# FRED Reports

ASSESSING THE WATER QUALITY OF
ROBE LAKE, ALASKA, 1981-1982

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J. P. Koenings[1], David Barto
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**Alaska Department of Fish & Game**
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Robert D. Burkett, Chief
Technology and Development Branch

P. O. Box 3-2000
Juneau, Alaska 99802-2000

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[1] Author to whom correspondence should be directed.

[2] Valdez Fisheries Development Association

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ABSTRACT

Since 1956 the people of Valdez began to notice changes in the water quality of Robe Lake. Specifically, Robe River gradually became less navigable; the lake water cleared and began to warm; and lake vegetation began to interfere with swimming, boating, and recreational fishing. Prompted by public concern, the City of Valdez, in cooperation with FRED Division and the private aquaculture sector, sought and received funding for a diagnostic study of Robe Lake water quality from the U. S. Environmental Protection Agency (Clean Lakes Program).

The basic water quality of Robe Lake was found to be quite good. That is, bacterial counts were well below the water-quality standard for body contact; nuisance algal blooms with accompanying odor and other aesthetically unpleasant effects were not apparent; and the watershed was relatively free of cottages and industrial point sources of pollution.

The most conspicuous water-quality problem centers on the abundant growth (2,100 tons) of aquatic weeds that choke 70%-80% of the lake from mid-July through October. The direct and indirect effects of the macrophytic growth on water quality are an exhaustion of inorganic nitrogen from the water column (lowered N:P), a drastic lowering of oxygen concentrations during the winter (potential fish kill), a reduction in algal biomass, and a concomitant low density of zooplankters (fish forage).

To correct these deficiencies and to restore multirecreational uses, we recommend altering the current state of the lake by either removal of macrophytes (mechanical and/or chemical) or prevention of new growth through habitat manipulation.

KEY WORDS: water quality, aquatic macrophyte, habitat alteration, salmon, nutrient ratio, winterkill, oxygen depletion.

## INTRODUCTION

Robe Lake (61°05'35"N, 146°8'0"W) is located in the Port Valdez area at the northern end of Prince William Sound in southcentral Alaska (Figure 1). The lake lies within the city limits of Valdez and is only 12.9 km from its center (Figure 2). The lake has a surface area of 276 ha (682 acres), a volume of 8.61 x $10^6 m^3$, and a mean depth of 3.12 m (Figure 3). The annual discharge from the 1,526-ha watershed, or catchment area, surrounding Robe Lake is estimated to be 25.3 x $10^6 m^3$, resulting in a theoretical water residence time for the lake of 0.34 yr.

The one major basin, located in the southeast corner of the lake, is only 5 m deep; the lake bottom is shallow from the extreme eastern border to the west end where it flows into the Robe River. Robe River flows west and enters the extreme eastern extension of Valdez Arm, southeast of the city of Valdez. Presently, three tributary streams are within the Robe River watershed: namely, Brownie Creek, Deep Creek, and Old Corbin Creek's previous channel. Prior to 1956, the Robe Lake watershed included the 3,129-ha catchment area of Corbin Creek, but a dike was constructed that effectively diverted any flowing portion of Valdez Glacier Stream and Corbin Creek from Robe Lake.

Commercial and sport fishing as well as hunting, canoeing, boating, swimming, hiking, and skiing are activities that comprise part of the life style of residents within the Valdez area. Historically, Robe Lake provided a living for a small group of commercial fishermen who primarily caught sockeye salmon, *Oncorhynchus nerka*, for sale to the local cannery, and it was possible to navigate from the salt water of Port Valdez into the lake. In addition, Robe Lake has long been the producer of

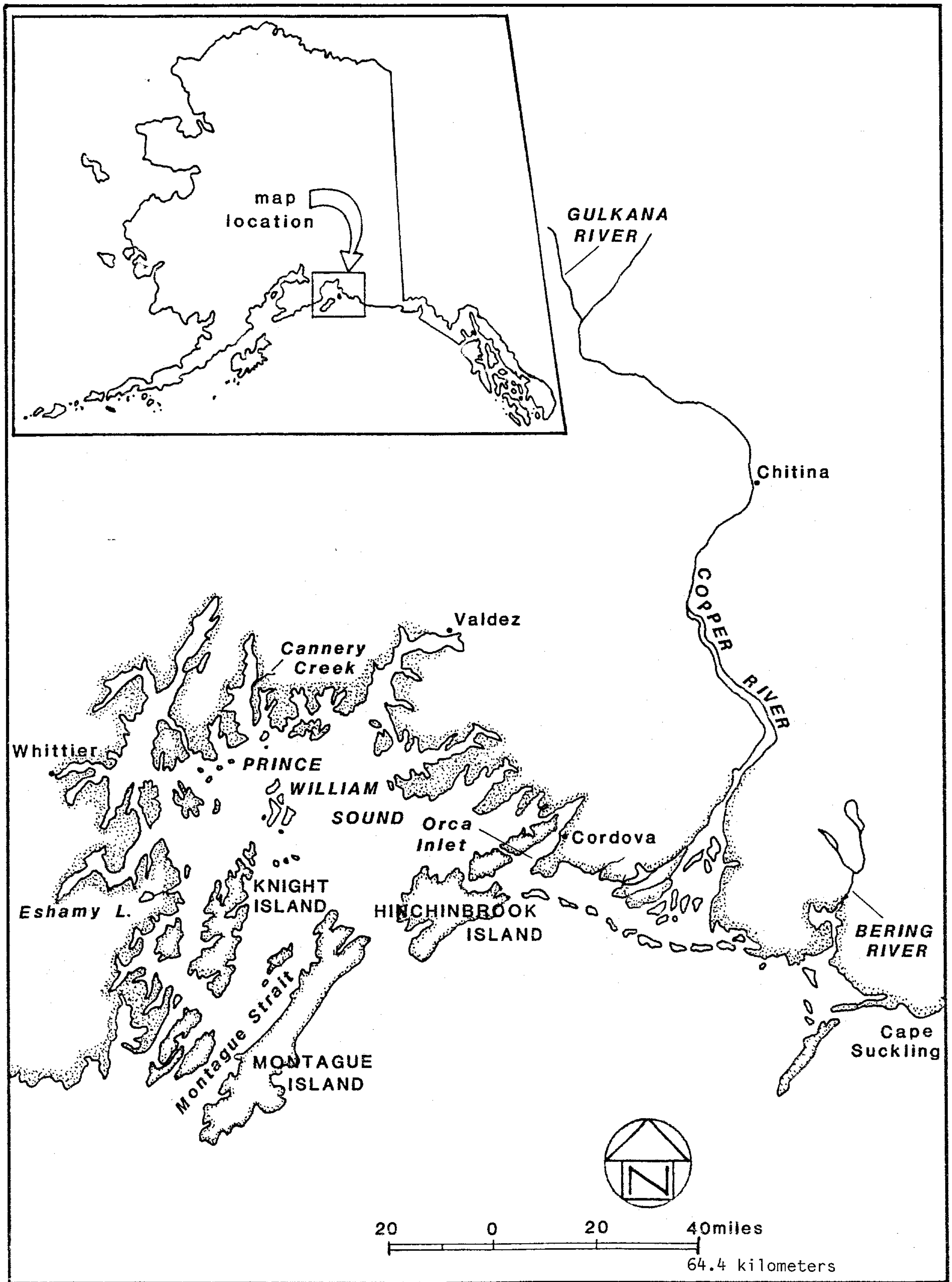


Figure 1. Geographical location of the city of Valdez within the South-central region of Alaska and specifically at the Northern extension of Prince William Sound.

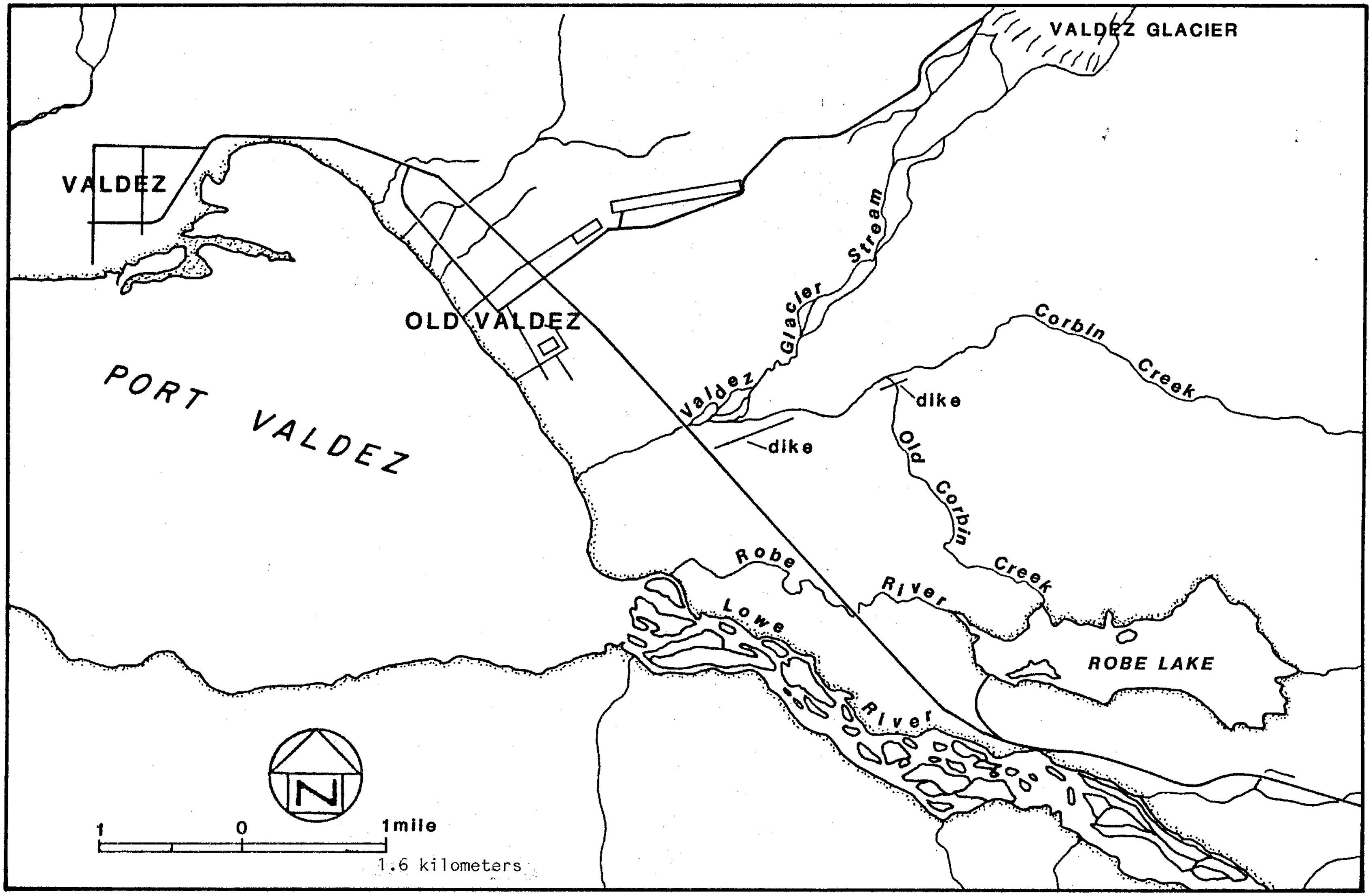


Figure 2. The location of Robe Lake to the City of Valdez within the Port Valdez area at the northeast extension of Valdez Arm.

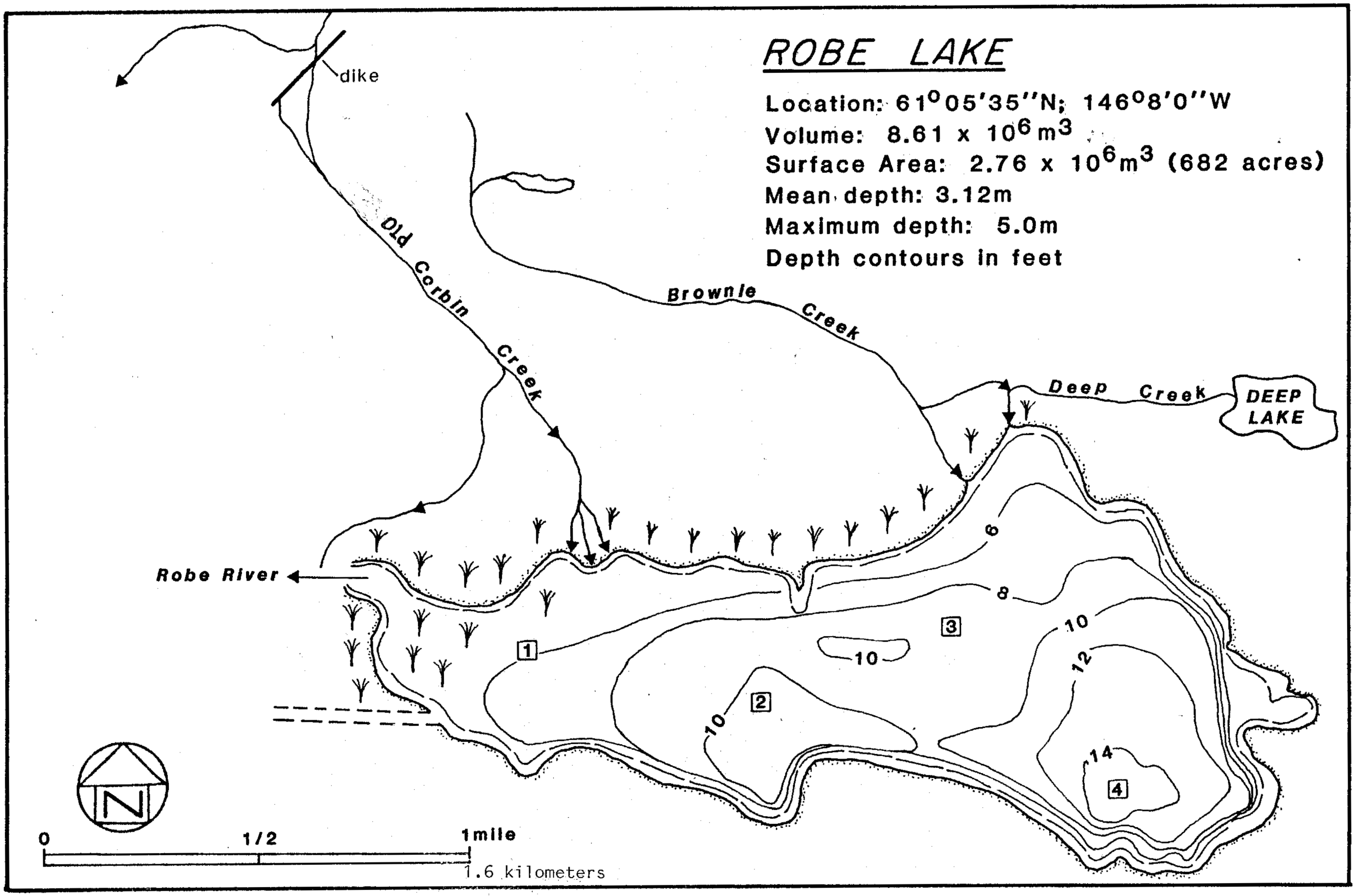


Figure 3. Morphometric map of Robe Lake showing the four limnological sampling stations and the location of Robe River relative to the three major tributary streams, Corbin Creek, Brownie Creek, and Deep Creek.

abundant stocks of salmon for sport fishermen. Sockeye salmon, *Oncorhynchus nerka*, coho salmon, *Oncorhynchus kisutch*, and Dolly Varden char, *Salvelinus malma*, have been a part of the historic sport catch.

A greater concern for fishstock management occurred with the advent of statehood, and all freshwater bodies were closed to sport fishing in Port Valdez, including Robe Lake. However, in 1958 the Valdez Chamber of Commerce instituted the ongoing Valdez Silver Salmon Derby; the primary contribution of adult coho to the derby originates from the Robe Lake system. Subsistence fishing and hunting have been longstanding traditions in the Robe Lake watershed. Although hunting restrictions have affected access in recent years, waterfowl hunters have found ducks and geese to be both abundant and obtainable.

It is this history of abundant recreational opportunities that prompted the people of Valdez to become alarmed when they began to notice changes in Robe Lake. The first noticeable change was the loss of Robe River as a navigable body of water. Second, the lake, which had been silty, cleared and warmed. Third, the lake vegetation, which heretofore had allowed excellent boating, tangled propellers and hindered swimmers. Within a period of 10 years, the lake began to shrink, the shoreline became less defined, and the residents of Valdez became aware that the only freshwater lake in the area had become less useable.

The primary cause of the rapid changes in the condition of Robe Lake occurred in 1956 when the streambed of Valdez Glacier Stream changed its course and entered Corbin Creek and, subsequently, Robe Lake. In order to stop flooding in the Robe Lake area and protect the Richardson Highway, the City of Valdez constructed a dike on Old Corbin Creek; this stopped the flooding of the Valdez Glacier Stream, but it also rerouted the primary tributary to Robe Lake (Corbin Creek) to a different watershed (*see* Figure 2).

The short-term benefits from this diversion were reduction of flooding, change in Robe Lake from a turbid to a clear lake and reduction of the flow of silt into Robe Lake. However, it has become apparent that the cold, turbid water carried during the summer months by Corbin Creek served the dual purpose of cooling Robe Lake and retarding the growth of weeds, or aquatic macrophytes. As a consequence, the Robe Lake system exchanged siltation and flooding problems for warming, weed enhancement, and potential winter fish-kill problems.

During the 1970s, public concern for the restoration of Robe Lake prompted the City of Valdez (in cooperation with the State of Alaska and the private aquaculture sector) to obtain funding for a diagnostic study of Robe Lake from the U.S. Environmental Protection Agency's (EPA) Clean Lakes Program. This diagnostic/feasibility study, administered through the City of Valdez by the EPA, was to provide the base-line data (physical, chemical, and biological) necessary to identify potential methods by which the lake might be restored. Upon completion of the research and analysis, public and private experts in the fields of engineering and limnology were to discuss the feasibility and benefit/cost of its rehabilitation.

The purpose of this report is to summarize the results of the Robe Lake study and to describe restoration alternatives.

## METHODS

### Laboratory

After mooring to permanent sampling stations, limnological samples were collected during all surveys. The frequency of sampling was designed to characterize the lake at 2-week intervals, from ice-off in the spring to ice-on in the winter, with six additional sampling periods during the ice-on period. The lake was sampled for algal nutrients (nitrogen, phosphorus, silicon, and carbon) as well as other water-quality parameters from both the epilimnetic (1 m) and near-bottom zones. Water samples from multiple (4) casts with a nonmetallic Van Dorn sampler were pooled, stored in 8- to 10-liter transluscent carboys, cooled, and immediately transported in light-proof containers to Valdez for filtering and preservation. Subsequent filtered and unfiltered water samples were either refrigerated or frozen in acid-cleaned, prerinsed polybottles. The preprocessed water samples were then sent to the Soldotna Limnology Laboratory for analysis.

All chemical and biological samples were analyzed by methods detailed by Koenings et al. (1985). In general, filterable reactive phosphorus (FRP) was analyzed by the molybdate-blue/ ascorbic-acid method of Murphy and Riley (1962), as modified by Eisenreich et al. (1975). Total phosphorus was determined by the FRP procedure after persulfate digestion. Nitrate and nitrite were determined as nitrite after cadmium reduction of nitrate, following Stainton et al. (1977). Ammonium analysis followed Stainton et al. (1977) using the phenolhypochlorite methodology, while reactive-silicon analysis followed the procedure of Strickland and Parsons (1972). Alkalinity levels were determined by acid titration (0.02 N $H_2SO_4$) to pH 4.5 using a Corning model-399A specific ion meter. Particulate carbon, nitrogen, and phosphorus were estimated directly from filtered seston prepared by drawing 1 to 2 liters of lake water through precleaned, 4.2-cm GF/F filters. The filters were frozen in individually marked plexislides and stored for future analysis.

Primary production (algal standing crop) was estimated by chlorophyll _a_ (chl _a_) analysis after the fluorometric procedure of Strickland and Parsons (1972). We used the low-strength acid addition recommended by Riemann (1978) to estimate phaeophytin.

Water samples (1-2 liters) were filtered through 4.25-cm GF/F filters to which 1 to 2 ml of saturated $MgCO_3$ solution were added just prior to the completion of filteration. The filters were then frozen in individual plexislides for later analysis.

Zooplankters were collected from bottom-to-surface vertical tows using a 0.2-m-diameter, 153-μm mesh, conical zooplankton net. The net was pulled at a constant 1 m/second and washed well before removing. The organisms were preserved in 10% neutralized sugar-formalin (Haney and Hall 1973). Identification of the genus *Daphnia* followed Brooks (1957); the genus *Bosmina*, Pennak (1978); and the copepods, Wilson (1959), Yeatman (1959), and Harding and Smith (1974). Enumeration consisted of counting triplicate 1-ml subsamples taken with a Hensen-Stempel pipette in a 1-ml Sedgewick-Rafter cell. Size (length) of the individual zooplankters was obtained by counting at least 10 individuals along a transect in each of the 1-ml subsamples used in identification and enumeration. Zooplankters were measured to the nearest 0.01 mm, as described in Edmondson and Winberg (1971).

Bottom profiles were recorded using a fathometer along several lake transects, and from these depth recordings, a bathymetric map was developed. The areas of component depth strata were determined with a polar planimeter, and lake volume (V) was computed by summation of successive strata after Hutchinson (1957):

$$\text{Lake Volume} = \sum_{i=1}^{n} \frac{h}{3} (A_1 + A_2 + \sqrt{A_1 A_2})$$

Where: $\sum_{i=1}^{n}$ = sum of strata volumes i through n

$A_1$ = surface area of upper depth strata ($m^2$)
$A_2$ = surface area of lower depth strata ($m^2$)
h = distance between $A_1$ and $A_2$ (m)

Lake mean depth ($\bar{z}$) were calculated as:

$$\bar{z} = V/A^L$$

Where: z= lake mean depth (m)
V = lake volume ($.10^6 m^2$)

The theoretical water residence time ($T_W$) was calculated as:

$$T_W \text{ (yr)} = V/TLO$$

Where: $T_W$ (yr) = theoretical water residence time (years)
V = total lake volume
TLO = total lake outflow

The collection of physical data included the measurement of lake temperatures and light penetration at all stations. Lake temperature profiles were measured using a YSI temperature/dissolved-oxygen model-57 meter. These recordings were taken at 0.5-m increments from the surface to lake bottom. The algal light compensation point was defined as the depth at which 1% of the subsurface light (photosynthetically available radiation [400-700 nm]) penetrated (Schindler 1971) and measured using a submersible Protomatic photometer. Recordings were taken at several depths between the surface and the compensation depth. Using these data, the natural logarithm of light intensity was plotted against depth, and the slope of this line was used to calculate the light extinction coefficient by date. In addition, water transparency was estimated using a 20-cm Secchi disk.

## Field

Four permanent stations established along the east-west axis of the lake were used in characterizing water quality at four major depth strata (*see* Figure 3). These stations were sampled every 2 weeks during the ice-free season and monthly during the winter period. At four intervals throughout the year, samples were taken to characterize the levels of total coliform and fecal coliform bacteria and the density of benthic invertebrates. In addition, sampling stations were established on each of the three major inlet streams (Brownie Creek, Old Corbin Creek, and Deep Creek) and on the Robe River, which drains the lake.

As all three inlet streams enter the lake through marshy areas, the sampling points were chosen at the farthest point downstream where a well defined channel permitted periodic discharge measurements. Total stream discharge was calculated from time vs. discharge curves using a polar planimeter. Continuously recording thermographs provided temperature data for the inlet streams, and grab samples were taken for water quality analysis. During the part of the year when surface water was present, water samples and discharge measurements were taken from Corbin Creek. Only discharge measurements were taken for Robe River, because epilimnetic water quality samples from the lake (Station 1) were assumed equivalent to the surface discharged river water.

