REC-ERC-82-8

COLORADO COOPERATIVE FISHERY RESEARCH UNIT STUDIES OF TWIN LAKES, COLORADO: 1980 REPORT OF FINDINGS

December 1981

Engineering and Research Center

U. S. Department of the Interior

Bureau of Reclamation

7-2090 (4-81)
Bureau of Reclamation

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
REC-ERC-82-8		

4. TITLE AND SUBTITLE

Colorado Cooperative Fishery Research Unit Studies at Twin Lakes, Colorado: 1980 Report of Findings

5. REPORT DATE

December 1981

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)

Eric P. Bergersen and
Melo Maiolie

8. PERFORMING ORGANIZATION REPORT NO.

REC-ERC-82-8

9. PERFORMING ORGANIZATION NAME AND ADDRESS

Colorado Cooperative Fishery Research Unit
Colorado State University
Fort Collins, Colorado

10. WORK UNIT NO.

11. CONTRACT OR GRANT NO.

7-07-83-V0700

12. SPONSORING AGENCY NAME AND ADDRESS

Engineering and Research Center
Bureau of Reclamation
Denver, Colorado 80225

13. TYPE OF REPORT AND PERIOD COVERED

1980 Report of Findings

14. SPONSORING AGENCY CODE

DIBR

15. SUPPLEMENTARY NOTES

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

Editor: EJH

16. ABSTRACT

The objectives of these investigations were to gather baseline data on the Twin Lakes system during the preoperational phase of the Mt. Elbert Pumped-Storage Powerplant, and to develop aquatic environmental monitoring techniques suitable for use during postconstruction operating periods. The five areas investigated were chosen specifically to fill gaps in present knowledge of the two-lake system, test methodologies, and point out monitoring problems which might be encountered during the operational phase of the project.

Study 1, "Lake Currents," characterized and documented natural, seasonal patterns in surface and bottom currents in the two-lake system. Data gathered during this study will allow detection of changes in natural current patterns produced by the powerplant.

Study 2, "Lake Trout Utilization of Shallows for Spawning," showed that it is unlikely that lake trout in Twin Lakes spawn in water less than 1.5 m deep, and thus the expected daily water level fluctuation of 0.7 to 1.1 m should not result in the exposure of lake trout eggs.

Study 3, "*Mysis* Population Estimates- A Photographic Technique," developed a photographic method of estimating *Mysis* shrimp densities that is not only more reliable than the previous bottom sled trawl method, but also eliminates depletion of the population. It was concluded that shrimp are at least 2.4 times as abundant in Twin Lakes as previously thought, with densities in the vicinity of the powerplant as high as 232 shrimp/m^2.

Study 4, "Sedimentation Rates," used both sediment traps and inflow/outflow suspended sediment sampling to estimate sedimentation rates in Twin Lakes. Estimates from these two methods differed greatly, although background sedimentation rates and probable sources were established for comparative purposes. It was concluded that the best time to monitor powerplant impacts on sediment movement and deposition would be during the winter months.

Study 5, "Organic Contribution of Vegetation Inundated by New Lake Levels," examined the possible consequences for the lakes' energy budget of inundating vegetated land areas on the west end of the upper lake when water levels are raised by the new Twin Lakes Dam. Potential input from this terrestrial vegetation was estimated to be over four times the present average annual primary production of the system. Suggestions are advanced to possibly minimize the harmful effects of this input.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. *DESCRIPTORS*-- / *lake currents/ *lake trout/ spawning/ *opossum shrimp/ fish food organisms/ *sedimentation rates/ *vegetation/ energy budget/ ecology/ eutrophication/ limnology/ pumped storage/ powerplants/ environmental effects

b. *IDENTIFIERS*-- / Twin Lakes, Colo./ Mt. Elbert Pumped-Storage Powerplant, Colo./ Frying-pan-Arkansas Project, Colo.

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

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (THIS REPORT)	21. NO. OF PAGES
Available from the National Technical Information Service, Operations Division, 5285 Port Royal Road, Springfield, Virginia 22161.	UNCLASSIFIED	59
	20. SECURITY CLASS (THIS PAGE)	22. PRICE
	UNCLASSIFIED	

REC-ERC-82-8

COLORADO COOPERATIVE FISHERY RESEARCH UNIT STUDIES AT TWIN LAKES, COLORADO: 1980 REPORT OF FINDINGS

Prepared and submitted to the
Bureau of Reclamation
Denver, Colorado

by
Eric P. Bergersen
Melo Maiolie
Colorado Cooperative Fishery Research Unit
Colorado State University, Fort Collins

December 1981

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

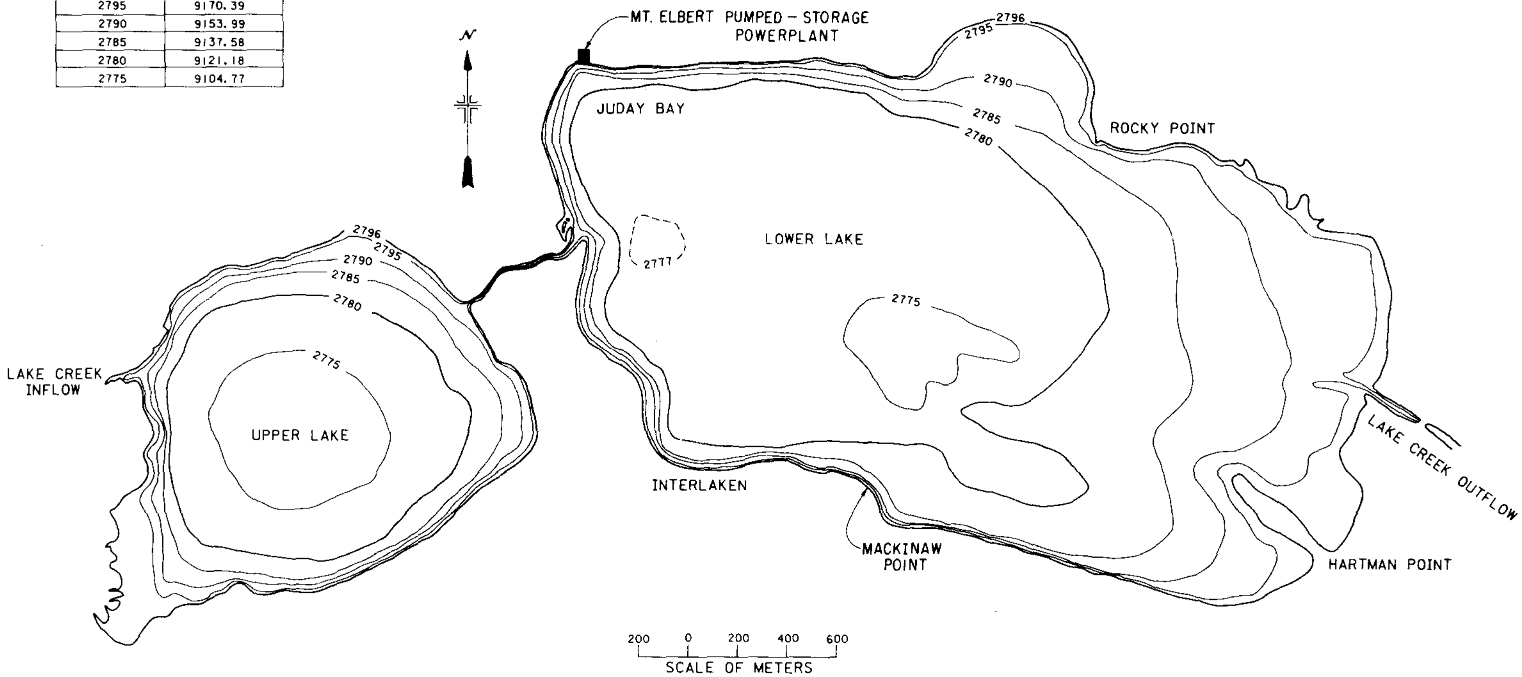
SI METRIC

UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION

ACKNOWLEDGMENTS

This report presents the results of studies conducted by personnel of the Colorado Cooperative Fishery Research Unit, Colorado State University, Fort Collins, Colo., for the Bureau of Reclamation, Engineering and Research Center, Denver, Colo., under USBR Contract No. 7-07-83-V0700. The Applied Sciences Branch of the Bureau's Division of Research is publishing this report as part of its research on the ecological effects of operating the Mt. Elbert Pumped-Storage Powerplant at Twin Lakes, Colo. This research is being funded by the Engineering and Research Center's Division of Research and the Lower Missouri Region's Fryingpan-Arkansas Project.

ELEVATIONS	
METERS	FEET
2796	9173.68
2795	9170.39
2790	9153.99
2785	9137.58
2780	9121.18
2775	9104.77



Frontispiece—Map of Twin Lakes, Colorado.

FOREWORD

Twin Lakes are a pair of connected montane drainage lakes of glacial origin located on Lake Creek at the eastern foot of the Sawatch Range in the Upper Arkansas River Valley of central Colorado. The lakes lie at an elevation of 2802 m above mean sea level at 39°05′ N. latitude and 106°20′ W. longitude. Maximum surface areas are about 263.4 ha for the upper lake and 736.5 ha for the lower, with corresponding depths of approximately 20 and 27 m, respectively. A controlled outlet works was built on the lower lake around the beginning of this century. The channel connecting the two lakes was dredged at about the same time, so that today both lakes fluctuate essentially as one. Twin Lakes are dimictic, with maximum surface temperatures reaching up to 18° C during late July to mid-August, and ice cover lasting usually from December to May. Chemically, Twin Lakes are soft, dilute calcium bicarbonate lakes, with pH being usually neutral to slightly basic. Phytoplankton flora consists mainly of diatoms and other golden-brown algal species, while the zooplankton fauna is a *mysis* shrimp-copepod-rotifer association. At present, Twin Lakes support a self-reproducing lake trout fishery and a put-and-take rainbow trout fishery. Both lake trout and *mysis* shrimp were introduced into Twin Lakes.

The northwest corner of the lower lake is the site of the Mt. Elbert Pumped-Storage Powerplant, Fryingpan-Arkansas Project. The powerplant houses two 100-MW pump-generators, the first of which began operating in September 1981, while the second is scheduled to begin operation in 1983. A forebay has been constructed on the ridge north of the lake, and a new dam has been built below the lower lake. When this new dam is closed, the maximum water surface elevation of Twin Lakes will be raised to about 2805 m, inundating the isthmus between the two lakes and creating one large reservoir.

Baseline studies of the limnology and fishery of Twin Lakes have been conducted by the Bureau of Reclamation and its cooperators since 1971, with the object of documenting and quantifying the effects of the Mt. Elbert Pumped-Storage development on the aquatic environment. The present report is one of a series presenting the results of these ongoing investigations. Information on pumped-storage effects acquired at Twin Lakes will be used to improve the Bureau's project planning capabilities so that the environmental impacts of future pumped-storage developments can be more accurately evaluated.

James J. Sartoris, Research Civil Engineer
Division of Research
Engineering and Research Center
Bureau of Reclamation
Denver, Colorado

CONTENTS

CONTENTS—Continued

TABLES

FIGURES

CONTENTS—Continued

CHAPTER 1. LAKE CURRENTS

INTRODUCTION

Although lentic waters are often characterized as being still or sluggish, lake waters in actuality are in constant motion. This motion plays an important role in determining the physical and chemical nature of lake environments and in the distribution of planktonic organisms and organisms which feed upon them. Because natural currents in Twin Lakes will be modified by the Mt. Elbert Powerplant and the increased size of the lake, it was important to document the nature of existing currents prior to these major environmental changes. In doing so, a better understanding of lake dynamics was gained and a baseline against which powerplant-induced changes can be compared.

It is suspected that the combined impact of operation of the powerplant and the increased lake size will affect currents, and consequently, lake biota in several ways. The increased fetch may result in higher velocity currents which could affect the *mysis* shrimp which are known to be sensitive to turbulence (Gregg and Bergersen, 1980 [1][1]). Larval fish, which are highly dependent on protected shoreline areas, could become dislodged by increased currents and be more susceptible to predation in less protected areas. Bottom sediments may also be resuspended by stronger lake currents. Powerplant-induced currents may also affect *mysis* and 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: (1) Changes may occur in the ice sheet in the form of erosions, pitting, or unequal freezing, making some areas of the lakes unsafe for recreational uses such as ice fishing, jeep and snowmobile racing, etc.; or (2) under-ice currents could be sufficiently strong to keep sediments suspended during the time when they would be expected to settle. This would result in increased turbidity and a subsequent change in the total energy budget of the lake. The consequences of this event are far reaching and could result in a total change in the Twin Lakes environment as we now know it.

[1]Numbers in brackets indicate references listed in the Bibliography.

The purpose of this report is to characterize and document seasonal patterns in surface and bottom currents in the two-lake system.

METHODS

Open Water

Wind measurements.—Wind data were gathered with a recording wind vane made by placing a Minolta time-lapse movie camera over a conventional wind vane. A Trade-Wind anemometer model 110 was mounted above the movie camera with its windspeed meter on the 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 windspeed and direction. The vane and camera were placed on a building 100 m from the lake. A street light, 5 m away, provided light for nighttime exposures.

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. 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 recorded at the lake. In the center of each wind rose is the corresponding average windspeed in meters per second.

Surface currents.—Surface currents were measured with vertical floating drogues. During daylight hours small flags were attached to the top of each drogue. Lighted flashing strobe drogues were used at night (figs. 1-1 and 1-2). Drogues were designed to move passively with the surface currents and be minimally affected by wind.

Each month, approximately 15 drogues were set on selected standard transect lines and followed from 8:00 a.m. to 4:00 p.m. Night surface currents, measured in November, were monitored between 5:00 p.m. and 2:00 a.m. Periodically, the position of each drogue was recorded by triangulation on known shore positions with a sextant. Velocities of surface currents were based

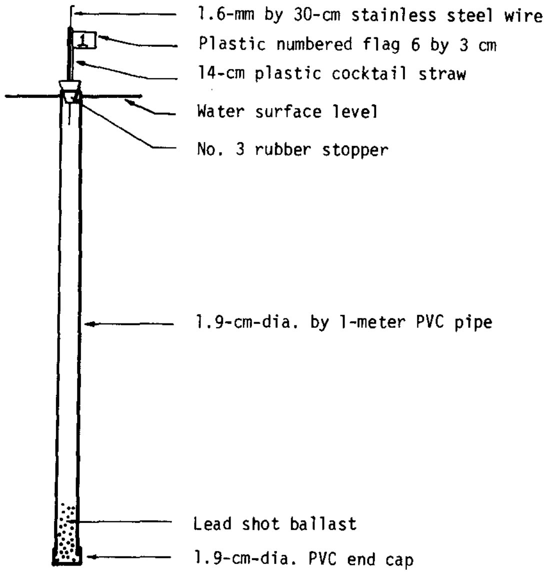


Figure 1-1—Drogue used to measure lake surface currents during daylight hours at Twin Lakes, Colo.

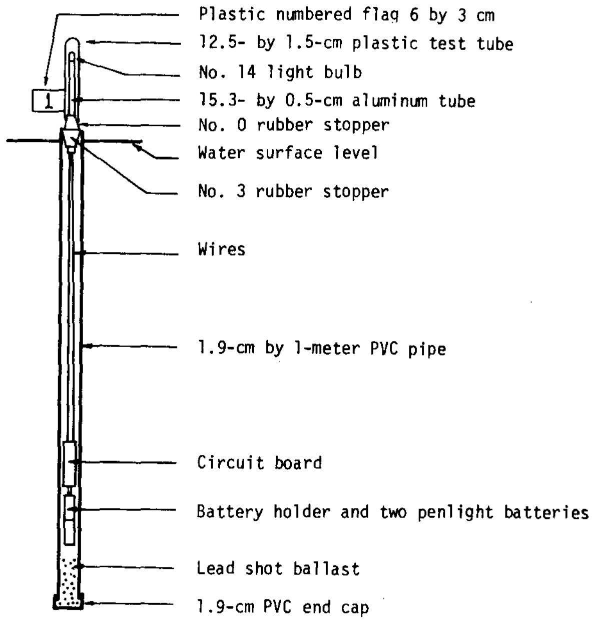


Figure 1-2—Strobe-lighted drogue for measuring nighttime lake surface currents at Twin Lakes, Colo.

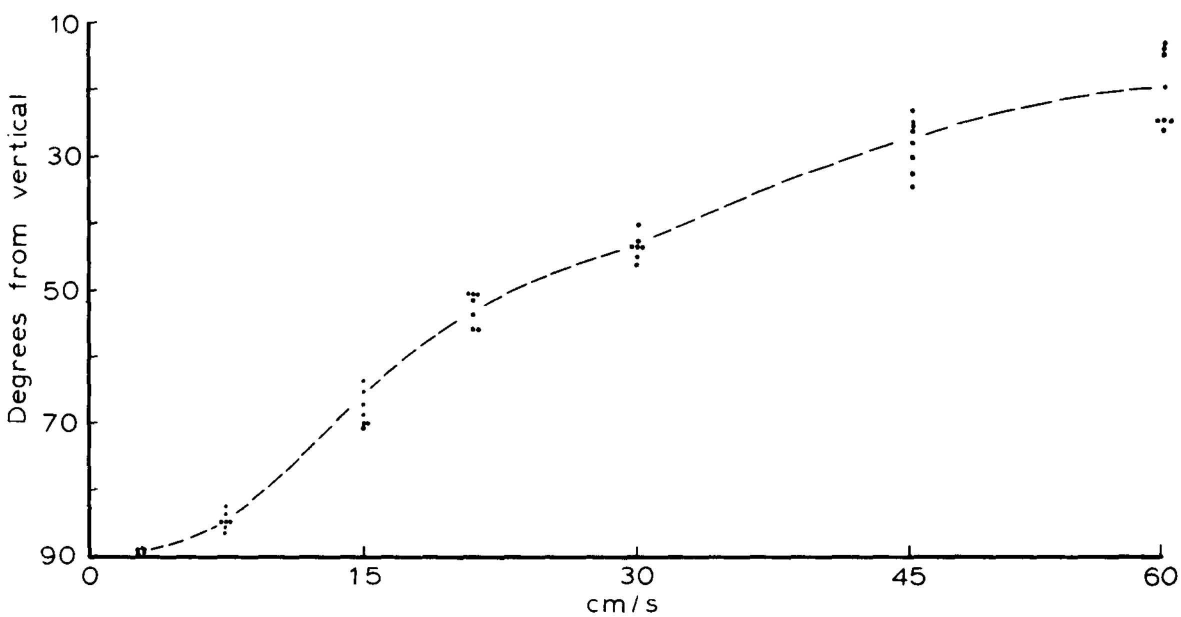


Figure 1-3—Calibration curve for leaning-tube current indicator.

on the straight line distance between recorded positions and therefore represent a minimum estimate. Anemometers at the center of each lake were used when precise windspeeds were needed (used in expressing currents as percent windspeed).

Bottom currents.—Direction and velocity of bottom currents were measured with modified "Pisa" current indicators (Carruthers, 1958 [2]). Indicators were calibrated at the Bureau of Reclamation's Denver Hydraulics Laboratory (fig. 1-3). Weighted Masonite boards (30 by 60 by 0.5 cm) were used as indicator bases to prevent sinking into bottom muds.

Bottom currents were measured monthly along three transects in the upper lake and four transects in the lower lake. Six to nine indicators were set along each transect. All sets on each lake were made the same day. Position of the set was triangulated by sextant and depth and time recorded. At least 30 minutes after setting, indicators were retrieved and degree tilt of gelatine measured. 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 held in the solidified gelatine. Velocities could only be measured down to 3 cm/s due to limitations of the indicator.

Under Ice

An ink tracing technique was developed to measure the velocity and direction of water currents under the ice sheet. On the bottom end of a 2-m (1.9-cm by 2-m PVC pipe (fig. 1-4)) probe, a 10-cm-long measuring bar was attached at right angles. A Quanterron 10-mL oral syringe was fitted onto the probe and a cap with a 0.8-mm hole in the tip was fitted over the end of the syringe.

When the probe was lowered through a 15-cm hole cut in the ice, a trail of ink would stream from the syringe tip. This line of ink was then disrupted by moving the probe several centimeters to one side. The break in the ink trail was timed as it moved the length of the measuring bar. Three velocity measurements were averaged at each location. Current direction was measured with a sextant in terms of degrees from a known point on shore. The sextant was also used to triangulate the location of each current measurement station. Current measurements were made in the months of April 1980 and January, February, March, and April 1981.

To note changes in current due to the frictional influence of the ice cover, four measurements of water velocity and direction were made at five depths from just under the ice to 2.6 m. Measurements at each depth at three locations were averaged.

Temperature profiles of the water and bottom sediments were recorded in each lake with a Hydrolab Model 8002 or T-4 Marine Thermometer. Temperature profiles within the bottom sediment were made by mounting the Hydrolab Model T-4 temperature probe in the end of a sectionalized 4-cm-dia. aluminum rod which was sufficiently long to reach the bottom sediments. This rod was forced into bottom sediments and readings taken at various depths.

RESULTS

Open Water

Current maps and corresponding wind data are shown in the appendix.

The maximum surface current velocity measured on the upper lake was 15.2 cm/s. Maximum observed velocity of surface current in the lower lake was 14.5 cm/s. Maximum observed bottom currents for the upper and lower lakes were 9.8 cm/s and 8.9 cm/s, respectively.

The percent of windspeed for each vector on the current maps was calculated. These proved to be quite variable, ranging from 0.4 to 17 percent windspeed within the same day. All vector percentages were combined to obtain an average percent windspeed for the lake on that particular day. The lake average ranged from a low of 0.9 percent windspeed in November (upper lake) to a high of 4 percent windspeed in September (upper lake).

Under Ice

Testing and temperatures.—No change in current direction occurred from just under the ice to a depth of 2.6 m. Current velocity increased with depth; however, at depths greater than 2 m little additional increase occurred (fig. 1-5).

Water temperatures were below that for the maximum density of water (3.94 °C) in April 1980 and January and February of 1981. By March 1981 water temperatures were at or above maximum density temperature (figs. 1-6 and 1-7).

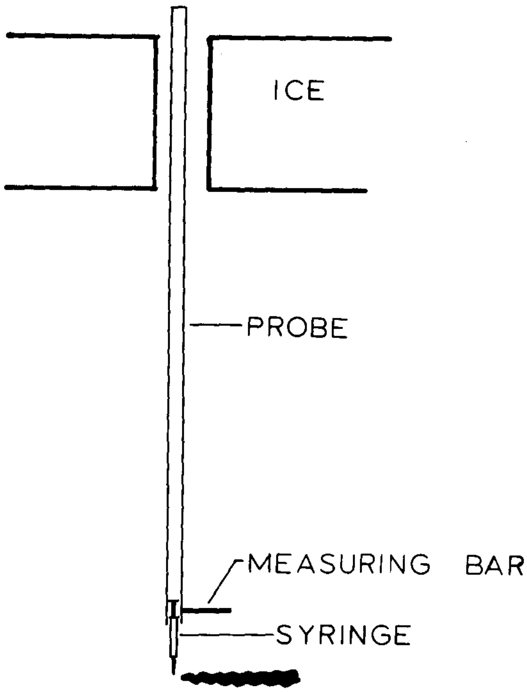


Figure 1-4—Probe used to measure under-ice currents by releasing ink.

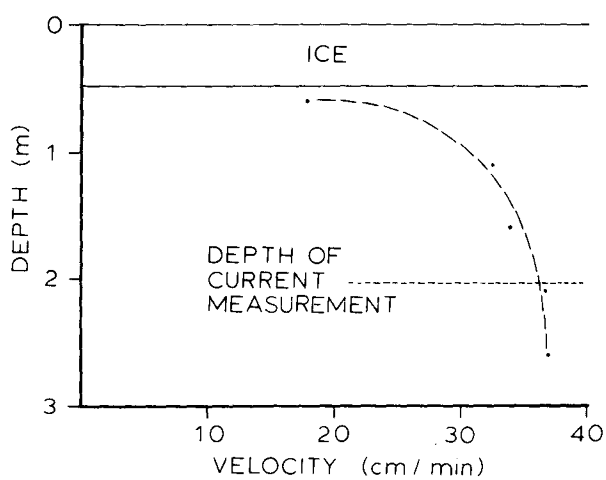


Figure 1-5—Current velocities at various depths. Each point represents the average of four readings at three different locations.

Bottom sediment temperature profiles measured in the shallow regions of the upper lake were warmer than temperature profiles measured in deeper regions (fig. 1-8). Under the shallow water (1.8 m) of the upper lake, temperature changed 2 °C/m into the sediments. Temperature changed 0.6 °C/m at deeper regions of the lake (13.6 m water depth). A similar, though not as pronounced, relation existed on the lower lake (fig. 1-9). Such profiles indicate that relatively more heat is being added to shallow portions of the lake than at the lake center.

Upper lake.—Anticyclonic (clockwise) circulation predominated in the upper lake in April 1980, and January, February, and April 1981.

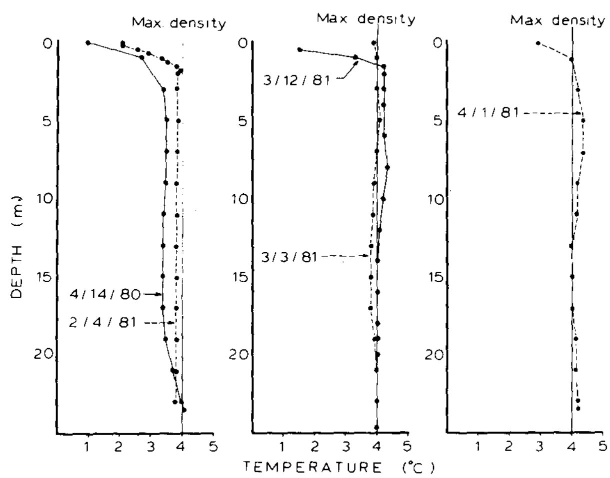


Figure 1-6—Temperature profiles of the upper lake.

