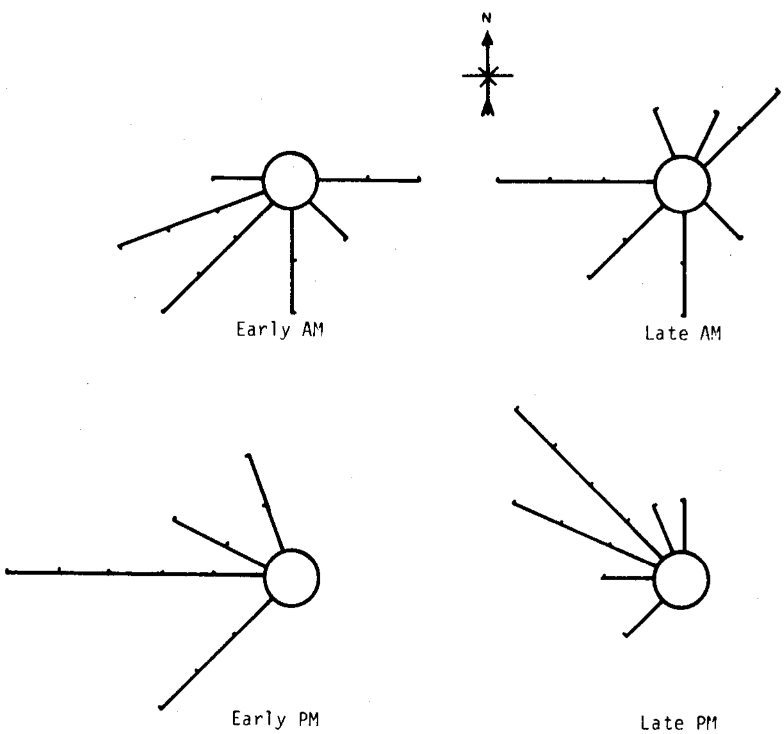


Figure 41A.—Wind roses for October 4, 1979.

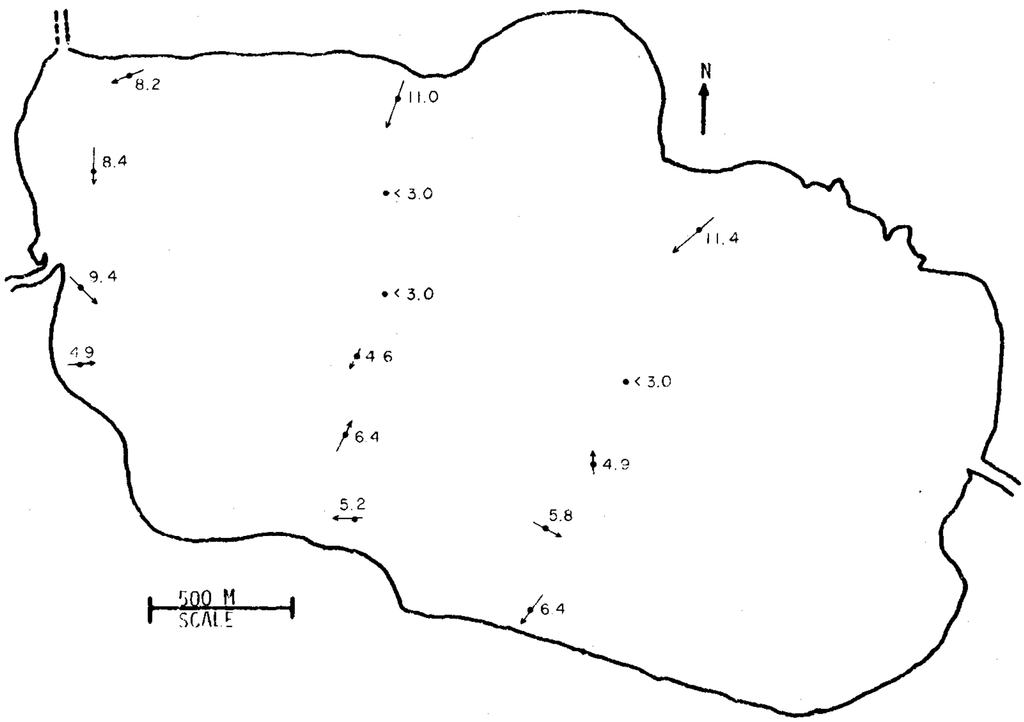


Figure 42A.—Bottom currents of Lower Twin Lake November 14, 1979. Current velocities are shown in cm per second. Direction of current is indicated by arrows.