In order to assess macrophyte growth through periodic standing-crop estimates, three transects were established at the middle and east and west ends of the lake. On each sampling date, three points were randomly selected along the transects; from each point, all macrophytes were harvested within 1 $m^2$ quadrats. Additional quadrats were established to estimate old-year, carryover biomass. Total wet and dry weights were obtained for each sample by drip-drying in mesh bags and oven drying (60°C for 24 hours), respectively.

The dried material was then shredded, mixed, and subsampled in triplicate; ash weight was determined by heating the material to 500°C in a muffle furnace and then cooling it to room temperature in a desiccator before weighing. Samples were not segregated according to species, but field notes recorded the density, species composition, and predominant life stage for each sample.

Finally, in the tables and figures we have used the designation of either mg $L^{-1}$ or µg $L^{-1}$ to report concentration data; however, in the body of the report we have used either parts per million (ppm) in lieu of mg $L^{-1}$ and parts per billion (ppb) in lieu of µg $L^{-1}$.

## RESULTS

### Hydrological Cycle

From 1979 to 1983, the total annual precipitation in the Robe Lake watershed, or catchment area, has ranged from 151.1 to 237.0 cm and averaged 177.8 cm. These precipitation patterns were recorded at the Valdez weather station located approximately 11 km from the study area. During 1982 the annual precipitation equalled 156.4 cm, which was close to the lowest precipitation recorded in Valdez from 1979 to 1983. However, the 1982 annual precipitation was slightly greater than the long-term mean annual precipitation (152.4 cm) of the Valdez area (USDA 1979).

Nearly two-thirds of the 156.4 cm of recorded precipitation for the Valdez area in 1982 (90.9 cm) fell during the 4-month period beginning in September and ending in December. As much of this precipitation fell as rain, stream flows were at maximal discharge during September and early October. Overall, the three major tributaries (Brownie Creek, Old Corbin Creek, and Deep Creek) accounted for only 54% of the water discharged out of the lake through Robe River. The mean annual discharges of Brownie Creek, Old Corbin Creek and Deep Creek equalled 13.3 $m^3$/min, 7.8 $m^3$/min, and 5.0 $m^3$/min, respectively.

Of the 1,518-ha Robe River watershed (Figure 4), 30% (459 ha) drains into Robe Lake via small undefined streams or through overland runoff; whereas 7.6% drains into the lake through Old Corbin Creek, 19.8% through Deep Creek, and 22.9% through Brownie Creek. Whereas the catchment area of Old Corbin Creek represented 15% of the combined creek drainage and only 7.6% of the Robe River drainage area, the creek discharge represented 51% of the combined discharge of the three creeks and 28% of the measured mean annual discharge of Robe River. Thus, Old Corbin Creek may receive flow augmentation from the adjacent Corbin Creek, which drains a 3,129-ha watershed that is nearly double that of the existing Robe River watershed.

The estimated 1982 summer discharge from Robe Lake is estimated to be $1.5 \times 10^7$ $m^3$ (68.6 $m^3$/min), which results in an ice-free lake water residence time of 0.6 years or a flushing rate of nearly twice each summer period (June-October). This assumes that no thermal-density stratification occurred during the summer period, which, in turn, agrees with the temperature profiles collected at the four lake stations.

Temperature Profiles

During the ice-over period (November through mid-May), recorded temperatures reflected the influence of nearly 1 m of ice and snow cover. At the shallow Station 1, temperatures were consistently below 4°C, reaching only 2.5°C, and falling as low as 1.5°C near the lake bottom (Figure 5). However, as the station depth increased, temperatures near the bottom strata increased to 4°C, but through most of the water column, temperatures were in the <1°C to 3°C range. After ice-out in May, the lake quickly warmed; 16°C temperatures were recorded by the end of June. Because of the shallow-basin configuration of the lake, isothermal conditions existed throughout the water column, except for a brief period of slightly warmer water (18.2°C to 18.7°C)

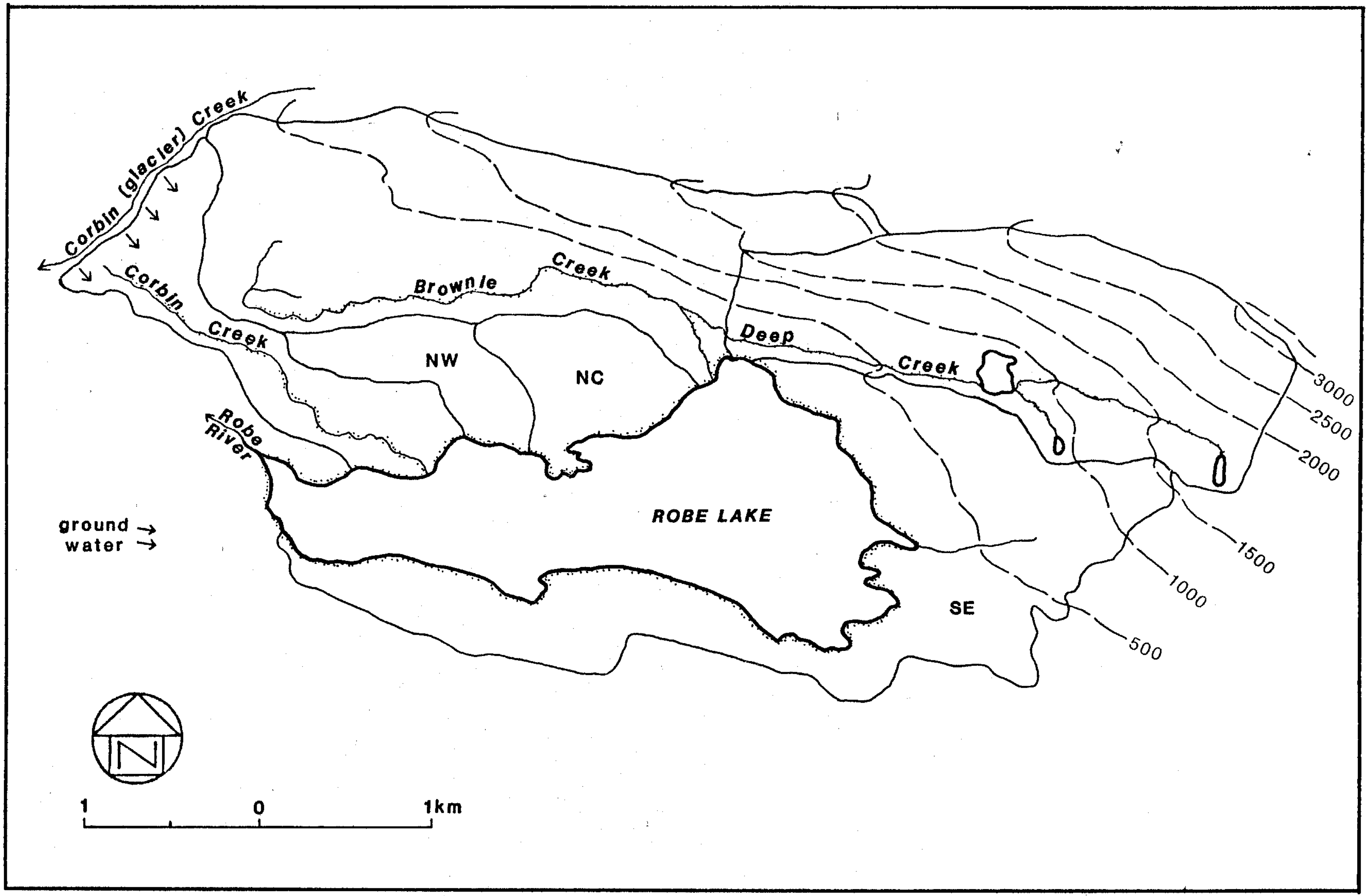


Figure 4. Topographic map of the Robe Lake watershed and catchment areas for the three major tributaries, Deep Creek, Brownie Creek, and Old Corbin Creek, along with the diked off Corbin (glacier) Creek.

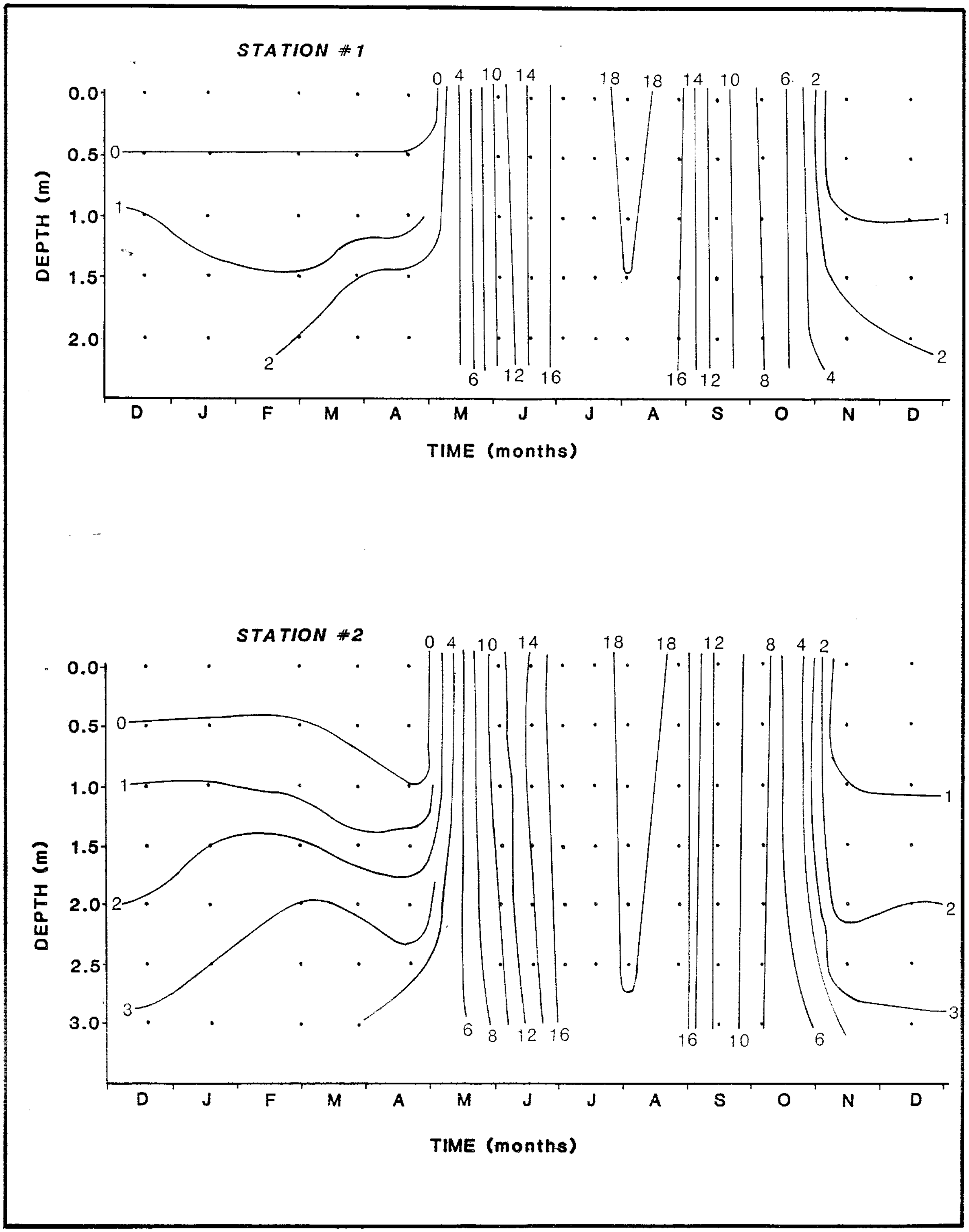


Figure 5. Annual temperature (°C) isotherms for Robe Lake during 1981-1982 taken at Stations 1, 2, 3, and 4 (values within the figure indicate temperatures in degrees Celsius).

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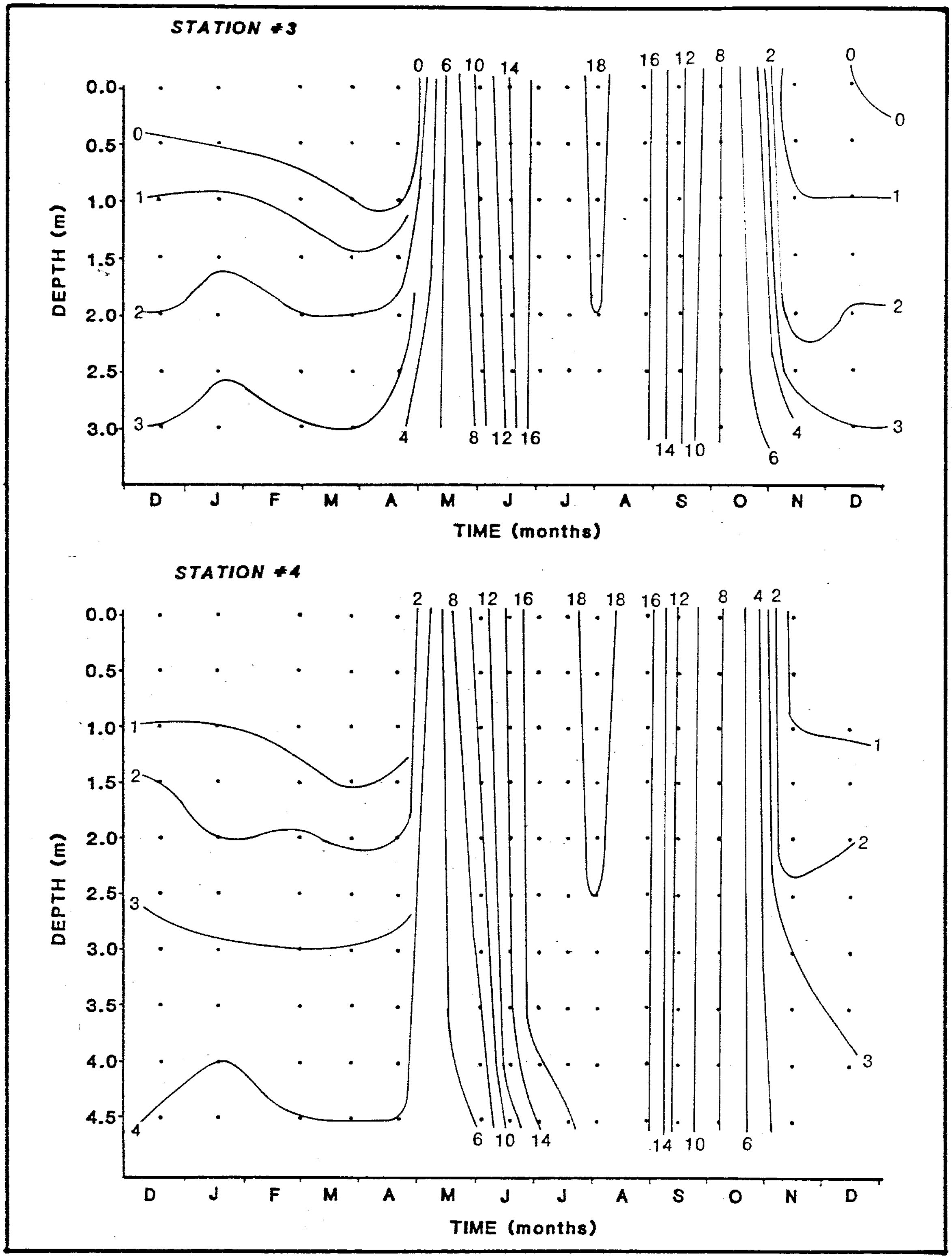


Figure 5 continued. Annual temperature (°C) isotherms for Robe Lake during 1981-1982 taken at Stations 1, 2, 3, and 4 (values within the figure indicate temperatures in degrees Celsius).

overlying 16.9°C to 17.9°C water during late July and into early August at Station 4. From late June to the end of August, the lake was very warm, exceeding 15°C from top to bottom and basically operating as an isothermal unit. Even the deepest water (4.5 m) at Station 4 was above 15°C during July and August. After August, rapid cooling of the entire water column occurred; 4°C temperatures were established by the end of October. Edge ice began to form by mid-November, with surface temperatures dropping to 0.1°C to 0.5°C.

## Light Penetration Patterns

Because suspended particles were relatively few during most of the year, photosynthetically available radiation (400 to 700 nm) penetrated the entire water column (Figure 6). At Stations 3 and 4 during late winter, however, light levels under the ice were attenuated to less than 1% of the surface values (April); this reoccurred the following winter. However, most of the lake sediments were within the littoral zone during the winter (under the ice) and throughout the summer, even at the height of the macrophyte growth.

Two general trends emerged: (1) light penetrated to a greater depth during the open-water period and (2) within the open-water period, light penetration increased from spring through summer and into the fall. The time period of maximal water clarity (August) coincided with the temperature maxima and with oxygen supersaturation. Overall, the sediments of Robe Lake were at low enough levels so that light would not appear to limit macrophytic or periphytic growth.

## Dissolved Gases

Lowered dissolved-oxygen (DO) concentrations were observed when the lake was ice-covered and, to a lesser degree, during the

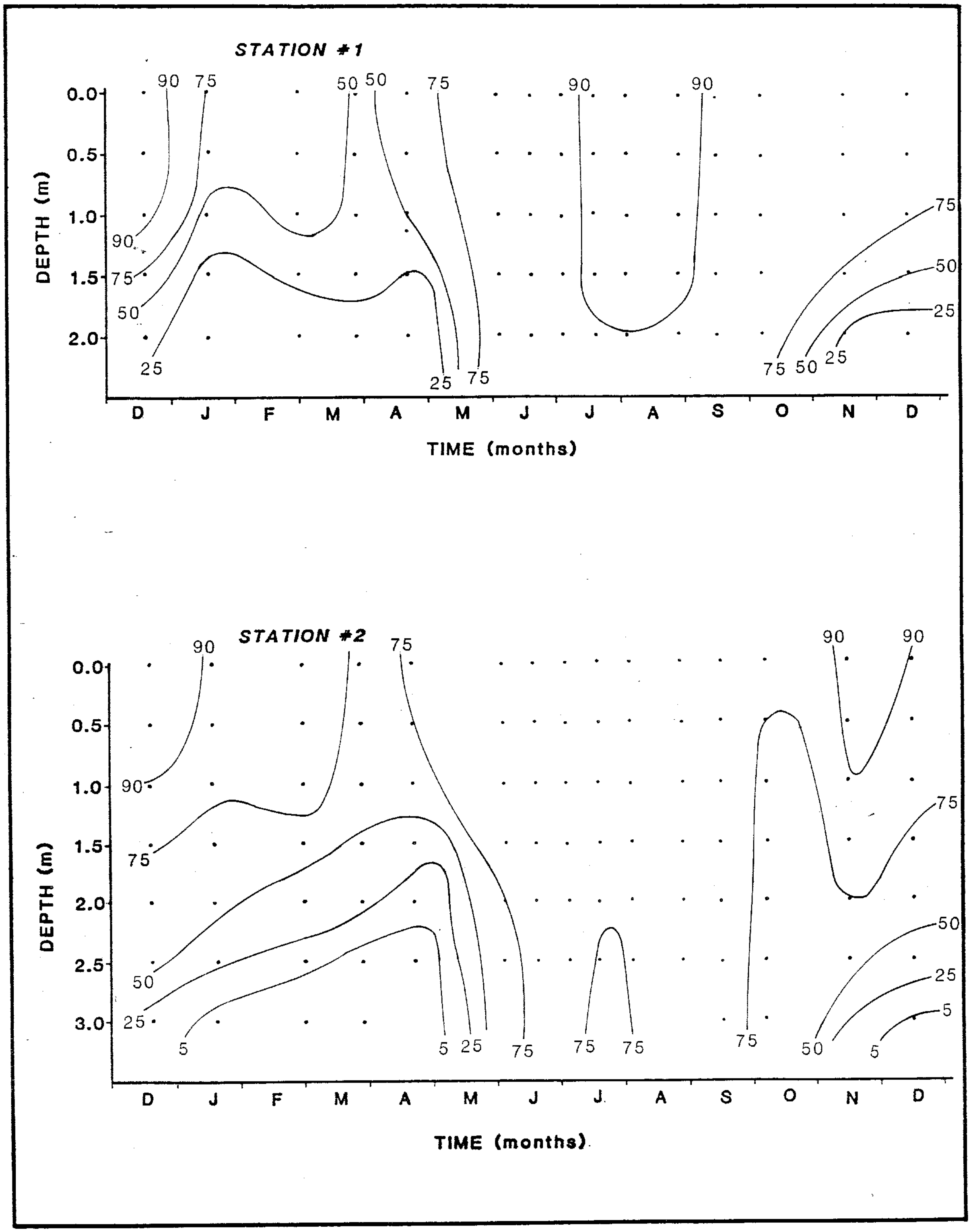


Figure 6. Annual light (400 nm to 700 nm) penetration profiles for Robe Lake during 1981-1982 taken at Stations 1, 2, 3, and 4 (values within the figure indicate percentages of available light).

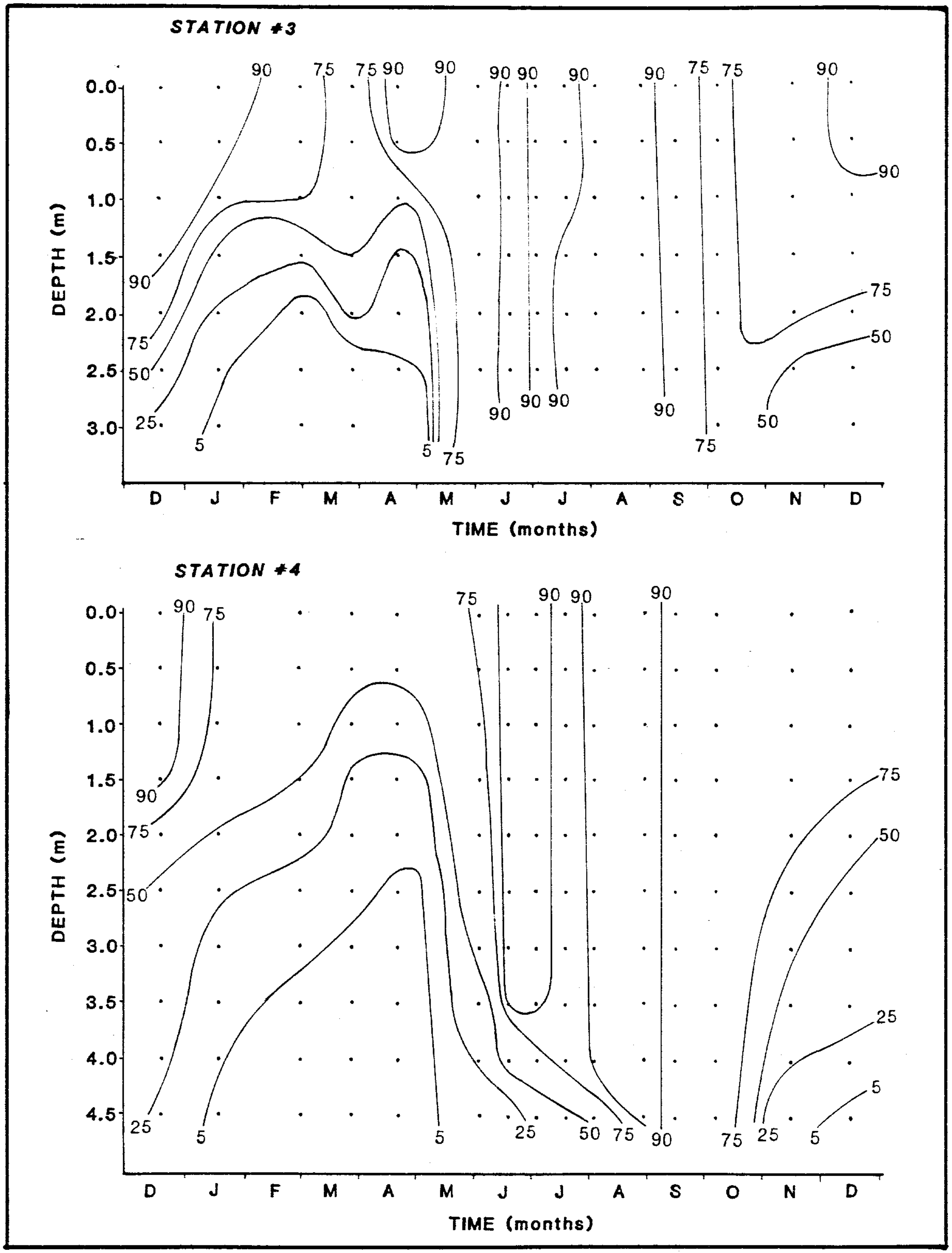


Figure 6 continued. Annual light (400 nm to 700 nm) penetration profiles for Robe Lake during 1981-1982 taken at Stations 1, 2, 3, and 4 (values within the figure indicate percentages of available light).

summer period within lower depths where temperature profiles indicated nonmixing water. Anoxic conditions were observed only below 3.5 m at Station 4 during late winter, but DO levels were less than 5.0 ppm at all stations below 1.5 m throughout the study period. In general, after lake overturn in the fall, oxygen saturation began to drop beginning as early as the middle of September and October at all four stations (Figure 7). As winter progressed with its accompanying ice and snow accumulation, the lake water became increasingly deoxygenated; in March and April, 50% of saturation was observed just under the ice. Following breakup, the lake became isothermal, and dissolved oxygen was restored to most of the water column; however, at the greatest depth (i.e., Station 4), partially deoxygenated water persisted through the summer and into the fall overturn. The beginning of the fall overturn period was the only time the entire lake was observed to be above 80% of oxygen saturation.