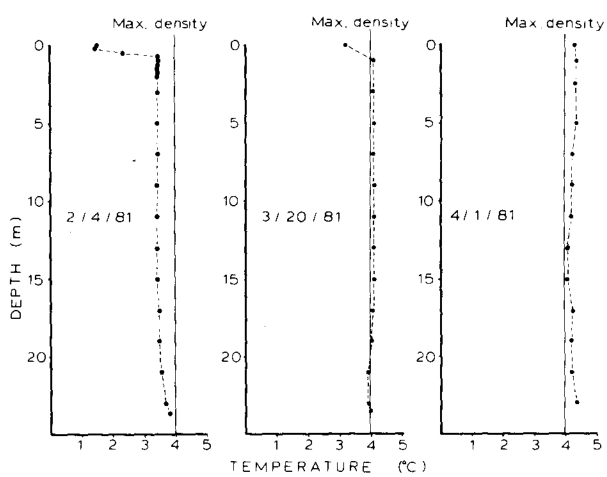


Figure 1-7—Temperature profiles of the lower lake.

The average measured current velocity for these 4 months was 24, 33, 38, and 16 cm/min, respectively. A maximum velocity of 67 cm/min was observed in January 1981. Currents recorded in February 1981 were typical of those observed under the ice (fig. 1-10). Some eddying occurred near the lake's perimeter with the center of the main gyre located toward the north shore.

In March 1981, current in the main gyre reversed direction (fig. 1-11). It became cyclonic (counterclockwise) with the perimeter of the lake anticyclonic. Current velocities dropped to an average of 13 cm/min with the gyre center located toward the south shore.

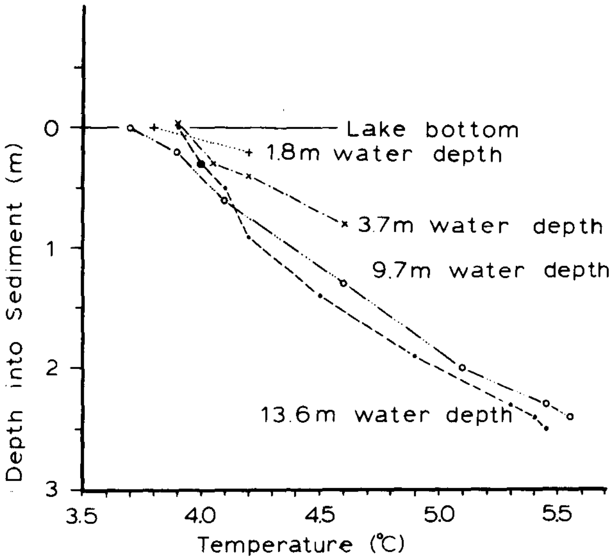


Figure 1-8—Sediment temperature profiles, made at various water depths, in the upper lake.

Lower lake.—Under-ice currents in the lower lake in April 1980 were often characterized by opposing pulses of water movements, sometimes occurring as a complete 180° change in direction in a matter of minutes. As a result, distinct circulation patterns were difficult to identify.

In January and February 1981 a general circulation pattern began to emerge (fig. 1-12). Water movement was much more complicated on the lower lake than the upper lake with numerous small gyres occurring around the lake. Apparent areas of upwelling and downwelling were also noted. The circulation pattern discerned was unstable, changing monthly. Average measured current velocity for January and February was 32 cm/min. Maximum observed velocity was 100 cm/min, which occurred in January.

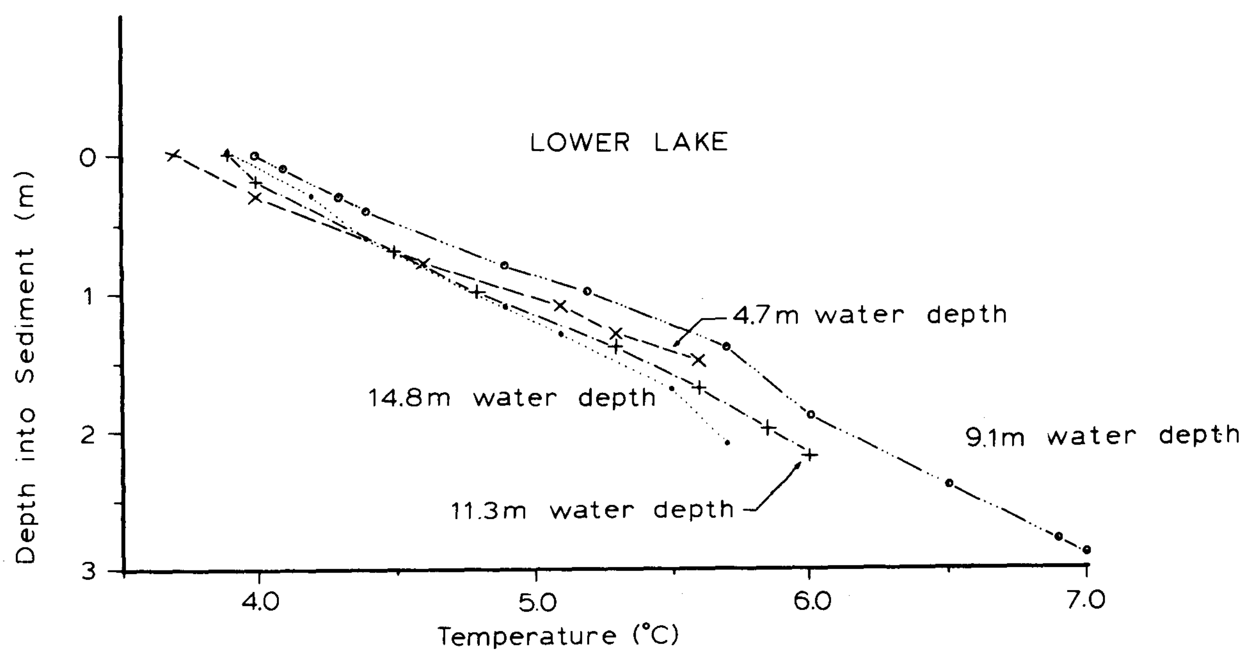


Figure 1-9—Sediment temperature profiles, made at various water depths, in the lower lake.

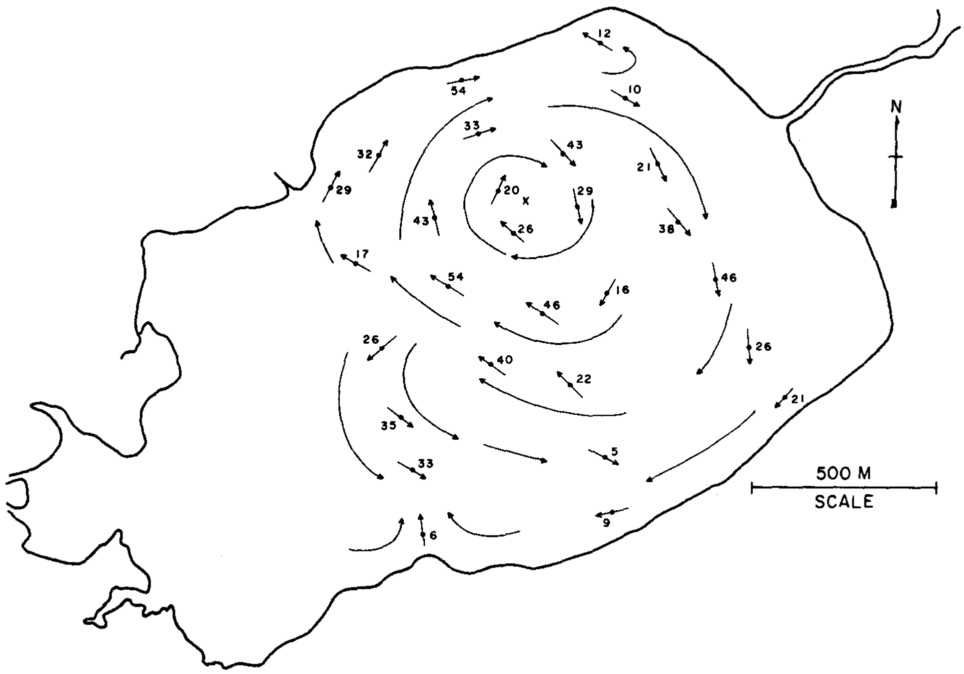


Figure 1-10—Under-ice currents of the upper lake on February 2, 1981. Current velocities are given in cm/min. Flow direction lines, fitted by inspection, were added for clarity.

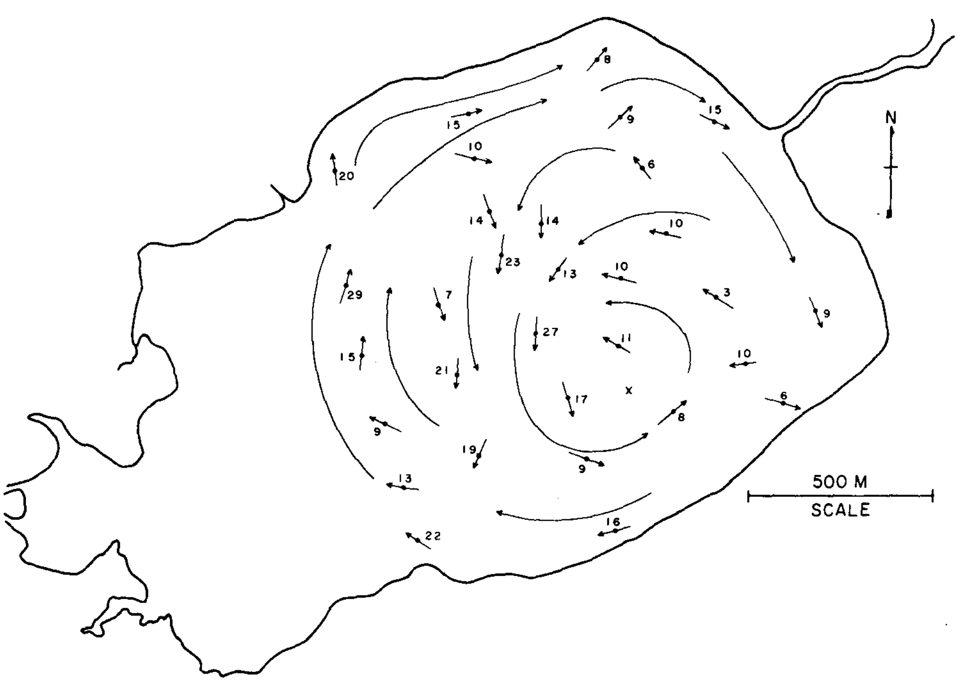


Figure 1-11—Under-ice currents of the upper lake on March 10, 1980. Current velocities are given in cm/min. Flow direction lines, fitted by inspection, were added for clarity.

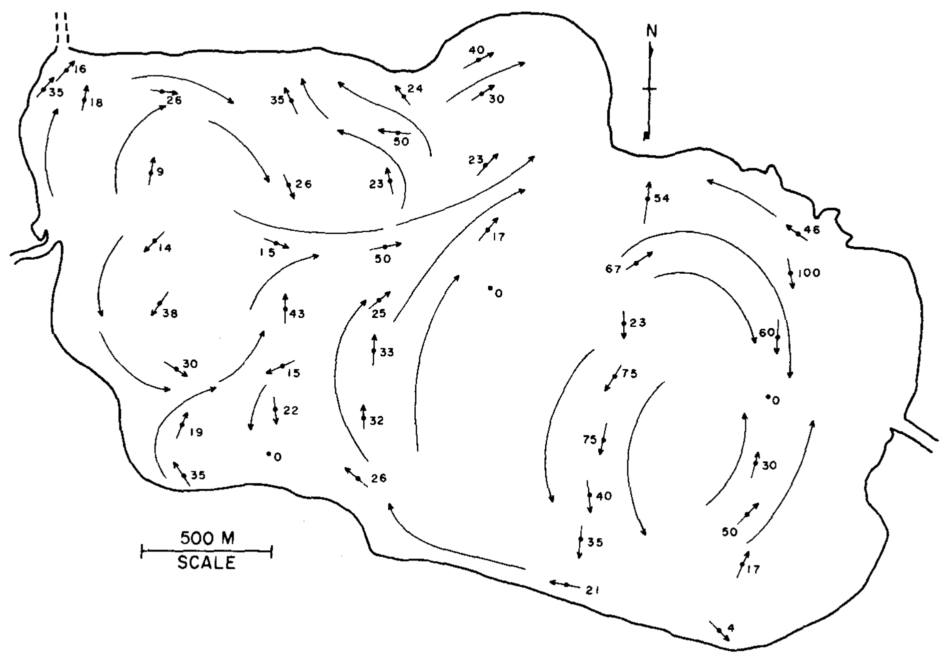


Figure 1-12—Under-ice currents in the lower lake on January 21-22, 1981. Current velocities are given in cm/min. Flow direction lines, fitted by inspection, were added for clarity.

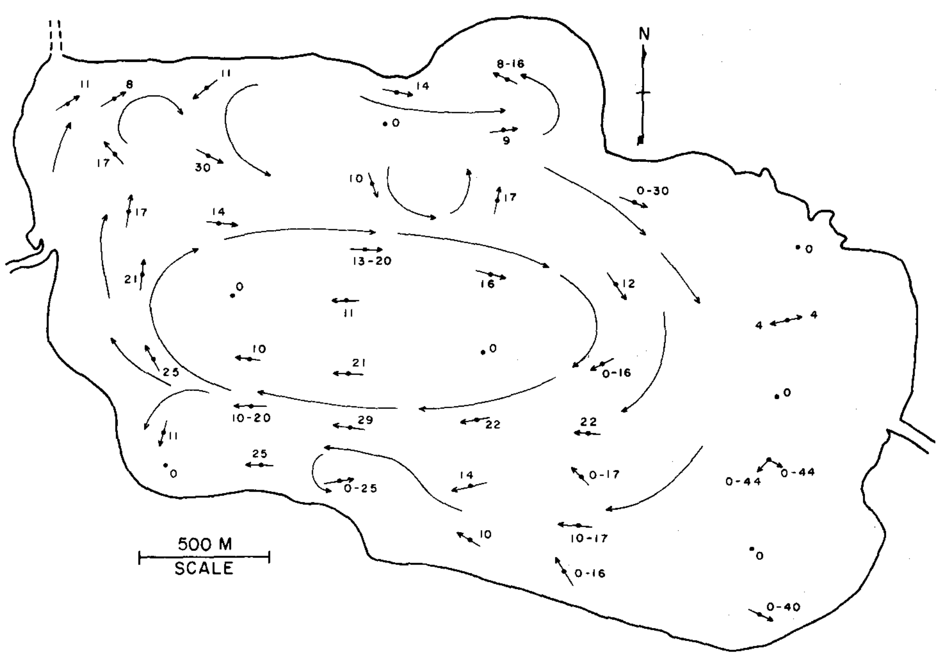


Figure 1-13—Under-ice currents in the lower lake on March 17-19, 1981. Current velocities are given in cm/min. Flow direction lines, fitted by inspection, were added for clarity.

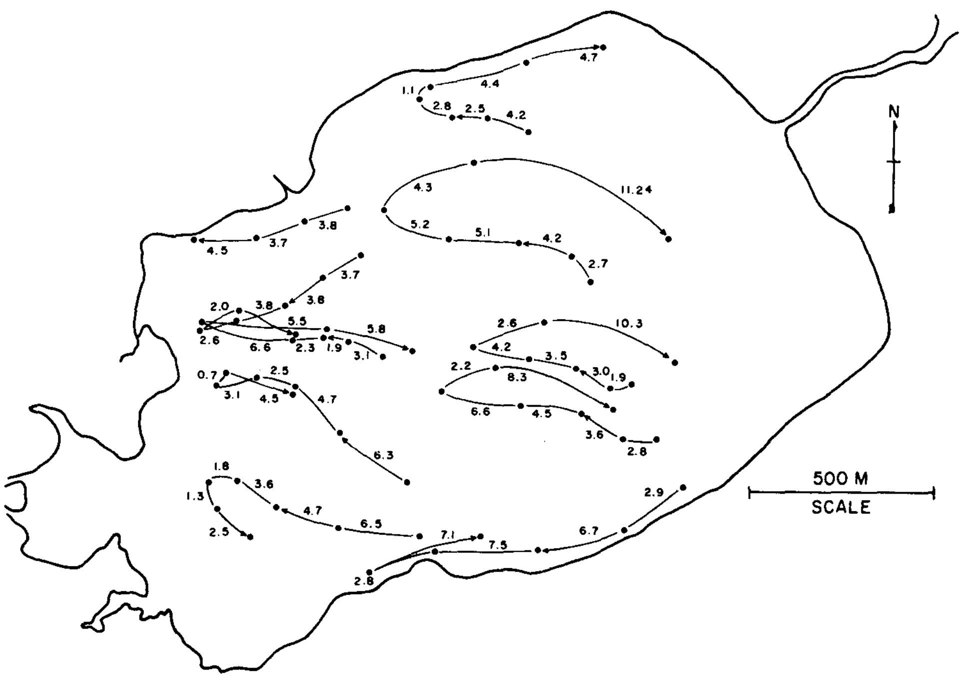


Figure 1-14—Surface currents measured on the upper lake, July 16, 1980. Velocities between drogue sitings are given in cm/s.

The current pattern changed to a central anticyclonic gyre in March. Current velocities at this time were greatly reduced with an average measured velocity of 13 cm/min. The eastern end of the lake appeared calm at this time (fig. 1-13).

DISCUSSION

Surface Currents

Upper lake.—A very strong dependence was noted between upper lake surface currents and wind velocity and direction. A good example of this was noted on the upper lake on July 16, 1980 (figs. 1-14 and 1-15). When winds shifted from a southeasterly to a northwesterly direction, corresponding changes were noted in current direction. As windspeeds increased throughout the day, lake current velocities, particularly in the middle of the lake, also increased.

On November 21, 1980 (figs. 1-16 and 1-17) windspeeds never exceeded 1.6 m/s. Under these calm wind conditions, current velocities

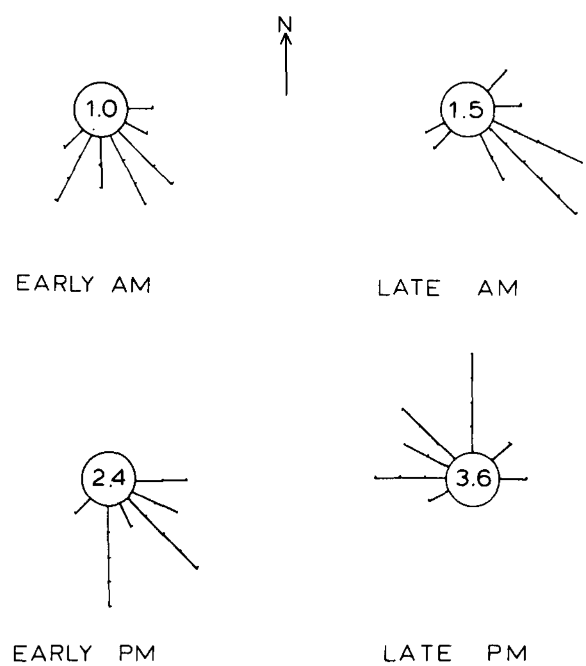


Figure 1-15—Wind roses for the daylight hours of July 16, 1980. Numbers within the circles indicate windspeed in m/s.

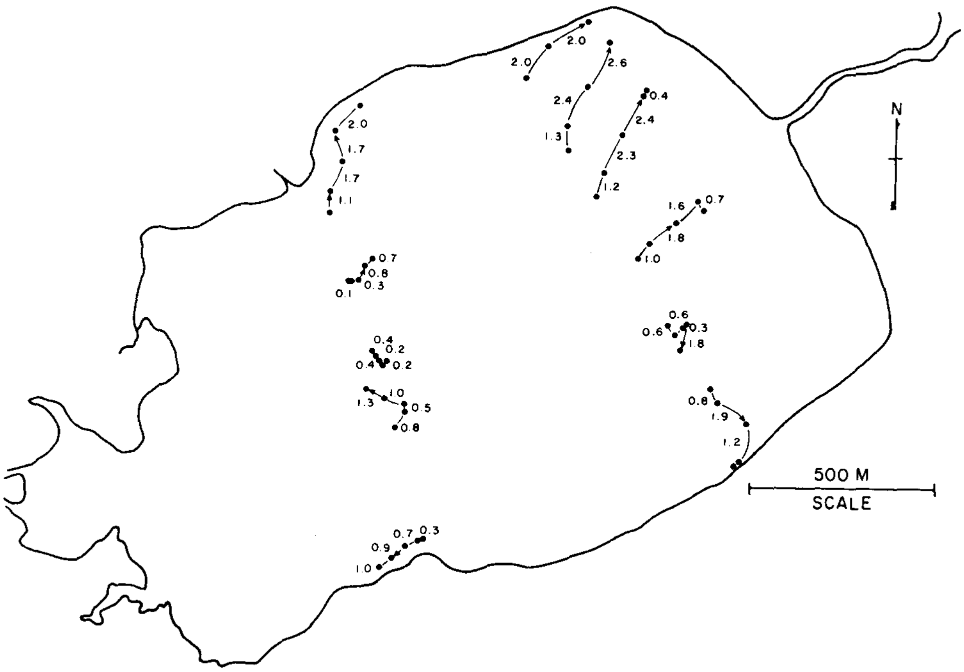


Figure 1-16—Surface currents measured on the upper lake, November 21, 1980. Velocities between drogue sitings are given in cm/s.

were the lowest ever recorded. Current velocities at this time, expressed as a percent of windspeed, were also the lowest ever recorded (0.9 percent) suggesting that low-velocity winds are poor current inducers.

Currents in November also showed a slight tendency toward clockwise rotation, particularly nearshore. It is suspected that on calm days, these nearshore clockwise movements of water are induced by convection currents. Nonlinear currents may also be in part responsible for these clockwise lake currents; however, these were also noted under the ice indicating a minimal wind influence.

In the upper lake, currents generally moved downwind at 1 to 4 percent of windspeed. When the downwind shore was reached, currents moved alongshore with decreased velocity (fig. 1-18). Undoubtedly, much of the surface-blown water sank to greater depths (depending on density gradient) when reaching the downwind shore.

Lower lake.—Under moderate to strong wind conditions, greater than 2 to 4 m/s, currents of

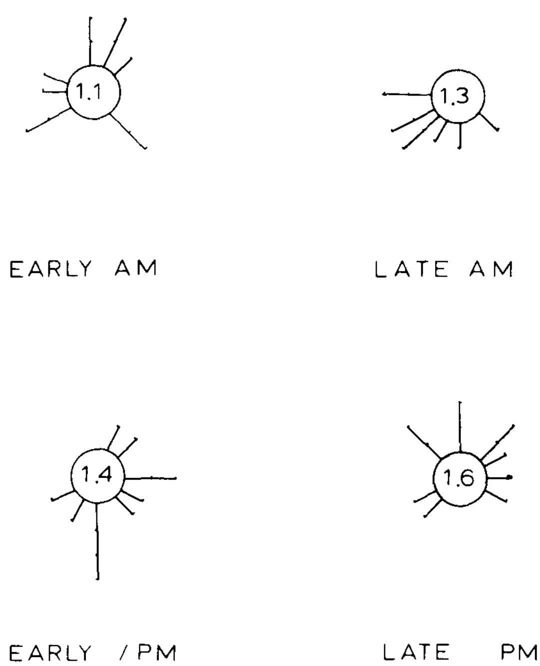


Figure 1-17—Wind roses for the daylight hours of November 21, 1980. Numbers within the circles indicate windspeed in m/s.

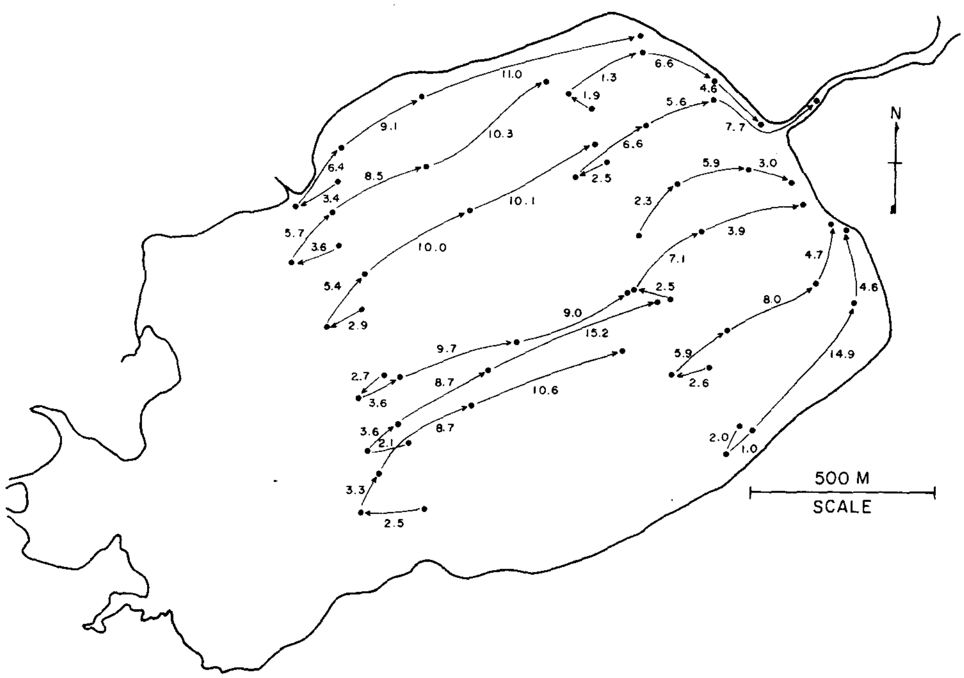


Figure 1-18—Surface currents measured on the upper lake, October 22, 1980. Velocities between drogue sitings are given in cm/s.

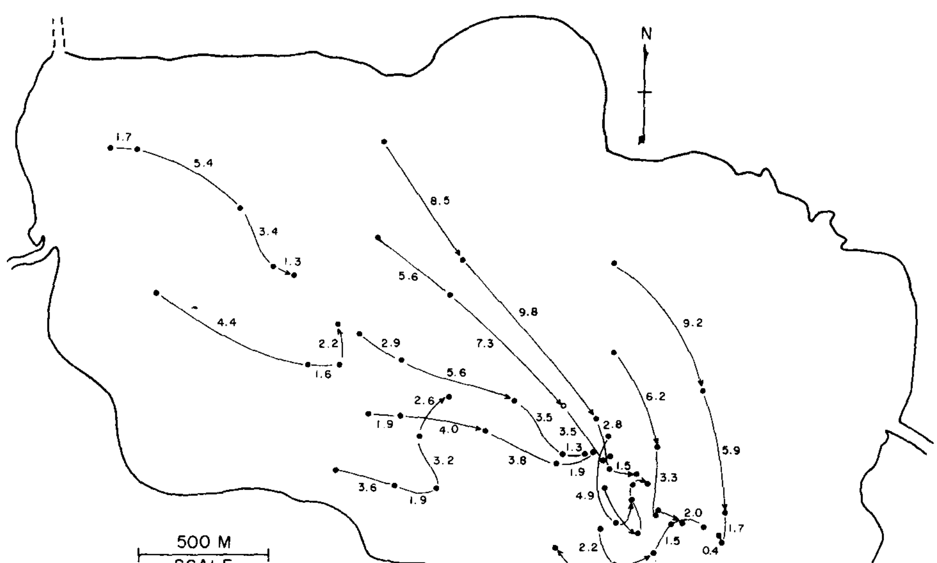


Figure 1-19—Surface currents measured on the lower lake during the night of November 5-6, 1980. Velocities between drogue sitings are given in cm/s.