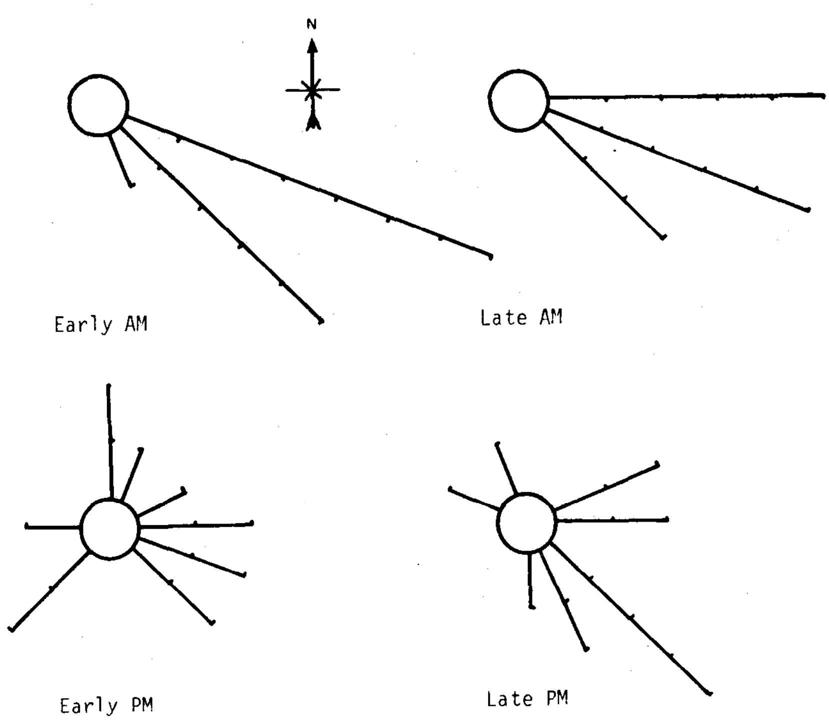


Figure 43A.—Wind roses for November 20, 1979.

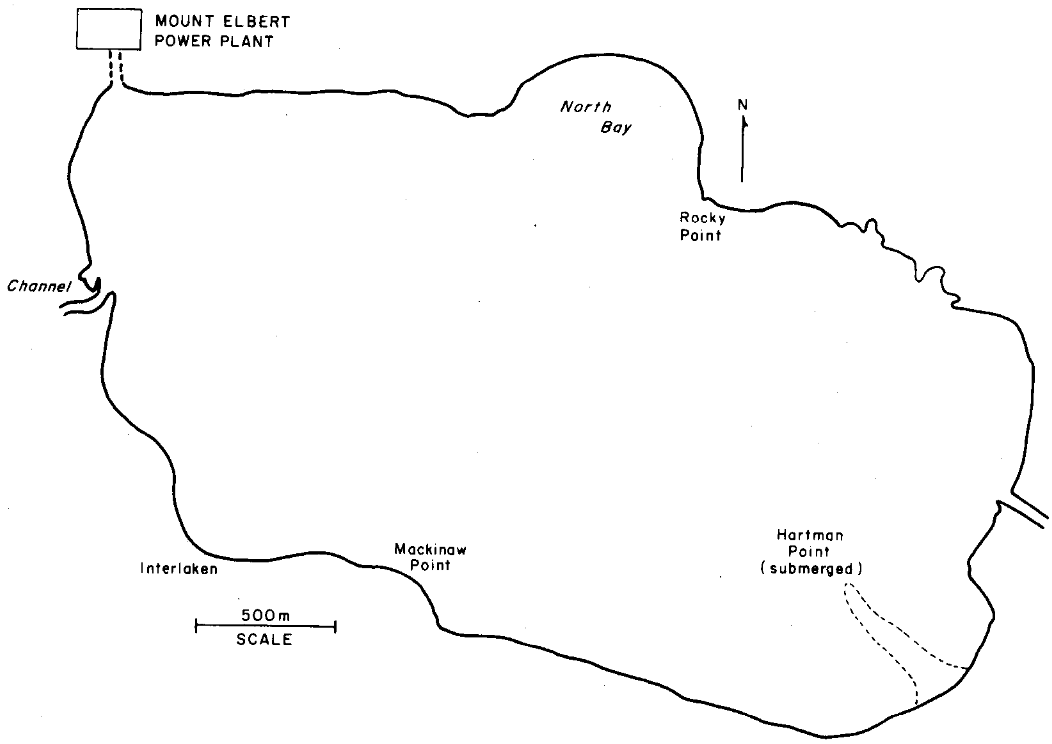


Figure 44A.—Salient features of Lower Twin Lake.