A further feature of the dissolved-oxygen profiles was the lack of supersaturated water. Oxygen saturation exceeded 100% only during July and August at Stations 1 and 3 and during June at Station 4. During these periods, saturation values reached as high as 121% but were usually between 100% and 105%. In general, oxygen supersaturation in the upper layer was accompanied by oxygen deficits in the lower layers when the lake became stagnant. Overall, the lake was deficient in oxygen (below 100% of saturation) throughout most of the year; reasonable oxygen concentrations were maintained throughout the year only within a narrow 1.0- to 1.5-m surface layer. Clearly, oxygen concentrations and percent saturation values were biologically mediated, reflecting a definite oxygen demand in the open water.

<u>General Water Quality Parameters</u>

Over the yearly sampling schedule (samples taken at two depths at each of the four stations), water quality parameters (*see* Appendix A) were monitored. The upper depth remained a constant

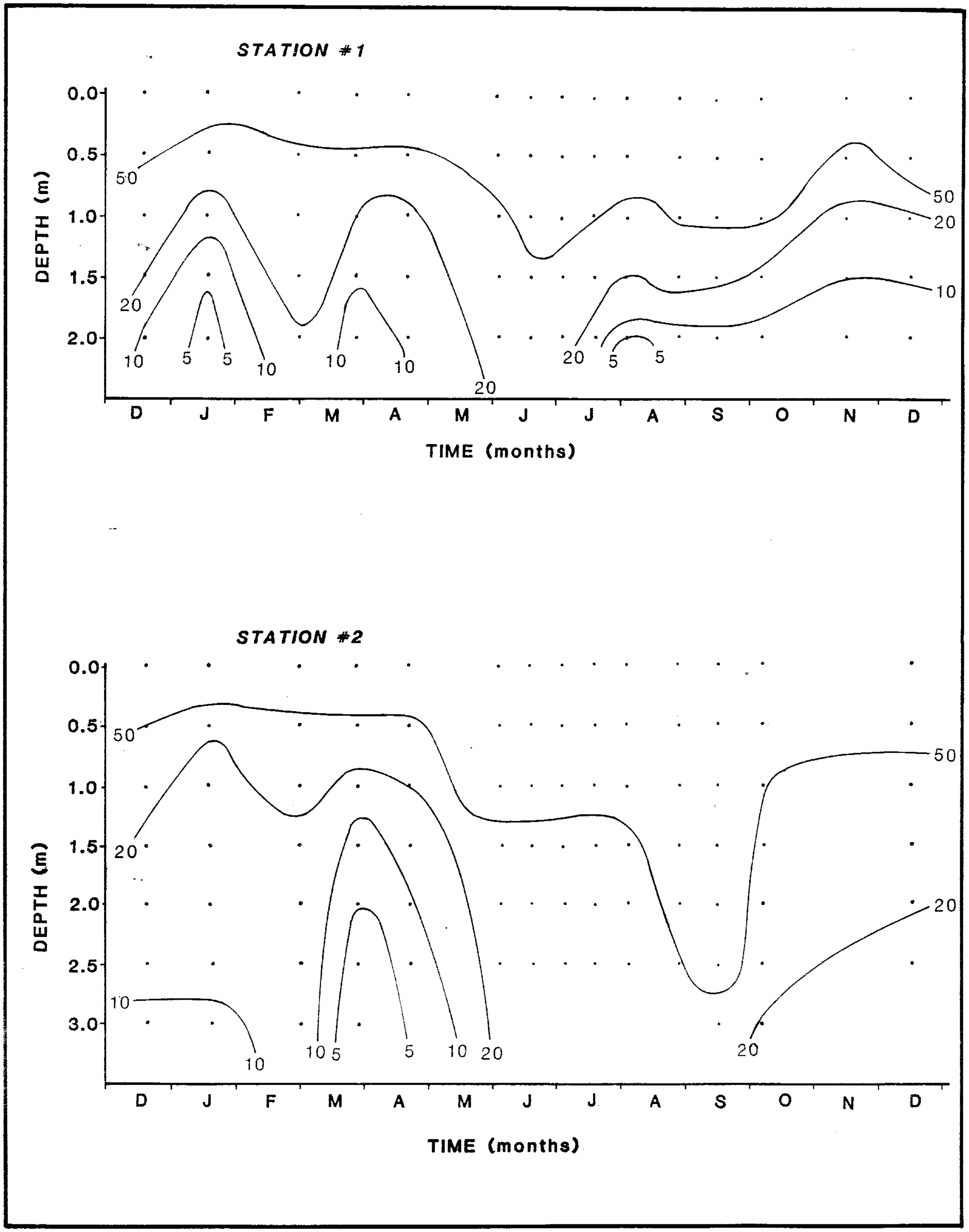


Figure 7. Annual oxygen saturation profiles for Robe Lake in 1981-1982 taken at Stations 1, 2, 3, and 4 (values within the figure indicate percent of oxygen saturation).

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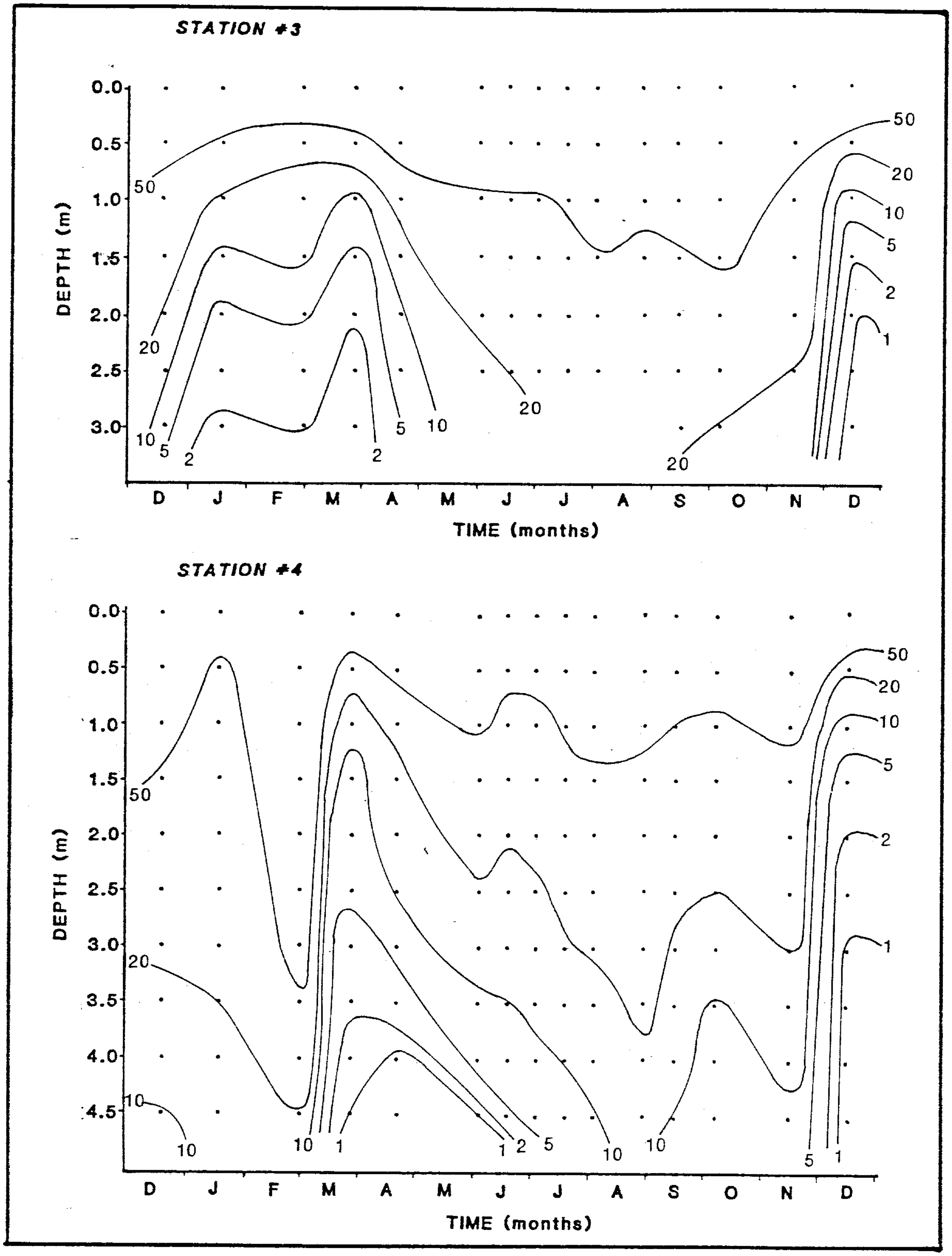


Figure 7 continued. Annual oxygen saturation profiles for Robe Lake in 1981-1982 taken at Stations 1, 2, 3, and 4 (values within the figure indicate percent of oxygen saturation).

1 m at all stations; however, the lower depth at each station varied. This was to ensure that the chemical changes at specific depth contours could be monitored as closely as possible to the sediment-water interface without disturbing the flocculent organic muds.

In general, the parameters we monitored showed seasonal patterns defined by the depth and extent of ice cover, station location, and/or thermal stagnation. Conductivity values ranged from 93 μmhos to 134 μmhos at the shallowest Station 1 and from 81 μmhos to 142 μmhos at the deepest Station 4. Elevated conductivity levels were found under the ice; lowered values generally occurred during the ice-free periods. For example, at Station 4 the conductivity during January through the end of April ranged from 93 μmhos to 142 μmhos, compared to a range of 81 μmhos to 95 μmhos for the June through October period. Higher values were also associated with the deeper areas sampled and reduced oxygen concentrations, especially during late winter.

Alkalinity (as $CaCO_3$) values ranged from 39 to 69 ppm at Station 1, compared to a similar range of between 36 to 94 ppm at Station 4. Alkalinity values showed the same general pattern found for conductivity: somewhat higher in range under the ice (e.g., 51 to 94 ppm at Station 4), compared to having a lower seasonal range during the open-water period (36 to 46 ppm at Station 4). Again, as established for conductivity, larger values tended to coincide with periods of lowered oxygen concentrations; e.g., late winter near the sediments.

In contrast to the timing of high/low cycles established for conductivity values and alkalinity concentrations, pH values showed an opposite cycle. Specifically, the pH rose during the open-water period but dropped under the influence of ice-cover. Again, using the shallow- and deep-water stations as examples, pH ranged from 6.8 to 7.3 units under the ice pack (January to April) at Station 1, compared to a similar range of between 6.8 and 7.3 units at Station 4 during the same time period. In contrast, during the open-water period (lasting from June through October), pH values at Station 1 ranged from 7.1 to 8.0 units (except for one 6.9 reading on 4 June), while those at Station 4 ranged between 7.0 and 8.2 units.

The seasonal cyclic patterns for these three parameters are interrelated and are established by the respiration/ photosynthesis ratio. With an increase in respiration (decomposition) under the ice, $CO_2$ levels are increased by aerobic-decomposition reactions that lower the dissolved-oxygen content of the water. This process is at maximal intensity at the midwater interface; thus, deoxygenation commences at the bottom and progresses into the water column over time. A rise in $CO_2$ causes an increase in alkalinity and a decrease in pH.

As the "aggressive $CO_2$" levels (resulting from decomposition reactions) rise, metals associated with carbonate minerals (e.g., calcium, magnesium, and iron) are liberated. Consequently, using data from Station 4 as an example, under-the-ice concentrations of calcium (18.9 to 31.5 ppm), magnesium (<0.3 to 3.8 ppm) and iron (25 to 5,414 ppb) tended to rise, compared to open-water-period concentrations ranging from 12.4 to 16.2 ppm (calcium), <0.3 to 0.9 ppm (magnesium), and 65 to 467 ppb (iron).

The iron levels are misleading, because the higher levels recorded for 3 June (450 and 467 ppb) were found in samples taken during spring turnover and result from the incomplete oxidation of the 5,414 ppb of iron found under the ice in late April. Thus the range in iron values should extend from 65 to only 170 ppb for the open-water period. Nonetheless, the higher concentrations of ionic species ($HCO_3^-$, Ca++, Mg++, and Fe++) under the ice (along with other ions; e.g., $NH_4^+$) that are generated by increased respiration or depletion of oxygen (compared to its resupply) are, in part, responsible for the generally elevated conductivity levels found under the ice (Mortimer 1941).

## Nutrient Cycles

The seasonal cycles established for the algal nutrients (phosphorus, silicon, and nitrogen) were very similar at Stations 1, 2, and 3 but differed slightly at Station 4. Thus, as was done for the general water quality parameters, only the results for Stations 1 and 4 will be discussed in detail; the results from Stations 2 and 3 will be used to expand specific points (*see* Appendix A).

Total phosphorus (TP) concentrations at Station 1 ranged from 8 to 15 ppb under the ice and then generally rose during the summer, reaching over 20 ppb in early August. Thereafter, TP levels dropped, reaching 5 to 10 ppb for the remainder of the year, except for a level of nearly 30 ppb in surface samples at Station 1 in early October (Figure 8). As the remaining stations did not reflect this exceptional value (Figures 9 and 10), the cause may be peculiar to the sampling site location, which is near the lake outlet (Robe River) and adjacent to the outlet of Old Corbin Creek (*see* Figure 3). Specifically, this sampling date coincided with peak recorded flows in the Robe River and Old Corbin Creek and may reflect the effects of flooding in the adjacent marshland.

At Station 4, TP showed an increasing trend in concentration (from 5 ppb in March to nearly 16 ppb by April) under the ice, especially within the deeper strata (Figure 11). This trend coincides with the anoxia and accompanying increase in iron and calcium levels developing at this site. During the spring overturn, phosphorus levels declined to approximately 10 ppb but then rose to over 16 ppb by late July. Except for an unusually low value in the early August samples (6 ppb), TP levels remained high (10 ppb) until iceover in November.

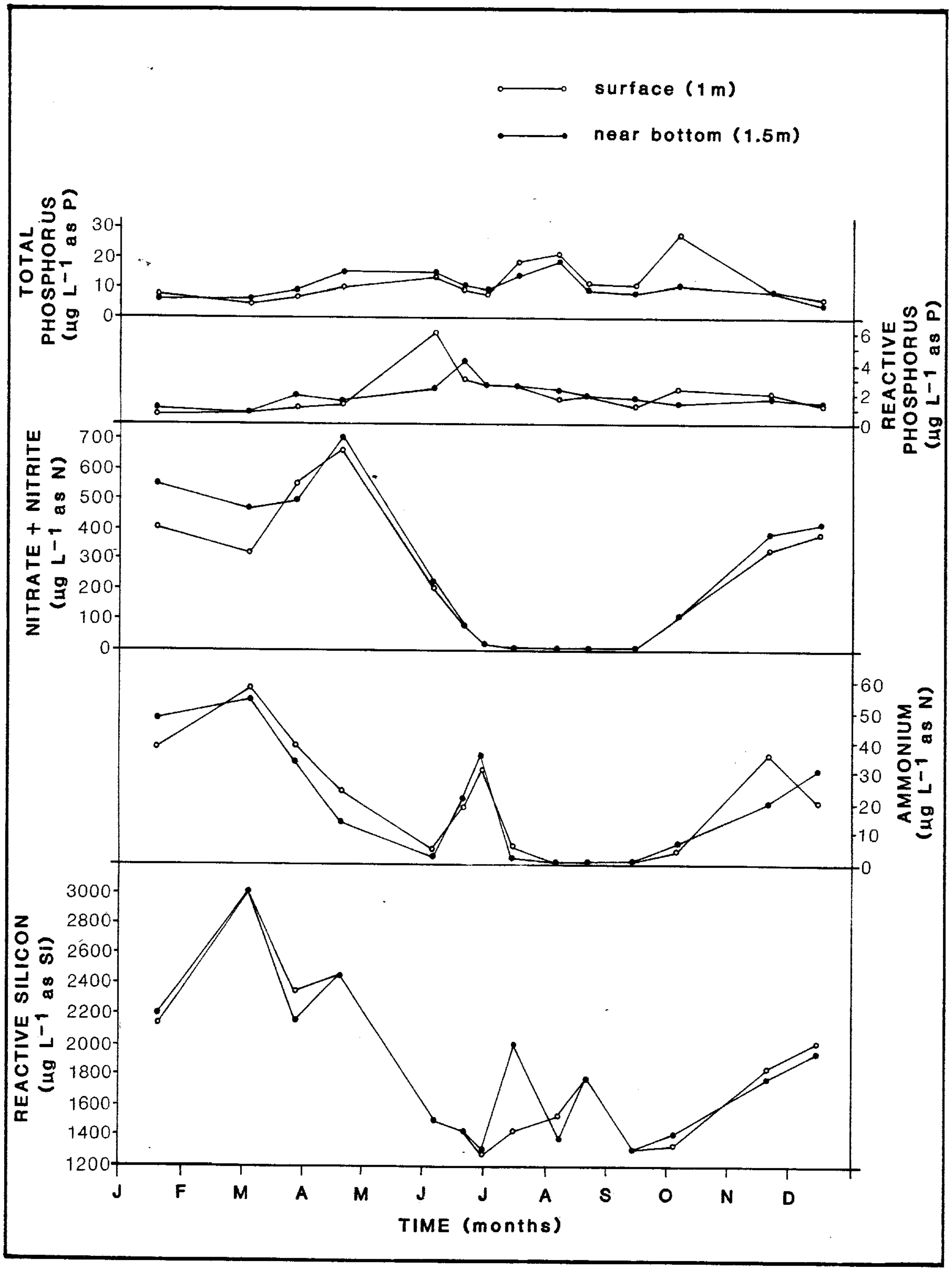


Figure 8. The seasonal dynamics of the algal nutrients phosphorus, nitrogen, and reactive silicon established for Robe Lake within the surface (1 m) and near-bottom (1.5 m) depths at Station 1 in 1982.

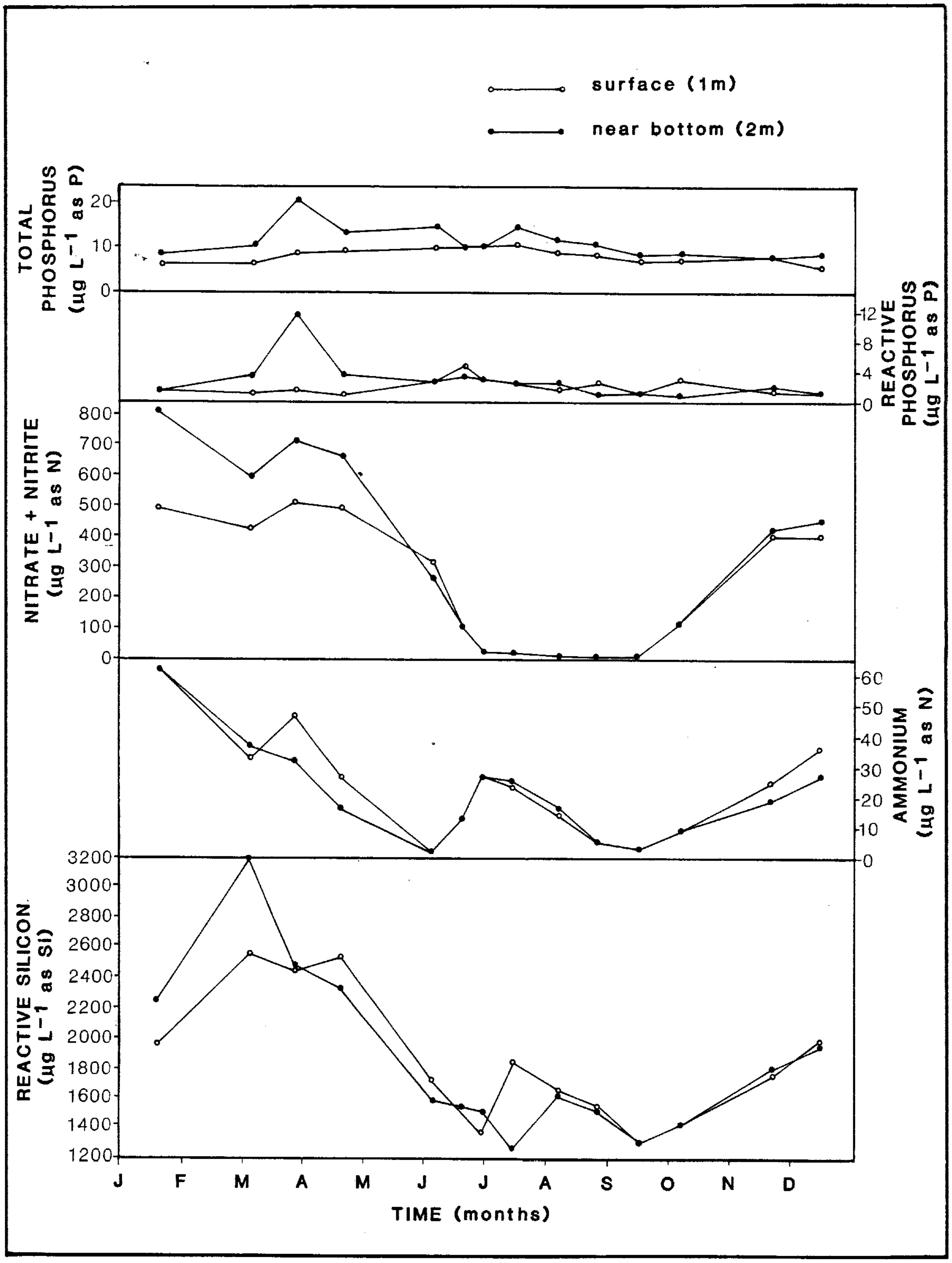


Figure 9. The seasonal dynamics of the algal nutrients phosphorus, nitrogen, and reactive silicon established for Robe Lake within the surface (1 m) and near-bottom (2 m) depths at Station 2 in 1982.