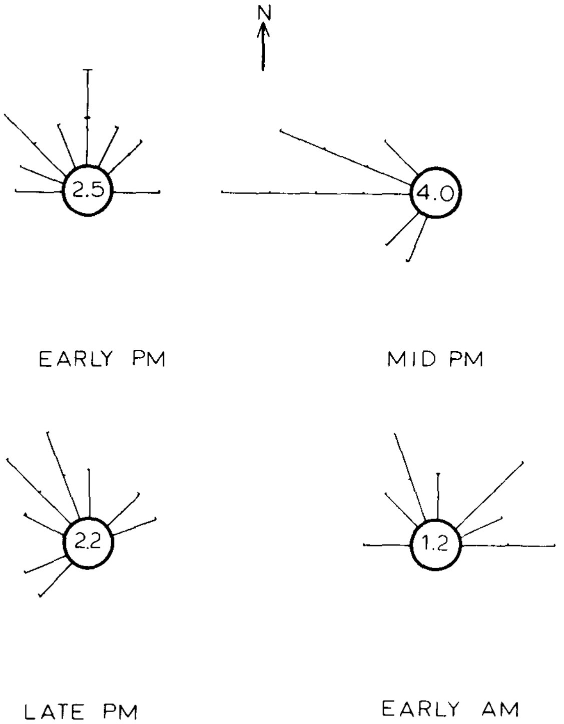


Figure 1-20—Wind roses for the night of November 5-6, 1980, during the time lake currents were measured. Numbers within the circles indicate windspeeds in m/s.

the lower lake proceed downwind at an average of 1 to 4 percent of windspeed. The flow to the downwind side of the lake is complicated by an intrinsic circulation pattern which appears as a clockwise oval circulation about the long axis of the lake. The center of this gyre may move further north or south but it is always clockwise.

The intrinsic pattern is evident in the first vector of lower lake surface current maps on calm days (app. figs. A-9, A-11, and A-13), when an initial clockwise circulation pattern emerges. As wind increases, (often very early in the day), the clockwise circulation pattern is overridden and surface currents proceed to the downwind shore. It is a combination of thermal- and wind-induced forces which are likely responsible for producing this intrinsic movement pattern.

In November 1979 and 1980, currents were measured at night (figs. 1-19 and 1-20). As would be expected under similar atmospheric conditions, surface currents were very similar. Currents initially proceeded downwind. As windspeeds dropped, current velocities slowed, and drogues were found to cluster in the southeastern corner of the lake. A change was then

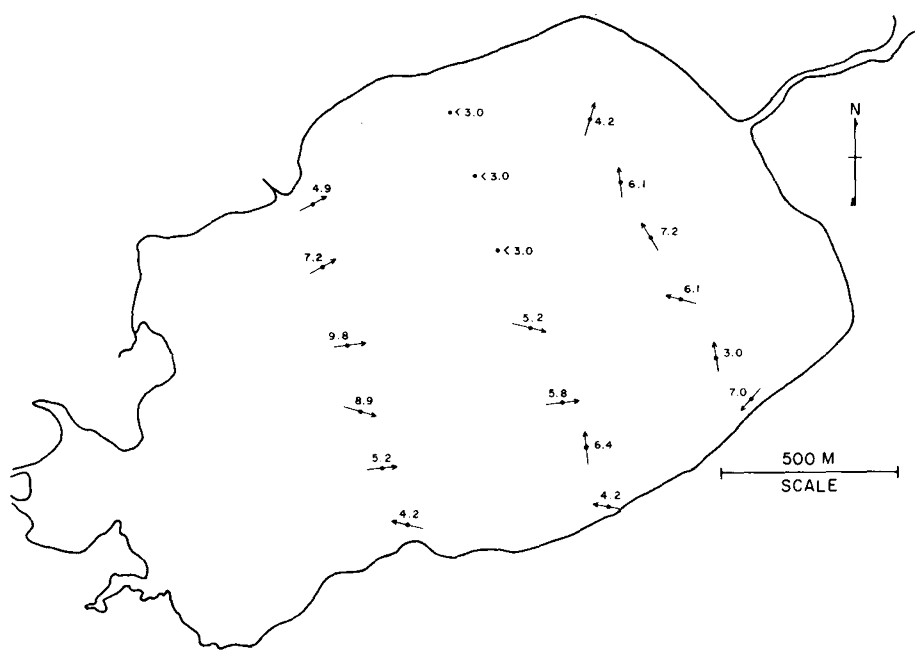


Figure 1-21—Bottom currents of the upper lake on October 28, 1981. Current velocities are shown in cm/s. Current direction is indicated by arrows.

noted in the paths of several drogues. Apparently, with the decrease in windspeed the typical clockwise circulation pattern again became established.

Bottom Currents

Upper lake.—During the summer of 1979 and 1980, bottom currents along the southeastern shore of the upper lake were relatively strong in response to the predominantly northwesterly winds (fig. 1-21). Currents here were sufficiently strong to keep rocky bottom areas free of silt and other sediment commonly found elsewhere in the lake.

Apparent irregularities in the bottom caused currents to be quite variable in direction. Although no consistent pattern was evident, overall velocities recorded will be useful in assessing any future current changes in the lake.

Lower lake.—A relationship between lake trout spawning areas and areas of strong bottom currents was evident in the lower lake. Hartman Point, Mackinaw Point, Rocky Point, and the south shore all were found to have currents exceeding 6 cm/s and all are suspected lake trout spawning areas (Walch, 1979 [3]). Constriction of the water mass by these projecting land features appears to have caused these increased velocities. For example, on November 15, 1980, a current of 7.0 cm/s was recorded on Hartman Point, the strongest reading on the eastern half of the lake that day (fig. 1-22). In August 1980, Mackinaw Point had the strongest current recorded that day (7.2 cm/s) (fig. 1-23). Similarly, strong currents were found on the south shore and Rocky Point (7.9 cm/s and 6.4 cm/s, respectively) (fig. A-27).

Construction of a road along the south shore and its subsequent removal resulted in a large amount of silt and sand being deposited on the lake trout spawning habitat in this area. (See ch. 4.) It is suspected that without further disturbance, the strong currents in this area will flush the rocks clean.

Although bottom currents in the lower lake are usually variable, a circulation pattern did become established on November 15, 1980, when strong easterly winds occurred (fig. 1-22). The lake was unstratified at this time and as expected, bottom currents moved west to east. Currents along the easternmost transect, however, moved in the opposite direction (i.e., east to west) and were generally of lower velocity. The west-to-east currents apparently lifted off the bottom before encountering the last transect and a back eddy occurred there. Similar bottom currents occurred on September 9, 1980, only with currents from east to west. Again, currents along the downwindmost transect changed direction and were of lower velocity. Such patterns, however, became established only after strong winds persisted from a constant direction.

Under Ice

Testing.—The smooth underside of the ice sheet apparently does not affect current direction. A semilog plot of current speed vs. depth approximates a straight line, indicating current velocity increases logarithmically with depth within the first 2.6 m. Beyond 2 m, little change in current speed occurred; thus, the readings made at 2.1 m are below most of the ice's influence.

Upper lake.—The energy necessary to move the great mass of water in the lake and cause the resulting circulation was believed to come from the heating and cooling of the lake's water. The sediments in the shallows of the upper lake were warmer than sediments at the center of the lake. Thus, relatively more heat was supplied to the water at the perimeter of the lake. Heated water then rose or sank, depending on the water's density gradient. Conversely, the upper layers of water at the center of the lake were cooled. Again, this water either rose or sank, depending on ambient water density.

The upper lake's bowl-like shape provided a nearly perfect location to study these currents. Regular contours caused a minimum of current disturbance. Waters were below 4 °C throughout the winter of 1980 and in January and February of 1981. Under these conditions, water heated in the shallows sank. Upper layers of water that became cooled rose. The result was ascending water at the center of the lake and descending water near the perimeter. Fultz (1951) [4] found that a dishpan of water (above 4 °C) heated at the bottom near the rim had a narrow clockwise current at the perimeter, with the center region moving counterclockwise. If the water temperatures were below 4 °C, currents

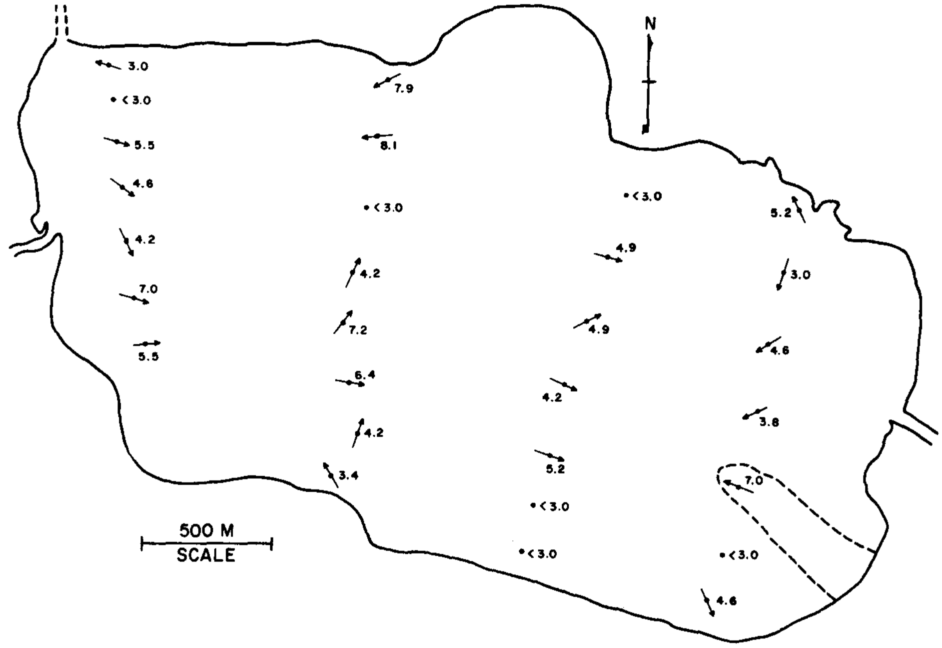


Figure 1-22—Bottom currents of the lower lake on November 15, 1980. Current velocities are shown in cm/s. Current direction is indicated by arrows.

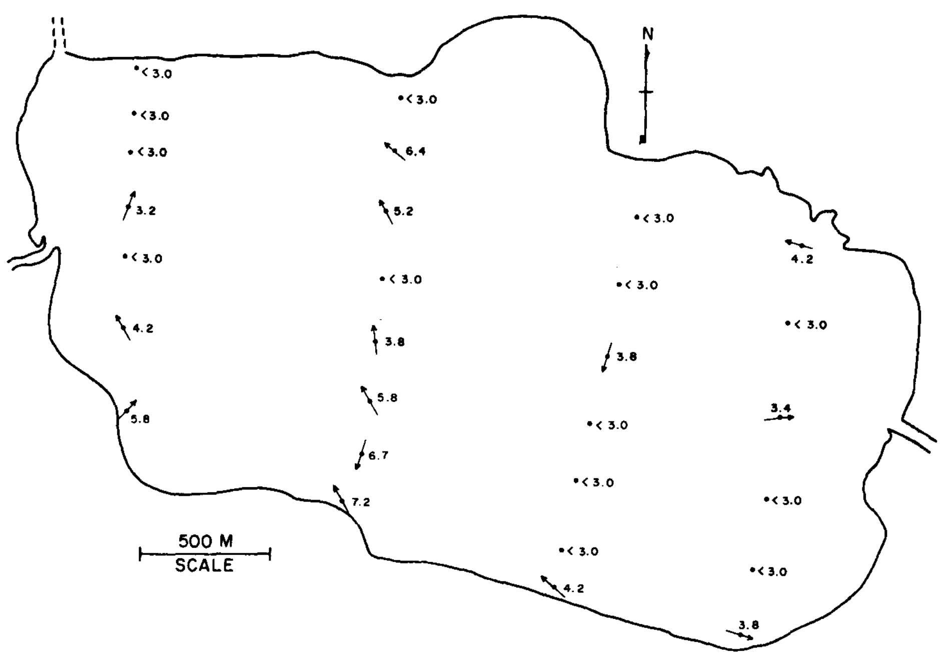


Figure 1-23—Bottom currents of the lower lake on August 21, 1980. Current velocities are shown in cm/s. Current direction is indicated by arrows.

moving in the opposite direction would be expected. Fultz (1960) [5] found that water-filled rotating cylinders, heated at the bottom, developed convection cells with ascending motion in their cores and anticyclonic rotation about their axes. Those cells driven by cooling at the top have descending motion in their cores and cyclonic rotation about each cell's axis. These modeling studies mimic closely the circulation pattern found on the upper lake in April 1980, and January and February 1981.

In March, water temperatures were greater than 4 °C. Water heated around the rim of the lake would now rise and cooler water at the center of the lake would sink. A similar situation was reported in Tub Lake, Wis. by Likens & Ragotzkie (1966) [6]: a cyclonic rotary movement at the center and anticyclonic movement near the perimeter. A very similar pattern existed in the upper lake during March. The decreased current velocities during this month were likely due to currents switching direction only a short time before measurement.

In April 1981, the upper lake was unexpectedly found to have anticyclonic rotation over most of the lake. Sufficient data were not available to explain why the March pattern was overridden; however, it is likely due to rapid heating at this time of year.

It is interesting to note that throughout this study the upper lake had only one large gyre; thus, it appears the lake functions as one very large convection cell. Such was not the usual case on the lower lake.

Lower lake.—Under-ice current patterns in the lower lake were more variable as a result of the irregular contours and suspected irregular heating and cooling. Currents were believed to be thermally driven, with many convection cells forming the irregular pattern. Strong currents were found to converge and diverge, suggesting areas of downwelling and upwelling.

Velocities on the lower lake were similar to the upper lake. Again, as the water reached 4 °C, current velocities dropped by more than half. This would tend to lend credence to the convection-induced current theory. At 4 °C, a current reversal was expected and partially observed. During this reversal, currents would need to stop, then start in the opposite direction; hence, the low velocities noted in March.

Circulation during March was in the form of a large anticyclonic gyre in the center of the lake. The reason for anticyclonic rotation and the appearance of only one gyre is speculative; however, rapid heating at the center of the lake could cause water to ascend, hence the rotation. Possibly, the heat influx was strong enough to override the many smaller gyres and create one large gyre.

Pulsed waterflows in varying directions were commonly found in the lower lake, particularly in April 1980 (app. figs. A-43 and A-44). These pulsed flows were much more common and of a more variable direction on the lower lake, indicating that lake size is a factor in their occurrence. Verber (1964) [7] concluded that differential pressure on the ice cover of frozen Lake Michigan by wind could have been responsible for some water movement in midwinter. Conceivably, changes in differential pressure could pulse under-ice currents of Twin Lakes, making the net flow and direction difficult to interpret. Because of its smaller size the upper lake could be expected to have less differential pressure, hence a less frequent occurrence of pulsed flows.

Lake Currents and the Powerplant

Open water.—The powerplant tailrace is located in the northwest corner of the lower lake. This area of the lake, because of its sheltered location, is not conducive to producing strong lake currents. Rarely did bottom currents in this area exceed 3 cm/s. The hillside to the north and west of this corner shelter it from the wind; thus, strong surface currents also did not occur (fig. 1-19). With calm water predominating in this area, the sedimentation rate here may be greater than elsewhere in the lake. If this has occurred, a higher degree of turbidity can be expected to eminate from this area than elsewhere in the lake once the powerplant begins operation, or at least until these sediments are flushed free.

Under ice.—Currents in the vicinity of the powerplant are generally well below the lake average because of the restrictive nature of this corner of the lake. Currents in 1981 flowed toward the mouth of the powerplant. Such currents could have several effects on the powerplant-generated currents. They may slow water coming from the powerplant, causing its energy to dissipate quicker, or lake currents could deflect powerplant flows, changing their direction (possibly downward).

Even in winter, lake currents are sufficiently strong to continually carry mysids into the vicinity of the powerplant. Assuming a straight line drift at an average of 32 cm/min, a passively drifting shrimp could travel from Interlaken to the powerplant (1.7 km) in less than 4 days. Winter powerplant operation may therefore subject major portions of the shrimp population to entrainment.

CONCLUSION

Surface currents in both the upper and lower lakes are strongly influenced by surface winds. During low wind or ice-cover periods an intrinsic clockwise pattern emerges and predominates which may be somewhat altered by local features. Bottom currents in both lakes are variable and are generally lower in velocity than surface currents, which may be as high as 15 cm/s.

With the data collected thus far during this part of the work at Twin Lakes, natural currents in the two-lake system can be characterized and, in many cases, predicted, with confidence. Any changes in natural current patterns produced by the powerplant should be readily apparent.

CHAPTER 2. LAKE TROUT UTILIZATION OF SHALLOWS FOR SPAWNING

INTRODUCTION

Because of the fluctuating lake levels which will occur during the pump-generation cycle, it is likely that any fish eggs deposited in less than 1.5 m of water would be exposed to the air and resulting extremes of environmental conditions which will not be favorable to their survival. Walch (1979) [3] reported catching ripe lake trout in as little as 1.5 m of water. It is not known, however, whether these fish would have spawned in water this shallow. The objective of this investigation was to determine whether lake trout do spawn in water less than 1.5 m deep. The presence of live trout eggs in shallow water would be prima facie evidence of spawning in this area.

METHODS

Fish eggs, if present, lake water, and loose gravel from interstitial areas of suspected spawning habitat were pumped into a 1 by 0.45-m hardware cloth-covered frame through a 5-cm-dia. hose with a Briggs and Stratton gasoline-powered water pump. To test the efficiency of this method, 100 lake trout eggs were scattered over about 2 m^2 of rocky bottom in water 0.30 to 1.00 m deep; then, as many as possible were recovered with the pump. No eggs were visible during the search. Thirty-seven eggs were recovered, leading to the conclusion that the method was capable of detecting lake trout eggs in shallow water.

During the 1979 spawning season (November 20, 21, 27), approximately 250 m of suspected shoreline spawning habitat were thoroughly vacuumed to a depth of 1.5 m with the pump device. Areas searched included the east side of Mackinaw Point and the west side of Rocky Point (fig. 2-1). During the 1980 spawning season (November 6, 7, 10), both sides of Rocky Point, riprap near the powerplant, and a section of the south shore of the upper lake (fig. 2-1) were searched. In total, 700 m of shoreline were searched in 1980.

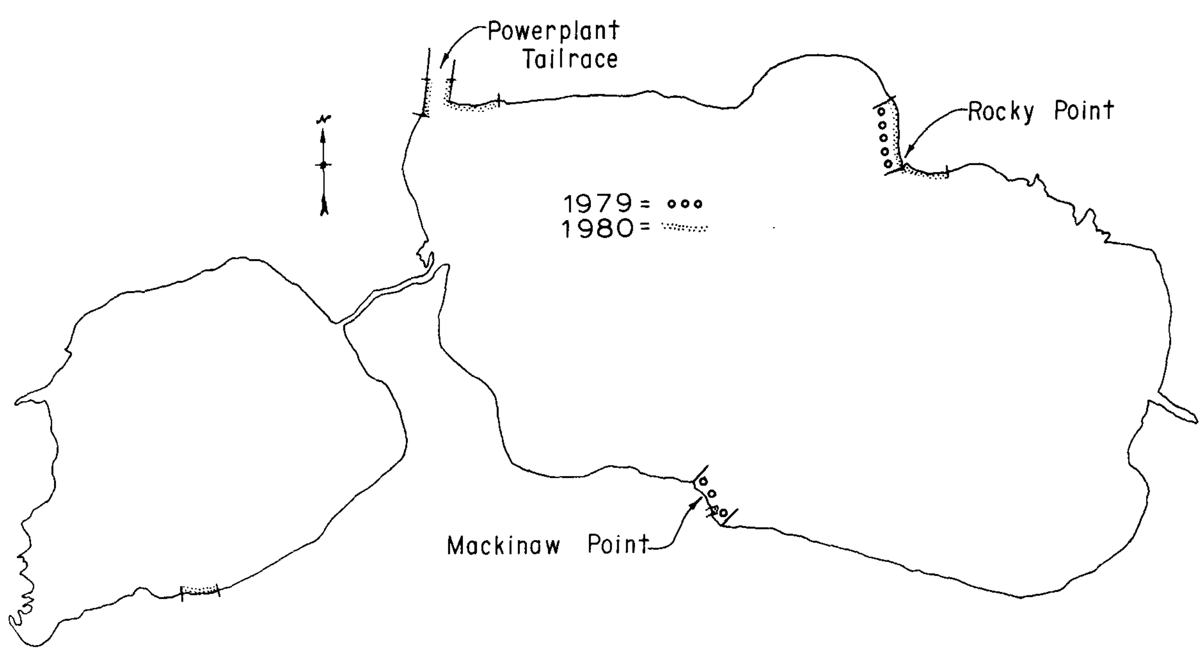


Figure 2-1—Shore areas (dotted) in which search for shallow spawn lake trout eggs was conducted.

RESULTS AND DISCUSSION

Although small suckers, black-nose dace (*Rhinichthys atratulus*), *Mysis* shrimp, scuds, and damselfly nymphs were collected during the search of over 950 m of shoreline, no trout eggs of any kind were found. From this it was concluded that it is unlikely that lake trout in Twin Lakes spawn in water less than 1.5 m deep and that the expected daily water level fluctuations of 0.7 to 1.1 m will not result in the exposure of lake trout eggs.

CHAPTER 3. *MYSIS* POPULATION ESTIMATES — A PHOTOGRAPHIC TECHNIQUE

INTRODUCTION

When the Mt. Elbert Pumped-Storage Powerplant starts operation, *Mysis* shrimp (*Mysis oculata* var. *relicta* [Loven]) will be entrained. Because these shrimp serve as a principal food of lake trout (*Salvelinus namaycush*) in Twin Lakes, it is important to monitor the *Mysis* population in relation to operation of the powerplant.

In the past, a bottom sled trawl was used to monitor the abundance of the shrimp. This proved to be a rather difficult and inefficient task. In an attempt to find a better technique, a photographic method was developed. It was believed greater accuracy could be achieved with photographs since a known area of bottom was sampled, the spatial distribution of the shrimp could be readily determined, and sampling in this manner eliminated depletion of the population and pointed out other problems inherent in net-trawling such as lifting off bottom and net avoidance by the shrimp.

METHODS

A bottom sled trawl (1.5 m long, 1.3 m wide, and 0.7 m high) made of 19-mm-dia. aluminum tubing was used in this study (fig. 3-1). Skids, 15 cm wide by 1.5 m long, flanked each side of the trawl and prevented the trawl from sinking into the bottom. A removable net, frame, and scoop could be attached to the center of the photo-trawl allowing shrimp samples to be taken. The net (45.4 by 28.8 cm) was 1.6 m long, with 1-mm bar mesh. Its cod end terminated in a removable bucket. When towed, the scoop preceded the net mouth and pushed the shrimp off the bottom, directing them into the net.

A bracket was mounted over the net mouth to hold a Farallon Oceanic Model 2001 Strobe. A Canon F1 camera, with a 35-mm lens and autowinder, in a waterproof housing, was suspended in front of the trawl. With the 35-mm lens (0.083 m^2 bottom exposure), shrimp larger than 0.8 cm were clearly visible. A 24-mm lens (0.204 m^2 bottom exposure), was tested and rejected because of difficulty in shrimp image resolution. Camera speed was set at 1/60 second at f-11 with the film plane 56 cm off bottom. A remote shutter cable 75 m long activated the camera and enabled an entire role of film to be exposed without servicing the camera. Kodachrome 64 ASA slide film and Kodacolor II, 100

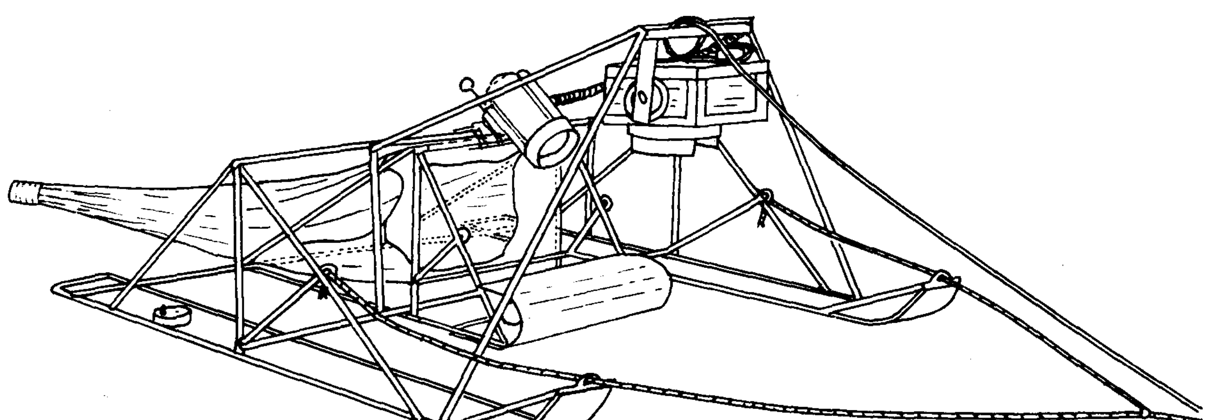


Figure 3-1 — Bottom sled trawl as used in the Twin Lakes study with both camera equipment and removable net-scoop assembly attached.

ASA print film were used. Infrared slide film (IE-135-20) was tested and rejected for failing to increase resolution.

A General Oceanics Inc. model 2030 digital flowmeter, in conjunction with a stopwatch, measured boat speed and distance trawled. Accuracy of the flowmeter was tested by pulling it along a submerged line stretched between two posts. The posts were 29.27 m apart and in 1 m of water. Twelve replicates of this test were conducted. The distance as measured by the flowmeter was then compared to the actual known distance.