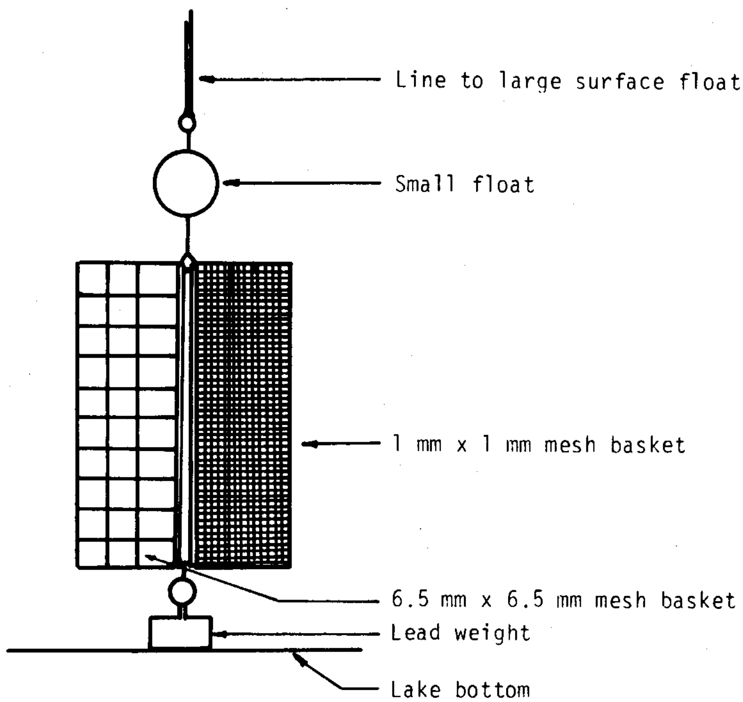


Figure 45A.—Paired baskets used in trout decomposition experiment at Twin Lakes, Colorado.

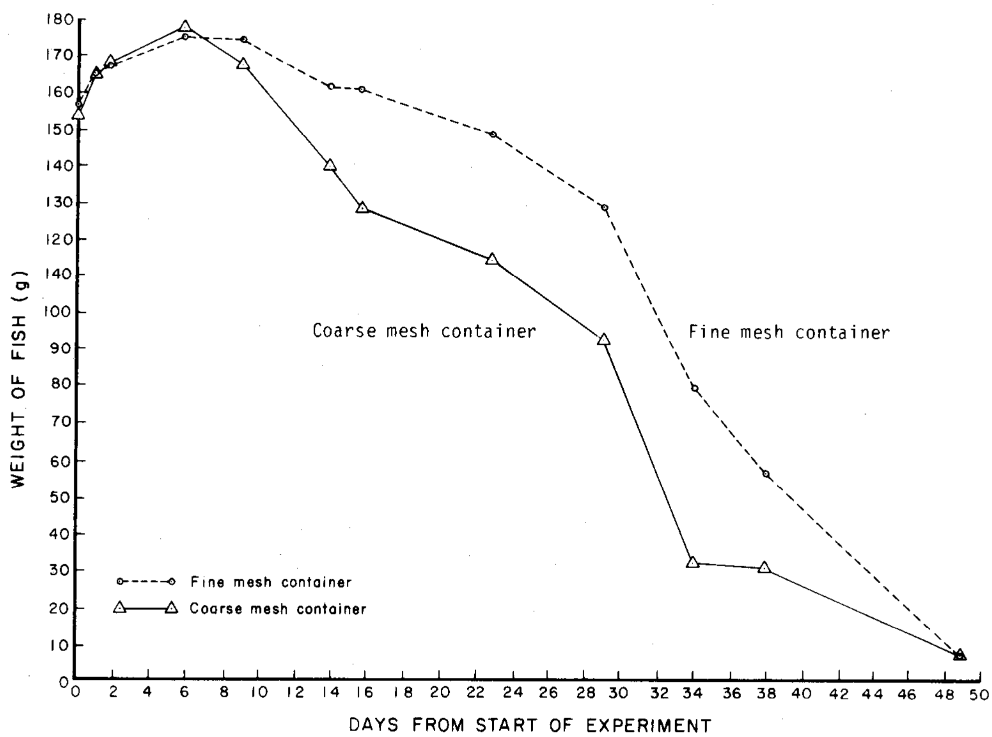


Figure 46A.—Decomposition rates of two rainbow trout enclosed in different size mesh bags on the bottom of Lower Twin Lake.

GPO 831-707