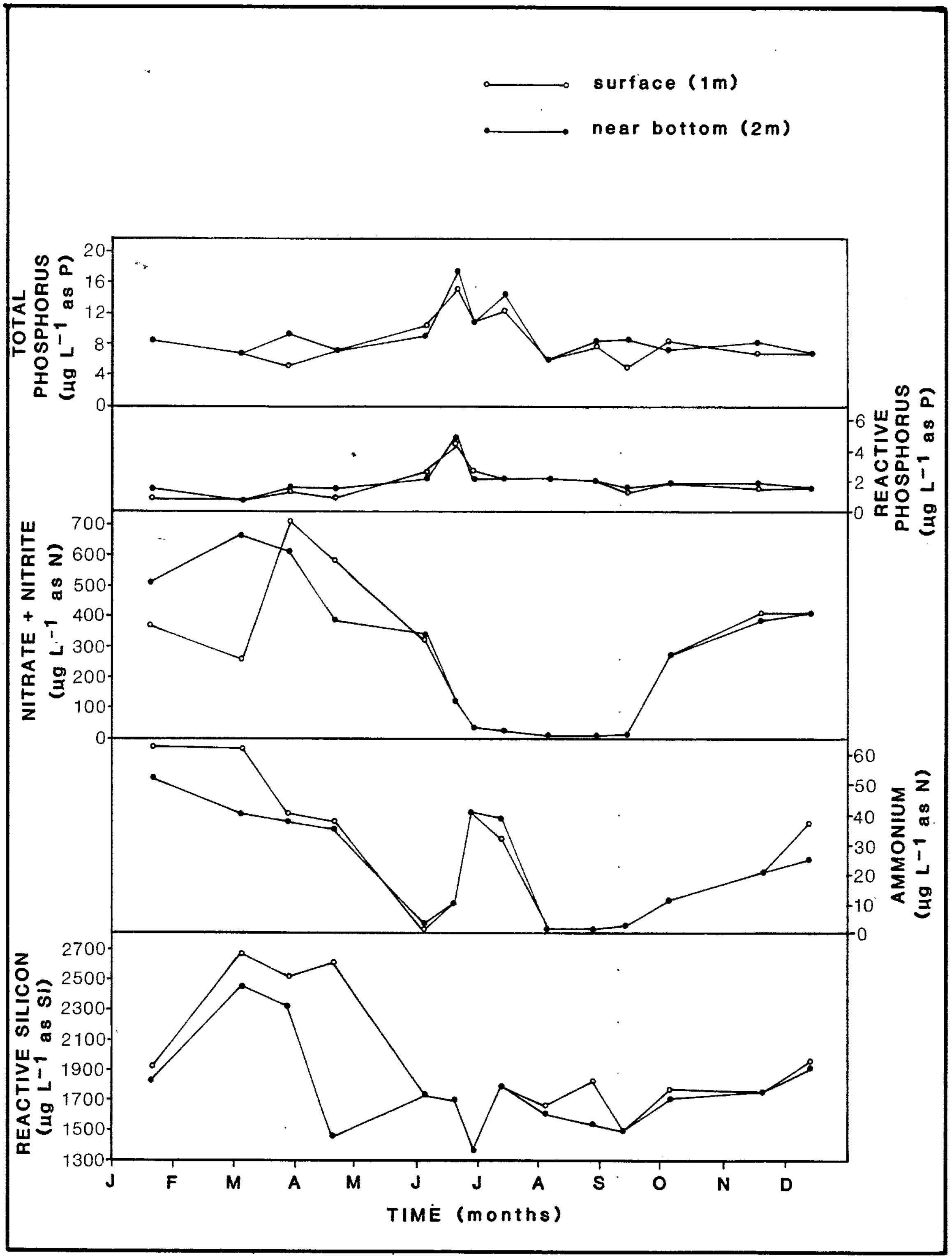


Figure 10. The seasonal dynamics of the algal nutrients phosphorus, nitrogen, and reactive silicon established for Robe Lake within the surface (1 m) and near-bottom (2 m) depths at Station 3 in 1982.

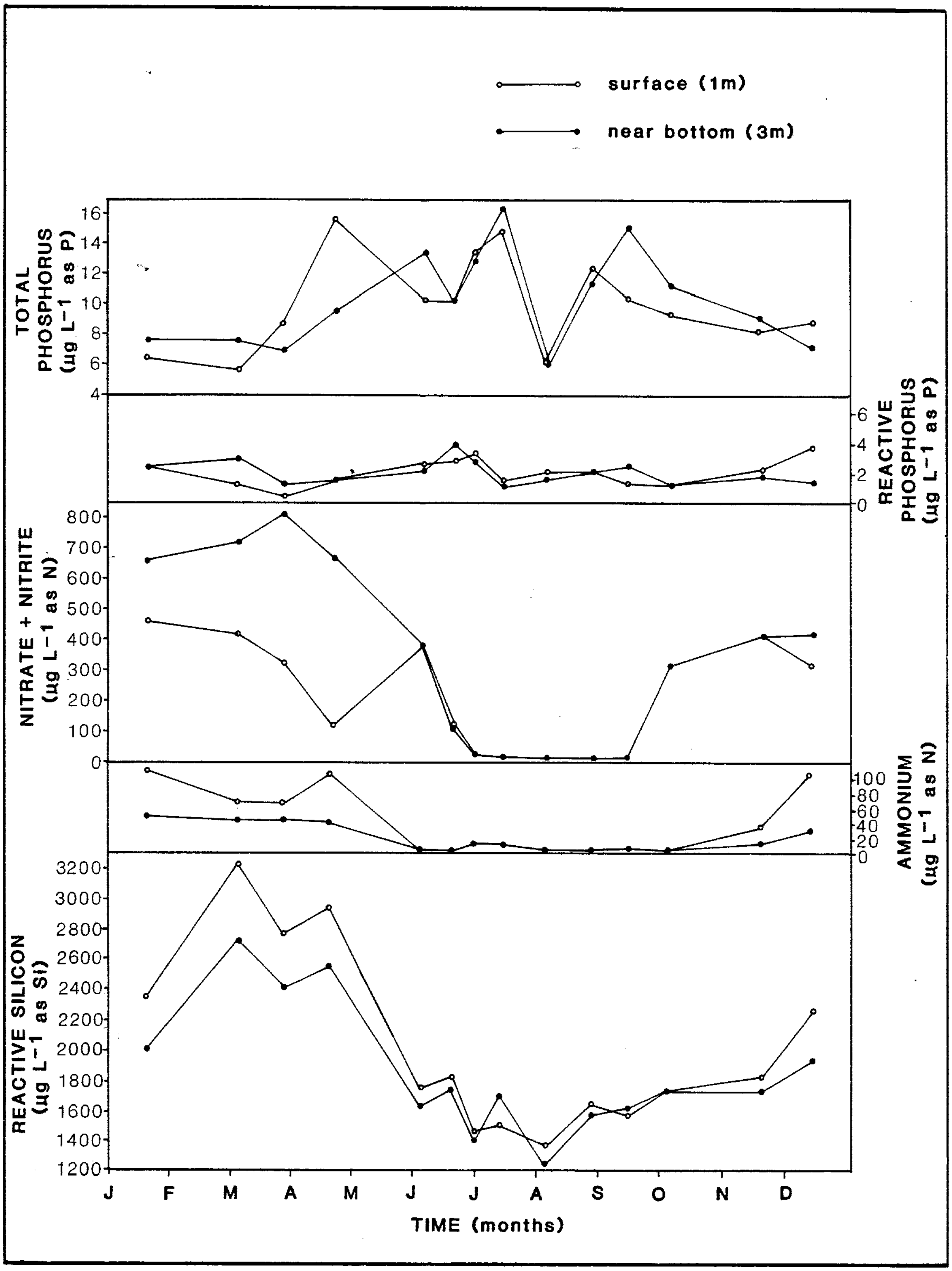


Figure 11. The seasonal dynamics of the algal nutrients phosphorus, nitrogen, and reactive silicon established for Robe Lake within the surface (1 m) and near-bottom (3m) depths at Station 4 in 1982.

Except for a brief period in January, reactive-phosphorus (RP) concentrations exceeded 1.0 ppb throughout the year, peaking at 4 to 6 ppb in June at both Stations 1 and 4 (Figures 8 and 11). Through most of the open-water period, RP levels fluctuated around 2.0 ppb, well above the 0.5 ppb detection limit of the analysis procedure. Thus RP concentrations were always detectable in Robe Lake at all stations and depths sampled.

In contrast to generally lower TP values under the ice and subsequent increasing levels during open-water periods, inorganic-nitrogen and reactive-silicon concentrations showed just the opposite seasonal cycle. The general pattern established at all four stations was for nitrate + nitrite to reach seasonal high levels at 700 to 800 ppb over the winter period under the ice (Figures 8, 9, 10, and 11). After ice-out, nitrate + nitrite nitrogen virtually disappeared from the water column, reaching analytically undetectable values by August. Thereafter, concentrations began to increase and by late December had recovered, reaching over 400 ppb. Similar trends were noted for ammonium nitrogen, although two time-separated processes seemed to be operating. Under-the-ice ammonium concentrations peaked in January and February and then slowly declined during March and April. At the same time, nitrate + nitrite values increased as ammonium concentrations fell. Apparently, the immediate product of decomposition (ammonium) was being converted to nitrate + nitrite by nitrification reactions. Following ice-out in May, nitrate + nitrite and ammonium levels became virtually undetectable (<1 ppb) during the summer period, rising only after the fall overturn.

Reactive-silicon (RS) concentrations followed the cyclic trend established by nitrate + nitrite concentrations because seasonal high levels occurred under the ice (Figures 8, 9, 10, and 11). Following ice-out, RS was quite rapidly removed from the water column. Again, as for nitrate + nitrite, RS levels began to rebuild after the fall overturn, reaching around 1800 ppb.

RS concentrations reached well over 3000 ppb under the ice, and although levels fell after ice-out, RS was maintained above 1200 ppb in the water column. Thus unlike nitrate + nitrite levels, RS concentrations never fell to levels approaching the analytical detection limits (10 ppb); and, unlike the nitrogen cycle, uptake by algae during the summer period did not outstrip its resupply from the watershed.

In summary, we found that the concentrations of algal nutrients followed similar seasonal patterns, but algal or macrophytic uptake of inorganic forms exceeded resupply during the summer only for the inorganic nitrogen species. For inorganic nitrogen to effectively balance the RP concentrations existing over the summer period, concentrations had to exceed 16-20 ppb. Concentrations of this magnitude were lacking for most of July, August, and part of September. Finally, another aspect of the chemistry of ammonium, which becomes important only after ammonium is released from decaying vegetation and is either converted to nitrate + nitrite or is metabolically removed from solution by algal cells, is its toxicity to aquatic organisms when converted to free ammonia ($NH_3$). This conversion is pH and temperature dependent and becomes critical at elevated total ammonium levels, because concentrations of $NH_3$ at or above 2 ppb are toxic to rearing fish. In Robe Lake, concentrations of total ammonium are low (August-September) when pH values are elevated (i.e., 8.0 to 8.2 units) and temperatures are high ~18°C. Under these conditions, $NH_3$ represents from 6% to 8% of the total ammonium within the water column and, as such, is of little concern to rearing fish.

<u>Phytoplankton Standing Crop (chl a)</u>

Phytoplankton standing crop was estimated through pigment analysis for both chlorophyll *a* (chl *a*) and for the chl *a* degradation product phaeophytin *a* (Tables 1, 2, 3, and 4).

Table 1. Algal pigment (ppb) and particulate organic carbon (ppb) concentrations at the 1- and 1.5-m depths within Robe Lake at Station 1 during 1982.

| Algal Pigments (ug $L^{-1}$) and Particulate Organic Carbon (ug $L^{-1}$ as C) | | | | | | |
|---|---|---|---|---|---|---|
| Depth | 1 m | | | 1.5 m | | |
| Date | Chl a | Phaeo a | POC | Chl a | Phaeo a | POC |
| 1-18-82 | 0.28 | 0.18 | 403 | 0.13 | 0.21 | 287 |
| 3-3-82 | 0.23 | 0.16 | 269 | 0.17 | 0.14 | 224 |
| 3-24-82 | 5.47 | 0.38 | 237 | 5.47 | 1.16 | 264 |
| 4-19-82 | 2.28 | 0.00 | 345 | 1.69 | 0.00 | 287 |
| 6-4-82 | 2.28 | 0.00 | | 1.69 | 0.02 | 408 |
| 6-17-82 | 0.99 | 0.47 | 272 | 0.99 | 0.39 | 227 |
| 6-30-84 | 1.37 | 0.00 | 166 | 1.52 | 0.00 | 131 |
| 7-14-82 | 2.43 | 0.27 | 301 | 2.74 | 1.09 | 390 |
| 8-3-82 | 2.77 | 3.92 | 490 | 4.35 | 3.88 | 443 |
| 8-23-82 | 1.32 | 0.69 | | 2.72 | 1.43 | |
| 9-13-82 | 0.92 | 0.00 | 217 | 0.66 | 0.02 | 429 |
| 10-5-82 | 5.77 | 0.19 | 372 | 36.51 | 0.49 | 278 |
| 11-19-82 | 0.60 | 0.15 | 154 | 0.50 | 0.17 | 219 |
| 12-14-82 | 0.20 | 0.07 | 139 | 0.09 | 0.06 | 256 |

Table 2. Algal pigment (ppb) and particulate organic carbon (ppb) concentrations at the 1- and 2-m depths within Robe Lake at Station 2 during 1982.

Algal Pigments (ug $L^{-1}$) and Particulate Organic Carbon (ug $L^{-1}$ as C)

| Depth | | 1 m | | | 2 m | |
|---|---|---|---|---|---|---|
| Date | Chl a | Phaeo a | POC | Chl a | Phaeo a | POC |
| 1-19-82 | 0.45 | 0.12 | 89 | 0.40 | 0.11 | 107 |
| 3-3-82 | 0.74 | 0.30 | 174 | 2.74 | 0.41 | 313 |
| 3-24-82 | 3.34 | 0.82 | 197 | 0.89 | 0.40 | 224 |
| 4-19-82 | 2.74 | | 282 | 1.37 | | 287 |
| 6-4-82 | 1.19 | 0.03 | 421 | 1.09 | 0.01 | 466 |
| 6-17-82 | 1.49 | 0.14 | 176 | 1.09 | 0.33 | 137 |
| 6-30-82 | 1.44 | | 201 | 1.67 | | 185 |
| 7-14-82 | 1.12 | 0.06 | 240 | 0.96 | 0.16 | 230 |
| 8-3-82 | 0.57 | 0.58 | 184 | 0.57 | 0.34 | 140 |
| 8-23-82 | 0.83 | 0.49 | | 0.88 | 0.47 | |
| 9-13-82 | 1.46 | 1.16 | 108 | 1.67 | 0.34 | 118 |
| 10-4-82 | 0.69 | 0.04 | 158 | 0.79 | 0.03 | 152 |
| 11-19-82 | 0.89 | 0.12 | 270 | 0.69 | 0.14 | 182 |
| 12-14-82 | 0.11 | 0.06 | 80 | 0.35 | 0.09 | 105 |

Table 3. Algal pigment (ppb) and particulate organic carbon (ppb) concentrations at the 1- and 2-m depths within Robe Lake at Station 3 during 1982.

| Algal Pigments (ug $L^{-1}$) and Particulate Organic Carbon (ug $L^{-1}$ as C) | | | | | | |
|---|---|---|---|---|---|---|
| Depth | | 1 m | | | 2 m | |
| Date | Chl a | Phaeo a | POC | Chl a | Phaeo a | POC |
| 1-19-82 | 0.26 | 0.17 | 157 | 0.21 | 0.23 | 421 |
| 3-1-82 | 0.37 | 0.26 | 166 | 0.29 | 0.21 | 448 |
| 3-26-82 | 0.67 | 0.18 | 89 | 0.67 | 0.57 | 139 |
| 4-21-82 | 0.91 | 0.33 | 89 | 0.20 | 0.19 | 264 |
| 6-3-82 | 1.39 | 0.17 | 497 | 1.59 | 0.16 | 444 |
| 6-16-82 | 8.52 | | 397 | 7.60 | | 422 |
| 7-1-82 | 0.91 | 0.83 | 294 | 0.76 | 1.04 | 233 |
| 7-13-82 | 0.64 | 0.43 | 198 | 0.64 | 0.54 | 192 |
| 8-3-82 | 1.14 | 0.83 | 211 | 1.32 | 1.05 | 232 |
| 8-24-82 | 0.75 | 0.42 | | 0.79 | 0.45 | |
| 9-14-82 | 0.83 | 0.09 | 72 | 1.04 | 0.11 | 158 |
| 10-4-82 | 0.99 | 0.15 | 129 | 0.99 | 0.21 | 157 |
| 11-16-82 | 1.16 | 0.35 | 130 | 0.26 | 0.13 | 120 |
| 12-14-82 | 0.25 | 0.08 | 74 | 0.30 | 0.09 | 194 |

Table 4. Algal pigment (ppb) and particulate organic carbon (ppb) concentrations at the 1- and 3-m depths within Robe Lake at Station 4 during 1982.

| Algal Pigments (ug $L^{-1}$) and Particulate Organic Carbon (ug $L^{-1}$ as C) | | | | | | |
|---|---|---|---|---|---|---|
| Depth | | 1 m | | | 3 m | |
| Date | Chl a | Phaeo a | POC | Chl a | Phaeo a | POC |
| 1-19-82 | 0.11 | .07 | 85 | 0.13 | 0.09 | 76 |
| 3-1-82 | 0.41 | 0.13 | 246 | 0.44 | 0.21 | 197 |
| 3-26-82 | 2.13 | 1.70 | 237 | 2.28 | 0.59 | 313 |
| 4-21-82 | 3.55 | 0.83 | 291 | 1.04 | 0.19 | 672 |
| 6-3-82 | 2.26 | 0.00 | 515 | 1.91 | 0.23 | 479 |
| 6-16-82 | 6.51 | 0.00 | 490 | 4.73 | 0.00 | 445 |
| 7-1-82 | 3.65 | 1.30 | 365 | 3.04 | 1.32 | 294 |
| 7-13-82 | 2.74 | 1.65 | 381 | 1.22 | 2.05 | 329 |
| 8-3-82 | 1.93 | 0.97 | 320 | 1.91 | 1.02 | 291 |
| 8-24-82 | 1.41 | 0.49 | | 1.19 | 0.50 | |
| 9-14-82 | 2.13 | 0.23 | 238 | 2.96 | 0.33 | 179 |
| 10-4-82 | 4.73 | 3.15 | 180 | 4.14 | 1.99 | 272 |
| 11-16-82 | 1.29 | 0.14 | 188 | 0.60 | 0.17 | 127 |
| 12-14-82 | 0.20 1/ | 0.07 1/ | 176 | 0.30 | 0.07 | 133 |

1/ Some sample lost during analysis procedure - may be a low value.

At Stations 1 and 2 (nearest the lake outlet), chl _a_ levels at 1.0 m increased under the ice to 5.47 ppb at Station 1 and 3.34 ppb at Station 2 during March. Throughout the year, concentrations of chl _a_ at both stations exceeded these levels only once, reaching 5.77 ppb on 5 October at Station 1. In contrast, chl _a_ levels at both Stations 3 and 4 peaked in mid-June (after ice-out) at 8.52 and 6.51 ppb, respectively.

A second, more muted peak in chl _a_ occurred in the fall at all stations during September through November. Peak concentrations were 5.77 ppb (Station 1), 1.45 ppb (Station 2), 1.16 ppb (Station 3), and 4.73 ppb (Station 4). Minimal levels of chl _a_ during the open-water period occurred in late summer (August-September); levels were reduced to 0.92 ppb (Station 1), 0.57 ppb (Station 2), 0.75 ppb (Station 3), and 1.41 ppb (Station 4). Overall, mean annual chl _a_ concentrations at Stations 1-4 equalled 1.92 ppb (n=14), 1.22 ppb (n=14), 1.34 ppb (n=14), and 2.36 ppb (n=14), respectively; annual minima were recorded in midwinter (December-January) and annual maxima occurred in the spring (either under the ice or just after ice-out).

In addition to the algal biomass of the surface strata, we observed significant concentrations of chl _a_ near the bottom of the lake at all stations. Annual chl _a_ concentrations averaged 1.75 ppb (n=13) or over 90% of the surface strata chl _a_ concentrations at Station 1 (36.51 ppb recorded on 5 October was not included). Similarly, Stations 2-4 averaged 1.08 ppb (n=14), 1.19 ppb (n=14), and 1.85 ppb (n=14), respectively. Finally, phaeophytin _a_ concentrations became a significant part of the algal pigments during July, August, and September as well as December, January, and early March. Thus during both the late winter-spring period and the subsequent fall period when chl _a_ levels were reaching either seasonal or annual peaks, algal populations were very robust, and cells contained little degraded chl _a_; i.e., phaeophytin.

Aquatic Macrophyte Standing Crop

We established the seasonal pattern in macrophyte growth by following biomass accrual throughout the open-water period (Figure 12). Biomass associated with old-growth stands (17.1 $g/m^2$ dry weight) was estimated from six samples taken before new growth was initiated (23-24 June). Corresponding to the three transect locations in the lake, three distinct growth patterns were observed. Transect 1, located nearest the outlet in the shallowest zone, showed the largest seasonal growth response by 26-27 July, expanding to over 66.3 $g/m^2$. Transect 2, located at midlake at an intermediate depth, showed little growth (19.5 $g/m^2$); while Transect 3, located near Station 4 across the deepest part of the lake, had a biomass of 35.2 $g/m^2$. Thus initiation of the new stands of growth was substantially in place by the last week in July.