Depths were recorded at the beginning and end of trawling using a Lowerance depthfinder. All trawls were conducted between 8 a.m. and noon.

An outboard-powered boat was used to tow the photo-trawl by a 75-m-long, 2.4-mm-dia. steel cable. Trawls lasted 2 minutes, with 9 to 11 pictures being taken at 12-second intervals. When shrimp samples were needed, the net-scoop assembly was attached to the trawl. In this manner the number of netted shrimp could be compared to photographic density estimates. The majority of trawls were conducted in the northwest corner of the lower lake in the vicinity of the powerplant tailrace.

To evaluate past trawling methods, a standardized procedure of using a houseboat equipped with power winch and 91 m of polyethylene towrope (9.5 mm diameter) was used to tow the trawl. Trawling speeds ranged from 0.5 to 0.7 m/s and were measured by timing three paper floats as they passed the length of the boat and by using the flowmeter. Thus, the float passage method could be evaluated.

All photodensity estimates (195) taken in 1981 were plotted on a frequency graph. Sterling's approximation was then used to calculate corresponding probability values of a negative binomial distribution. The two curves were compared for agreement using the Chi-square test. If the two curves were found to agree, experimental data would be shown to approximate a negative binomial distribution, which is indicative of a clumped distribution pattern for the shrimp population.

RESULTS

Speed and Distance Measuring

The digital flowmeter was found to be very accurate. Its 95 percent confidence interval for the distance measured was found to be ± 4 percent of the actual distance (fig. 3-2). Float passage, however, was considerably less accurate. By comparing float passage distance measurements to flowmeter results (fig. 3-3) its 95 percent confidence interval was found to be ±14 percent. Also, under windy conditions, float passage error increased to as much as 16 percent; whereas, flowmeter results remained unchanged.

Off-Bottom Trawling

Photographs showed that the sled trawl, using 91 m of polyethelene towrope, frequently lifted off the lake bottom. Of 10 standardized "traditional" trawls, one remained on the bottom (0.48 m/s trawling speed), and five were off bottom over 50 percent of the time (at speeds greater than 0.6 m/s) (fig. 3-4). Water depth also influenced the trawl's performance. Two trawls conducted at the center of the upper lake, where the water depth is several meters deeper than other areas trawled, remained off bottom 100 percent of the time at 0.61 and 0.62 m/s.

Net Trawl Efficiency

By taking photographs and simultaneously netting shrimp on trawl runs, it was possible to calculate a conversion factor between the two methods. Only trawls which stayed on the bottom more than 70 percent of the time were used to calculate this factor. Trawl net samples were corrected for the amount of time the trawl was off bottom. The net was found to capture only 42 percent of the shrimp seen in the photographs. Thus, at least 2.4 times more shrimp were present than would be indicated by the trawl estimates (fig. 3-5). This is considered a minimum number since the photographic estimates increased at higher speeds (fig. 3-6). Apparently, the scoop which precedes the net was scaring shrimp off the bottom (possibly by creating a pressure wave) and thus out of the area photographed. At higher speeds, the shrimp had less time to react and therefore, more appeared in the photographs.

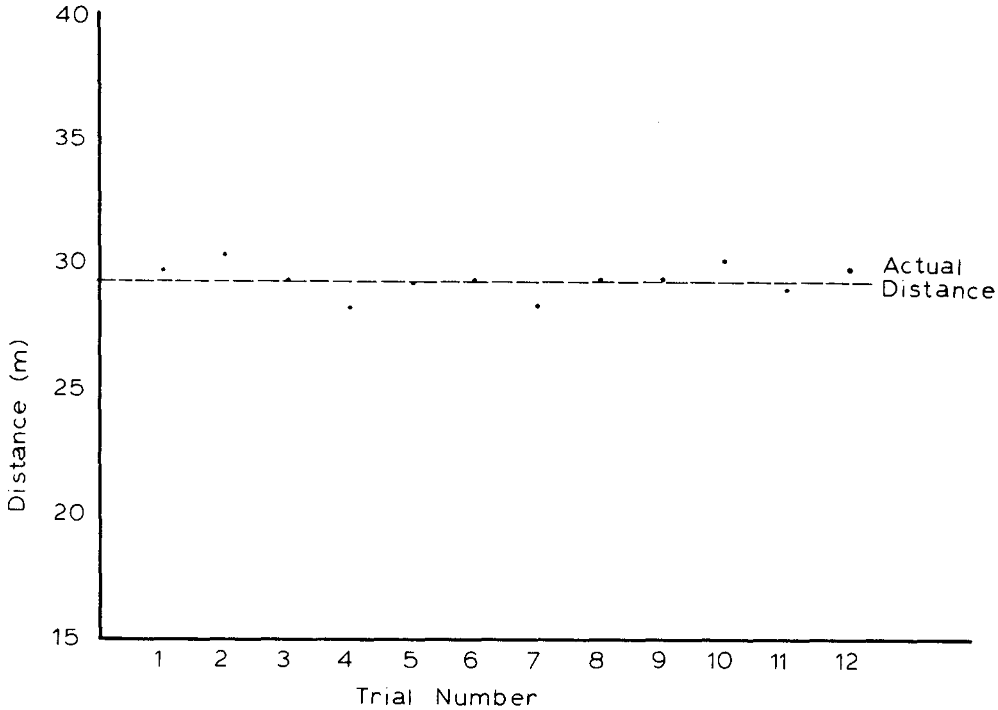


Figure 3-2—Results of General Oceanic's Digital Flowmeter testing.

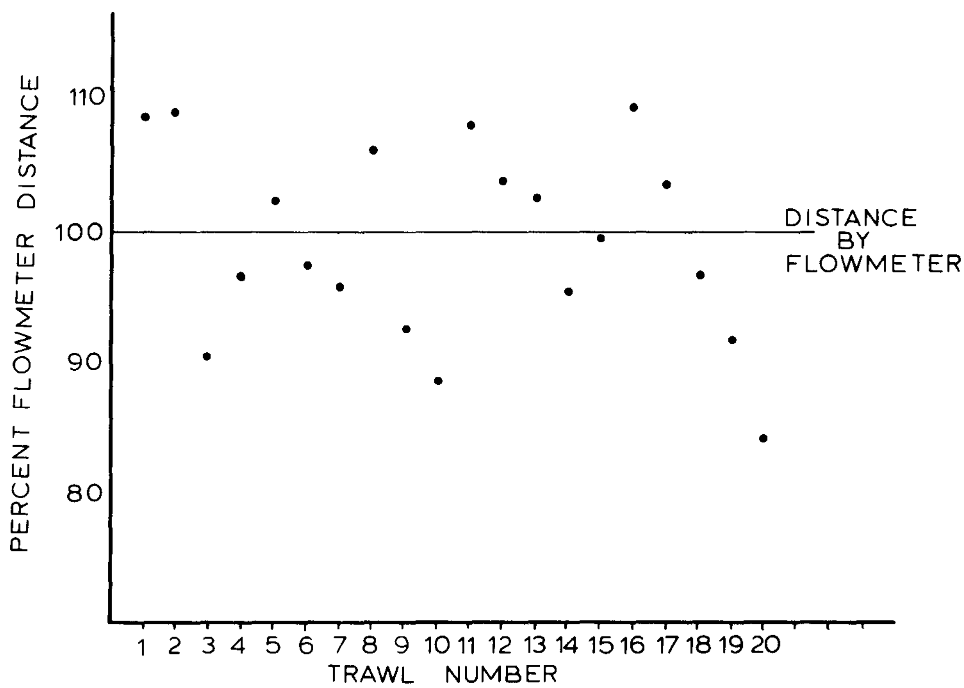


Figure 3-3—Results of testing the float passage method of measuring boat speed against flowmeter results.

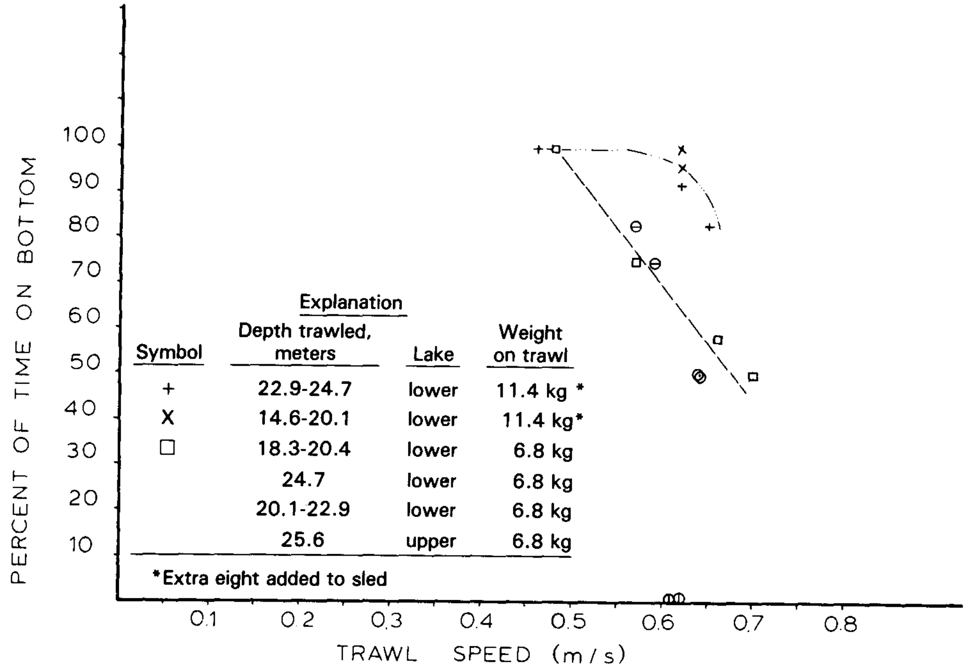


Figure 3-4. Trawl speed and its relation to the amount of time trawl was on bottom. All trawls used 9/m of polypropylene towrope (as used in the past).

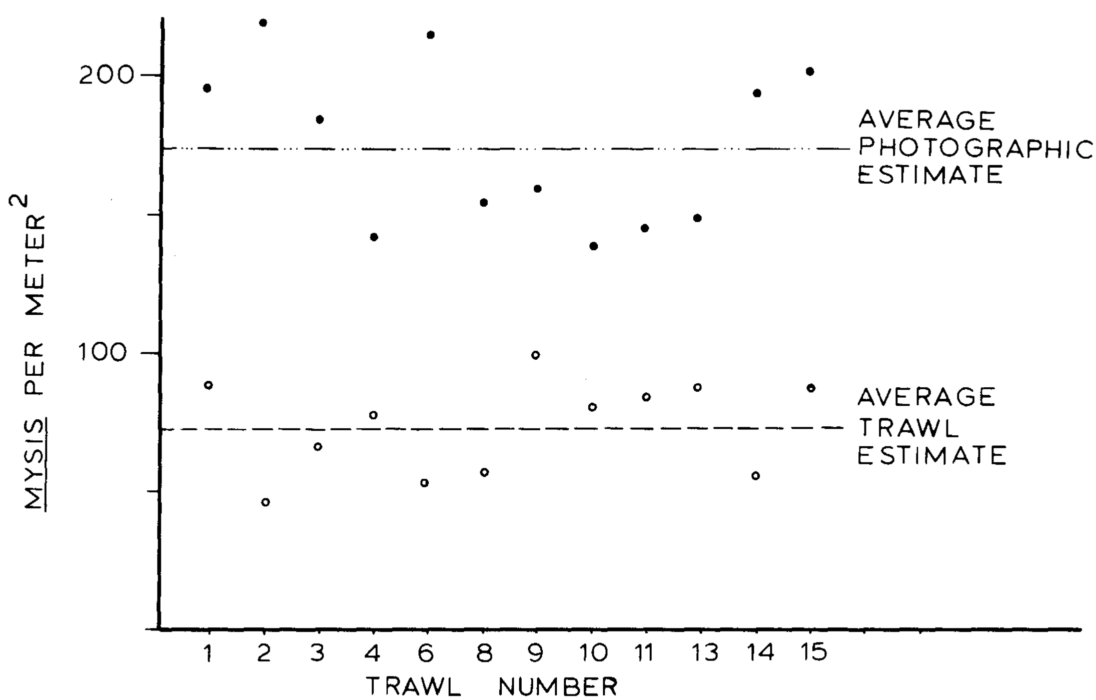


Figure 3-5—Photographic shrimp density estimates and simultaneously made net trawl density estimates.

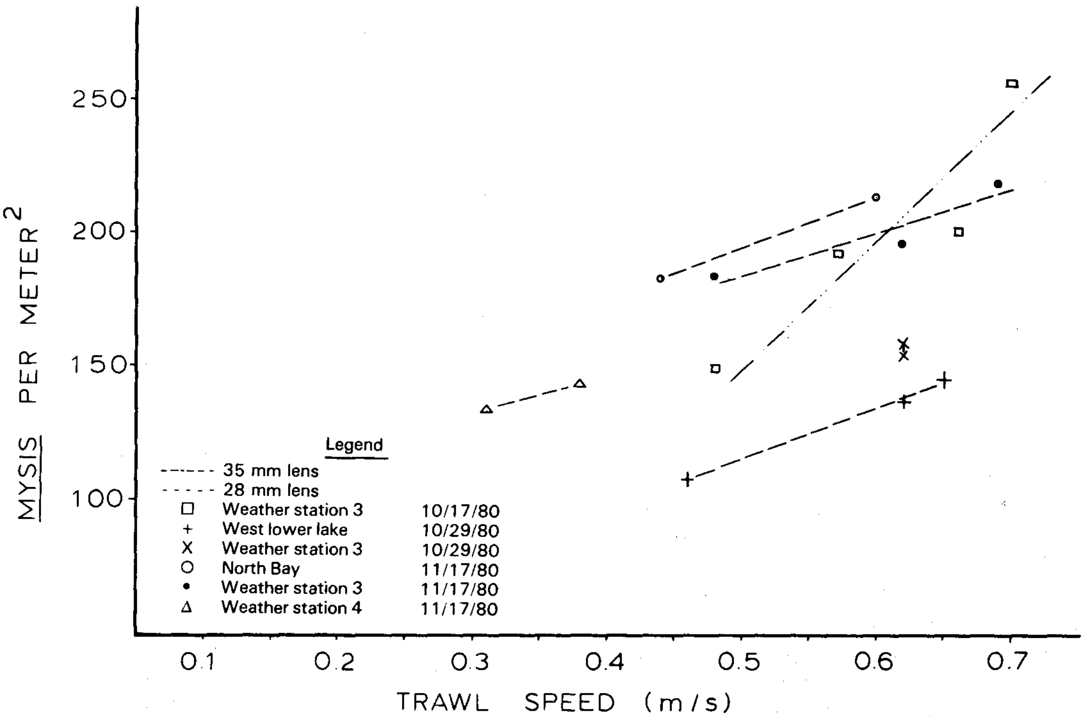


Figure 3-6. Trawl speed and estimated shrimp density relationship.

Shrimp Density Estimates

In 1980, shrimp density estimates in front of the powerplant (15 to 20 m water depth) were 157 shrimp/m² on October 17, and 199 shrimp/m² on November 17. On June 4, 1981, densities were estimated at 89 shrimp/m². Densities increased to 112 shrimp/m² on June 10, 1981, and then to 232 shrimp/m² on June 20, 1981. By July 10, 1981, the density of shrimp decreased to 142 shrimp/m².

Distribution

Analysis of 195 photographs taken in 1981 suggests that the shrimp exhibit a negative binomial distribution (fig. 3-7). A Chi-square test ($x^2 = 5.36 < x^2_{0.95(4)} = 9.49$) indicated that the observed distribution was not significantly different from that of a negative binomial, which would mean that the shrimp are distributed in a clumped pattern.

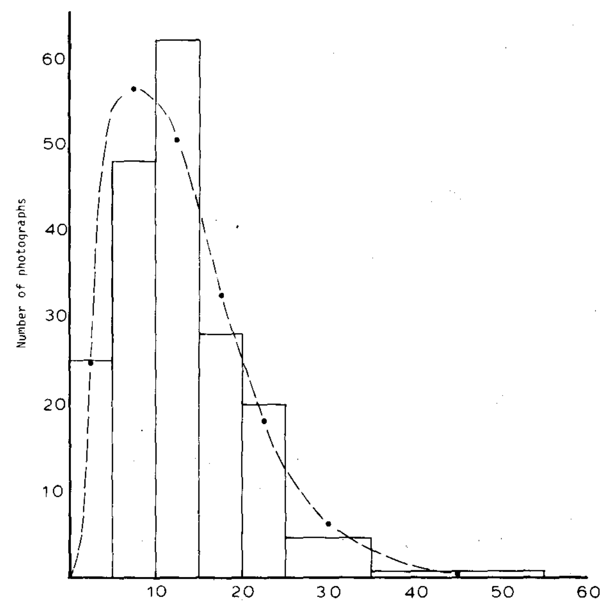


Figure 3-7—Frequency histogram of 195 photographs taken in 1981. Dots indicate expected frequency based on Sterling's approximation to a negative binomial.

DISCUSSION

Problems with Past Trawling Methods

With net trawling, an accurate measurement of distance is essential since any errors in the length of trawl would be expressed as an error in *Mysis* density. The float passage method, as used at Twin Lakes before 1980, with its 14 percent error should be discontinued. Use of a digital flowmeter not only greatly increased accuracy (4 percent error), but also saved considerably on manpower and sampling time.

The biggest problem with previous trawling methods was that the sled trawl frequently lifted off the bottom. The bouyancy and large diameter of polyethylene towrope appeared to pull the trawl off bottom at the start of trawling, giving extremely variable density estimates. In deep water, such as in the central region of the upper lake, lifting off bottom became more severe. Density estimates made in this region would be expected to be more erratic and greatly underestimate the actual population. Variability of these past estimates had been attributed to the clumped distribution of the shrimp. It appears, though, that this variability was more closely related to poor sampling technique. Thus, previous estimates of shrimp density using the small trawl and polyethylene towrope should be viewed cautiously.

The problem of the trawl lifting off bottom was solved by using steel tow cable. When this was done, all trawls conducted under 0.9 m/s remained on the bottom 100 percent of the time. The use of steel cable is essential for deepwater trawling.

Another serious problem discovered was that the net trawl was only 42 percent efficient. Past estimates assumed the trawl would catch all the shrimp in its pathway. Many however were actively avoiding the net, were run over by the trawl, or were pushed away from the net mouth by a pressure wave of water. Netted shrimp estimates would need to be multiplied by at least 2.4 times to more closely approximate the actual population.

Shrimp Density Estimates

The shrimp population near the powerplant was found to fluctuate from 89 to 232 shrimp/m^2. These fluctuations are likely due to lake currents moving shrimp in or out of the area. Growth of young-of-the-year shrimp (missed in springtime photographs) would not account for the 260-percent increase in shrimp in 16 days.

Should whole lake population estimates of shrimp be required once a year, the best month for sampling would be October. At this time, young-of-the-year shrimp would be large enough to be readily identified in the photographs, and bottom oxygen levels would not preclude the presence of shrimp (Keefe, 1980 [8]).

Distribution

Based on an analysis of their frequency distribution, *Mysis* shrimp in Twin Lakes are distributed in a contagious or clumped pattern on a general background of low density. Successive photographs taken during trawls (generally 10 to 11 m apart) show a wide variation in shrimp density. By considering the time interval and speed of travel between bottom photographs, it is estimated that the density clumps are less than 10 m in diameter. This contention is in agreement with observations made during scuba dives. Also, only rarely did a photo show less than 60 shrimp/m^2, indicating a background scattering of shrimp between clumps.

CONCLUSION

The photographic bottom trawls have considerably changed the thinking regarding shrimp densities. It is now believed that shrimp are at least 2.4 times as abundant as previously thought, with densities in the vicinity of the powerplant as high as 232 shrimp/m^2.

The development of the photographic method has pointed out deficiencies in methods used in the past. Information gained in this study will help to reduce errors encountered in estimating shrimp densities and make future estimates considerably more reliable and useful when judging the impact of the powerplant.

CHAPTER 4. SEDIMENTATION RATES

INTRODUCTION

The sediments in Twin Lakes play an integral part in the ecology of the lake system, both as a nutrient sink and as habitat for lower food chain organisms. Operation of the Mt. Elbert Pumped-Storage Powerplant, as well as the new dam built below the lower lake, could cause changes in sedimentation rates. Three possible methods exist to measure sedimentation rates. The first is by aging bengthic core samples (Bergersen, 1976 [9]). The second method is to measure incoming and outgoing suspended sediments, and lastly, sediments can be collected in traps placed on the lake bottom. The latter two methods were employed in this study.

METHODS

Sediment Trapping

Sediment trap frames were built of 1.9-cm PVC pipe and attached to sheet metal skids (15 by 91 cm) to prevent sinking into the soft bottom. Each trap held two 1-L Imhoff cones in a vertical position (fig. 4-1). A sonic-activated float release device (fig. 4-2) was mounted to the top of each trap used during open water periods of 1980. Traps deployed during winter were connected to a post mounted in the ice with a nylon rope. Three traps set in the spring of 1981 used only a float and line for recovery.

Nine sediment traps were placed in the upper lake between July 6, 1980 and July 11, 1981 (fig. 4-3). Two traps were lowered through the ice and seven were placed during open water periods. Twelve sediment traps were placed in the lower lake between June 23, 1980 and July 11, 1981, two traps through the ice, and ten during open water (fig. 4-4). Periodically, the traps were pulled, sediments filtered through tared fiberglass filters, and dried at 104 °C.

Processing filters involved drying at 104 °C for 1 hour, cooling in a desiccator, and weighing to the nearest 0.1 mg. Filters were then incinerated at 550 °C for 15 minutes and reweighed (American Public Health Association et al., 1975 [10]). This analysis gave the total deposited sediment as well as an estimate of organic and inorganic fractions.

Suspended Sediment Sampling

At approximately 3-week intervals (2-week intervals during runoff) between August 7, 1980 and July 21, 1981, suspended sediments were sampled in Lake Creek above the upper lake, in the channel between the lakes, and in Lake Creek below the lower lake. Six 400-mL water bottles were filled at each station using a suspended sediment hand sampler (US DH model 48). Two or three 800- to 1000-mL replicates from each station were filtered through fiberglass filters which had previously been dried and weighed. Filters were then redried and stored for analysis at a later date by the same procedure used on sediment trap filters. To calculate the kilograms of sediment transported per day, the amount of sediment was multiplied by flow rates obtained from the Colorado Division of Water Resources.

Conversion Factors

For both methods (sediment trapping and suspended sediment sampling), a conversion factor was needed to calculate volume of wet sediment from weight of dried filtered residue. To obtain this factor, ten 17.6-mL samples of lake benthos were dried at 104 °C to a constant weight (10 hours' drying time) and weighed to the nearest tenth of a milligram. Five samples were then analyzed for organic and inorganic fractions by incinerating them at 550 °C until a constant weight was achieved (50 min).

RESULTS

Conversion Factors

By drying samples of lake benthos, it was found that 1 g of dry filtered residue equaled 3.86 mL of wet sediment. Composition of the lake benthos was found to be 92 percent inorganic and 8 percent organic.

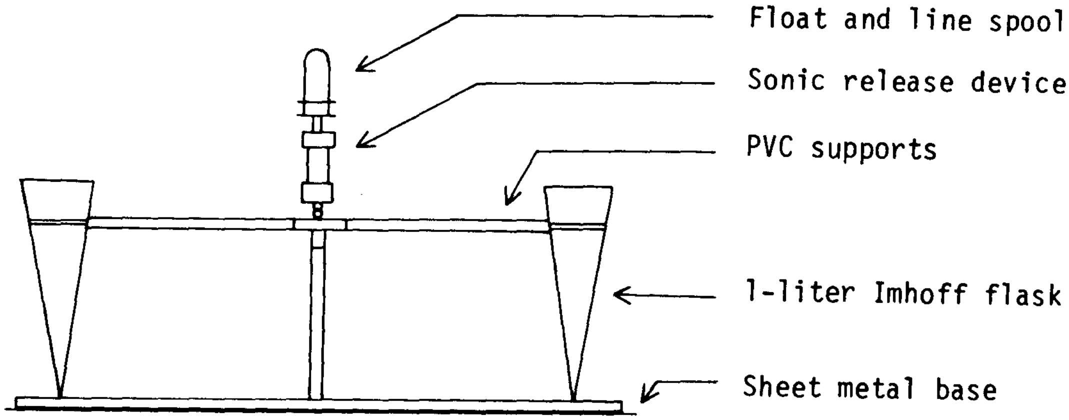


Figure 4-1—Schematic of sediment trap used in Twin Lakes.

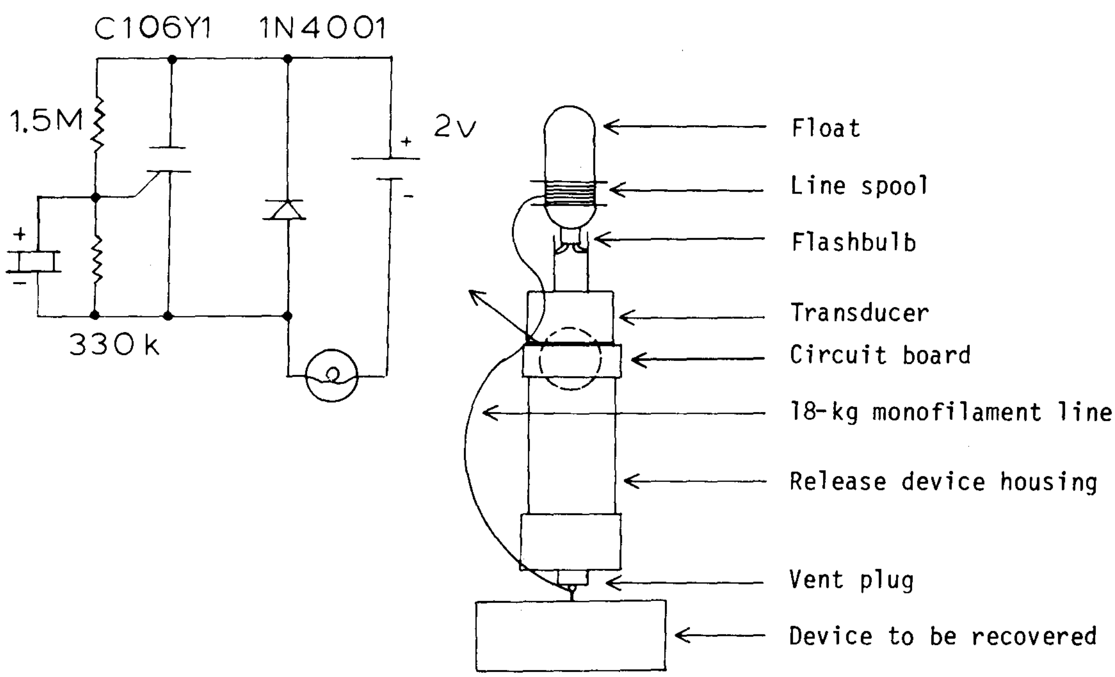


Figure 4-2—Sonic-activated float release device used to retrieve sediment traps.