Specific growth patterns of each transect were observed over the remaining growth period. Transect 1 showed a continuation of growth until mid-August, when biomass accrual ceased, and then standing crop remained constant (110 $g/m^2$ to 120 $g/m^2$) until the end of September. Transect 2 showed a similar seasonal pattern, except for being compressed in both time and in overall magnitude. Peak biomass levels were formed by the end of August at 87 $g/m^2$; however, by mid-August 74.8 $g/m^2$ biomass had already been accrued. Finally, at Transect 3 we observed a further seasonal compression in biomass accrual, but we did find peak biomass levels at the end of August (82.9 $g/m^2$) to be similar to those at Transect 2. However, in contrast to Transect 2, Transect 3 biomass levels during mid-August equalled only 39.5 $g/m^2$ (48% of peak), compared to 86% of peak at Transect 2 and 100% of peak at Transect 3. In general, the macrophytes began to undergo senescence by the middle of September, reaching close to old-growth levels by the middle of October. Thus we considered July

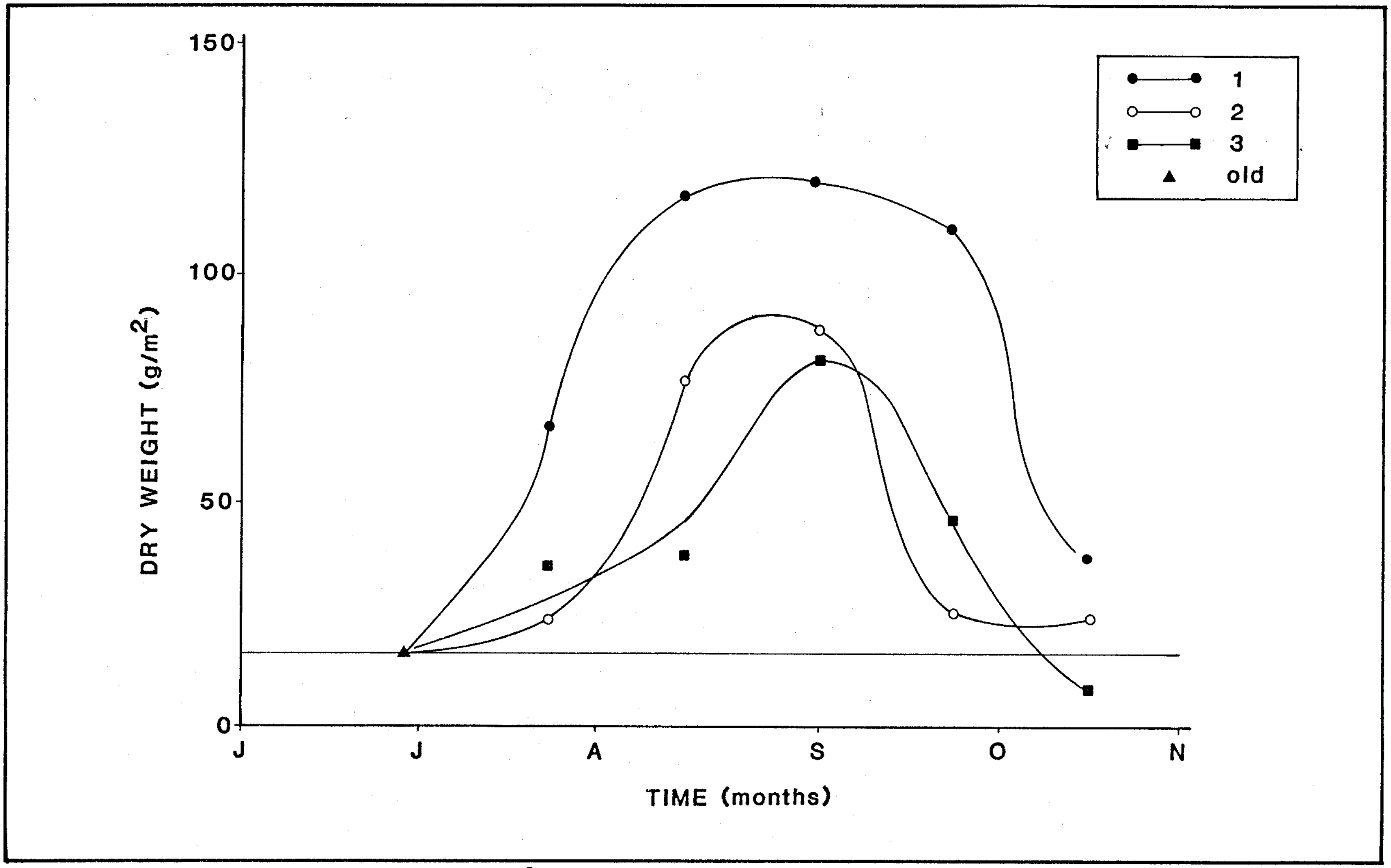


Figure 12. The dry weight biomass (g/m$^2$) accrual of aquatic macrophytes near the lake outlet (Transect 1), midlake (Transect 2), and east end (Transect 3) at Robe Lake in 1982.

through August as the active growth period, and we used biomass levels at the end of August for estimating maximal tonnage of growth to be removed from the lake by mechanical harvesting.

In addition to the biomass accrual patterns, we also estimated dry and ash weights and the nitrogen and phosphorus content of the macrophytes. We found that the dry weight biomass not only varied seasonally but also in terms of its percentage of wet weight. In mid-August the water content of the macrophyte stands ranged from 88.7% to 90.1%, compared to 92.6% to 94.2% for mid-October. Thus a consistent trend was observed for the macrophytes to gain water (or lose dry weight) after mid-August (the period after peak biomass was recorded) at each of the three transects. Overall, water represented 90.8% (n=40) of the wet-weight biomass. The carbon content of the macrophyte stands ranged from 18.6% to 38.2% of dry weight and averaged 25.0% (n=40). Thus for every 100 g (wet weight) of macrophyte, water comprised 90.8 g, and of the remaining 9.2 g, carbon contained 2.3 g. Finally, because of our interest in the relative role of the macrophytes in the nutrient economy of the lake, we determined the nitrogen (N) and phosphorus (P) content as well as that of carbon. On the average, the macrophytes contained 220 mg C/g of dried macrophyte, compared to 22.4 mg N/g and 2.6 mg P/g, or a C:N:P atom ratio of 219:19:1.

Zooplankter Density and Community Composition

The zooplankton community of Robe Lake was composed of five taxa of cladoceran, two taxa of copepods, and three genera of rotifers (Tables 5, 6, 7, and 8). The cladoceran component consisted of three pond-dwelling species that usually inhabit the weedy fringes of lakes (*Chydorus* sp., *Ceriodaphnia* sp., and *Sida crystallina*) as well as two species that can also be found in the limnetic area (*Bosmina longirostris* and *Holopedium gibberum*). The copepod component consisted of *Cyclops* sp. and a benthic-

Table 5. Seasonal density patterns of zooplankters by taxa within Robe Lake during 1981-1982 at Station 1.

| | Number/m² | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1981 | 1982 | | | | | | | | | | | | |
| Date | 12/18 | 01/18 | 03/03 | 03/24 | 04/19 | 06/04 | 06/17 | 06/30 | 07/14 | 08/03 | 08/23 | 09/13 | 10/05 | 12/14 |
| *Bosmina longirostris* | -- | -- | -- | -- | -- | 28 | 294 | 486 | 736 | 34 | 137 | 144 | 48 | -- |
| *Ceriodaphnia* | -- | -- | -- | -- | -- | -- | 7 | -- | -- | -- | 20 | -- | -- | -- |
| *Chydorinae* | 35 | 14 | -- | 41 | 82 | 7 | -- | 34 | 6,909 | 48 | 363 | 165 | 89 | 14 |
| *Sididae (Sida Crystallina)* | -- | -- | -- | -- | -- | 7 | -- | -- | -- | -- | -- | 7 | -- | -- |
| *Holopedium gibberum* | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Subtotal (cladocera) | 35 | 14 | -- | 41 | 82 | 42 | 301 | 520 | 7,645 | 82 | 520 | 316 | 137 | 14 |
| *Cyclops* sp. | 55 | 14 | 7 | -- | 7 | -- | 123 | 41 | 4,326 | 89 | 1,231 | 315 | 28 | 137 |
| *Diaptomus* | | | | | | | | | | | | | | |
| Harpacticoid sp. | -- | -- | -- | -- | -- | -- | -- | 376 | 975 | 34 | 205 | 75 | 69 | -- |
| Subtotal (copepod) | 55 | 14 | 7 | -- | 7 | -- | 123 | 417 | 5,301 | 123 | 1,436 | 390 | 97 | 137 |
| Total macro-zooplankton | 90 | 28 | 7 | 41 | 89 | 42 | 424 | 937 | 12,946 | 205 | 1,956 | 706 | 234 | 151 |
| *Kellicottia longispina* | -- | -- | -- | -- | -- | -- | -- | -- | 240 | -- | 21 | -- | -- | -- |
| *Asplachia* sp. | 7 | 7 | -- | 7 | -- | -- | 308 | 171 | -- | -- | -- | -- | -- | -- |
| *Karatella* sp. | -- | -- | -- | -- | -- | -- | 14 | -- | -- | -- | 274 | -- | -- | -- |
| Other | -- | -- | -- | -- | -- | -- | 14 | 7 | 1,488 | 28 | 41 | 7 | 21 | -- |

Table 6. Seasonal density patterns of zooplankters by taxa within Robe Lake during 1981-1982 at Station 2.

| | Number/m$^2$ | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1981 | 1982 | | | | | | | | | | | | | |
| Date | 12/18 | 01/18 | 03/03 | 03/24 | 04/19 | 06/04 | 06/17 | 06/30 | 07/14 | 08/03 | 08/23 | 09/13 | 10/05 | 11/16 | 12/14 |
| *Bosmina longirostris* | -- | -- | -- | -- | -- | 41 | 376 | 1,067 | 5,383 | 110 | 110 | 274 | 164 | -- | 7 |
| *Ceriodaphnia* | -- | -- | -- | -- | -- | -- | -- | 7 | 69 | 21 | 21 | -- | -- | -- | -- |
| *Chydorinae* | 49 | -- | -- | 21 | -- | 14 | 28 | 21 | 800 | 48 | 21 | 14 | 7 | -- | 28 |
| *Sididae (Sida crystallina)* | -- | -- | -- | -- | -- | -- | -- | -- | 69 | 14 | -- | -- | -- | -- | -- |
| *Holopedium gibberum* | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Subtotal (cladocera) | 48 | -- | -- | 21 | -- | 55 | 404 | 1,095 | 6,321 | 193 | 151 | 288 | 171 | -- | 35 |
| *Cyclops* sp. | 62 | 7 | -- | -- | -- | 7 | 185 | 109 | 669 | 253 | 151 | 27 | -- | -- | 130 |
| *Diaptomus* sp. | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Harpacticoid sp. | -- | -- | -- | -- | -- | -- | -- | 630 | 1,416 | 985 | 2,914 | 206 | 75 | -- | -- |
| Subtotal (copepod) | 62 | 7 | -- | -- | -- | 7 | 185 | 739 | 2,085 | 1,238 | 3,065 | 233 | 75 | -- | 130 |
| Total macro-zooplankton | 110 | 7 | -- | 21 | -- | 62 | 589 | 1,834 | 8,406 | 1,431 | 3,217 | 521 | 246 | -- | 164 |
| *Kellicottia longispina* | -- | 7 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| *Asplanchia* sp. | 14 | 75 | -- | 35 | -- | 7 | 671 | 165 | 48 | -- | -- | -- | -- | -- | -- |
| *Karatella* | -- | -- | -- | -- | -- | -- | -- | -- | -- | 21 | 21 | -- | -- | -- | -- |
| Chironomid larvae | -- | -- | -- | -- | -- | 7 | 7 | -- | 89 | 69 | -- | -- | -- | -- | -- |

Table 7. Seasonal density patterns of zooplankters by taxa within Robe Lake during 1981-1982 at Station 3.

| | Number/m$^2$ | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1981 | 1982 | | | | | | | | | | | | | |
| Date | 12/17 | 01/19 | 03/01 | 03/26 | 04/21 | 06/03 | 06/17 | 06/30 | 07/13 | 08/02 | 08/24 | 09/14 | 10/04 | 11/16 | 12/13 |
| *Bosmina longirostris* | -- | -- | -- | -- | -- | 41 | 445 | 1,259 | 7,356 | 62 | 96 | 876 | 117 | -- | -- |
| *Ceriodaphnia* | -- | -- | -- | -- | -- | -- | 14 | -- | 31 | 28 | 7 | -- | -- | -- | -- |
| *Chydorinae* | 14 | -- | -- | -- | -- | 14 | 14 | 206 | 103 | 28 | 7 | 41 | 48 | 178 | 82 |
| *Sididae (Sida crystallina)* | -- | -- | -- | -- | -- | -- | -- | -- | -- | 7 | -- | -- | -- | -- | -- |
| Subtotal (cladocera) | 14 | -- | -- | -- | -- | 55 | 473 | 1,465 | 7,490 | 125 | 110 | 917 | 165 | 178 | 82 |
| *Cyclops* sp. | 14 | -- | -- | -- | -- | 14 | 199 | 431 | 411 | 55 | 7 | 41 | -- | 144 | 48 |
| Harpacticoid | -- | -- | -- | -- | -- | -- | -- | 616 | 1,642 | 192 | 479 | 246 | 171 | -- | -- |
| Subtotal (copepod) | 14 | -- | -- | -- | -- | 14 | 199 | 1,047 | 2,053 | 247 | 486 | 287 | 171 | 144 | 48 |
| Total macro-zooplankton | 28 | -- | -- | -- | -- | 69 | 672 | 2,512 | 9,543 | 372 | 596 | 1,204 | 336 | 322 | 130 |
| *Kellicottia longispina* | -- | -- | -- | -- | -- | -- | -- | 48 | -- | -- | -- | -- | -- | -- | -- |
| *Asplanchia* | 27 | 41 | 14 | -- | -- | 28 | 1,793 | 773 | -- | 7 | -- | -- | -- | -- | -- |
| *Karatella* | -- | -- | -- | -- | -- | -- | -- | -- | -- | 41 | -- | -- | -- | -- | -- |
| Chironomid larvae | -- | -- | -- | -- | -- | -- | -- | -- | -- | 41 | -- | -- | -- | -- | -- |
| Other | -- | -- | -- | -- | -- | 185 | 21 | 117 | 31 | -- | -- | -- | -- | 21 | 7 |

Table 8. Seasonal density patterns of zooplankters by taxa within Robe Lake during 1981-1982 at Station 4.

| | Number/m² | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1981 | 1982 | | | | | | | | | | | | | |
| Date | 12/18 | 01/19 | 03/01 | 03/26 | 04/21 | 06/03 | 06/16 | 07/01 | 07/13 | 08/02 | 08/24 | 09/14 | 10/05 | 11/16 | 12/13 |
| *Bosmina longirostris* | -- | -- | -- | -- | -- | 27 | 499 | 7,073 | 77,702 | 17,613 | 2,305 | 3,942 | 349 | -- | -- |
| *Ceriodaphnia* | -- | -- | -- | -- | -- | -- | 48 | -- | 1,368 | 1,026 | 48 | -- | -- | -- | -- |
| *Chydorinae* | 48 | -- | -- | -- | 14 | 14 | 20 | 137 | 479 | -- | 21 | 199 | 130 | -- | -- |
| *Sididae (Sida crystallina)* | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Subtotal (cladocera) | 48 | -- | -- | -- | 14 | 41 | 567 | 7,210 | 79,549 | 18,639 | 2,374 | 4,141 | 479 | -- | -- |
| *Cyclops* sp. | -- | 7 | -- | -- | -- | 7 | 411 | 1,546 | 3,215 | 2,223 | 212 | 301 | 55 | 7 | 7 |
| Harpacticoid sp. | -- | -- | -- | -- | -- | -- | -- | 6,662 | 3,899 | 1,710 | 500 | 370 | 206 | -- | -- |
| Subtotal (copepod) | -- | 7 | -- | -- | -- | 7 | 411 | 8,208 | 7,114 | 3,933 | 712 | 671 | 261 | 7 | 7 |
| Total macro-zooplankton | 48 | 7 | -- | -- | 14 | 48 | 978 | 15,418 | 86,663 | 22,572 | 3,086 | 4,812 | 740 | 7 | 7 |
| *Kellicottia longispina* | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| *Asplanchia* | 137 | 96 | 7 | 48 | -- | 21 | 4,173 | 5,335 | -- | 513 | -- | 82 | 21 | 27 | 7 |
| *Karatella* | -- | -- | -- | -- | -- | -- | -- | 137 | 479 | 1,585,158 | 21 | -- | -- | -- | -- |
| Chironomid larvae | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 7 | 14 | -- | -- |
| Other | -- | -- | -- | -- | -- | -- | 69 | 274 | 3,146 | 45,144 | -- | -- | 41 | -- | -- |

dwelling species of Harpacticoid that are characteristically associated with the bottom sediments or vegetation of shallow lakes or ponds. In addition to the macro-zooplankton, Robe Lake supported populations of the rotifers *Kellicottia longispina*, *Asplanchia* sp., and *Karatella* sp.

Generally, the population densities of all species were extremely sparse prior to July and after November, especially at the shallower Stations 1, 2, and 3. In addition, peak population densities of the filter-feeding macro-zooplankters were observed in July and August, especially at the more limnetic Station 4. However, throughout the lake, zooplankters responded to open-water conditions by increasing population sizes, probably as a response to warmer temperatures.

Seasonal density patterns of the macro-zooplankters were fairly uniform in time. *Bosmina* peaked in density at 77,702 organisms/$m^2$, *Ceriodaphnia* at 1,368/$m^2$, and *Chydorus* at 800/$m^2$; with the exception of *Chydorus*, these density patterns peaked at Station 4. Compared to the densities established for the above taxa, *Sida crystallina* and *Holopedium gibberum* made sporadic appearances in the zooplankton assemblage but were never numerous.

The seasonal density patterns for the copepods generally followed that of the cladocerans; *Cyclops* sp. density peaked on 14 July at Station 1 (4,326/$m^2$) and Station 4 (3,215/$m^2$). Harpacticoid copepods peaked in density on 1 July at Station 4 (6,662/$m^2$). Additionally, the density of this group, in particular, seemed to peak soon after ice-out and then to slowly decline throughout the summer season. Moreover, for most of the numerically abundant forms of zooplankton, peak densities were observed in July and, characteristically, at the deepest of the four sampling stations. Not surprisingly, a majority of the species found in Robe Lake are normally associated with weed-infested margins or bottom deposits of lakes. Only *Bosmina*, which is abundant within the limnetic area of most Alaskan lakes, reached meaningful densities, and those were restricted to one station during a single sampling period. Thus, relative to zooplankton communities associated with deeper lakes, the densities exhibited by the individual taxa in Robe Lake were virtually nonexistent. Corroborating this point was the total absence of the limnetic-dwelling species of copepods *Diaptomus* and *Epischura*, along with the usually ubiquitous cladoceran *Daphnia longiremis*. Finally, as with the various forms of macro-zooplankters, the numerical density of the open-water rotifers was sparse as well as sporadic. Only *Karetella* sp. reached a significant density, but like *Bosmina* this was restricted to a single sampling period (2 August) at Station 4.

In any discussion of zooplankter communities, the body-size of the individual taxa (Tables 9, 10, 11, and 12) is equally important to species composition and numerical density considerations, and Robe Lake lags behind most Alaskan lakes in this area. Particularly, the body-sizes exhibited by *Bosmina* at the four stations were consistently below a threshold size necessary for effective capture, even by obligate planktivores such as sockeye salmon fry. Thus, without exception, the body-size of *Bosmina* on any sample date or location was below 0.40 mm; the largest *Bosmina* counted exceed 0.50 mm only once (17 June). Likewise, the body-size for the numerically weak *Chydorus* consistently fell under 0.40 mm; however, the body-size of the even less numerous *Ceriodaphnia* was slightly larger. Only the Harpacticoid copepod and *Cyclops* sp. achieved body-sizes of significance to vertebrate planktivores, as seasonal body-sizes often exceeded 0.55 mm for the Harpacticoids and 0.70 mm for *Cyclops* sp. Yet given the vastly superior escape ability of the copepods and their relatively small size (< 1.00 mm), fish predation on these individuals would be relatively inefficient.

Table 9. Seasonal mean and weighted seasonal mean body-size (mm) and range of body-sizes for zooplankters within Robe Lake at Station 1 during 1981-1982.

| Date | Body size | Number m$^2$ | Size weighted | Range | Body size | Number m$^2$ | Size weighted | Range | Body size | Number m$^2$ | Size weighted | Range |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Cyclops* | | | | *Chydorinae* | | | | *Bosmina* | | | |
| 12/18/81 | .99 | 55 | 54 | .67-1.15 | .32 | 35 | 11 | .24-.36 | -- | -- | -- | -- |
| 01/18/82 | .76 | 14 | 11 | .67- .84 | .33 | 14 | 5 | .32-.33 | -- | -- | -- | -- |
| 03/24/82 | -- | -- | -- | -- | .24 | 41 | 10 | .22-.28 | -- | -- | -- | -- |
| 04/19/82 | -- | -- | -- | -- | .27 | 82 | 22 | .23-.32 | -- | -- | -- | -- |
| 06/04/82 | -- | -- | -- | -- | .22 | 7 | 2 | .22 | .30 | 28 | 8 | .28-.36 |
| 06/17/82 | .42 | 123 | 52 | .37- .47 | -- | -- | -- | -- | .36 | 294 | 106 | .26-.58 |
| 06/30/82 | .70 | 41 | 29 | .50- .98 | .34 | 34 | 12 | .31-.37 | .30 | 486 | 146 | .23-.39 |
| 07/14/82 | .76 | 4,326 | 3,288 | .43- .93 | .30 | 2,073 | 6,909 | .22-.38 | .33 | 736 | 243 | .26-.43 |
| 08/03/82 | .46 | 89 | 41 | .41- .58 | .33 | 48 | 16 | .24-.38 | -- | -- | -- | -- |
| 08/23/82 | .52 | 1,231 | 640 | .40- .70 | .29 | 363 | 105 | .21-.36 | .28 | 137 | 38 | .26-.31 |
| 09/13/82 | .65 | 315 | 205 | .42-1.28 | .31 | 165 | 51 | .23-.36 | .27 | 144 | 39 | .21-.30 |
| 10/05/82 | .44 | 28 | 12 | .35- .52 | .29 | 89 | 26 | .21-.33 | .32 | 48 | 15 | .28-.36 |
| 12/14/82 | 1.14 | 137 | 156 | .56-1.72 | -- | -- | -- | -- | -- | -- | -- | -- |
| | Σ=6.84<br>x̄=.68 | Σ=6,359 | Σ=4,488<br>x̄=.71 | .35-1.72 | Σ=3.24<br>x̄=.29 | Σ=7,787 | Σ=2,333<br>x̄=.30 | .21-.38 | Σ=2.16<br>x̄=.31 | Σ=1,873 | Σ=595<br>x̄=.32 | .21-.58 |

| Date | Body size | Number m$^2$ | Size weighted | Range | Body size | Number m$^2$ | Size weighted | Range |
|---|---|---|---|---|---|---|---|---|
| | Harpacticoid | | | | *Ceriodaphnia* | | | |
| 12/18/81 | -- | -- | -- | -- | -- | -- | -- | -- |
| 01/18/82 | -- | -- | -- | -- | -- | -- | -- | -- |
| 03/24/82 | -- | -- | -- | -- | -- | -- | -- | -- |
| 04/19/82 | -- | -- | -- | -- | -- | -- | -- | -- |
| 06/04/82 | -- | -- | -- | -- | -- | -- | -- | -- |
| 06/17/82 | -- | -- | -- | -- | -- | -- | -- | -- |
| 06/30/82 | .51 | 376 | 146 | .23-.39 | -- | -- | -- | -- |
| 07/14/82 | .59 | 975 | 575 | .47-.80 | -- | -- | -- | -- |
| 08/03/82 | .49 | 34 | 17 | .38-.59 | -- | -- | -- | -- |
| 08/23/82 | .48 | 205 | 98 | .39-.63 | .87 | 20 | 17 | .82-.92 |
| 09/13/82 | .57 | 75 | 43 | .57 | -- | -- | -- | -- |
| 10/05/82 | .49 | 69 | 34 | .37-.56 | -- | -- | -- | -- |
| 12/14/82 | -- | -- | -- | -- | -- | -- | -- | -- |
| | Σ=3.13<br>x̄=.31 | Σ=1,873 | Σ=595<br>x̄=.55 | .21-.58 | | | | |

Table 10. Seasonal mean and weighted seasonal mean body-size (mm) and range of body-sizes for zooplankters within Robe Lake at Station 2 during 1981-1982.