Sediment Trapping

Four traps were recovered from the lower lake and one trap from the upper lake during open water in 1980. One sediment trap set during open water in 1981 was recovered from the upper lake and all four traps set under the ice were recovered from the upper lake and all four traps set under the ice were recovered. Positions of the traps, dates set, and sedimentation rates for the time they were set, are shown in figures 4-3 and 4-4.

Three of the traps in the upper lake were pulled at different times of the year. Sedimentation rates were thus calculated for summer, winter, and during spring runoff. Between these times of the year, the sedimentation rate was estimated by interpolating between known data points. The incoming suspended sediment load

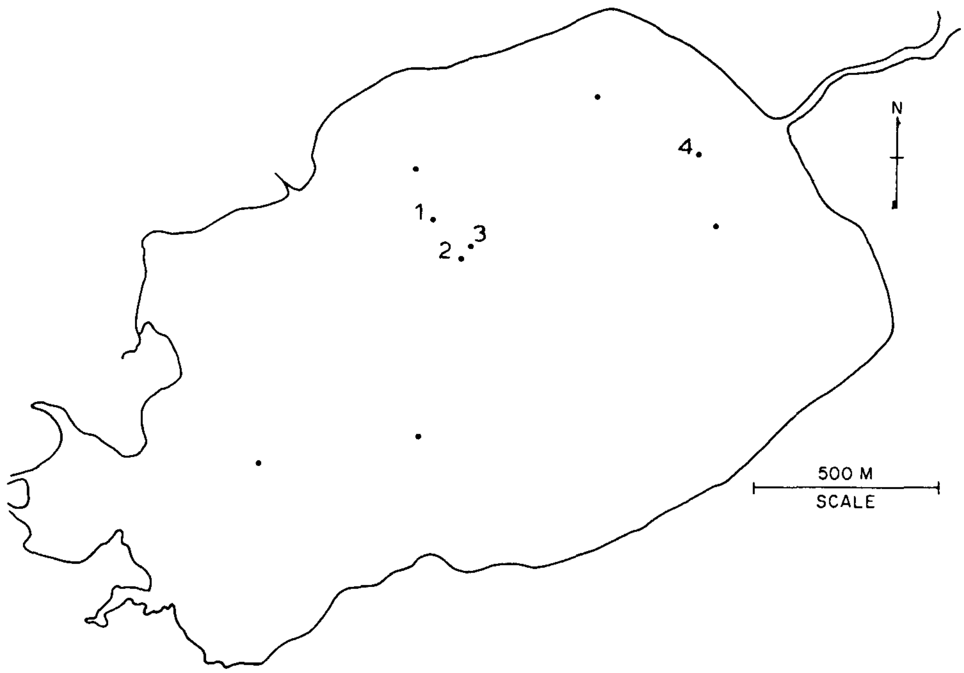


Figure 4-3. Location (dots) of nine sediment traps placed in the upper lake. Sedimentation rate for dates given and inorganic and organic fractions are listed for those traps recovered.

Explanation

Trap Number	Result
1	1/28/81 - 4/20/81, 1.15 mm/a, 89% inorganic; 11% organic
2	9/3/80 - 11/26/80, 1.68 mm/a, 83% inorganic; 17% organic
3	5/23/81 - 7/11/81, 9.36 mm/a, 89% inorganic; 11% organic
4	1/29/80 - 4/20/81, 0.183 mm/a, 63% inorganic; 37% organic

was used in the interpolation to derive the proportion of change over time (fig. 4-5). By weighting for time, an annual sedimentation rate of 2.2 mm/a was estimated for the upper lake.

No sedimentation rate was calculated for the lower lake since sediment traps set during spring runoff were not recovered. Summer, fall, and winter rates, as well as sediment outfall near the south shore road, however, were estimated (fig. 4-4).

Suspended Sediment Sampling

Using the inorganic sediment figures (table 4-1), 235 220 kg/a entered the upper lake and 177 544 kg/a left the lake. Thus, 57 676 kg of inorganic material were deposited. This results in a sedimentation rate of 0.084 mm/a, based on the entire lake surface area. Analysis of the five 17.6-mL samples of bottom material showed bottom composition to be 92 percent inorganic and 8 percent organic. Thus, an additional 8 percent should be added to the sedimentation rate for the organic fraction bringing the total sedimentation rate for the upper lake to 0.091 mm/a.

The amount of sediment being transported to the lakes was highest during the spring runoff of 1981 (late May to early July). Lowest levels of sediment transport occurred during the late winter months of February and March (fig. 4-6).

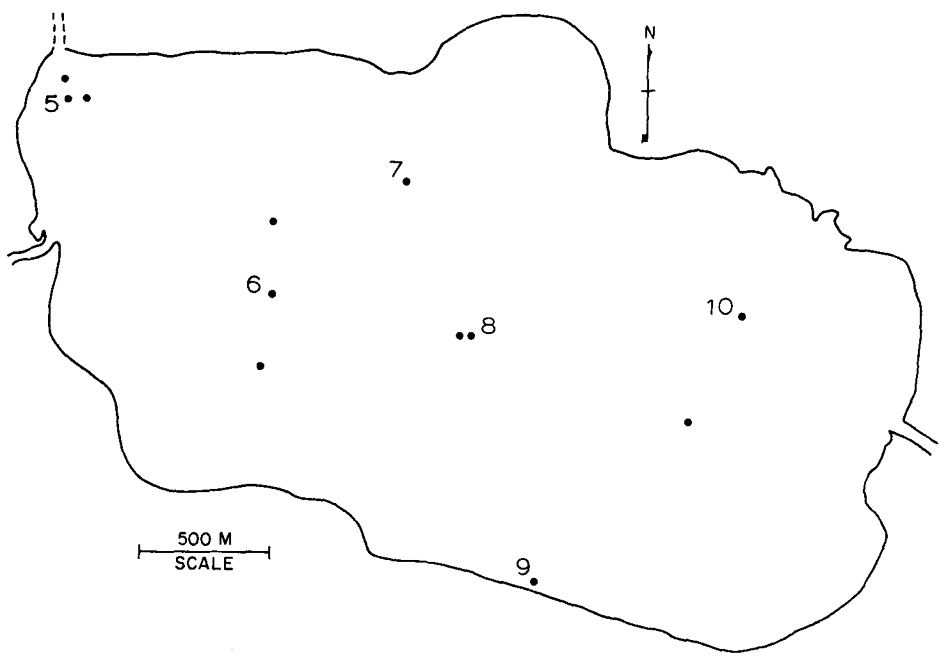


Figure 4-4. Location (dots) of twelve sediment traps placed in the lower lake. Sedimentation rate for dates given and inorganic and organic fractions are listed for those traps recovered.

Explanation

Trap Number	Result
5	1/28/81 - 4/20/81, 2.96 mm/a, 80% inorganic; 20% organic
6	9/3/80 - 8/26/80, 4.01 mm/a, 87% inorganic; 13% organic
7	1/29/81 - 4/20/80, 0.28 mm/a, 81% inorganic; 19% organic
8	7/1/80 - 10/9/80, 3.7 mm/a, 88% inorganic; 12% organic
9	7/6/80 - 8/26/80, 33.83 mm/a, 96% inorganic; 4% organic
10	7/11/80 - 8/13/80, 3.06 mm/a, 88% inorganic; 12% organic

Table 4-1 *Suspended sediments passing through Twin Lakes and respective organic and inorganic fractions*

	Lake Creek above upper lake	Channel between lakes	Lake Creek below lower lake
		kg/a	
Organic fraction	90 677	110 565	
Inorganic fraction	235 220	177 544	
Total suspended sediment	325 897	288 109	726 949

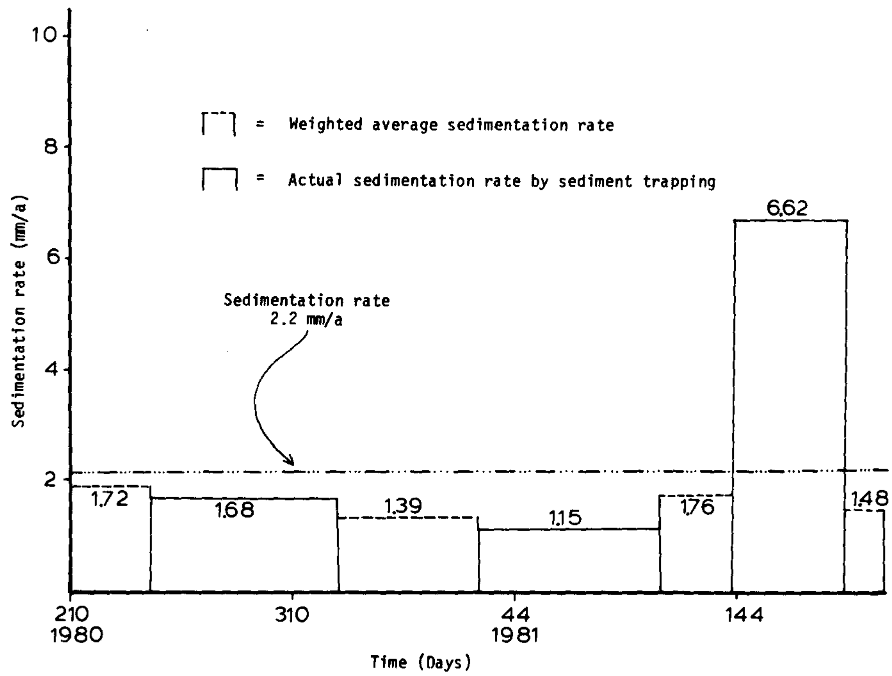


Figure 4-5—Sedimentation rates in the upper lake based on sediment trapping.

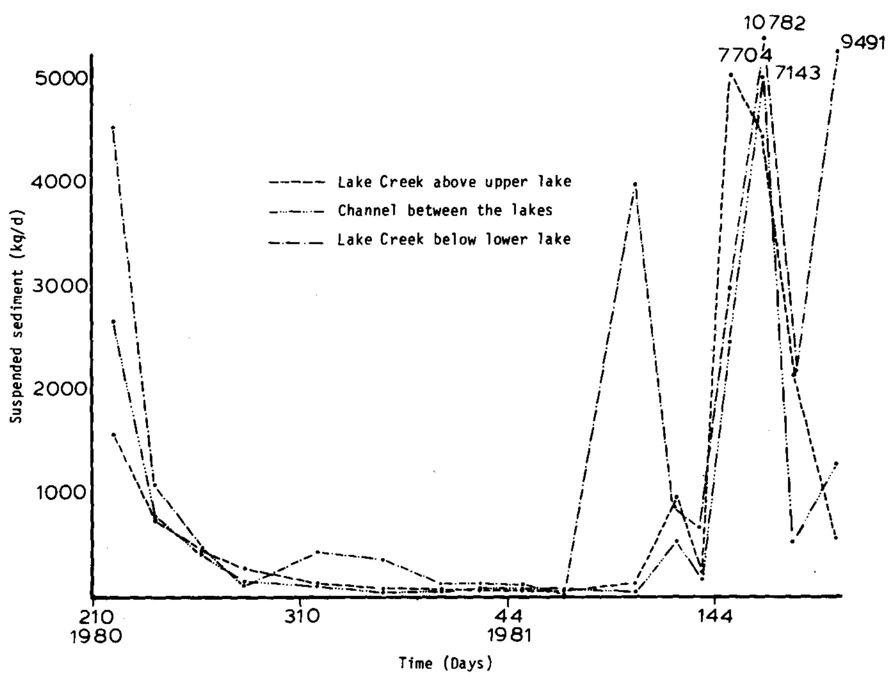


Figure 4-6—Total suspended sediment budget in Twin Lakes, Colorado.

DISCUSSION

Sediment Trapping

One sediment trap was set near the south shore of the lower lake. A road was built along this shore in the spring of 1980 to allow access to the Interlaken Hotel. Results showed an order-of-magnitude increase in sedimentation rate at this time, with 96 percent being inorganic in composition. This clearly was a direct result of the new road construction. The shoreline consisted of broken rock and cobblestone, suitable substrate for lake trout spawning. Visual examination of nearshore littoral substrate in this area showed most rock crevices necessary for spawning to be filled with silt. Since this sediment trap was at a depth of 5 m, sediments generated by the road construction were apparently carried to a considerable depth. The horizontal extent of these construction-caused sediments is unknown. Of the ripe lake trout netted by Walch (1979) [3], 33 percent were taken along this shoreline. Thus, construction activity associated with this road appears to have adversely affected, if not completely destroyed, a substantial amount of lake trout spawning habitat.

Bergersen (1976) [9], using sediment cores, estimated the annual sedimentation rate in Twin Lakes as 0.63 mm/a, with a possible range of 0.42 to 0.83 mm/a. Results of sediment trapping in 1980–81 indicated that considerably higher rates may occur. Annual winter rates were as low as 0.2 mm/a in the upper lake to 0.3 mm/a in the lower lake. Spring and summer rates, however, were as high as 66.6 mm/a in the upper lake during runoff to a more typical value of 3.7 mm/a in the lower lake during summer. A yearly sedimentation rate (fig. 4-5) of 2.2 mm/a was estimated for the upper lake. This is considerably higher (3.5 times) than Bergersen's estimate. He did note however that sedimentation rates near the Lake Creek Inlet might be as much as 2½ to 3 times greater than elsewhere in the lake, which would be partially consistent with present estimates. It appears that the traps in this study were catching not only sediments falling to the bottom for the first time, but also bottom material which had become resuspended. This seems all the more likely when the ultrafine nature of the glacial flour bottom is considered. It has been reported that divers swimming 1 to 2 m above the bottom would disturb the glacial flour, which would remain suspended for several days (LaBounty, 1976 [11]). It is also believed bottom currents were sufficiently strong to cause some resuspension, leading to a higher sedimentation rate.

Resuspension of bottom sediments appears to occur throughout the year and not just during periods of turnover. This becomes apparent by comparing the trapping sedimentation rate to the suspended sediment sampling sedimentation rate (fig. 4-7). Traps set at various times of the year caught 10 to 150 times what would be expected from suspended sediment sampling. Sartoris et al. (1977) [12] reported an occasional drop in transmissivity near the lake bottom and attributed this in part to the presence of cold, sediment-laden water of Lake Creek plunging to the bottom. This would tend to lend further credibility to the supposition that near-bottom movements of sediments do occur. It is also possible that the traps themselves tended to collect a disproportionate amount of any horizontally moving sediments, which would result in the higher rates recorded with this method.

Background sedimentation rates and probable sources have been established for comparative purposes. The best time to monitor powerplant impacts on sediment movement and deposition will probably be during the winter months. At that time, background sedimentation rates are low and fairly constant at 0.3 mm/a. The organic fraction is constant at 19 to 20 percent, lake current velocities are at their lowest levels, and vandalism or accidental disruption of sampling devices is not likely.

Suspended Sediment Sampling

Suspended sediments must be sampled for a year before a sedimentation rate can be estimated. To illustrate this point, consider the month of August 1980, when a negative sedimentation rate occurred (more sediment leaving each lake than entering). This phenomenon may be explained if the retention time of each lake is considered. In the fall, Lake Creek above the upper lake cleared, while the upper lake still carried a considerable sediment load and the lower lake had an even higher sediment load. Gradually, the sediments worked through the lakes and clearer water prevailed. Sampling over this time period would be meaningless without the rest of the year's data.

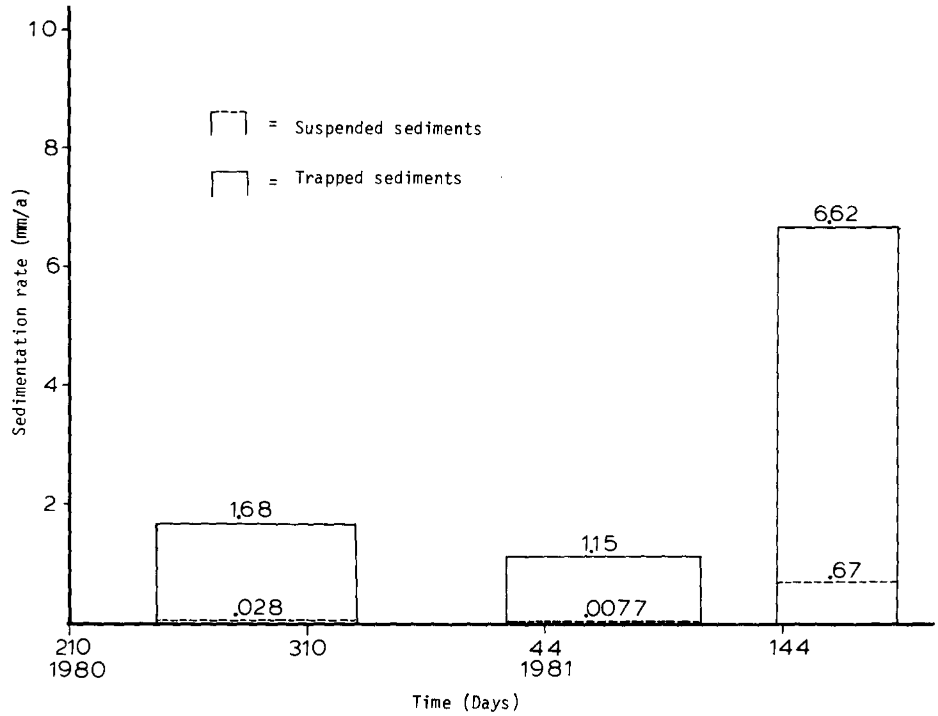


Figure 4-7 —Comparison between sedimentation rates in the upper lake as estimated by sediment trapping and suspended sediment sampling methods.

Also, it was interesting to note that the upper lake "trapped" 24.5 percent of the incoming inorganic suspended sediments. Organic material, however, was produced in the upper lake (22 percent more left the upper lake than had entered).

The sedimentation rate estimated by suspended sediment sampling (0.091 mm/a) was only one-seventh of the rate reported by Bergersen (1976) [9]. Several factors could account for the present lower estimation. Current estimates were based on the entire surface area of the lake and did not allow for concentration of the sediments at deeper strata, which undoubtedly does occur. Also, the winter of 1980–81 had below-average snowfall, resulting in decreased spring runoff. These two factors could explain the difference between the two estimates.

CHAPTER 5. ORGANIC CONTRIBUTION OF VEGETATION INUNDATED BY NEW LAKE LEVELS

INTRODUCTION

Vegetated land areas will be inundated when water is backed up behind the new dam built below the lower lake. The energy content of this vegetation will become part of the lakes' energy budget and the potential for short-term stimulation of lake productivity exists. The objective of this investigation was to estimate the caloric content of this vegetation and to examine possible consequences of its inundation on Twin Lakes.

METHODS

The line intercept method (Smith, 1979 [13]) was used to sample vegetation below the proposed high-water line of the "new" lake. Twenty random stations were chosen between the elevations of 2799 and 2805 m (fig. 5-1). At each station, a 30-m tape was stretched to the south. Each plant species and the distance it covered along the tape was recorded.

The cover dominance of each species was calculated as follows:

$$\text{Cover dominance} = \frac{\text{total intercept length species A}}{\text{total transect length}} \times 100\%$$

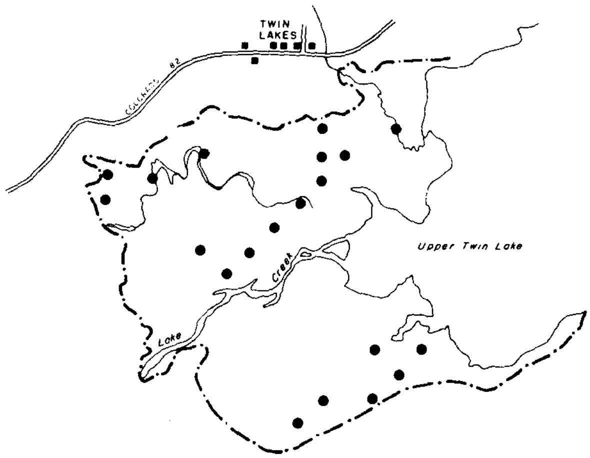


Figure 5-1.—Study area west of the upper lake which will be unundated by new lake levels. Dots indicate 20 random sampling positions.

Known areas of each vegetation type were cut, weighed, dried at 103 °C for 4 hours, and reweighed. Cover dominance of each species (divided by 100) was then multiplied by the total area sampled, its dry weight per square meter, and its respective caloric content (Cummins and Wuycheck 1971 [14]).

Table 5-1.—*Cover dominance, weight, and caloric content of the major vegetation types found in the study area above the upper lake.*

Vegetation type	Cover dominance (%)	Wet weight (kg)	Calories
Mixed old field grass (Graminae)	44.2	247 503	5.734×10^{11}
Willows (Salicaceae)	37.9	3 358 588	9.5389×10^{12}
Alpine sedges (Cyperaceae)	10.8	83 400	1.6099×10^{11}
Brushy cinquefoil (Rosaceae)	3.2	81 593	2.1810×10^{11}
Sagebrush (Carduaceae)	1.9	64 603	1.9004×10^{11}
Alders, birches (Betulaceae)	1.8	159 511	4.7202×10^{11}
Rushes (Juncaceae)	0.4	1 594	3.6643×10^{9}
Pine (Pinaceae)	0.1	9 116	2.7371×10^{10}
Totals	100.3	4 005 908	1.1186×10^{13}

RESULTS

Cover dominance of the major vegetation types, their wet weight, and total calories in the soon-to-be inundated areas are shown in table 5-1. The major contribution of organic material will come in the form of willows. The total caloric content of the inundated vegetation (4000 metric tons) was estimated at 11.2×10^9 kilocalories (64.9×10^9 kJ)

DISCUSSION

By using the 1977 to 1981 average for station 2 of 6497.3 micrograms of carbon per square meter per hour fixed by plankton[2] and expanding this number, it was possible to estimate the annual lower lake primary productivity as 2.095×10^8 g C/a. (This is equal to 78 mg C/($m^2 \cdot d$), which is within Wetzel's (1975) [15] oligotrophic lake range of 50 to 300 mg C/($m^2 \cdot d$).) An estimate was made by Sartoris[2] for the upper lake using an average plankton carbon fixation rate of 2025 $\mu g/(m^2 \cdot h)$, which resulted in a primary productivity estimate of 2.336×10^7 g C/a. In total, 2.3295×10^8 g C/a are fixed in the Twin Lakes system. Grams of carbon were then converted to kcal by the following equations:

1 g C = 3.205 g O_2 (Kajak, et al., 1972 [16])
1 g O_2 = 3600 cal (Odum and Smalley, 1959 [17])
$\therefore$ 1 g C = 11.538 kcal

Rabinowitch and Govindjee (1969 [18] state that all carbohydrates have approximately the same energy content of about 112 kcal/g atom (12 g) of carbon contained in them. This results in a conversion factor of 9.33 kcal/g C, which is slightly less but similar in magnitude to the 11.538 figure given above. To accommodate the differences in these conversion factors, both are discussed. Thus, the grams of carbon fixed annually by plankton in both lakes is equal to 2.173×10^9 kcal or 2.689×10^9 kcal, depending on the conversion factor used. Potential input from terrestrial vegetation is therefore equal to 4.2 or 5.1 times the average annual plankton primary production, again depending on the conversion factor. Regardless of the factor used, it is evident that the potential exists for an increase in energy in the system when lake levels rise. Although these estimates are admittedly crude, they do reflect a very likely future energy scenario for the Twin Lakes system.

Not all the calories from terrestrial vegetation will be available the first year. Temperature, age of plant parts, flushing rate, and other factors will undoubtedly play a role in this process. Woody plant parts may take more than several years to decompose. A large initial input, however, would be expected as easily decomposable material (such as grasses, sedges, rushes, and leaves) breaks down.

Undoubtedly, changes will occur in the food chain. Likely, these will be first noted as increases in the plankton population or changes in their species composition. The addition of organic material will also increase the lake's biological oxygen demand, which may become particularly critical toward the end of the first winter. As a precaution, water level should be kept down to the 2800 m elevation throughout the first several winters. Through the summer, the large influx of organic material would contribute to decreased hypolimnetic oxygen. Such a result could be particularly deleterious to the lake trout, which need cold, oxygenated water.

To minimize harmful effects, the water level should be raised half way to the maximum water level the first spring to inundate and kill much of the vegetation. A summer drawdown would then expose most of the killed vegetation, allowing it to decompose on dry ground. The second spring, water could be raised to full pool, which would kill the remaining vegetation; but a summer-through-winter drawdown would still be advisable. Even with the above precautions in lake filling, nutrients will still be taken up by the plankton, recycled throughout the summer, and contribute to under-ice anoxia.

[2] J. J. Sartoris, Bureau of Reclamation, Division of Research, Denver, Colo., personal communication.

BIBLIOGRAPHY

[1] Gregg, R.E., and E.P. Bergersen, "*Mysis relicta*: Effects of Turbidity and Turbulence on Short Term Survival," Trans., Am. Fish. Soc., No. 109, pp. 207-212, 1980.

[2] Carruthers, J. N., "A Leaning-Tube Current Indicator ('Pisa')," Bull. Inst. Oceanogr., No. 1126 (Sept. 15, 1958), Monaco, 1958.

[3] Walch, L. A., "Movements of Lake Trout in Twin Lakes, Colorado, in Relation to a Pumped-Storage Powerplant," M.S. thesis, Colo. State Univ., Fort Collins, 129 pp., 1979.

[4] Fultz, D., "Experimental Analogies to Atmospheric Motions," *In:* Compendium of Meteorology, T. F. Malone (ed.), Am. Meteorol. Soc., Boston, pp. 1235-1248, 1951.

[5] _____, "Experimental Models of Rotating Fluids and Possible Avenues for Future Research." *In:* Dynamics of Climate, R. L. Pfeffer (ed.), Pergamon Press, N.Y., pp. 71-77, 1960.