| Date | Body size | Number $m^2$ | Size weighted | Range | Body size | Number $m^2$ | Size weighted | Range | Body size | Number $m^2$ | Size weighted | Range |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Cyclops* | | | | *Chydorinae* | | | | *Bosmina* | | | |
| 12/18/81 | 1.03 | 62 | 64 | .69-1.06 | .28 | 48 | 13 | .26-.30 | -- | -- | -- | -- |
| 01/18/82 | .97 | 7 | 7 | .97 | -- | -- | -- | -- | -- | -- | -- | -- |
| 03/24/82 | -- | -- | -- | -- | .25 | 21 | 5 | .23-.27 | -- | -- | -- | -- |
| 04/19/82 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 06/04/82 | -- | -- | -- | -- | .44 | 14 | 6 | .30-.57 | -- | -- | -- | -- |
| 06/17/82 | .44 | 185 | 81 | .37- .51 | .44 | 28 | 12 | .36-.55 | .37 | 376 | 139 | .25-.50 |
| 06/30/82 | .62 | 109 | 68 | .38- .74 | -- | -- | -- | -- | .30 | 1,067 | 320 | .22-.38 |
| 07/14/82 | .48 | 669 | 321 | .37- .99 | .33 | 800 | 264 | .25-.39 | .33 | 5,383 | 1,776 | .24-.46 |
| 08/03/82 | .46 | 253 | 116 | .38- .68 | .30 | 48 | 14 | .30 | -- | -- | -- | -- |
| 08/23/82 | .54 | 151 | 82 | .42- .75 | -- | -- | -- | -- | .26 | 110 | 29 | .21-.28 |
| 09/13/82 | .70 | 27 | 19 | .47- .88 | -- | -- | -- | -- | .29 | 274 | 79 | .26-.31 |
| 10/05/82 | -- | -- | -- | -- | -- | -- | -- | -- | .35 | 164 | 57 | .31-.39 |
| 11/16/82 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 12/14/82 | 1.28 | 130 | 166 | .71-1.64 | .32 | 28 | -- | .30-.33 | -- | -- | -- | -- |
| | $\Sigma$=6.52 $\bar{x}$=.72 | $\Sigma$=1,593 | $\Sigma$=924 $\bar{x}$=.58 | .37-.99 | $\Sigma$=2.36 $\bar{x}$=.34 | $\Sigma$=959 | $\Sigma$=314 $\bar{x}$=.33 | .23-.55 | $\Sigma$=1.90 $\bar{x}$=.32 | $\Sigma$=7,374 | $\Sigma$=2,400 $\bar{x}$=.33 | .21-.50 |
| | Harpacticoid | | | | *Ceriodaphnia* | | | | *Sididae* | | | |
| 12/18/81 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 01/18/82 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 03/24/82 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 04/19/82 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 06/04/82 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 06/17/82 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 06/30/82 | .49 | 630 | 309 | .34-.60 | -- | -- | -- | -- | -- | -- | -- | -- |
| 07/14/82 | .53 | 1,416 | 750 | .48-.61 | .34 | 69 | 23 | .31-.38 | 1.16 | 69 | 80 | .83-1.66 |
| 08/03/82 | .52 | 985 | 512 | .44-.61 | .34 | 21 | 7 | .28-.44 | -- | -- | -- | -- |
| 08/23/82 | .52 | 2,914 | 1,515 | .44-.61 | .44 | 21 | 9 | .36-.51 | -- | -- | -- | -- |
| 09/13/82 | .55 | 206 | 113 | .43-.63 | -- | -- | -- | -- | -- | -- | -- | -- |
| 10/05/82 | .55 | 75 | 41 | .48-.60 | -- | -- | -- | -- | -- | -- | -- | -- |
| 11/16/82 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 12/14/82 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| | $\Sigma$=3.16 $\bar{x}$=.53 | $\Sigma$=6,226 | $\Sigma$=3,240 $\bar{x}$=.52 | .34-.63 | $\Sigma$=1.12 $\bar{x}$=.37 | $\Sigma$=111 | $\Sigma$=.39 $\bar{x}$=.52 | .28-.51 | | | | |

Table 11. Seasonal mean and weighted seasonal mean body-size (mm) and range of body-sizes for zooplankters within Robe Lake at Station 3 during 1981-1982.

| Date | Body size | Number m² | Size weighted | Range | Body size | Number m² | Size weighted | Range | Body size | Number m² | Size weighted | Range |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Cyclops* | | | | *Chydorinae* | | | | *Bosmina* | | | |
| 12/18/81 | 1.27 | 14 | 18 | 1.10-1.43 | -- | -- | -- | -- | -- | -- | -- | -- |
| 01/18/82 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 03/24/82 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 04/19/82 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 06/04/82 | .61 | 14 | 9 | .60- .61 | .30 | 14 | 4 | .24-.36 | .36 | 41 | 15 | .28-.40 |
| 06/17/82 | .49 | 199 | 98 | .37- .67 | -- | -- | -- | -- | .37 | 445 | 165 | .26-.48 |
| 07/01/82 | .53 | 431 | 228 | .41- .90 | .38 | 206 | 78 | .30-.53 | .32 | 1,259 | 403 | .27-.42 |
| 07/13/82 | .53 | 411 | 218 | .41- .86 | .34 | 103 | 35 | .31-.38 | .33 | 7,356 | 2,427 | .30-.41 |
| 08/02/82 | .50 | 55 | 28 | .42- .71 | .31 | 28 | 9 | .29-.33 | .31 | 62 | 19 | .27-.38 |
| 08/24/82 | -- | -- | -- | -- | -- | -- | -- | -- | .26 | 96 | 25 | .23-.28 |
| 09/13/82 | .54 | 41 | 22 | .39- .90 | .31 | 41 | 13 | .30-.31 | .30 | 876 | 263 | .23-.33 |
| 10/05/82 | -- | -- | -- | -- | .34 | 48 | 16 | .30-.37 | .34 | 117 | 40 | .28-.37 |
| 11/16/82 | .97 | 144 | 140 | .48-1.16 | .29 | 178 | 52 | .21-.39 | -- | -- | -- | -- |
| 12/14/82 | 1.28 | 48 | 61 | 1.22-1.36 | .31 | 82 | 25 | .28-.35 | -- | -- | -- | -- |
| | Σ=6.72<br>x̄=.75 | Σ=1,357 | Σ=804<br>x̄=.59 | .39-1.36 | Σ=2.58<br>x̄=.32 | Σ=700 | Σ=232<br>x̄=.33 | .21-.53 | Σ=2.59<br>x̄=.32 | Σ=10,252 | Σ=3,357<br>x̄=.33 | .23-.48 |
| | Harpacticoid | | | | *Certodaphnia* | | | | | | | |
| 12/18/81 | -- | -- | -- | -- | -- | -- | -- | -- | | | | |
| 01/18/82 | -- | -- | -- | -- | -- | -- | -- | -- | | | | |
| 03/24/82 | -- | -- | -- | -- | -- | -- | -- | -- | | | | |
| 04/19/82 | -- | -- | -- | -- | -- | -- | -- | -- | | | | |
| 06/04/82 | -- | -- | -- | -- | -- | -- | -- | -- | | | | |
| 06/17/82 | -- | -- | -- | -- | -- | -- | -- | -- | | | | |
| 07/01/82 | .51 | 616 | 314 | .41-.67 | -- | -- | -- | -- | | | | |
| 07/13/82 | .56 | 1,642 | 920 | .46-.65 | -- | -- | -- | -- | | | | |
| 08/02/82 | .56 | 192 | 108 | .44-.63 | -- | -- | -- | -- | | | | |
| 08/24/82 | .55 | 479 | 263 | .42-.61 | .51 | 7 | 3 | .45-.51 | | | | |
| 09/13/82 | .54 | 246 | 133 | .41-.62 | -- | -- | -- | -- | | | | |
| 10/05/82 | .56 | 171 | 96 | .46-.62 | | | | | | | | |
| 11/16/82 | -- | -- | -- | -- | -- | -- | -- | -- | | | | |
| 12/14/82 | -- | -- | -- | -- | -- | -- | -- | -- | | | | |
| | Σ=3.28<br>x̄=.55 | Σ=3,346 | Σ=1,834<br>x̄=.55 | .41-.67 | | | | | | | | |

Table 12. Seasonal mean and weighted seasonal mean body-size (mm) and range of body-sizes for zooplankters within Robe Lake at Station 4 during 1981-1982.

| Date | Body size | Number m$^2$ | Size weighted | Range | Body size | Number m$^2$ | Size weighted | Range | Body size | Number m$^2$ | Size weighted | Range |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Cyclops* | | | | *Chydorinae* | | | | *Bosmina* | | | |
| 12/18/81 | -- | -- | -- | -- | .26 | 48 | 12 | .23-.31 | -- | -- | -- | -- |
| 01/18/82 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 03/01/82 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 03/24/82 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 04/19/82 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 06/04/82 | -- | -- | -- | -- | -- | -- | -- | -- | .34 | 27 | 9 | .31-.36 |
| 06/17/82 | .46 | 411 | 189 | .38- .73 | -- | -- | -- | -- | .37 | 499 | 185 | .23-.47 |
| 06/30/82 | .63 | 1,546 | 974 | .42-1.14 | -- | -- | -- | -- | .31 | 7,073 | 2,193 | .27-.42 |
| 07/14/82 | .63 | 3,215 | 2,025 | .42- .89 | .34 | 479 | 163 | .31-.36 | .34 | 77,702 | 26,419 | .28-.42 |
| 08/03/82 | .49 | 2,223 | 1,089 | .33- .79 | -- | -- | -- | -- | .24 | 17,613 | 4,227 | .22-.29 |
| 08/23/82 | .53 | 212 | 112 | .41- .86 | -- | -- | -- | -- | .28 | 2,305 | 645 | .24-.36 |
| 09/13/82 | .46 | 301 | 138 | .37- .61 | .34 | 199 | 68 | .30-.40 | .31 | 3,942 | 1,222 | .26-.37 |
| 10/05/82 | .44 | 55 | 24 | .41- .51 | .38 | 130 | 49 | .30-.63 | .34 | 349 | 119 | .25-.38 |
| 11/16/82 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 12/14/82 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| | Σ=3.64 x̄=.52 | Σ=7,963 | Σ=4,551 x̄=.57 | .33-1.14 | Σ=1.32 x̄=.33 | Σ=856 | Σ=292 x̄.34 | .23-.63 | Σ=2.53 x̄=.32 | Σ=109,510 | Σ=35,019 x̄=.32 | .23-.47 |

| Date | Body size | Number m$^2$ | Size weighted | Range | Body size | Number m$^2$ | Size weighted | Range |
|---|---|---|---|---|---|---|---|---|
| | Harpacticoid | | | | *Ceriodaphnia* | | | |
| 12/18/81 | -- | -- | -- | -- | -- | -- | -- | -- |
| 01/18/82 | -- | -- | -- | -- | -- | -- | -- | -- |
| 03/01/82 | -- | -- | -- | -- | -- | -- | -- | -- |
| 03/24/82 | -- | -- | -- | -- | -- | -- | -- | -- |
| 04/19/82 | -- | -- | -- | -- | -- | -- | -- | -- |
| 06/04/82 | -- | -- | -- | -- | -- | -- | -- | -- |
| 06/17/82 | -- | -- | -- | -- | .50 | 48 | 24 | .50 |
| 06/30/82 | .52 | 6,662 | 3,464 | .42- .61 | -- | -- | -- | -- |
| 07/14/82 | .59 | 3,899 | 2,300 | .50- .67 | .40 | 1,368 | 547 | .32-.48 |
| 08/03/82 | .56 | 1,710 | 958 | .43- .64 | .35 | 1,026 | 359 | .31-.38 |
| 08/23/82 | .54 | 500 | 270 | .42- .63 | .36 | 48 | 17 | .28-.46 |
| 09/13/82 | .54 | 370 | 200 | .44- .62 | -- | -- | -- | -- |
| 10/05/82 | .54 | 206 | 111 | .40- .61 | -- | -- | -- | -- |
| 11/16/82 | -- | -- | -- | -- | -- | -- | -- | -- |
| 12/14/82 | -- | -- | -- | -- | -- | -- | -- | -- |
| | Σ=3.29 x̄=.55 | Σ=13,347 | Σ=7,303 x̄=.55 | .40- .67 | Σ=1.61 x̄=.40 | Σ=2,490 | Σ=947 x̄=.38 | .28-.50 |

# DISCUSSION

The objective of this diagnostic study is to determine the present water quality of the Robe Lake system in terms of physical (temperature, light), chemical (nutrients, dissolved gases, metals), biologic (primary production [phytoplankton and aquatic macrophytes] and secondary production [zooplankton]) parameters and the hydrologic budget. Since the lake is the only freshwater resource in the Valdez area and since the lake in the past has been heavily used by the residents of Valdez, it is of tremendous local interest to return Robe Lake to the major recreational area it once was. In addition, the envisioned population growth of Valdez, increased tourism, and newly started industrial expansion have placed added pressures on improving the recreational use of the Robe Lake system.

## Robe Lake: Historical Perspective

Before the 1956 dike construction, the flow from the extensive Corbin Creek watershed and, perhaps, a portion of the flow from the Valdez Glacier Stream entered Robe Lake (*see* Figures 2 and 3). This flow flushed the lake approximately once every month, instead of the present rate of once every 5 months. In addition, because this water was cooler (originating from snow and glacier melt), lake temperatures may have been significantly reduced. Moreover, glacial flour, which clouds water, would have certainly reduced light penetration. If the turbidity had been as little as 40 NTU, the 1% light level would not have extended beyond 1 m; this factor, along with the large influx of cold, turbid water, would have effectively excluded extensive macrophytic growth and/or restricted it to narrow shoreline groves. Finally, the extensive quantity of water entering the lake would have produced a larger outlet. Thus Robe River had been extensive enough to be entirely navigable from salt water to the lake and, in turn, may have been a considerably larger body of water. As the Valdez area is essentially a flat delta that has been built up by millennia of silt, sand, and gravel deposition from the surrounding mountains, Robe Lake must have been shallower, its shoreland expanding in a westerly direction towards Valdez Glacier Stream (*see* Figure 2). Given seasonal surges in influx caused by 150 cm of precipitation and the seasonally derived glacial meltwater, both the discharge of Robe River and the lake margins would have fluctuated widely and, perhaps, periodically flooded extensive areas, including the Richardson Highway. A widely fluctuating lake shoreline would further retard macrophytic growth, and the flooded area would provide extensive rearing area for both juvenile salmonids and aquatic birds. The above synopsis best describes the historic Robe Lake; however, it does not apply to its current state.

## Robe Lake: Present Condition

Within the Robe Lake watershed, total precipitation in 1982 equalled 150 cm, which statistically should result in approximately $17.9 \times 10^6 m^3$ of water moving annually through the lake and out the Robe River (USDA 1979). However, our measurements indicated that the Robe River actually discharged approximately $25.3 \times 10^6 m^3$ of water during 1982. Thus the outflow of the Robe River may have been increased by subsurface water flowing into the Robe Lake watershed from either the adjacent Valdez Glacier Stream watershed or the now diked portion of Corbin Creek (*see* Figure 4).

The augmented flow would tend to improve the water quality of Robe Lake by decreasing lake temperatures, by continually flushing accumulated autochthonous production, and by renewing dissolved-oxygen concentrations. In addition, given the excellent water quality of the tributary streams (*see* Appendix B), the increased flow would tend to ameliorate, rather than exacerbate, any algal nutrient imbalances within the open lake water.

The basic water quality of the open lake water is generally good; fecal coliform counts were usually 0 colonies/100 ml of lake water with a peak value of 3 colonies/100 ml of lake water (*see* Appendix C). Moreover, the peak value is well below State of Alaska standards for body contact of 20 colonies/100 ml. In addition, algal blooms with accompanying odor and other aesthetically unpleasant effects were not apparent, and the watershed was relatively free of cottages or other potential point sources of pollution. However, this is not to say that the lake is entirely free of significant water quality problems.

The most conspicuous water quality problem of Robe Lake centers on an abundant growth of aquatic macrophytes that choke the lake from mid-July through October. During this period, the lake is unfit for recreational use, including swimming, boating, fishing, or operating float planes. As light penetrates to the entire bottom of the lake throughout most of the year, macrophytic stands are not light limited and occupy most of the bottom area. In addition, the rapid, uniform temperature increase throughout the water column immediately after ice-out encourages widespread macrophyte growth. Moreover, the present shallow configuration of the lake itself (mean depth of 3 meters) and the nutrient-rich substrate formed by years of glacial-silt deposition forms ideal conditions for explosive macrophytic growth.

Presently the direct and indirect effects of the extensive macrophytic growth permeates every aspect of the assessment of Robe Lake water quality. In the middle of July, macrophyte growth begins each season out of incompletely decayed old-growth stands. At this time, the daylight period is nearly 20 hours long, and the sun swings north, traveling along the east-west axis of the lake. Because of the extensive daylight, the lake quickly warms from top to bottom, stimulating explosive new growth of the macrophyte stands. However, just prior to the beginning of the new growth, the rapid temperature increase of the open-water sediment interface in late May, June, and July stimulates the decay of old, prior-year macrophyte stands, causing an increase in ammonium levels (*see* Figures 8, 9, and 10) at the shallow stations that is not seen at the macrophyte-free, deeper-water Station 4 (*see* Figure 11). This decay process continues as temperatures rise; however, ammonium levels decline as new-growth macrophyte stands reach maximal growth in August and September (*see* Figure 12). That is, the release of ammonium by decay is accompanied by a greater rate of nitrogen uptake to satisfy the metabolic demands of the rapidly growing macrophytes.

The uptake of nitrogen is so extensive that during August and September inorganic nitrogen disappears from the water column (*see* Figures 8, 9, 10, and 11). Our estimates of the input of phosphorus (P), nitrogen (N), and reactive silicon (Si) during July and August from the three tributary Creeks (combined discharge at this time equals nearly 70% of the discharge of Robe River) equals 6 kg P, 1,408 kg N, and 5,567 kg Si. However, the loss of these same nutrients in the discharge of Robe River amounts to 9 kg P, 21 kg N, and 5,700 kg Si. Clearly, the lake may be exporting P, in balance with Si, but it serves as a tremendous sink for nitrogen; i.e., 1,408 kg N incoming, compared to only 21 kg outgoing (Figure 13).

Through the use of a nutrient budget constructed for the lake during July through August, we have identified the aquatic macrophytes as the nutrient sink within the lake. Specifically, using 92.1 $g/m^2$ of dry-weight biomass (weighted by transect area) found in the lake during August, we estimated a total of 1002 $g/m^2$ of macrophytic growth. Since air surveys revealed nearly 70%, or $1.9 \times 10^6$ $m^2$, of the lake surface to be occluded by macrophytic growth, we estimate that 1,904 metric tons of macrophyte growth were present in the lake by the end of August. By this time the macrophytes had reached maximal biomass accrual and, in the process, converted 3,192 kg of N from inorganic to organic form.

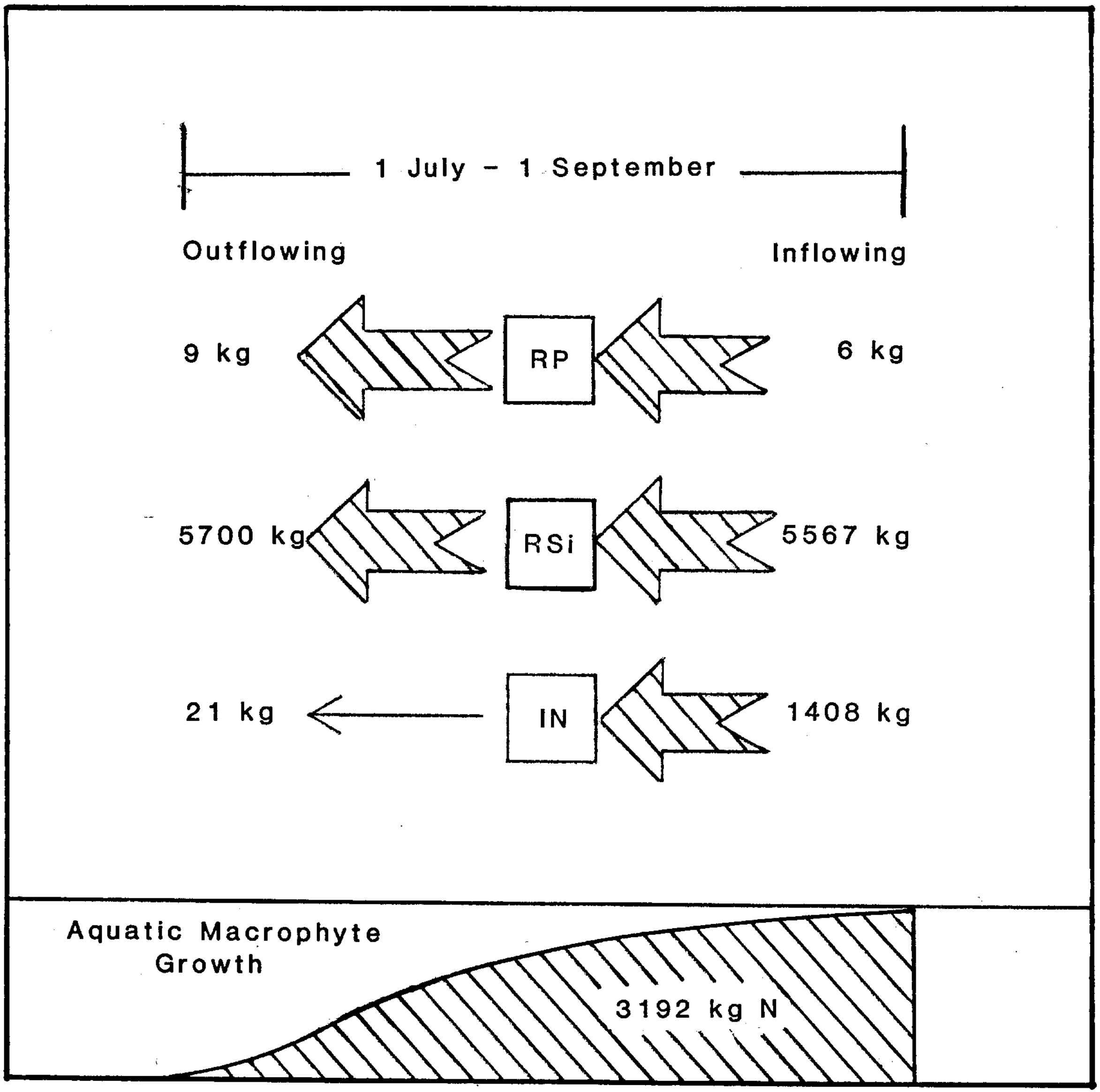


Figure 13. The temporal relationship between aquatic macrophyte biomass accrual and the differences between inflowing versus outflowing amounts of inorganic phosphorus (RP), reactive silicon (RSi), and inorganic nitrogen (IN) at Robe Lake.

As 2,580 kg of inorganic nitrogen were present in the lake as of 1 July and as 1,408 kg entered the lake from the watershed streams during July and August (versus a loss of 21 kg out the Robe River), the net useable N is estimated to be 3,967 kg. Our estimate of nitrogen used for macrophyte growth during this same period equalled 3,192 kg, or fully 80% of the available inorganic nitrogen within the lake. This estimate agrees with the essential lack of in-lake inorganic nitrogen during much of July and August and its reappearance in September when the macrophytes began to undergo senescence (*see* Figures 8, 9, 10 and 11). Thus we feel the extremely low IN to RP ratio of the open lake water was caused in large part by the demand of the growing macrophytes, which selectively removed nitrogen from the water. In contrast, phosphorus is not stripped from the open water because of its plentiful supply from the glacial silt within the sediments (Carignan and Kalff 1980).

After October when the current-year macrophytes become senescent (*see* Figure 12), the decay process begins to deplete the dissolved oxygen of the open water. This process is severely blunted by the extremely cold water (0.1°C to 2.0°C) found throughout the lake during winter (Figure 5). We believe that if temperatures under the ice warm to even 4°C, the lake's entire oxygen supply would be depleted, and consequently, rearing salmonids would suffocate. This synergistic process already takes place on a micro-scale in April and May under the ice. Specifically, the most severe oxygen deficits are found near the sediments when the daylight period is rapidly increasing and the sun begins to heat the bottom water to 4°C (at the shallow stations). At the deeper Station 4, where 4°C water is consistently found, dissolved-oxygen deficits are most severe.

Water temperatures are not only important in reducing the rate of oxygen depletion over winter, but are also important during the summer period. That is, the >15°C temperatures found throughout the water column during July and August are not conducive to optimal fry growth rates (Narver 1970; Shelbourn et al. 1973; Goodlad et al. 1974). These warmer temperatures coincide with maximal macrophytic growth and generally minimal water renewal rates. The combination of explosive macrophyte growth and lowered water renewal rates alters both the nutrient ratios and concentrations within the open lake water. This had a deleterious effect on phytoplankton standing crop (Canfield et al. 1983), and the low IN to RP ratios may have altered species composition by favoring populations of green and bluegreen algae (Vollenweider 1976; Kuenzler et al. 1979; Barcia et al. 1980). Such forms of algae are less available as forage to nonselective filter-feeding, herbivorous zooplankters (Porter 1977). The combination of low algal density in combination with an altered species composition would effectively curtail the reproductive potential of cladoceran zooplankters. In turn, as cladoceran zooplankters are preferred food items for salmonid fry (Goodlad et al. 1974) because of a less refined predator-escaping ability than copepods (O'Brien 1979), the rearing capacity of the lake for limnetic-feeding fishes may be reduced. Thus the extensive growth of the macrophyte stands and the resulting effects on water temperatures, dissolved-oxygen levels, algal-nutrient ratios, and zooplankter production may retard the ability of the lake to rear juvenile salmonids.