[6] Likens, G. E., and R. A. Ragotzkie, "Rotary Circulation of Water in an Ice-covered Lake," Verh. Int. Ver. Limnol., No. 16, pp. 126-133, 1966.

[7] Verber, J. L., "Initial Current Studies in Lake Michigan," Limnol. Oceanogr., No. 9, pp. 426-430, 1964.

[8] Keefe, T. J., "Statistical Review of the Limnological Data Collected at Twin Lakes, Colorado, 1974-1979," EnviroStat Associates, Fort Collins, Colo., 1980.

[9] Bergersen, E. P., "Aging and Evaluation of Twin Lakes Sediments." *In:* Studies of the Benthic Environment of Twin Lakes, Colorado, J. F. LaBounty (ed.), Bur. Reclam. Rep. REC-ERC-76-12, 1976.

[10] American Public Health Association, American Waterworks Association, and Water Pollution Control Federation, "Standard Methods for the Examination of Water and Wastewater," 14th ed., APHA, Washington, D.C., 1193 pp., 1975.

[11] LaBounty, J. F., and J. J. Sartoris, "The Profundal Benthic Environment of Twin Lakes, Colorado." *In:* Studies of the Benthic Environment of Twin Lakes, Colorado, J. F. LaBounty (ed.), Bur. Reclam. Rep. REC-ERC-76-12, 1976.

[12] Sartoris, J. J., J. F. LaBounty, and H. D. Newkirk, "Historical, Physical, and Chemical Limnology of Twin Lakes, Colorado," Bur. Reclam. Rep. REC-ERC-77-13, 1977.

[13] Smith, R. L., *Ecology and Field Biology,* 2nd ed., Harper and Row, N. Y., 850 pp., 1979.

[14] Cummins, K. W., and J. C. Wuycheck, "Caloric Equivalents for Investigations in Ecological Energetics," Int. Ver. Theor. Angew. Limnol., No. 18, pp. 1-151, 1971.

[15] Wetzel, R. G., *Limnology,* W. B. Saunders Co., Philadelphia, Pa., 743 pp., 1975.

[16] Kajak, A., Al Hillbricht-Illkowska, and E. Pieczynska, "The Production Process in Several Polish Lakes." *In:* A Manual on Methods for Measuring Primary Production in Aquatic Environments, R. A. Volenweider (ed.), Blackwell Scientific Publications, London, p. 141, 1972.

[17] Odum, E. P., and A. E. Smalley, "Comparison of Population Energy Flow of an Herbivorous and Deposit-feeding Invertebrate in a Salt Marsh Ecosystem," Proc., Nat. Acad. Sci., India, vol. 45, pp. 617-622, 1959.

[18] Rabinowitch, E., and Govindjee, *Photosynthesis,* John Wiley and Sons, Inc., N. Y., 273 pp., 1969.

APPENDIX

Surface, bottom, and under-ice current maps for Twin Lakes, Colo., including corresponding wind data. Surface and bottom current velocities are given in cm/s. Under-ice current velocities are given in cm/min. Where measured, average windspeeds (m/s) are shown in the center circle of each wind rose. Arrows indicate direction of current.

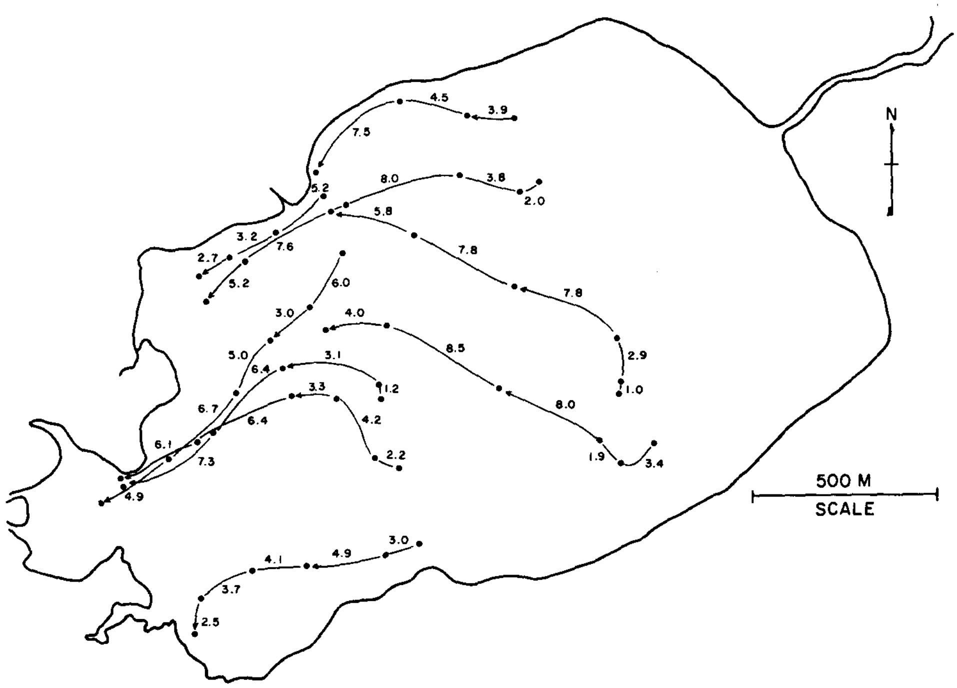


Figure A-1.—Surface—the upper lake—Aug. 11, 1980.

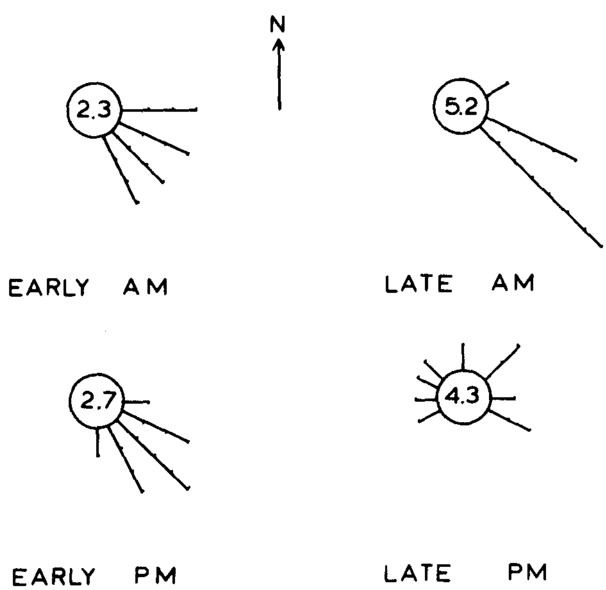


Figure A-2.—Windspeed and direction—Aug. 11, 1980.

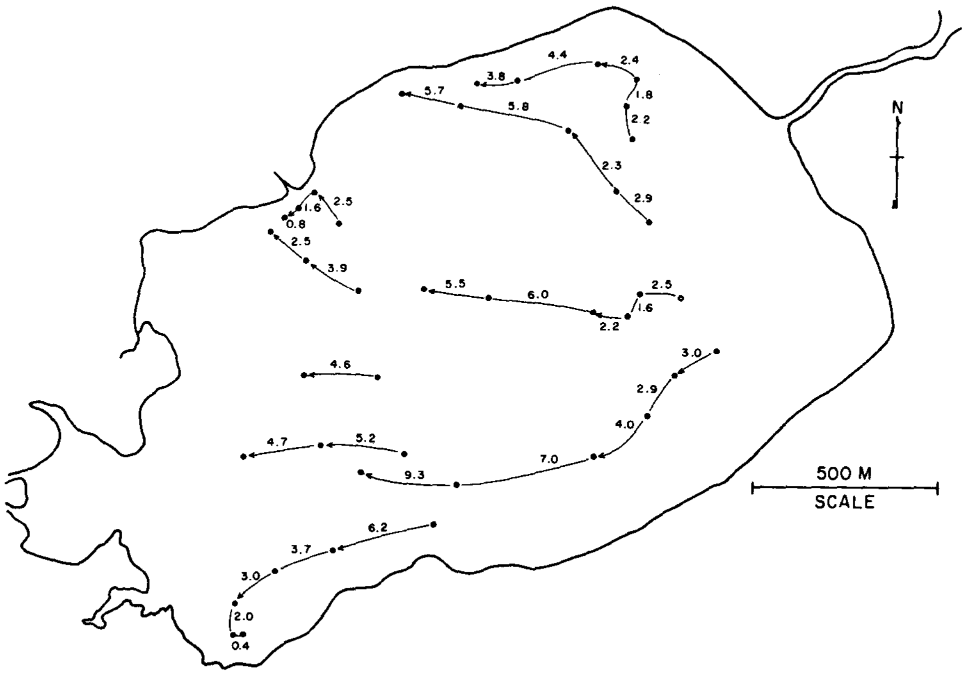


Figure A-3.—Surface—the upper lake—Sept. 4, 1980.

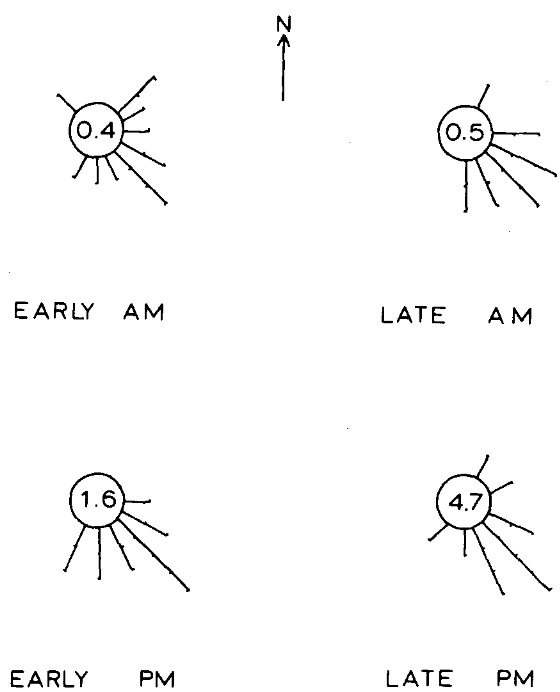


Figure A-4.—Windspeed and direction—Sept. 4, 1980.

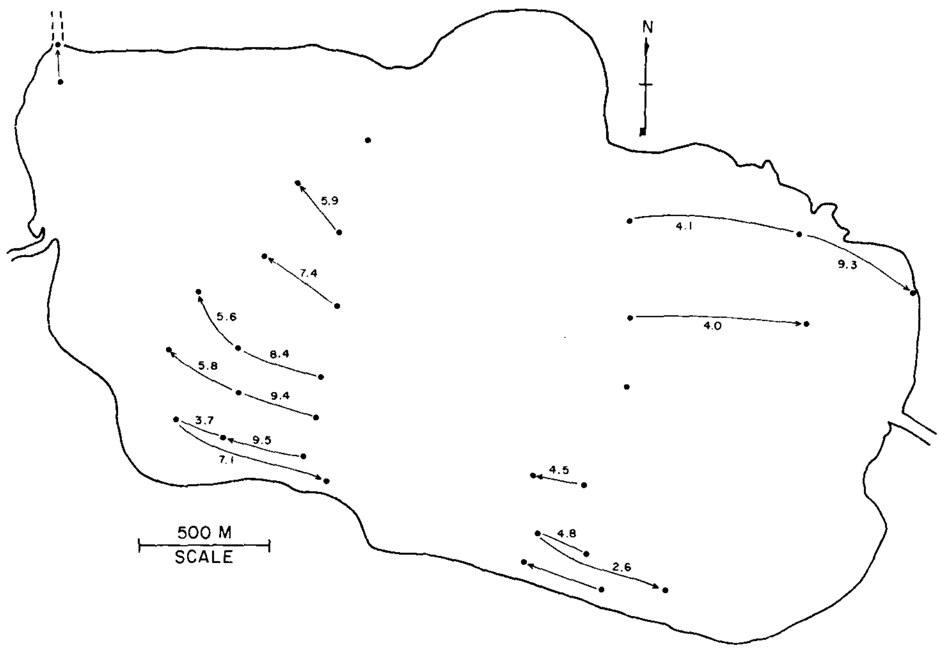


Figure A-5.—Surface—the lower lake—June 20, 1980.

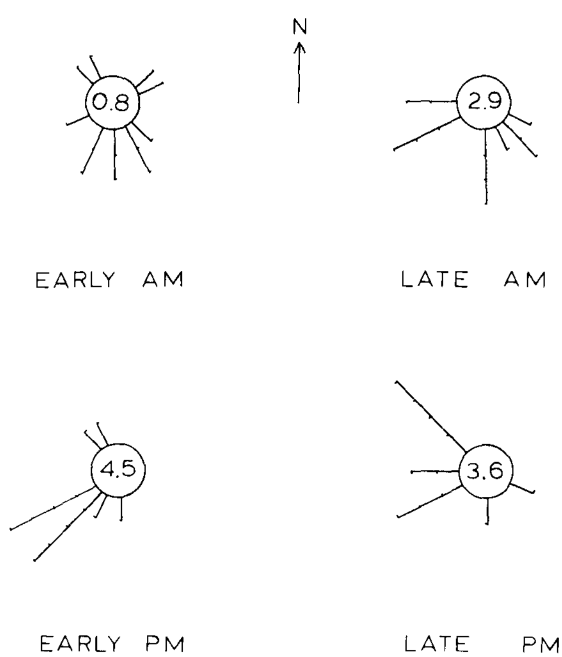


Figure A-6.—Windspeed and direction—June 20, 1980.

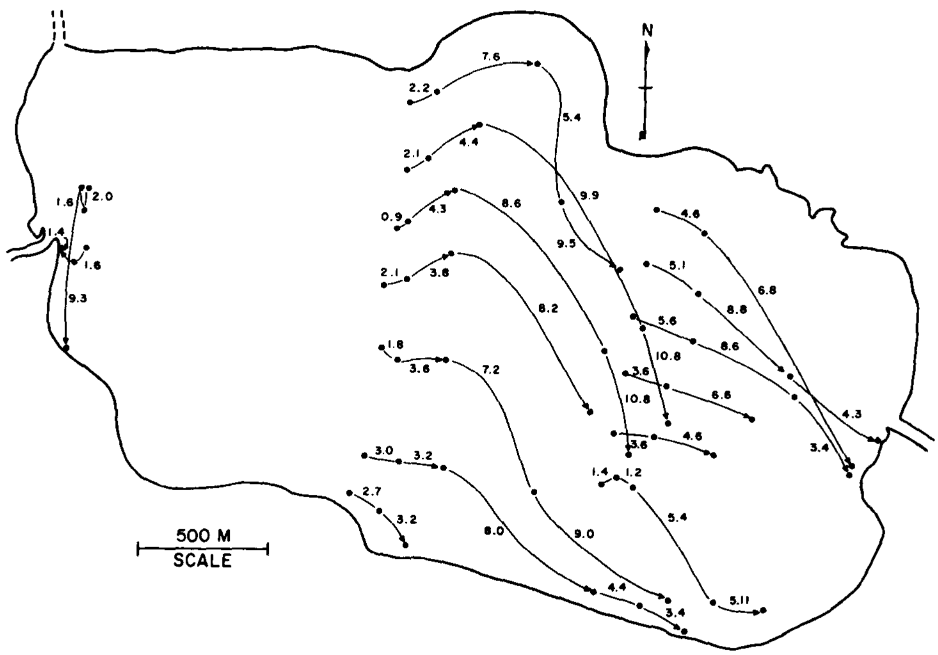


Figure A-7.—Surface—the lower lake—July 22, 1980.

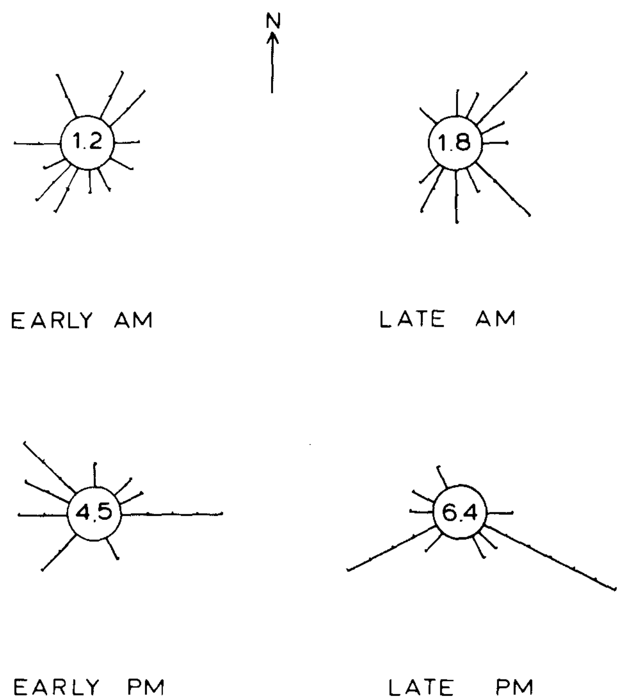


Figure A-8.—Windspeed and direction—July 22, 1980.

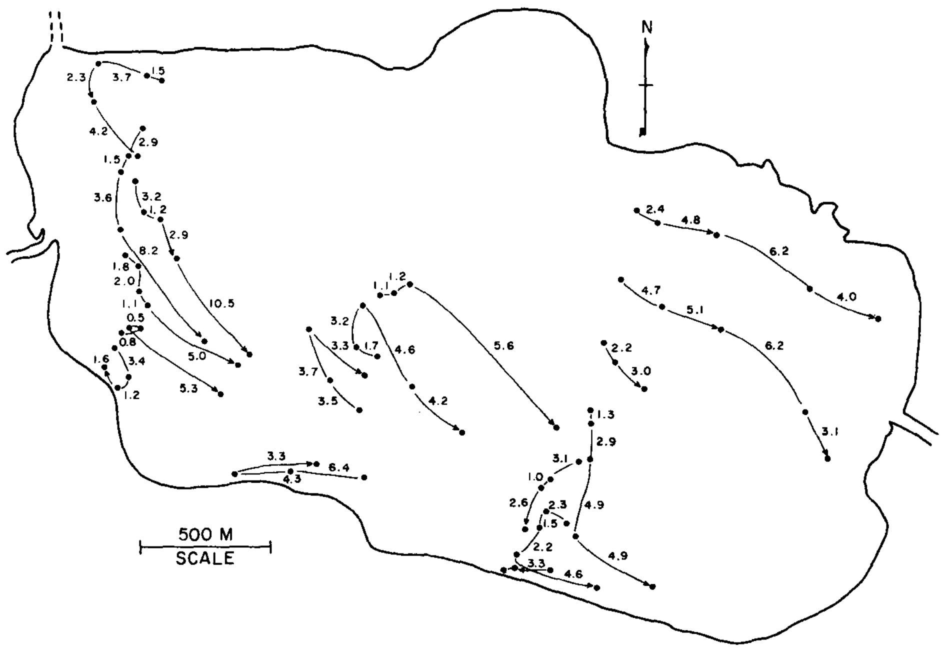


Figure A-9.—Surface—the lower lake.—Aug. 13, 1980.

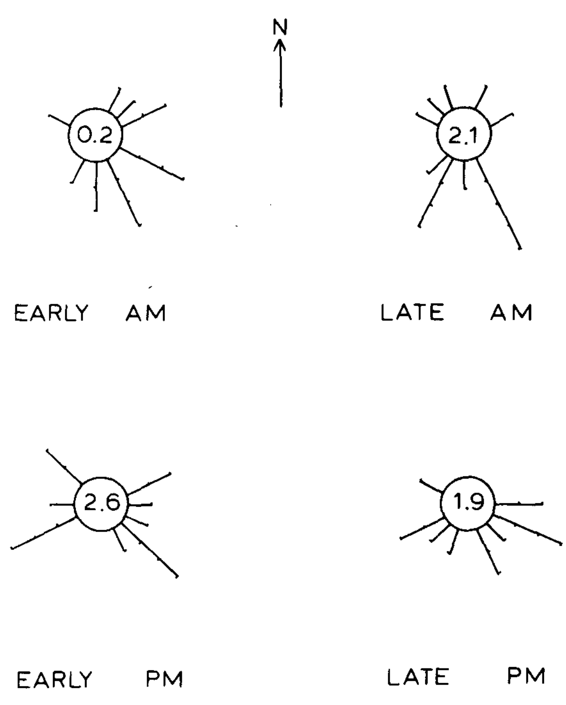


Figure A-10.—Windspeed and direction—Aug. 13, 1980.

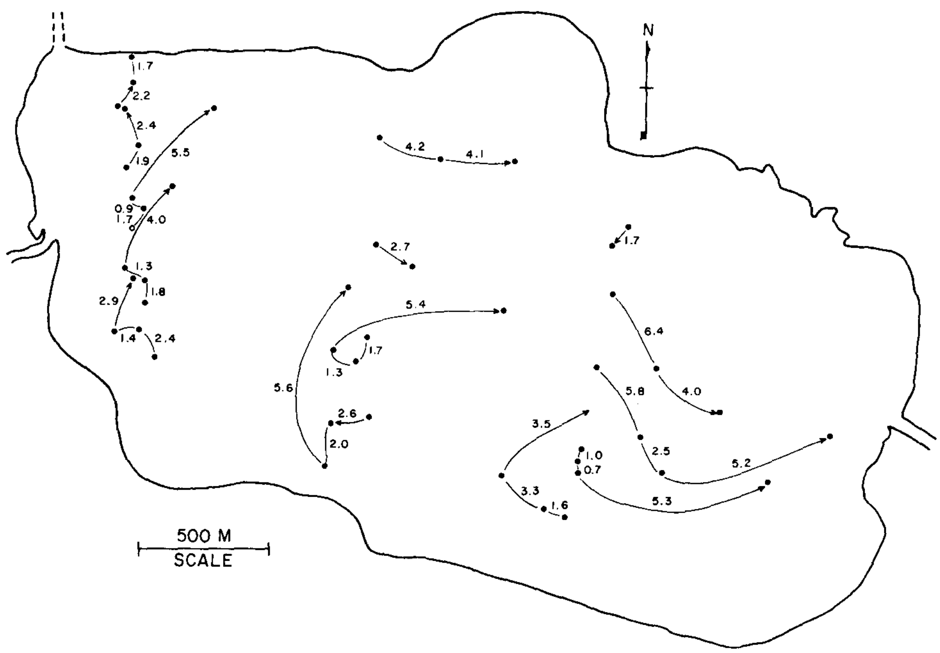


Figure A-11.—Surface—the lower lake.—Sept. 8, 1980.

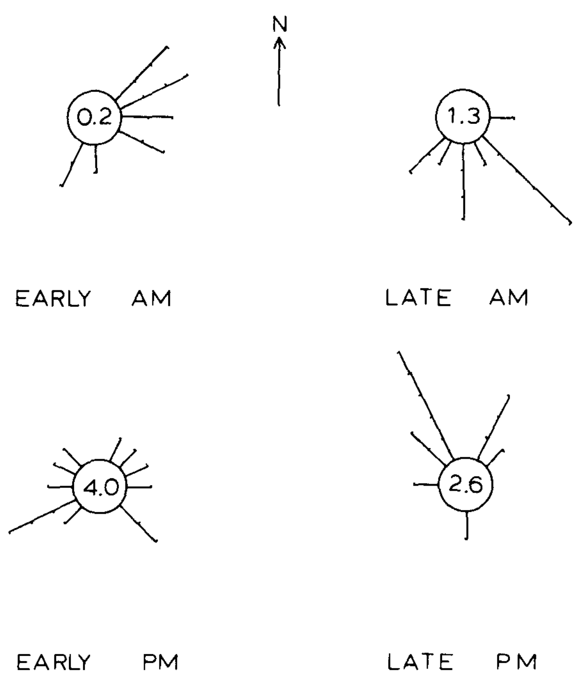


Figure A-12.—Windspeed and direction—Sept. 8, 1980.

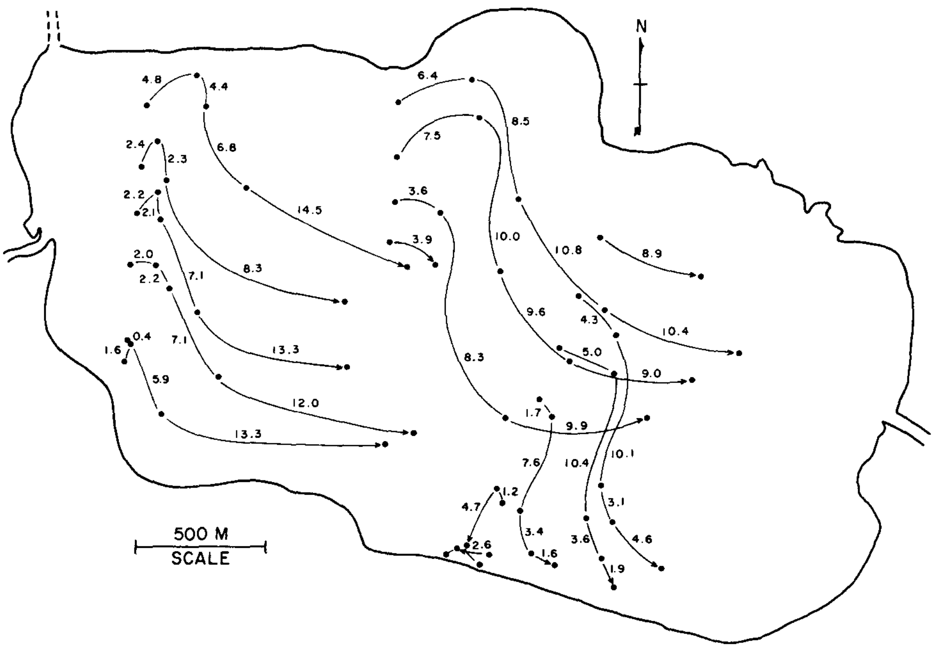


Figure A-13.—Surface—the lower lake—Oct. 24, 1980.

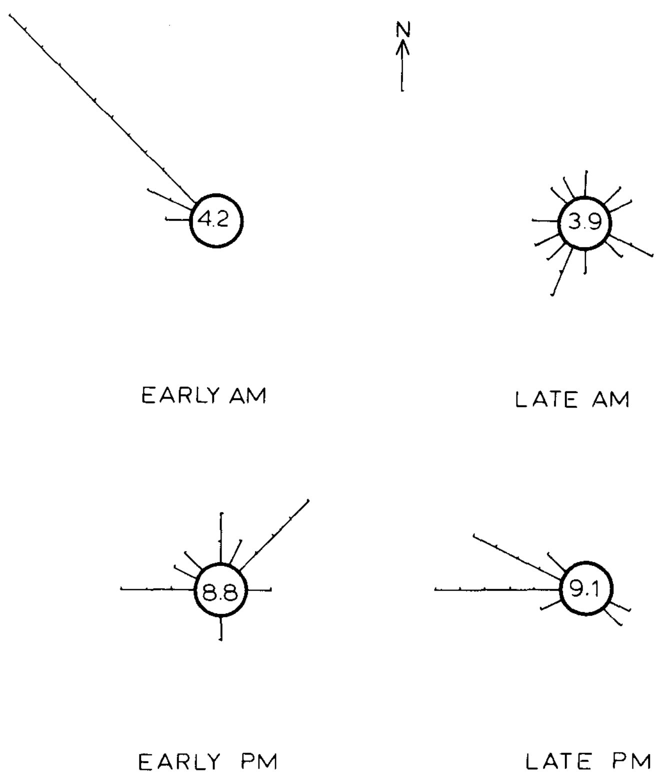


Figure A-14.—Windspeed and direction—Oct. 24, 1980.

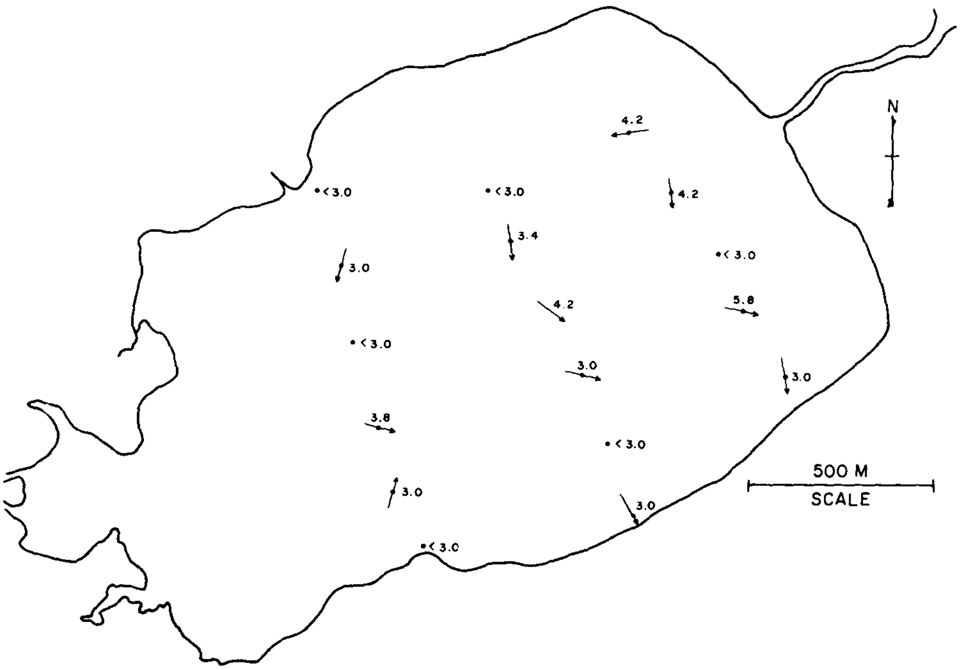


Figure A-15.—Bottom—the upper lake—June 26, 1980.

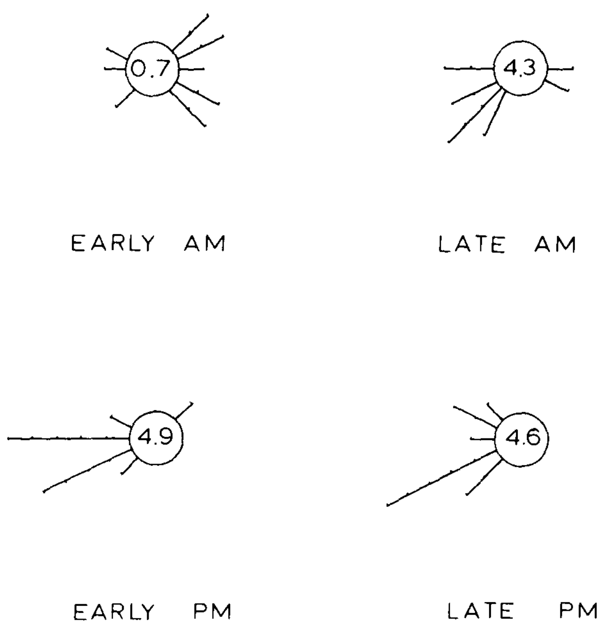


Figure A-16.—Windspeed and direction—June 25, 1980.

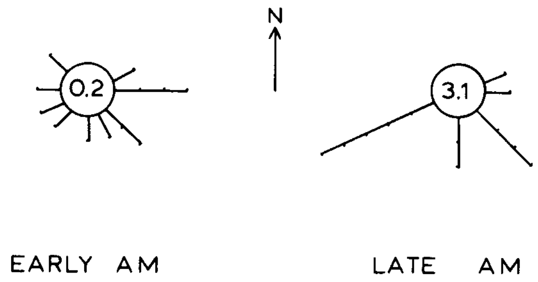


Figure A-17.—Windspeed and direction—June 26, 1980.

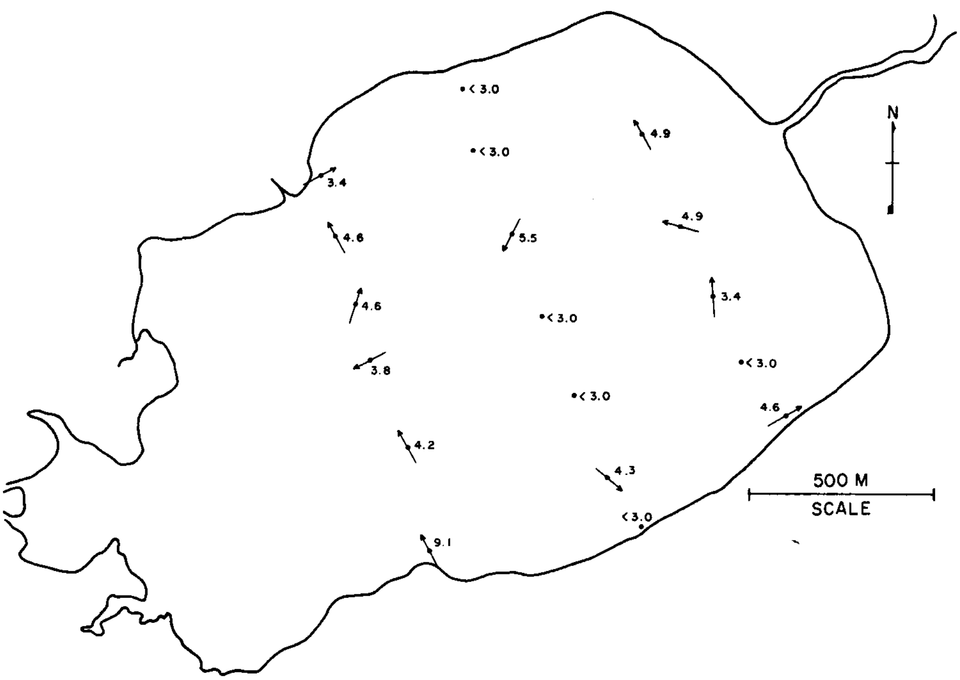


Figure A-18.—Bottom—the upper lake.—July 24, 1980.

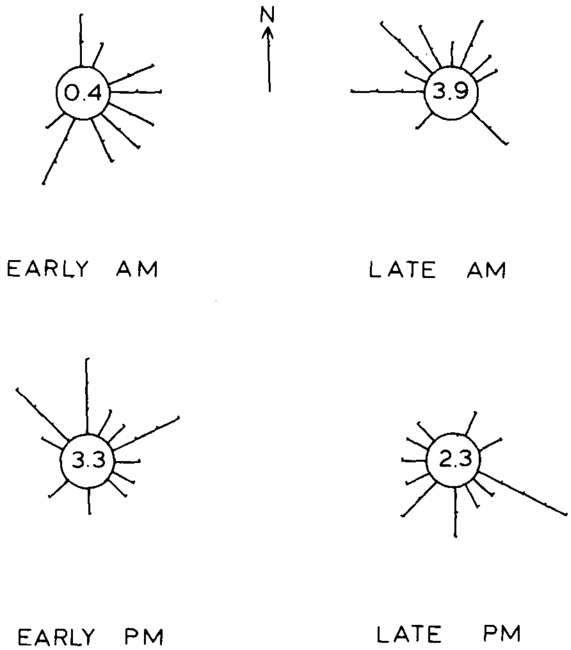


Figure A-19.—Windspeed and direction—July 23, 1980.

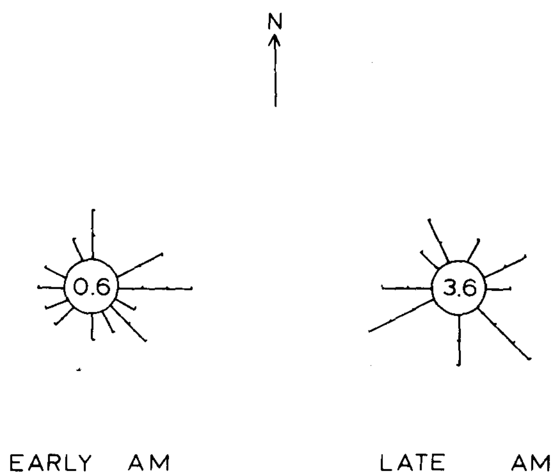


Figure A-20.—Windspeed and direction—July 24, 1980.

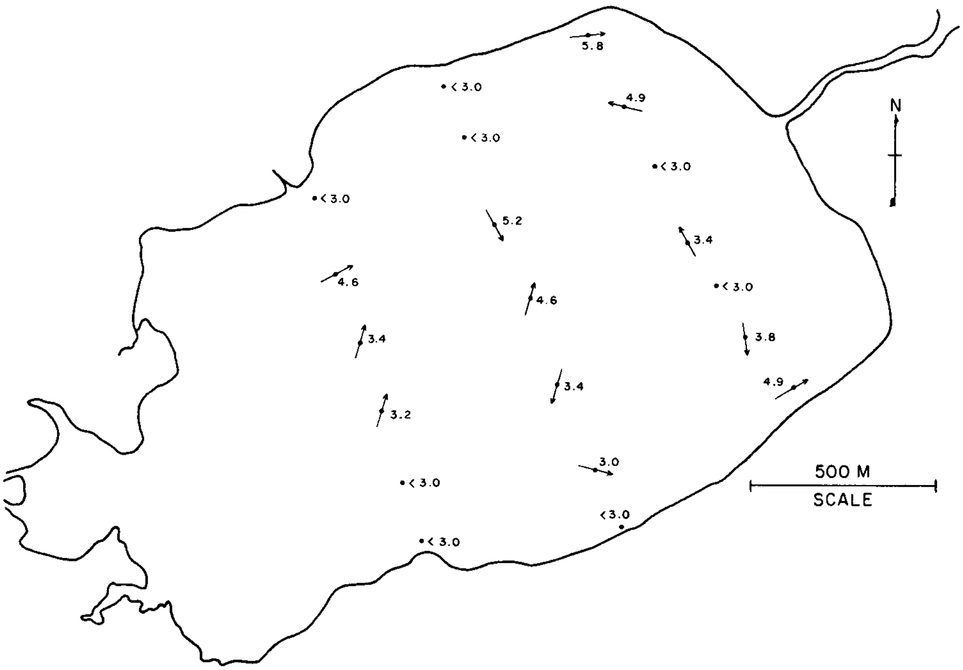


Figure A-21.—Bottom—the upper lake.—Aug. 15, 1980.

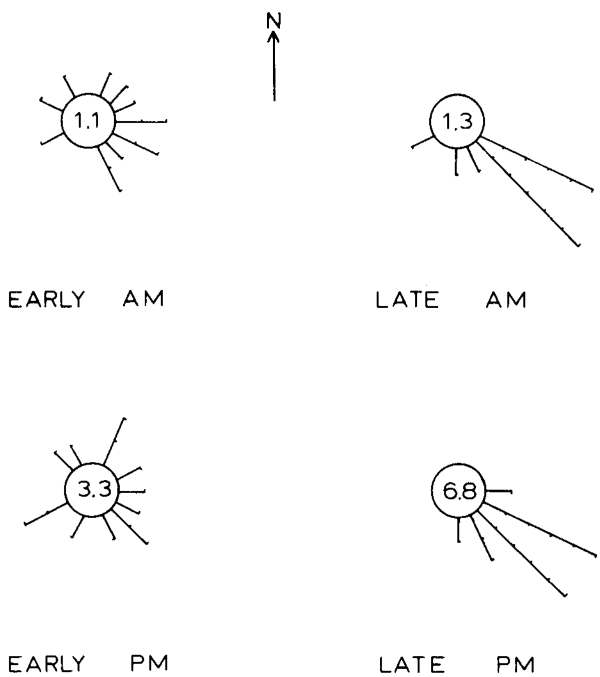


Figure A-22.—Windspeed and direction—Aug. 14, 1980.

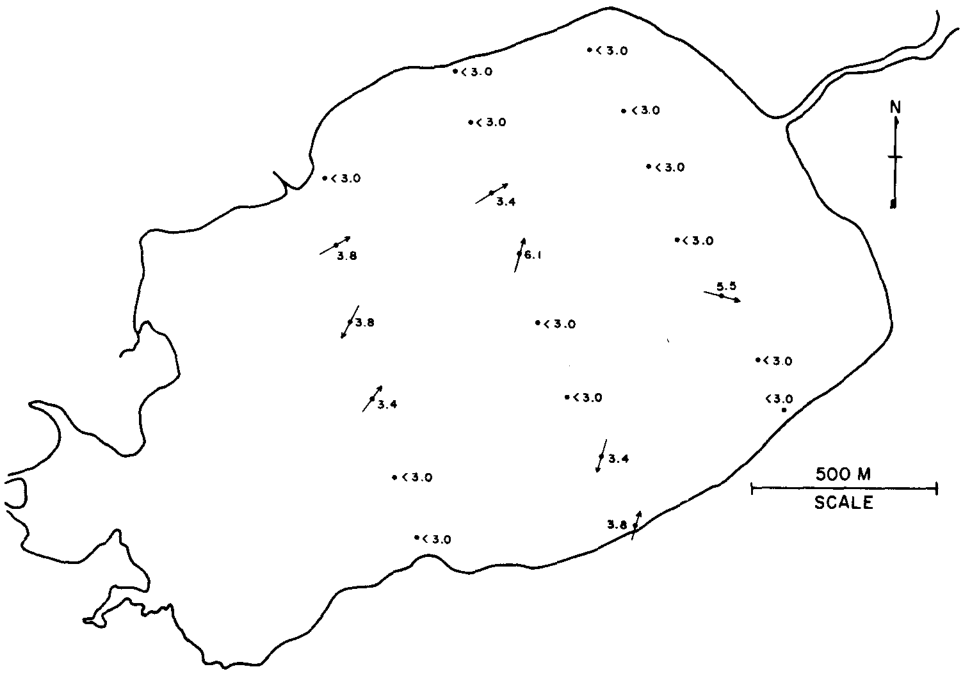


Figure A-23.—Bottom—the upper lake.—Sept. 11, 1980.

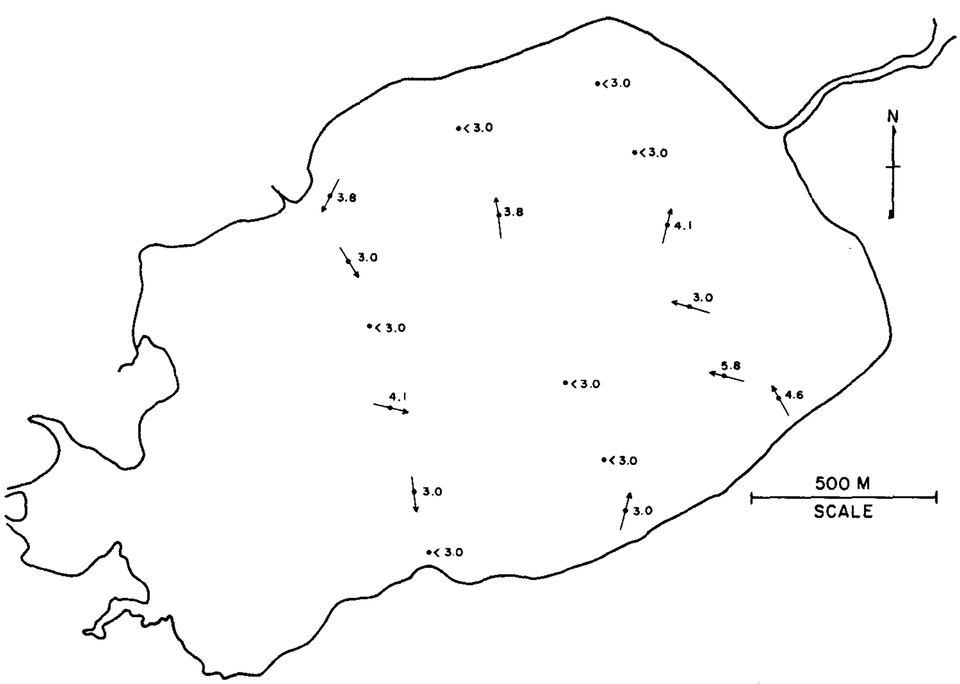


Figure A-24.—Bottom—the upper lake—Nov. 19, 1980.

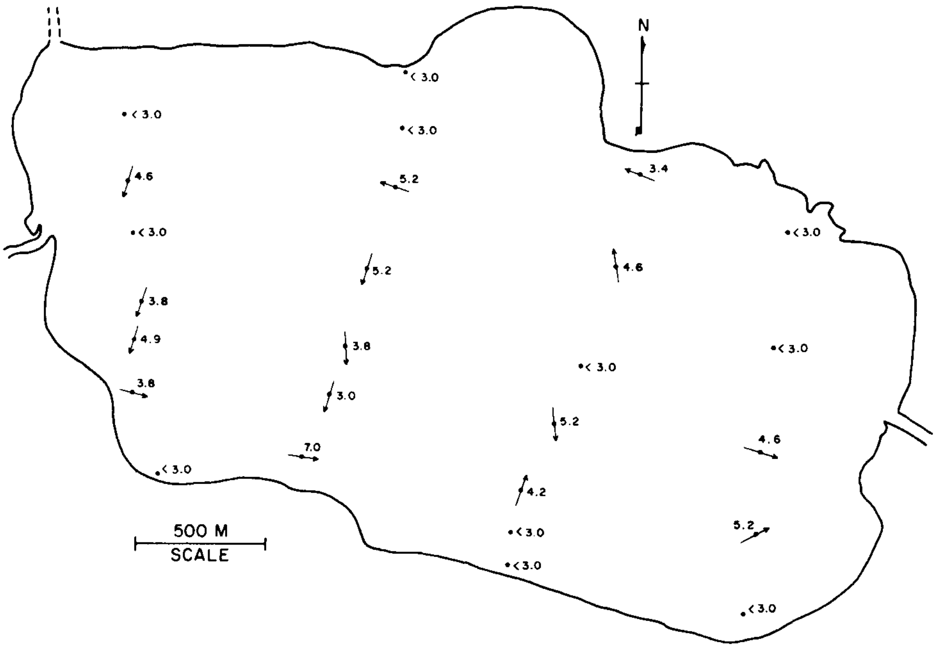


Figure A-25.—Bottom—the lower lake—June 25, 1980.

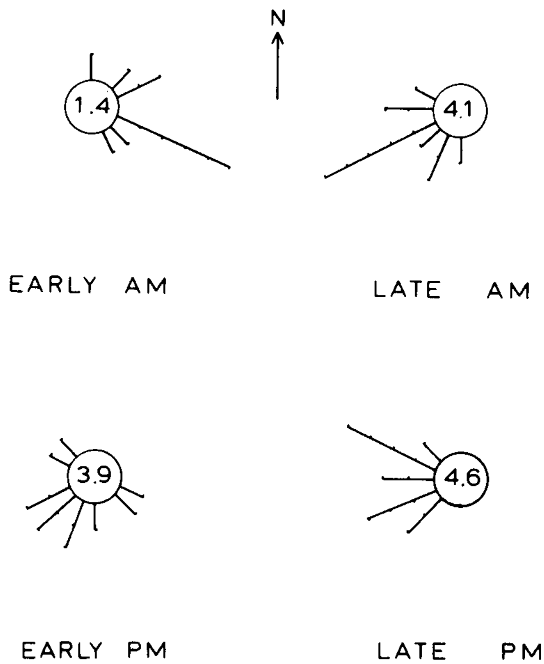


Figure A-26.—Windspeed and direction—June 24, 1980.

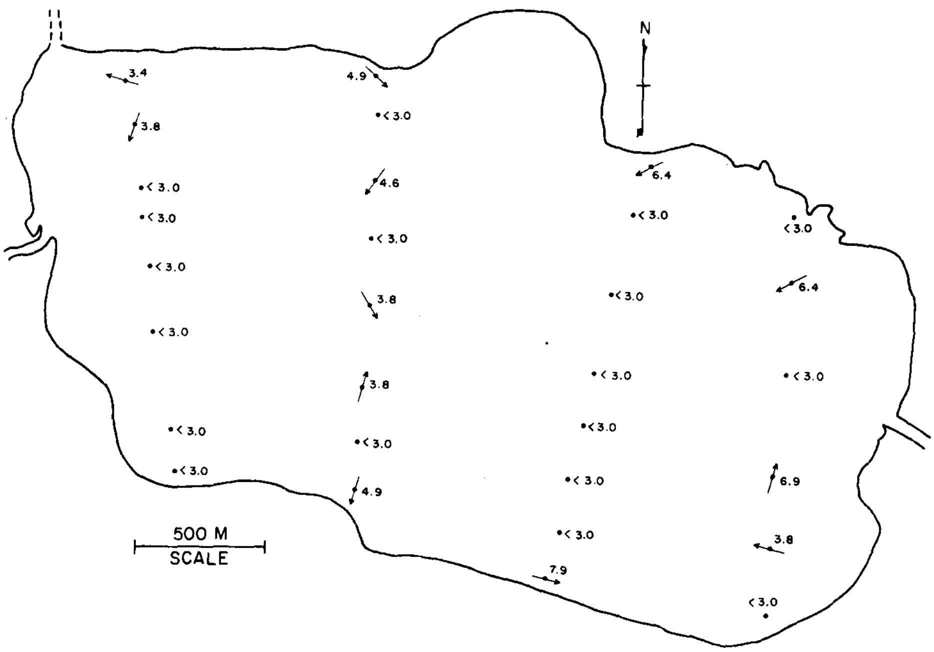


Figure A-27.—Bottom—the lower lake—July, 28, 1980.

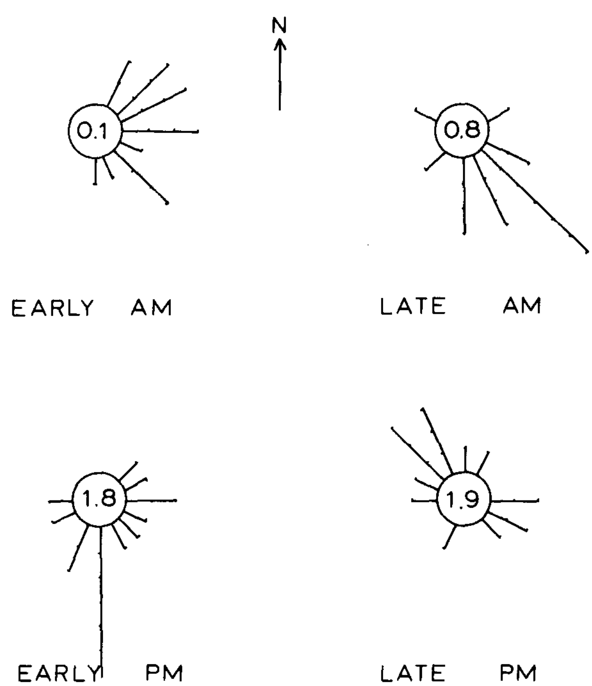


Figure A-28.—Windspeed and direction—July 27, 1980.

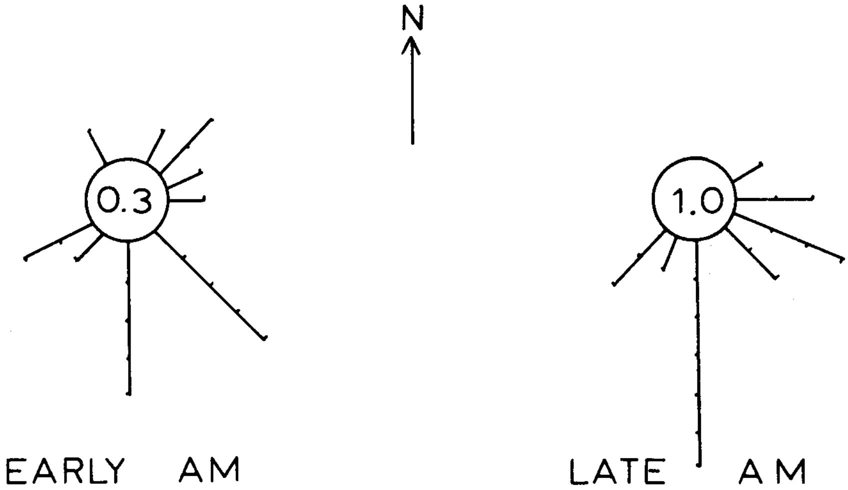


Figure A-29.—Windspeed and direction—July 28, 1980.