Finally, we wish to stress that the overall quality of the open water of Robe Lake is very good. Problems do develop in terms of temperature regimes, oxygen deficits, nutrient imbalances, and extremely low zooplankter populations; but these can be corrected, in large part, by removing the macrophyte growth. That is, directly or indirectly much of what is physically, chemically, and/or biologically wrong or undesirable about Robe Lake water quality can be substantially reversed by harvesting or by preventing the growth of aquatic macrophytes.

Recommendations

1) Ensure the continuation of the waterflow through Robe Lake and, if possible, augment the flow as much as possible. Any reduction in water renewal time could trigger severe water quality deterioration.

2) Any dredging of the lake, even to 4 to 5 m, could result in warming the lake to 4° C during winter; thus to prevent a potential winter-kill situation from developing, it should be accompanied by the prevention of macrophyte growth or by macrophyte removal.

3) Mechanical removal or harvesting of macrophytes should take place in August when biomass accrual is essentially complete, and it should be designed to minimize adverse effects on fish-forage production.

4) Removal of macrophyte growth would result in the harvesting of $1.9 \times 10^6$ kg or 2,100 tons of macrophytes annually.

5) Chemical control of macrophyte growth might be feasible, but the toxicity of such compounds to the highly sensitive salmonid population needs to be thoroughly reviewed.

6) Study the potential of removing the dike(s) that restrict the flow of cold, turbid water into the lake. Such a step may be the most cost-effective way to reverse the current state of Robe Lake.

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APPENDIX A

Summary of water quality parameters found for Robe Lake at Stations 1, 2, 3, and 4 in both the surface (1.0 m) and near bottom strata during 1982.

Robe Lake Site #1 — WATER ANALYSIS SUMMARY

| Date/Depth | 01-18-82 | | 03-03-82 | | 03-24-82 | | 04-19-82 | | 06-04-82 | | 06-17-82 | | 06-30-82 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | 1 m | 1.5 m | 1 m | 1.5 m | 1 m | 1.5 m | 1 m | 1.3 m | 1 m | 1.4 m | 1 m | 1.4 m | 1 m | 1.4 m |
| Conductivity (umhos $cm^{-1}$) | 107 | 115 | 105 | 107 | 107 | 111 | 103 | 106 | 82 | 82 | 85 | 84 | 93 | 88 |
| pH | 7.1 | 7.2 | 7.1 | 7.1 | 6.8 | 6.8 | 7.2 | 7.3 | 6.9 | 7.1 | 7.5 | 7.6 | 7.7 | 7.8 |
| Alkalinity (mg $L^{-1}$ as $caCO_3$) | 54 | 62 | 64 | 69 | 59 | 63 | 58 | 62 | 40 | 43 | 47 | 47 | 48 | 48 |
| Calcium (mg $L^{-1}$) | 20.7 | 23.4 | 22.8 | 24.8 | 19.7 | 19.7 | 21.4 | 20.6 | 14.7 | 16.2 | 13.1 | 13.7 | 16.5 | 16.5 |
| Magnesium (mg $L^{-1}$) | <0.3 | <0.3 | <0.3 | 0.8 | 1.5 | 0.9 | 0.5 | 0.5 | 0.9 | 1.4 | 0.4 | 0.4 | <0.3 | <0.3 |
| Iron (ug $L^{-1}$) | 280 | 389 | 292 | 393 | 116 | 88 | 84 | 103 | 408 | 341 | 177 | 182 | 144 | 141 |
| Total Phosphorus (ug $L^{-1}$ as P) | 7.8 | 7.4 | 6.6 | 5.3 | 9.6 | 7.4 | 15.6 | 11.1 | 15.9 | 14.1 | 11.8 | 11.9 | 10.3 | 8.9 |
| Total Filterable Phosphorus (ug $L^{-1}$ as P) | 5.5 | 3.6 | 2.9 | 2.0 | 6.8 | 4.9 | 9.0 | 6.0 | 7.7 | 15.5 | 14.3 | 8.1 | 8.6 | 4.8 |
| Filterable Reactive Phosphorus (ug $L^{-1}$ as P) | 1.1 | 0.9 | 0.9 | 0.9 | 2.0 | 1.1 | 1.6 | 1.4 | 2.5 | 6.1 | 4.3 | 3.0 | 2.8 | 2.8 |
| Nitrate+Nitrate (ug $L^{-1}$ as N) | 553 | 405 | 469 | 334 | 490 | 552 | 710 | 667 | 234 | 212 | 89 | 85 | 32 | 33 |
| Ammonium (ug $L^{-1}$ as N) | 47 | 38 | 54 | 57 | 34 | 39 | 14 | 24 | 3 | 5 | 22 | 19 | 36 | 32 |
| Reactive Silica (ug $L^{-1}$ as Si) | 2,207 | 2,155 | 3,087 | 3,049 | 2,179 | 2,365 | 2,444 | 2,454 | 1,513 | 1,520 | 1,424 | 1,438 | 1,311 | 1,289 |
| Kjeldahl N (ug $L^{-1}$ as N) | 136 | 121 | 190 | 171 | 166 | 154 | 128 | 119 | 157 | 139 | 141 | 145 | 157 | 159 |

Summary of water quality parameters found for Robe Lake at Stations 1, 2, 3, and 4 in both the surface (1.0 m) and near bottom strata during 1982. (continued)

Robe Lake Site #1 (Continued)

WATER ANALYSIS SUMMARY

| Date/Depth | 07-14-82 | | 08-03-82 | | 08-23-82 | | 09-13-82 | | 10-05-82 | | 11-19-82 | | 12-14-82 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | 1 m | 1.5 m | 1 m | 1.5 m | 1 m | 1.5 m | 1 m | 1.5 m | 1 m | 1.5 m | 1 m | 1.5 m | 1 m | 1.5 m |
| Conductivity (umhos cm$^{-1}$) | 106 | 104 | 129 | 131 | 133 | 134 | 127 | 128 | 95 | 93 | 100 | 115 | 100 | 112 |
| pH | 7.8 | 7.9 | 7.9 | 8.0 | 7.9 | 7.9 | 7.5 | 7.5 | 7.6 | 7.6 | 6.4 | 6.7 | 6.7 | 6.6 |
| Alkalinity (mg L$^{-1}$ as $caCO_3$) | 54 | 54 | 61 | 61 | 62 | 63 | 60 | 59 | 41 | 41 | 39 | 45 | 46 | 50 |
| Calcium (mg L$^{-1}$) | 18.4 | 18.0 | 20.3 | 19.9 | 21.9 | 21.9 | 22.2 | 21.4 | 16.2 | 16.6 | 15.5 | 18.7 | 25.0 | 25.0 |
| Magnesium (mg L$^{-1}$) | <0.3 | <0.3 | <0.3 | <0.3 | 0.4 | <0.3 | <0.3 | <0.3 | <0.3 | <0.3 | <0.3 | <0.3 | <0.3 | <0.3 |
| Iron (ug L$^{-1}$) | 202 | 254 | 235 | 387 | 130 | 199 | 96 | 151 | 232 | 557 | 141 | 219 | 167 | 327 |
| Total Phosphorus (ug L$^{-1}$ as P) | 14.6 | 19.5 | 19.9 | 21.0 | 11.9 | 12.6 | 9.3 | 12.1 | 13.1 | 28.1 | 10.2 | 10.1 | 6.8 | 7.5 |
| Total Filterable Phosphorus (ug L$^{-1}$ as P) | 9.2 | 6.4 | 7.3 | 9.5 | 9.9 | 8.9 | 6.6 | 4.3 | 6.3 | 7.2 | 5.1 | 4.6 | 4.3 | 3.1 |
| Filterable Reactive Phosphorus (ug L$^{-1}$ as P) | 2.7 | 2.8 | 2.3 | 1.9 | 2.0 | 2.0 | 1.7 | 1.4 | 1.5 | 2.5 | 1.9 | 2.1 | 1.6 | 1.4 |
| Nitrate+Nitrate (ug L$^{-1}$ as N) | 14 | 9 | 0.6 | <0.5 | <0.5 | <0.5 | 6 | 4 | 129 | 124 | 396 | 344 | 427 | 391 |
| Ammonium (ug L$^{-1}$ as N) | 3 | 6 | 1 | 1 | <1 | <1 | 2 | 2 | 7 | 5 | 20 | 36 | 32 | 22 |
| Reactive Silica (ug L$^{-1}$ as Si) | 2,037 | 1,426 | 1,395 | 1,521 | 1,797 | 1,782 | 1,304 | 1,301 | 1,417 | 1,345 | 1,791 | 1,851 | 1,942 | 2,070 |
| Kjeldahl N (ug L$^{-1}$ as N) | 162 | 212 | 201 | 243 | 163 | 180 | 133 | 159 | 162 | 400 | 127 | 170 | 135 | 123 |

Summary of water quality parameters found for Robe Lake at Stations 1, 2, 3, and 4 in both the surface (1.0 m) and near bottom strata during 1982. (continued)

Robe Lake Site #2 — WATER ANALYSIS SUMMARY

| Date/Depth | 01-19-82 | | 03-03-82 | | 03-24-82 | | 04-19-82 | | 06-04-82 | | 06-17-82 | | 06-30-82 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | 1 m | 2 m | 1 m | 2 m | 1 m | 2 m | 1 m | 2 m | 1 m | 2 m | 1 m | 2 m | 1 m | 2 m |
| Conductivity (umhos $cm^{-1}$) | 106 | 107 | 104 | 100 | 113 | 101 | 100 | 110 | 88 | 90 | 85 | 85 | 91 | 88 |
| pH | 7.4 | 7.3 | 7.2 | 7.2 | 7.0 | 6.8 | 7.2 | 7.4 | 7.1 | 7.0 | 7.6 | 7.6 | 7.7 | 7.7 |
| Alkalinity (mg $L^{-1}$ as $CaCO_3$) | 54 | 58 | 64 | 61 | 62 | 65 | 57 | 64 | 45 | 46 | 48 | 48 | 48 | 48 |
| Calcium (mg $L^{-1}$) | 20.7 | 21.6 | 24.0 | 22.5 | 21.3 | 21.4 | 21.3 | 22.3 | 16.5 | 16.9 | 13.4 | 13.7 | 16.1 | 16.5 |
| Magnesium (mg $L^{-1}$) | <0.3 | <0.3 | 0.5 | <0.3 | 0.4 | <0.3 | 0.4 | 0.8 | 1.2 | 1.2 | <0.3 | <0.3 | <0.3 | <0.3 |
| Iron (ug $L^{-1}$) | 47 | 66 | 102 | 129 | 80 | 130 | 126 | 144 | 453 | 444 | 172 | 146 | 131 | 136 |
| Total Phosphorus (ug $L^{-1}$ as P) | 8.9 | 6.5 | 10.7 | 6.8 | 21.7 | 8.0 | 14.1 | 9.7 | 15.5 | 10.0 | 11.0 | 10.8 | 11.4 | 10.3 |
| Total Filterable Phosphorus (ug $L^{-1}$ as P) | 6.5 | 3.5 | 4.8 | 2.1 | 16.9 | 4.3 | 8.6 | 5.1 | 10.6 | 6.7 | 9.0 | 16.8 1/ | 8.2 | 7.9 |
| Filterable Reactive Phosphorus (ug $L^{-1}$ as P) | 1.1 | 1.1 | 2.7 | 0.8 | 11.7 | 1.4 | 3.5 | 1.2 | 2.6 | 2.4 | 3.1 | 4.5 | 2.8 | 2.9 |
| Nitrate+Nitrate (ug $L^{-1}$ as N) | 802 | 499 | 595 | 429 | 719 | 512 | 658 | 591 | 278 | 318 | 111 | 111 | 33 | 32 |
| Ammonium (ug $L^{-1}$ as N) | 62 | 61 | 36 | 33 | 31 | 46 | 16 | 26 | 2 | 2 | 13 | 14 | 27 | 28 |
| Reactive Silicon (ug $L^{-1}$ as si) | 2,249 | 1,956 | 3,213 | 2,547 | 2,487 | 2,447 | 2,302 | 2,519 | 1.590 | 1,708 | 1,558 | 1,566 | 1,517 | 1,391 |
| Kjeldahl N (ug $L^{-1}$ as N) | 173 | 147 | 212 | 166 | 268 | 158 | 150 | 114 | 122 | 122 | 135 | 142 | 145 | 165 |

1/ sample contaminated

Summary of water quality parameters found for Robe Lake at Stations 1, 2, 3, and 4 in both the surface (1.0 m) and near bottom strata during 1982.

Robe Lake Site #2 (Continued)

WATER ANALYSIS SUMMARY

| Date/Depth | 08-03-82 | | 08 23-82 | | 09-13-82 | | 10-04-82 | | 07-14-82 | | 11-19-82 | | 12-14-82 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | 1 m | 2 m | 1 m | 2 m | 1 m | 2 m | 1 m | 2 m | 1 m | 2 m | 1 m | 2 m | 1 m | 2 m |
| Conductivity (umhos $cm^{-1}$) | 100 | 100 | 98 | 98 | 114 | 114 | 89 | 89 | 96 | 96 | 94 | 96 | 98 | 104 |
| pH | 7.8 | 7.7 | 7.9 | 7.8 | 7.5 | 7.5 | 7.5 | 7.5 | 7.7 | 7.7 | 7.0 | 6.9 | 6.7 | 6.7 |
| Alkalinity (mg $L^{-1}$ as $CaCO_3$) | 44 | 43 | 44 | 42 | 52 | 52 | 40 | 40 | 47 | 47 | 39 | 38 | 43 | 46 |
| Calcium (mg $L^{-1}$) | 14.1 | 14.1 | 15.3 | 15.3 | 18.9 | 18.5 | 15.2 | 15.7 | 15.9 | 15.5 | 16.0 | 16.0 | 23.8 | 25.0 |
| Magnesium (mg $L^{-1}$) | <0.3 | <0.3 | 0.4 | 0.4 | <0.3 | <0.3 | <0.3 | <0.3 | <0.3 | <0.3 | <0.3 | <0.3 | 1.4 | 0.8 |
| Iron (ug $L^{-1}$) | 79 | 89 | 32 | 30 | 66 | 68 | 132 | 353 | 164 | 170 | 72 | 95 | 57 | 84 |
| Total Phosphorus (ug $L^{-1}$ as P) | 11.9 | 9.9 | 10.8 | 8.5 | 8.3 | 7.6 | 9.5 | 8.1 | 14.5 | 11.3 | 8.8 | 8.8 | 9.7 | 6.5 |
| Total Filterable Phosphorus (ug $L^{-1}$ as P) | 6.6 | 5.6 | 11.4 1/ | 10.8 1/ | 6.8 | 4.7 | 6.6 | 6.4 | 5.7 | 4.9 | 4.0 | 3.5 | 7.3 | 4.0 |
| Filterable Reactive Phosphorus (ug $L^{-1}$ as P) | 2.1 | 1.8 | 1.5 | 2.1 | 1.2 | 1.5 | 1.5 | 2.8 | 2.3 | 2.1 | 2.0 | 1.7 | 1.7 | 1.6 |
| Nitrate+Nitrate (ug $L^{-1}$ as N) | 24 | 22 | 5 | 6 | 9 | 8 | 122 | 115 | 32 | 33 | 432 | 412 | 451 | 412 |
| Ammonium (ug $L^{-1}$ as N) | 16 | 14 | 5 | 5 | 4 | 3 | 9 | 9 | 25 | 23 | 18 | 25 | 27 | 36 |
| Reactive Silica (ug $L^{-1}$ as Si) | 1,621 | 1,667 | 1,515 | 1,533 | 1,304 | 1,297 | 1,421 | 1,413 | 1,230 | 1,833 | 1,801 | 1,762 | 1,946 | 1,978 |
| Kjeldahl N (ug $L^{-1}$ as N) | 188 | 178 | 186 | 174 | 141 | 125 | 143 | 148 | 167 | 170 | 161 | 171 | 135 | 150 |

1/ sample contaminated

Summary of water quality parameters found for Robe Lake at Stations 1, 2, 3, and 4 in both the surface (1.0 m) and near bottom strata during 1982.

Robe Lake Station 3 — WATER ANALYSIS SUMMARY

| Date/Depth | 01/19/82 | | 03/01/82 | | 03/26/82 | | 04/21/82 | | 06/03/82 | | 06/16/82 | | 07/01/82 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | 1 m | 2 m | 1 m | 2 m | 1 m | 2 m | 1 m | 1.9 m | 1 m | 1.9 m | 1 m | 2 m | 1 m | 2 m |
| Conductivity ($\mu$mhos $cm^{-1}$) | 94 | 103 | 100 | 112 | 105 | 117 | 70 | 106 | 93 | 90 | 82 | 84 | 89 | 90 |
| pH | 7.3 | 7.1 | 7.3 | 7.2 | 6.9 | 6.9 | 7.1 | 7.2 | 7.0 | 7.0 | 7.6 | 7.6 | 7.7 | 7.7 |
| Alkalinity (mg $L^{-1}$ as $CaCO_3$) | 46 | 53 | 61 | 73 | 56 | 64 | 33 | 63 | 46 | 47 | 45 | 45 | 46 | 46 |
| Calcium (mg $L^{-1}$) | 18.0 | 18.8 | 21.8 | 21.9 | 20.1 | 23.2 | 12.5 | 22.3 | 16.9 | 16.2 | 14.9 | 14.9 | 16.5 | 15.7 |
| Magnesium (mg $L^{-1}$) | <0.3 | <0.3 | <0.3 | 0.7 | 1.1 | 1.1 | 1.1 | <0.3 | 0.9 | 0.9 | <0.3 | <0.3 | <0.3 | <0.3 |
| Iron ($\mu$g $L^{-1}$) | 183 | 1,032 | 90 | 934 | 44 | 63 | 124 | 158 | 484 | 473 | 169 | 187 | 115 | 113 |
| Total Phosphorus ($\mu$g $L^{-1}$ as P) | 8.1 | 8.3 | 6.9 | 6.8 | 9.7 | 5.5 | 7.5 | 7.8 | 9.3 | 10.7 | 17.7 | 14.9 | 10.8 | 10.7 |
| Total Filterable Phosphorus ($\mu$g $L^{-1}$ as P) | 7.3 | 2.7 | 5.2 | 4.8 | 7.3 | 3.7 | 4.9 | 3.3 | 6.1 | 6.0 | 13.2 | 11.2 | 9.6 | 7.7 |
| Filterable Reactive Phosphorus ($\mu$g $L^{-1}$ as P) | 1.4 | 0.9 | 0.7 | 0.7 | 1.4 | 1.1 | 1.4 | 0.8 | 2.2 | 2.5 | 4.9 | 4.5 | 2.2 | 2.6 |
| Nitrate + Nitrite ($\mu$g $L^{-1}$ as N) | 512 | 367 | 666 | 251 | 623 | 717 | 396 | 590 | 347 | 335 | 130 | 131 | 41 | 41 |
| Ammonium ($\mu$g $L^{-1}$ as N) | 52 | 63 | 40 | 62 | 37 | 40 | 35 | 37 | 4 | 2 | 11 | 10 | 42 | 42 |
| Reactive Silicon ($\mu$g $L^{-1}$ as Si) | 1,860 | 1,923 | 2,467 | 2,670 | 2,313 | 2,519 | 1,471 | 2,614 | 1,772 | 1,782 | 1,686 | 1,708 | 1,390 | 1,370 |
| Kjeldahl N ($\mu$g $L^{-1}$ as N) | 121 | 158 | 183 | 174 | 134 | 96 | 155 | 117 | 110 | 115 | 160 | 174 | 153 | 160 |

Summary of water quality parameters found for Robe Lake at Stations 1, 2, 3, and 4 in both the surface (1.0 m) and near bottom strata during 1982.

Robe Lake Station 3 (continued)

WATER ANALYSIS SUMMARY

| Paramter | 07/13/82 | | 08/03/82 | | 08/24/82 | | 09/14/82 | | 10/04/82 | | 11/16/82 | | 12/14/82 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 m | 1.9 m | 1 m | 2 m | 1 m | 1.9 m | 1 m | 2 m | 1 m | 2 m | 1 m | 2 m | 1 m | 2 m |
| Conductivity ($\mu$mhos $cm^{-1}$) | 92 | 94 | 97 | 96 | 96 | 95 | 97 | 98 | 89 | 89 | 93 | 93 | 97 | 99 |
| pH | 7.7 | 7.7 | 8.3 | 8.3 | 7.9 | 8.1 | 7.5 | 7.4 | 7.6 | 7.5 | 7.0 | 7.0 | 6.7 | 6.7 |
| Alkalinity (mg $L^{-1}$ as $CaCO_3$) | 45 | 46 | 42 | 42 | 42 | 42 | 43 | 43 | 39 | 40 | 39 | 38 | 42 | 42 |
| Calcium (mg $L^{-1}$) | 15.0 | 14.6 | 14.1 | 13.7 | 14.4 | 15.3 | 16.8 | 16.0 | 15.2 | 15.2 | 15.1 | 16.4 | 25.0 | 22.5 |
| Magnesium (mg $L^{-1}$) | <0.3 | <0.3 | <0.3 | <0.3 | 0.4 | <0.3 | <0.3 | <0.3 | <0.3 | <0.3 | 0.8 | <0.3 | <0.3 | <0.3 |
| Iron ($\mu$g $L^{-1}$) | 178 | 218 | 107 | 124 | 56 | 55 | 79 | 87 | 95 | 120 | 98 | 98 | 180 | 198 |
| Total Phosphorus ($\mu$g $L^{-1}$ as P) | 14.5 | 12.6 | 5.9 | 5.7 | 8.5 | 7.8 | 8.3 | 5.7 | 7.6 | 8.4 | 8.4 | 7.0 | 6.9 | 6.8 |
| Total Filterable Phosphorus ($\mu$g $L^{-1}$ as P) | 8.5 | 4.8 | 11.9 | 8.3 | 7.8 | 7.5 | 5.7 | 4.8 | 5.4 | 5.4 | 6.6 | 5.9 | 5.0 | 3.8 |
| Filterable Reactive Phosphorus ($\mu$g $L^{-1}$ as P) | 2.0 | 2.0 | 2.2 | 2.0 | 2.1 | 2.1 | 1.7 | 1.3 | 1.7 | 1.9 | 1.9 | 1.6 | 1.7 | 1.6 |
| Nitrate + Nitrite ($\mu$g $L^{-1}$ as N) | 31 | 33 | 4 | 6 | <2.0 | <2.0 | 8 | 6 | 284 | 281 | 393 | 412 | 414 | 425 |
| Ammonium ($\mu$g $L^{-1}$ as N) | 38 | 33 | 2 | 2 | 2 | 1 | 4 | 3 | 12 | 11 | 21 | 20 | 25 | 37 |
| Reactive Silicon ($\mu$g $L^{-1}$ as Si) | 1,806 | 1,785 | 1,621 | 1,671 | 1,566 | 1,829 | 1,516 | 1,498 | 1,718 | 1,766 | 1,778 | 1,778 | 1,925 | 1,959 |
| Kjeldahl N ($\mu$g $L^{-1}$ as N) | 168 | 159 | 165 | 165 | 154 | 147 | 129 | 120 | 143 | 151 | 154 | 150 | 137 | 158 |

Summary of water quality parameters found for Robe Lake at Stations 1, 2, 3, and 4 in both the surface (1.0 m) and near bottom strata during 1982.