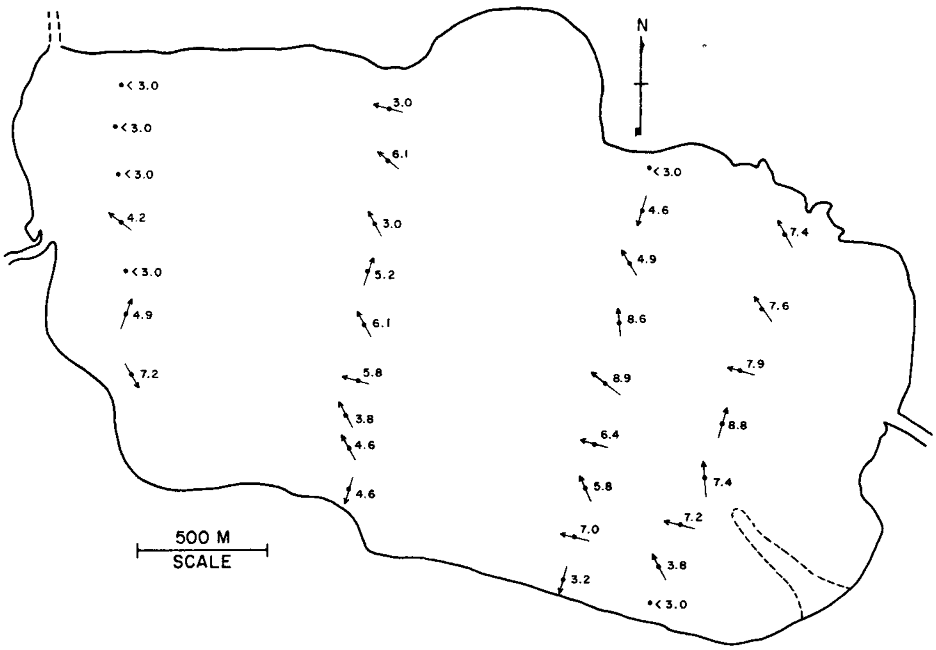


Figure A-30.—Bottom—the lower lake—Sept. 23, 1980.

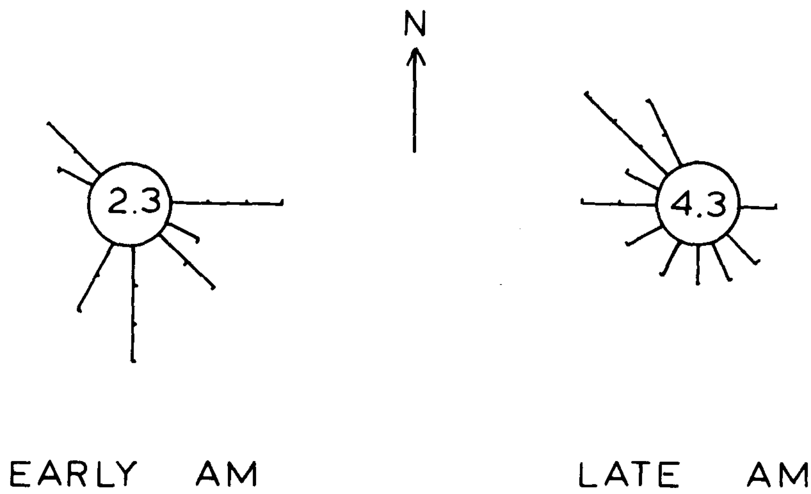


Figure A-31.—Windspeed and direction—Sept. 23, 1980.

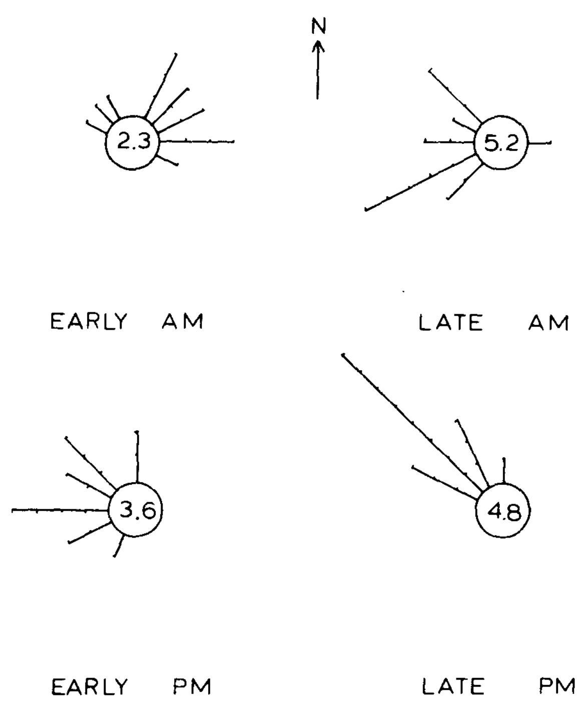


Figure A-32.—Windspeed and direction—Aug. 24, 1980.

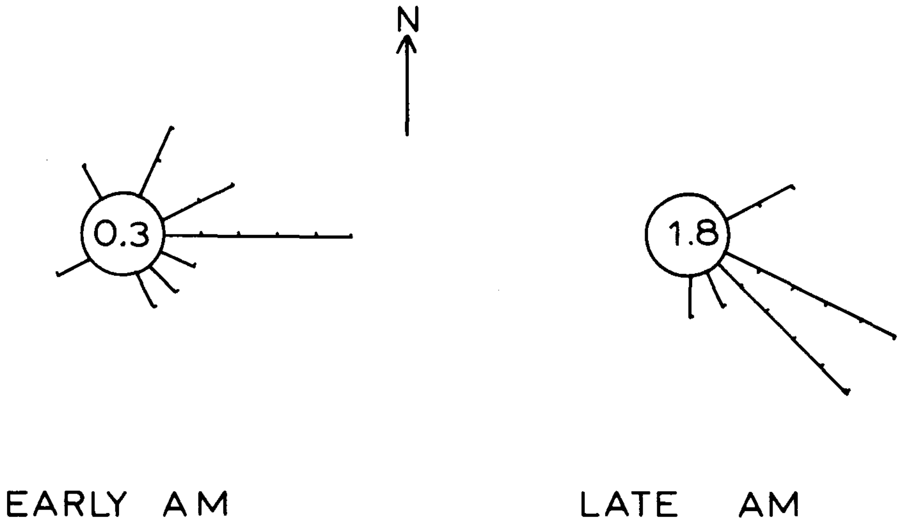


Figure A-33.—Windspeed and direction—Aug. 21, 1980.

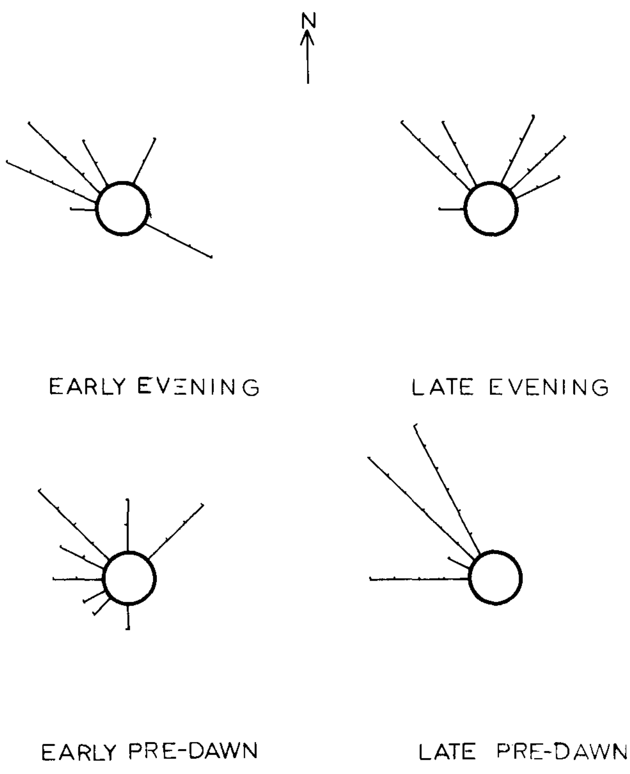


Figure A-34.—Windspeed and direction—Oct. 21-22, 1980.

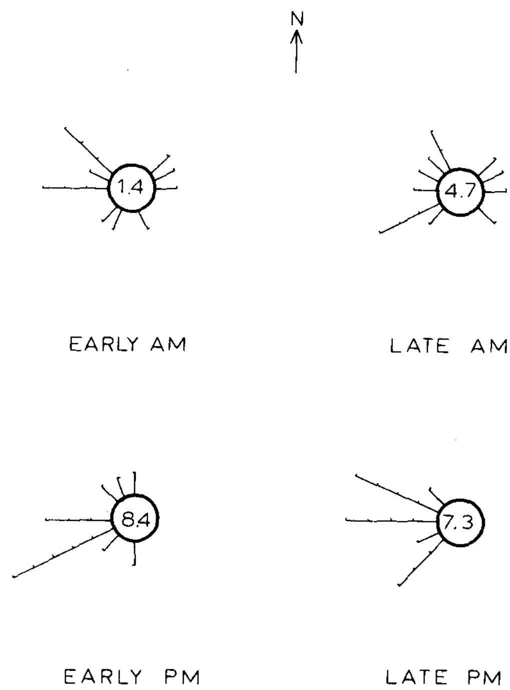


Figure A-35.—Windspeed and direction—Oct. 22, 1980.

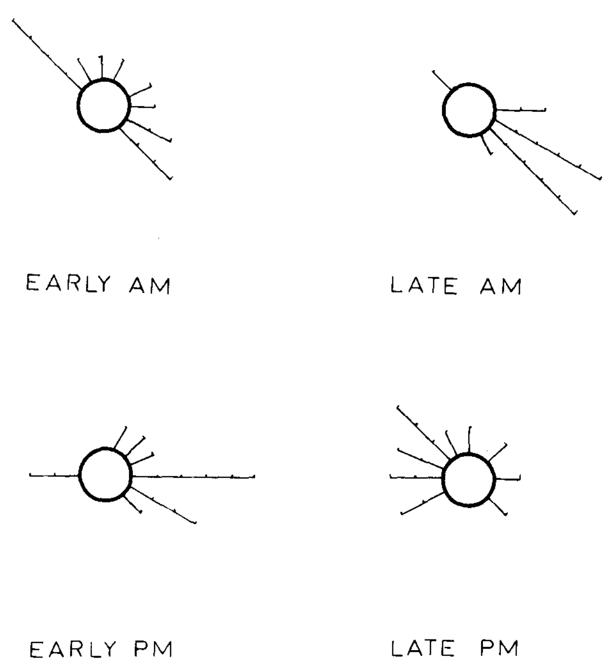


Figure A-36.—Windspeed and direction—Oct. 27, 1980.

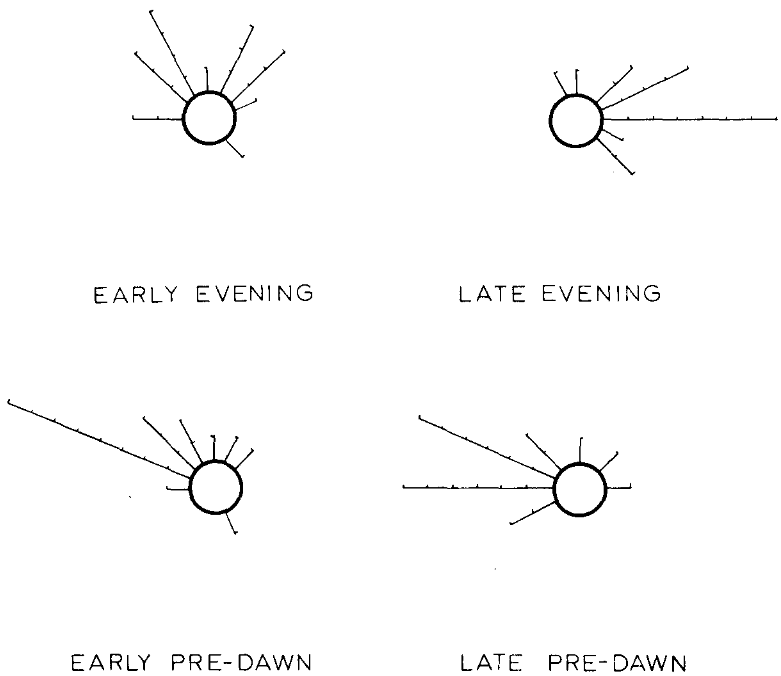


Figure A-37.—Windspeed and direction—Oct. 27-28, 1980.

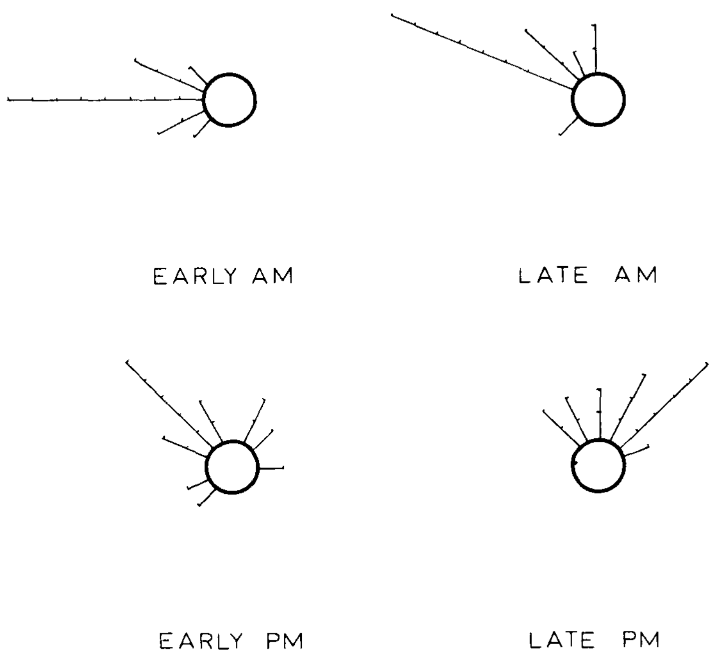


Figure A-38.—Windspeed and direction—Oct. 28, 1980.

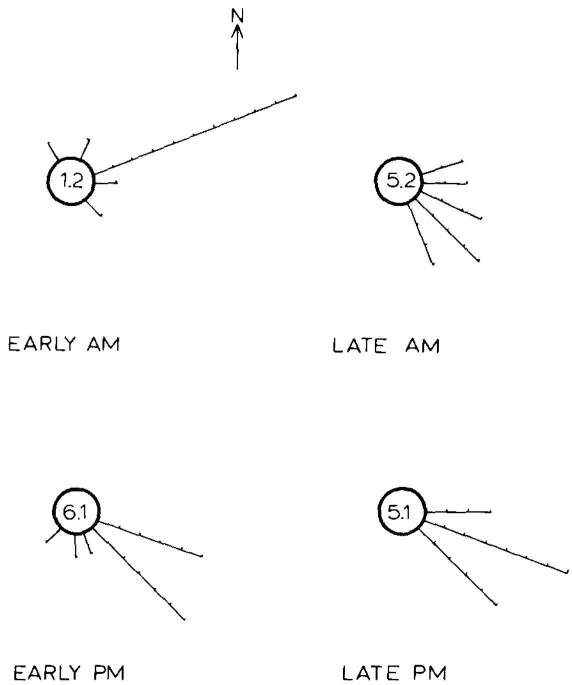


Figure A-39.—Windspeed and direction—Nov. 13, 1980.

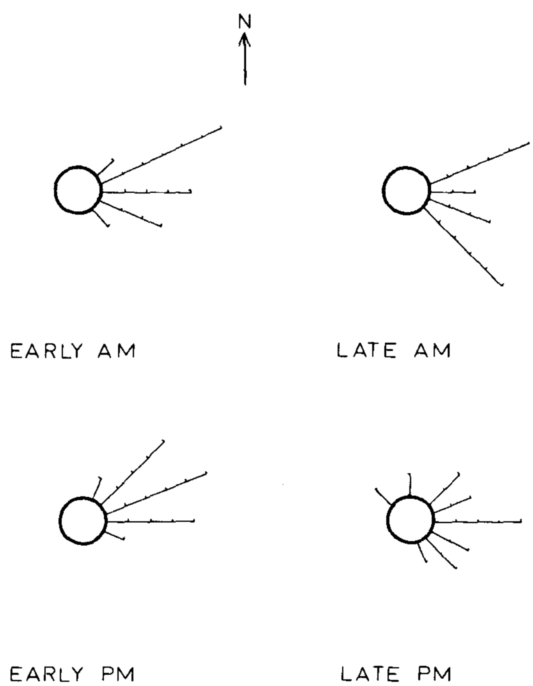


Figure A-40.—Windspeed and direction—Nov. 14, 1980.

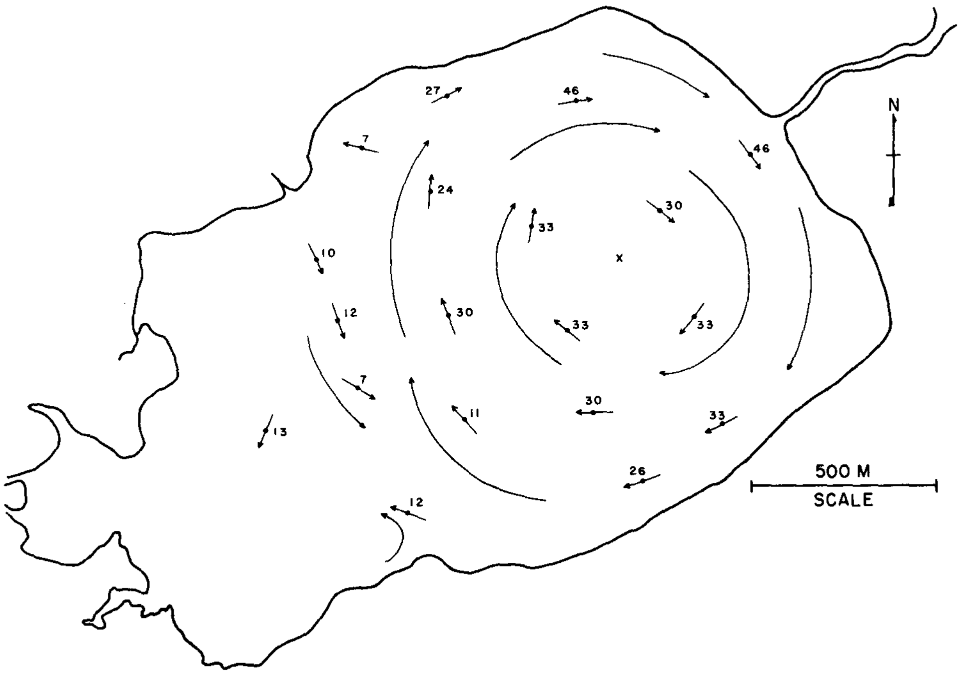


Figure A-41.—Under-ice currents—the upper lake—April 17, 1980. Current velocities are given in cm/min.

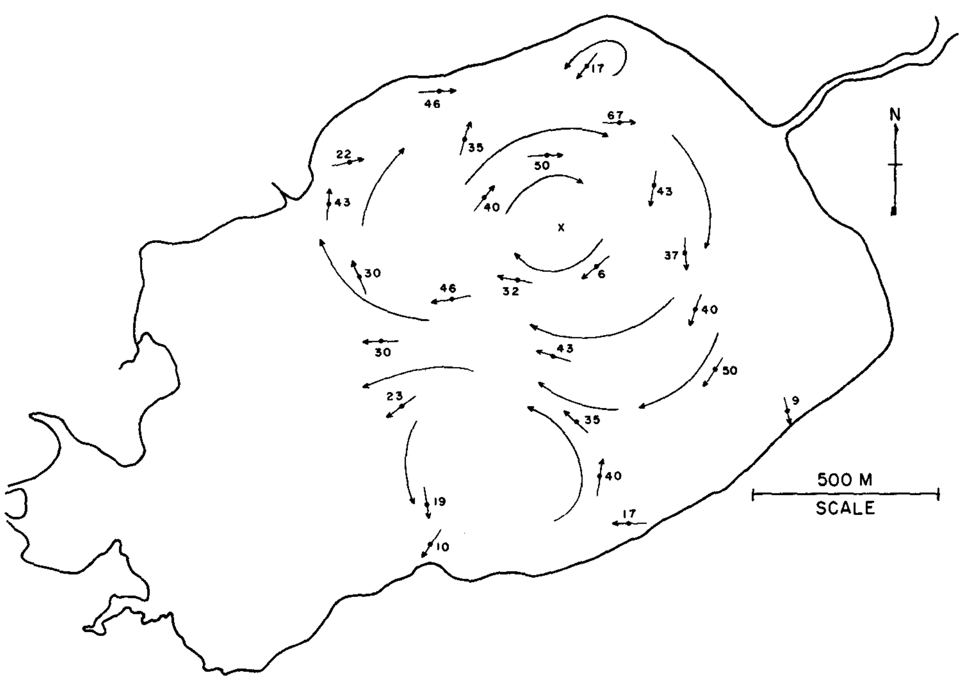


Figure A-42.—Under-ice currents—the upper lake.—Jan. 19, 1981. Current velocities are given in cm/min.

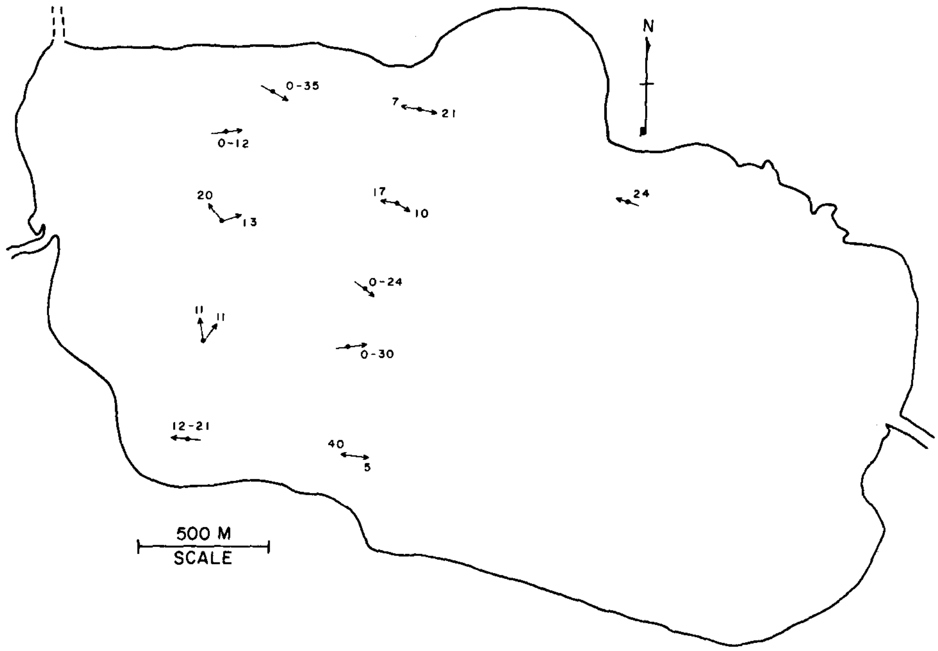


Figure A-43.—Under-ice currents—the lower lake—April 16, 1980. Current velocities are given in cm/min.

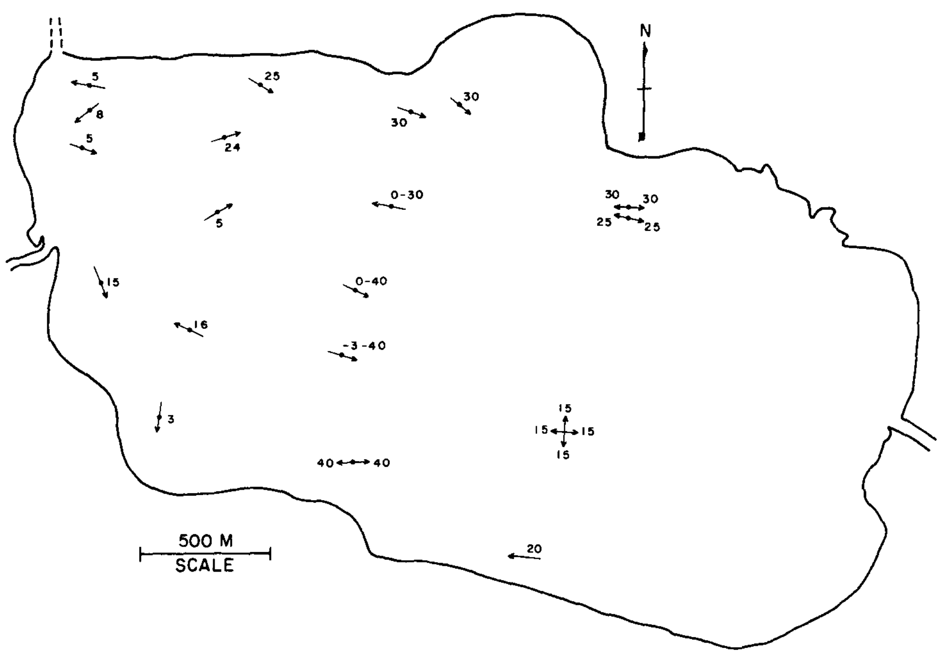


Figure A-44.—Under-ice currents—the lower lake—April 8-10, 1980. Current velocities are given in cm/min.

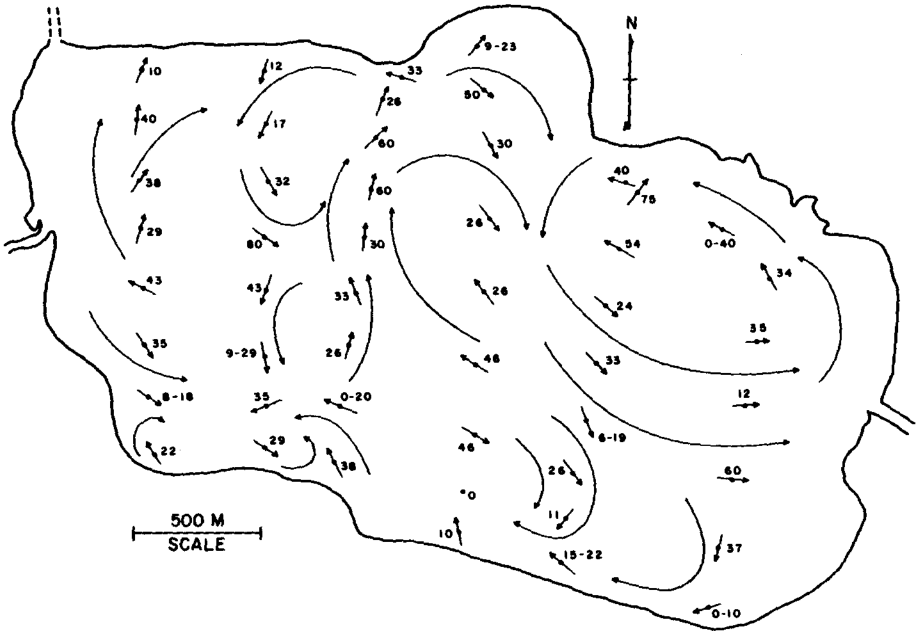


Figure A-45.—Under-ice currents—the lower lake—Feb. 18, 1981. Current velocities are given in cm/min.

GPO 835-584