Robe Lake Site #4 — WATER ANALYSIS SUMMARY

| Date/Depth | 01-18-82 | | 03-01-82 | | 03-26-82 | | 04-21-82 | | 06-03-82 | | 06-16-82 | | 07-01-82 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | 1 m | 3 m | 1 m | 3 m | 1 m | 3 m | 1 m | 3 m | 1 m | 3 m | 1 m | 3 m | 1 m | 3 m |
| Conductivity (umhos $cm^{-1}$) | 97 | 130 | 105 | 125 | 110 | 142 | 93 | 139 | 83 | 89 | 81 | 81 | 88 | 88 |
| pH | 7.3 | 7.3 | 7.3 | 7.2 | 6.9 | 6.8 | 7.1 | 7.0 | 7.0 | 7.0 | 7.7 | 7.6 | 7.8 | 7.8 |
| Alkalinity (mg $L^{-1}$ as $CaCO_3$) | 51 | 77 | 64 | 89 | 57 | 84 | 51 | 94 | 43 | 45 | 45 | 45 | 46 | 46 |
| Calcium (mg $L^{-1}$) | 18.9 | 27.9 | 23.2 | 31.1 | 21.9 | 29.1 | 17.9 | 31.5 | 15.4 | 16.2 | 12.4 | 12.4 | 15.7 | 16.1 |
| Magnesium (mg $L^{-1}$) | 3.3 | 3.8 | <0.3 | 1.1 | 0.5 | 1.4 | 0.8 | 1.9 | 0.9 | 0.9 | 0.4 | 0.4 | 0 | 0 |
| Iron (ug $L^{-1}$) | 25 | 50 | 35 | 223 | 48 | 1,187 | 222 | 5,414 | 450 | 467 | 170 | 126 | 74 | 83 |
| Total Phosphorus (ug $L^{-1}$ as P) | 7.7 | 6.6 | 7.7 | 5.8 | 7.0 | 8.7 | 9.6 | 15.9 | 13.6 | 10.3 | 15.9 | 11.7 | 13.0 | 13.4 |
| Total Filterable Phosphorus (ug $L^{-1}$ as P) | 3.9 | 3.2 | 6.0 | 1.6 | 4.3 | 2.1 | 4.6 | 2.6 | 8.7 | 9.8 | 10.1 | 10.3 | 8.2 | 10.0 |
| Filterable Reactive Phosphorus (ug $L^{-1}$ as P) | 2.2 | 2.3 | 2.8 | 1.1 | 1.1 | 0.6 | 1.5 | 1.5 | 2.1 | 2.4 | 3.9 | 2.8 | 2.8 | 3.1 |
| Nitrate+Nitrate (ug $L^{-1}$ as N) | 654 | 451 | 731 | 423 | 805 | 336 | 662 | 106 | 396 | 385 | 119 | 127 | 35 | 34 |
| Ammonium (ug $L^{-1}$ as N) | 49 | 112 | 44 | 69 | 41 | 67 | 41 | 107 | 2 | 2 | 5 | 4 | 14 | 13 |
| Reactive Silica (ug $L^{-1}$ as Si) | 2,004 | 2,340 | 2,738 | 3,258 | 2,423 | 2,779 | 2,559 | 2,956 | 1,644 | 1,763 | 1,760 | 1,828 | 1,406 | 1,442 |
| Kjeldahl N (ug $L^{-1}$ as N) | 146 | 166 | 143 | 151 | 100 | 138 | 126 | 216 | 113 | 99 | 195 | 146 | 167 | 165 |

Summary of water quality parameters found for Robe Lake at Stations 1, 2, 3, and 4 in both the surface (1.0 m) and near bottom strata during 1982.

Robe Lake Site #4 (Continuation) WATER ANALYSIS SUMMARY

| Date/Depth | 07-13-82 | | 08-03-82 | | 08-24-82 | | 09-14-82 | | 10-04-82 | | 11-16-82 | | 12-14-82 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | 1 m | 3 m | 1 m | 3.2 m | 1 m | 3.1 m | 1 m | 3.2 m | 1 m | 3.2 m | 1 m | 3 m | 1 m | 3 m |
| Conductivity (umhos $cm^{-1}$) | 90 | 91 | 95 | 94 | 88 | 87 | 91 | 93 | 83 | 83 | 93 | 95 | 95 | 123 |
| pH | 7.8 | 7.9 | 7.8 | 7.9 | 8.1 | 8.2 | 7.5 | 7.5 | 7.6 | 7.6 | 7.2 | 6.9 | 6.7 | 6.7 |
| Alkalinity (mg $L^{-1}$ as $CaCO_3$) | 46 | 45 | 41 | 41 | 39 | 38 | 40 | 41 | 36 | 36 | 38 | 40 | 41.0 | 63.0 |
| Calcium (mg $L^{-1}$) | 15.0 | 14.6 | 14.1 | 14.1 | 13.1 | 13.1 | 14.3 | 13.5 | 15.7 | 14.6 | 15.1 | 15.1 | 25.0 | 28.8 |
| Magnesium (mg $L^{-1}$) | 0 | 0 | 0 | 0 | 0.4 | 0.4 | <0.5 | 0.7 | 0 | 0 | <0.5 | <0.5 | <0.5 | 0.8 |
| Iron (ug $L^{-1}$) | 134 | 132 | 96 | 99 | 65 | 65 | 87 | 122 | 116 | 65 | 98 | 67 | 46 | 62 |
| Total Phosphorus (ug $L^{-1}$ as P) | 16.4 | 14.9 | 6.2 | 6.2 | 11.6 | 12.7 | 15.2 | 10.5 | 11.2 | 9.6 | 9.2 | 8.6 | 7.6 | 9.0 |
| Total Filterable Phosphorus (ug $L^{-1}$ as P) | 5.3 | 4.9 | 10.1 1/ | 9.5 1/ | 8.7 | 8.2 | 8.6 | 5.5 | 6.6 | 5.2 | 4.9 | 4.0 | 5.0 | 6.0 |
| Filterable Reactive Phosphorus (ug $L^{-1}$ as P) | 1.2 | 1.5 | 1.7 | 2.0 | 2.1 | 2.1 | 2.3 | 1.5 | 1.2 | 1.4 | 1.9 | 2.1 | 1.7 | 3.9 |
| Nitrate+Nitrate (ug $L^{-1}$ as N) | 18 | 18 | 10 | 8 | <0.5 | <0.5 | 14 | 6 | 334 | 332 | 408 | 429 | 431 | 323 |
| Ammonium (ug $L^{-1}$ as N) | 10 | 11 | 3 | 5 | 1 | 1 | 4 | 3 | 6 | 6 | 17 | 39 | 28 | 106 |
| Reactive Silica (ug $L^{-1}$ as Si) | 1,712 | 1,512 | 1,251 | 1,373 | 1,593 | 1,658 | 1,609 | 1,585 | 1,754 | 1,732 | 1,722 | 1,823 | 1,922 | 2,299 |
| Kjeldahl N (ug $L^{-1}$ as N) | 176 | 171 | 184 | 191 | 193 | 191 | 151 | 115 | 153 | 150 | 137 | 193 | 150 | 210 |

1/ High value probably due to sample contamination.

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# APPENDIX B

Summary of water quality parameters found for surface waters in Corbin Creek, Deep Creek, Brownie Creek, and Glacier Creek during 1982.

Corbin Creek - Robe Lake

WATER ANALYSIS SUMMARY

| Date | 01-20-82 | 02-24-82 | 03-29-82 1/ | 03-26-82 2/ | 04-23-82 1/ | 06-08-82 | 06-18-82 |
|---|---|---|---|---|---|---|---|
| Conductivity (umhos $cm^{-1}$) | 200 | 179 | 174 | 195 | 165 | 226 | 196 |
| pH | 7.7 | 7.4 | 7.6 | 7.4 | 7.9 | 8.1 | 8.2 |
| Alkalinity (mg $L^{-1}$ as $CaCO_3$) | 134 | 157 | 138 | 157 | 129 | 131 | 126 |
| Calcium (mg $L^{-1}$) | 49.6 | 53.9 | 48.7 | 58.1 | 47.9 | 49.8 | 43.3 |
| Magnesium (mg $L^{-1}$) | 2.3 | 2.7 | <0.3 | <0.3 | 0.4 | <0.3 | <0.3 |
| Iron (ug $L^{-1}$) | 17 | 551 | 38 | 722 | 142 | 82 | 56 |
| Total Phosphorus (ug $L^{-1}$ as P) | | | 2.8 | 54.7 | 3.9 | 2.5 | 4.8 |
| Total Filterable Phosphorus (ug $L^{-1}$ as P) | | | | | | | |
| Filterable Reactive Phosphorus (ug $L^{-1}$ as P) | | | 2.4 | 32.2 | 0.9 | 3.5 | 1.4 |
| Nitrate+Nitrate (ug $L^{-1}$ as N) | | | 113 | 404 | 125 | 258 | 297 |
| Ammonium (ug $L^{-1}$ as N) | | | 1.4 | 2.4 | <0.5 | 2.6 | 4.7 |
| Reactive Silica (ug $L^{-1}$ as Si) | 2,150 | 2,605 | 2,636 | 2,231 | 2,602 | 1,781 | 1,857 |
| Kjeldahl N (ug $L^{-1}$ as N) | | | 30 | 325 | 65 | 111 | 48 |

1/The 3-29-82 and 4-23-82 samples were collected 1 km upstream from the original sampling site due to extreme ice conditions.
2/This sample was collected from a pool on the overflow ice at the original sampling location.

Summary of water quality parameters found for surface waters in Corbin Creek, Deep Creek, Brownie Creek, and Glacier Creek during 1982.

Corbin Creek - Robe Lake (Continued) — WATER ANALYSIS SUMMARY

| Date | 07-01-82 | 07-15-82 | 08-04-82 | 08-25-82 | 9-15-82 | 10-06-82 | 11-19-82 | 12-14-82 |
|---|---|---|---|---|---|---|---|---|
| Conductivity (umhos $cm^{-1}$) | 209 | 222 | 258 | 258 | 231 | 248 | 256 | 256 |
| pH | 8.3 | 8.2 | 8.0 | 8.1 | 7.7 | 7.8 | 7.4 | 7.3 |
| Alkalinity (mg $L^{-1}$ as $CaCO_3$) | 124 | 129 | 128 | 135 | 116 | 128 | 133 | 134 |
| Calcium (mg $L^{-1}$) | <0.3 | 42.9 | 44.5 | 48.4 | 39.9 | 45.2 | 49.2 | 12.5 |
| Magnesium (mg $L^{-1}$) | | <0.3 | <0.3 | 0.4 | <0.3 | <0.3 | <0.3 | <0.3 |
| Iron (ug $L^{-1}$) | 59 | 56 | 54 | 42 | 118 | 714 | 30 | 52 |
| Total Phosphorus (ug $L^{-1}$ as P) | 2.8 | 4.1 | 4.4 | 3.3 | | 37.1 | 7.0 | 18.7 |
| Total Filterable Phosphorus (ug $L^{-1}$ as P) | | | | | | | | |
| Filterable Reactive Phosphorus (ug $L^{-1}$ as P) | | | | | | 51.9 | | |
| Nitrate+Nitrate (ug $L^{-1}$ as N) | | | | | | | 539 | 657 |
| Ammonium (ug $L^{-1}$ as N) | | | | | | | 3.1 | 5.1 |
| Reactive Silica (ug $L^{-1}$ as Si) | | 2,197 | 2,316 | 2,462 | 1,646 | 2,399 | 845 | 2,262 |
| Kjeldahl N (ug $L^{-1}$ as N) | 29 | | | | | | 89 | 103 |

Summary of water quality parameters found for surface waters in Corbin Creek, Deep Creek, Brownie Creek, and Glacier Creek during 1982.

Deep Creek - Robe Lake

WATER ANALYSIS SUMMARY

| Date | 01-20-82 | 02-24-82 | 03-26-82 | 04-23-82 | 06-07-82 | 06-16-82 | 06-30-82 |
|---|---|---|---|---|---|---|---|
| Conductivity (umhos $cm^{-1}$) | 51 | 60 | 55 | 55 | 46 | 43 | 46 |
| pH | 7.5 | 7.3 | 7.2 | 7.2 | 7.3 | 7.4 | 7.6 |
| Alkalinity (mg $L^{-1}$ as $CaCO_3$) | 21 | 23 | 20 | 18 | 19 | 20 | 22 |
| Calcium (mg $L^{-1}$) | 14.4 | 9.0 | 10.4 | 9.0 | 8.1 | 7.9 | 8.7 |
| Magnesium (mg $L^{-1}$) | <0.3 | <0.3 | <0.3 | <0.3 | <0.3 | <0.3 | <0.3 |
| Iron (ug $L^{-1}$) | 12 | 8 | 32 | 19 | 165 | 427 | 18 |
| Total Phosphorus (ug $L^{-1}$ as P) | | 1.3 | 2.7 | 2.0 | 8.2 | 5.9 | 4.0 |
| Total Filterable Phosphorus (ug $L^{-1}$ as P) | | | | | | | |
| Filterable Reactive Phosphorus (ug $L^{-1}$ as P) | | 1.1 | 0.6 | 2.2 | 1.3 | 1.0 | |
| Nitrate+Nitrate (ug $L^{-1}$ as N) | | 1,248 | 1,219 | 1,267 | 828 | 752 | |
| Ammonium (ug $L^{-1}$ as N) | | 1.1 | 0.6 | 0.9 | 1.8 | 0.7 | |
| Reactive Silica (ug $L^{-1}$ as Si) | 2,505 | 2,648 | 2,717 | 2,660 | 1,737 | 1,826 | 1,937 |
| Kjeldahl N (ug $L^{-1}$ as N) | | 66 | 59 | 66 | 82 | 76 | |

Summary of water quality parameters found for surface waters in Corbin Creek, Deep Creek, Brownie Creek, and Glacier Creek during 1982.

Deep Creek - Robe Lake (Continued)

WATER ANALYSIS SUMMARY

| Date | 07-13-82 | 08-02-82 | 08-25-82 | 09-14-82 | 10-04-82 | 11-17-82 | 12-14-82 |
|---|---|---|---|---|---|---|---|
| Conductivity (umhos $cm^{-1}$) | 54 | 61 | 65 | 54 | 56 | 59 | 58 |
| pH | 7.6 | 7.6 | 7.7 | 7.3 | 7.6 | 7.0 | 6.8 |
| Alkalinity (mg $L^{-1}$ as $CaCO_3$) | 23 | 25 | 26 | 22 | 21 | 20 | 21 |
| Calcium (mg $L^{-1}$) | 11.7 | 8.4 | 9.1 | | 8.7 | 9.7 | 68.8 |
| Magnesium (mg $L^{-1}$) | <0.3 | <0.3 | <0.3 | | <0.3 | <0.3 | 1.4 |
| Iron (ug $L^{-1}$) | 22 | 18 | <3 | 48 | 46 | 41 | 7 |
| Total Phosphorus (ug $L^{-1}$ as P) | 5.0 | 4.9 | 4.7 | 4.2 | 3.9 | 3.3 | 4.2 |
| Total Filterable Phosphorus (ug $L^{-1}$ as P) | | | | | | | |
| Filterable Reactive Phosphorus (ug $L^{-1}$ as P | | | | | 2.1 | | |
| Nitrate+Nitrate (ug $L^{-1}$ as N) | 572 | | | | | 1,092 | 1,225 |
| Ammonium (ug $L^{-1}$ as N) | 2.5 | | | | | 1.1 | 0.7 |
| Reactive Silica (ug $L^{-1}$ as Si) | 2,327 | 2,234 | 2,351 | 2,241 | 2,376 | 2,550 | 1,265 |
| Kjeldahl N (ug $L^{-1}$ as N) | 22 | | | | | 61 | 82 |

Summary of water quality parameters found for surface waters in Corbin Creek, Deep Creek, Brownie Creek, and Glacier Creek during 1982.

Brownie Creek - Robe Lake — WATER ANALYSIS SUMMARY

| Date | 01-20-82 | 02-24-82 | 03-26-82 | 04-29-82 | 06-07-82 | 06-16-82 | 06-30-82 |
|---|---|---|---|---|---|---|---|
| Conductivity (umhos $cm^{-1}$) | 140 | 107 | 105 | 73 | 134 | 114 | 134 |
| pH | 7.2 | 6.9 | 6.7 | 7.2 | 7.6 | 7.5 | 7.9 |
| Alkalinity (mg $L^{-1}$ as $CaCO_3$) | 82 | 69 | 60 | 30 | 71 | 70 | 76 |
| Calcium (mg $L^{-1}$) | 29.7 | 21.8 | 20.5 | 11.9 | 28.6 | | 27.3 |
| Magnesium (mg $L^{-1}$) | 3.3 | 1.6 | 1.9 | <0.3 | <0.3 | | <0.3 |
| Iron (ug $L^{-1}$) | 515 | 3,712 | 5,497 | 1,529 | 463 | 183 | 425 |
| Total Phosphorus (ug $L^{-1}$ as P) | | 15.4 | 16.2 | 5.3 | 4.8 | 13.3 | 5.7 |
| Total Filterable Phosphorus (ug $L^{-1}$ as P) | | | | | | | |
| Filterable Reactive Phosphorus (ug $L^{-1}$ as P) | | 5.3 | 6.6 | 1.4 | 1.8 | 3.1 | |
| Nitrate+Nitrate (ug $L^{-1}$ as N) | | 685 | 795 | 1,159 | 724 | 699 | 657 |
| Ammonium (ug $L^{-1}$ as N) | | 233 | 145 | 24 | 2 | 2 | 7 |
| Reactive Silica (ug $L^{-1}$ as Si) | 2,714 | 3,116 | 3,113 | 2,887 | 1,910 | 1,956 | 1,995 |
| Kjeldahl N (ug $L^{-1}$ as N) | | 470 | 317 | 136 1/ | 160 | 434 | 85 |

1/ Bottle dated 04-23-82.

Summary of water quality parameters found for surface waters in Corbin Creek, Deep Creek, Brownie Creek, and Glacier Creek during 1982.

Brownie Creek - Robe Lake (Continued) — WATER ANALYSIS SUMMARY

| Date | 07-13-82 | 08-02-82 | 08-25-82 | 09-14-82 | 10-04-82 | 11-17-82 | 12-14-82 |
|---|---|---|---|---|---|---|---|
| Conductivity (umhos cm-1) | 149 | 151 | 191 | 110 | 145 | 209 | 180 |
| pH | 7.8 | 7.6 | 7.9 | 7.1 | 7.7 | 7.4 | 7.1 |
| Alkalinity (mg $L^{-1}$ as $CaCO_3$) | 75 | 67 | 90 | 48 | 67 | 100 | 86 |
| Calcium (mg $L^{-1}$) | 26.0 | 22.3 | 33.0 | 17.6 | 26.5 | 35.7 | 42.5 |
| Magnesium (mg $L^{-1}$) | <0.3 | 0.7 | 0.4 | <0.3 | <0.3 | <0.3 | 0.8 |
| Iron (ug $L^{-1}$) | 1,091 | 1,135 | 522 | 108 | 301 | 149 | 194 |
| Total Phosphorus (ug $L^{-1}$ as P) | 20.9 | 39.1 | 21.9 | 10.9 | 6.9 | 5.4 | 7.3 |
| Total Filterable Phosphorus (ug $L^{-1}$ as P) | | | | | | | |
| Filterable Reactive Phosphorus (ug $L^{-1}$ as P) | | | | | 4.8 | | |
| Nitrate+Nitrate (ug $L^{-1}$ as N) | 611 | | | | | 765 | 704 |
| Ammonium (ug $L^{-1}$ as N) | 26 | | | | | 31 | 3 |
| Reactive Silica (ug $L^{-1}$ as Si) | 1,519 | 2,509 | 2,495 | 2,463 | 2,523 | 2,246 | 2,545 |
| Kjeldahl N (ug $L^{-1}$ as N) | 142 | | | | | 109 | 80 |

Summary of water quality parameters found for surface waters in Corbin Creek, Deep Creek, Brownie Creek, and Glacier Creek during 1982.

Glacier Creek - Robe Lake

WATER ANALYSIS SUMMARY

| Date | 06-08-82 1/ | 06-18-82 2/ | 07-01-82 | 07-15-82 | 08-04-82 | 08-25-82 | 09-15-82 | 10-06-82 | 11-19-82 |
|---|---|---|---|---|---|---|---|---|---|
| Conductivity (umhos $cm^{-1}$) | 47 | 51 | 56 | 61 | 65 | 65 | 63 | 123 | 296 |
| pH | 7.3 | 7.5 | 7.8 | 7.6 | 7.6 | 7.6 | 7.7 | 7.6 | 7.3 |
| Alkalinity (mg $L^{-1}$ as $CaCO_3$) | 22 | 26 | 29 | 27 | 27 | 29 | 28 | 54 | 147 |
| Calcium (mg $L^{-1}$) | 9.6 | 10.2 | 24.2 | 16.0 | 9.6 | 11.3 | 12.7 | 22.3 | 51 |
| Magnesium (mg $L^{-1}$) | <0.3 | <0.3 | | <0.3 | 0.7 | 0.9 | <0.3 | <0.3 | 2.3 |
| Iron (ug $L^{-1}$) | 5,241 | 5,589 | | 9,731 | 7,673 | 6,624 | 14,338 | 431 | 27 |
| Total Phosphorus (ug $L^{-1}$ as P) | 172.2 | 215.3 | | 962.5 | 320.0 | 327.0 | 1,169.9 | 5.5 | 2.9 |
| Total Filterable Phosphorus (ug $L^{-1}$ as P | | | | | | | | | |
| Filterable Reactive Phosphorus (ug $L^{-1}$ as P) | 172.6 | 168.8 | | | | | | 12.1 | |
| Nitrate+Nitrate (ug $L^{-1}$ as N) | 186 | 153 | | 118 | | | | | 1,014 |
| Ammonium (ug $L^{-1}$ as N) | 68 | 53 | | 100 | | | | | 1 |
| Reactive Silica (ug $L^{-1}$ as Si) | 942 | 992 | 2,008 | 2,206 | 912 | 743 | 2,009 | 1,571 | 1,948 |
| Kjeldahl N (ug $L^{-1}$ as N) | 136 | 78 | | 239 | | | | | 29 |

1/ The 06-08-82 sample was collected from the Twin Cottonwood Glacier.

2/ The 06-18-82 through 11-19-82 samples were collected from the Corbin Creek Glacier.

APPENDIX C

| Date | | Station 1 | Station 2 | Station 3 | Station 4 | |
|---|---|---|---|---|---|---|
| 3/3/82 | total | 0 | 4/100 ml | 1/100 ml | 1/100 ml | 0 |
| | fecal | 0 | 0 | 0 | 3/100 ml | 0 |
| | | 1 meter | 1 meter | 1 meter | 1 meter | 3 meter |
| 4/19/82 | total | 4/100 ml | | | 73/100 ml | |
| | fecal | 0 | | | 0 | |
| | | 1.8 meter | | | 4.3 meter | |
| 6/4 | total | 482/100 ml | 385/100 ml | 55/100 ml | 248/100 ml | 49/100 ml |
| | fecal | 0 | 0 | 0 | 0 | 0 |
| | | 1 meter | 1 meter | 1 meter | 1 meter | 3 meter |
| 6/17/82 | total | 164/100 ml | 28/100 ml | 143/100 ml | 79/100 ml | 98/100 ml |
| | fecal | 0 | 0 | 0 | 0 | 0 |
| | | 1 meter | 1 meter | 1 meter | 1 meter | 3 meter |
| 8/24 | total | too many to count | 312/100 ml | 8/100 ml | 235/100 ml | 196/100 ml |
| | fecal | 1 | 2/100 ml | 0 fecal | 2/100 ml | 0/100 ml |
| | | 1 meter | 1 meter | 1 meter | 1 meter | 3.1 meter |

Summary of total and fecal coliform bacteria counts found at Stations 1, 2, 3, and 4 in Robe Lake during 1982.