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# WATER QUALITY OF FOUR LAKES IN LAKEVILLE, MINNESOTA

U. S. GEOLOGICAL SURVEY

Water–Resources Investigations 80–66

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**16. Abstract (Limit: 200 words)**

Water-quality characteristics were determined for four selected lakes to provide background data for evaluating changes that may occur in the lakes because of urbanization. Precipitation of calcium carbonate is suggested by high pH values and a decrease in the calcium concentration when magnesium, sodium, and chloride concentrations increase. Pollution is indicated by chloride concentrations that increased from 18 to 57 milligrams per liter in 1978. The eutrophic state of the lakes is suggested by dissolved oxygen supersaturated near the surface and less than 0.1 milligram per liter near the deepest parts of the lakes. Determination of the trophic state of the lakes provided trophic state indices as high as 69.2. Phosphorus concentrations were significantly higher in two of the lakes sampled. *Anacystic* and *Oscillatoria* were the dominant phytoplankton genera. Phytoplankton blooms occurred throughout the year with the highest sampled concentration yielding 890,000 cells per milliliter.

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By L. H. Tornes and M. R. Have

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city of Lakeville, Minnesota

July 1980

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, Secretary

GEOLOGICAL SURVEY

H. William Menard, Director

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For additional information write to:

U.S. Geological Survey
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St. Paul, Minnesota 55101

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## CONVERSION FACTORS

| Multiply inch-pound unit | By | To obtain SI unit |
|---|---|---|
| inch (in) | 25.40 | millimeter (mm) |
| foot (ft) | 0.3048 | meter (m) |
| mile (mi) | 1.609 | kilometer (km) |
| acre | 0.4047 | hectare (ha) |

## GLOSSARY

Algacide - Chemical used to kill algae.

Algal bloom - A large number of a particular algal species.

Bloom - See algal bloom.

Blue-green algae - Algae of the division Cyanophyta that lack chloroplasts and have pigments dispersed through the entire protoplast.

Bottom slope - The slope profile of a lake bottom expressed as a percentage ratio of the maximum depth to the mean lake diameter and given as:

$$\text{Bottom slope} = \frac{D}{\bar{d}} \times 100$$

where: $D$ = maximum lake depth
$\bar{d}$ = mean lake diameter where $\bar{d} = \frac{2\sqrt{A}}{\sqrt{\pi}}$
$A$ = lake area

Bottom slope is a measure of the extent of shallow water and is important to the growth of rooted aquatic plants and the potential for wind mixing of water with bottom sediments.

Cations - Ions having a net positive (+) electrical charge and which, in electrolytes, characteristically move toward a negative electrode.

Detritus - Fragmented material of inorganic or organic origin.

Diatoms - Algae of the division Chrysophyta characterized by a cell wall of pectic materials impregnated with silica.

Dimictic - Pertaining to lakes in which circulation periods occur twice each year (spring and autumn).

Epilimnion - The upper, relatively warm, circulating zone of water in a thermally stratified lake.

Euglenoids - Algae of the division Euglenophyta that are unicellular and flagellated. The algae lack cell walls and store food in granules.

Euphotic zone - That part of the aquatic environment in which light is sufficient for photosynthesis; commonly considered to be that part of a water body in which the intensity of underwater light equals or exceeds 1 percent of the intensity of surface light.

Eutrophic - Pertaining to waters in which primary production is high as a consequence of a large supply of available nutrients and, in this report, having a trophic state index greater than about 50.

Fetch - The uninterrupted straight-line distance from the shore to the point of interest on the lake, usually associated with wave formation.

Green algae - Algae of the division Chlorophyta that contain chloroplasts in which chlorophyll is the predominant pigment.

Hypolimnion - The lower, relatively cold, noncirculating water zone in a thermally stratified lake.

Inorganic - Not composed of organic matter.

Littoral zone - The shallow zone of a body of water where light penetrates to the bottom.

Macrophytes - Plants that can be seen without the aid of magnification. As used in this report, rooted vascular plants, both submerged and emergent.

Mesotrophic - Pertaining to a lake having a moderate amount of dissolved nuitrients and, in this report, a trophic state index between about 40 and 50.

Metalimnion - The middle layer of water in a thermally stratified lake in which temperature decreases rapidly with increasing depth. See also thermocline.

Oligotrophic - Pertaining to waters in which primary production is low as a consequence of a small supply of available nutrients and, in this report, having a trophic state index less than about 40.

Organic - Of, pertaining to, or derived from living organisms.

Particulate - Pertaining to suspended material that will not pass through a 0.45-micrometer filter.

pH - Indicates the degree of acidity or alkalinity of a solution, and is a measure of the hydrogen-ion activity of the solution.

Photosynthesis - A biochemical synthesis of carbohydrates from water and carbon dioxide in the chlorophyll-containing tissues of plants in the presence of light.

Phytoplankton - Plant organisms of the plankton.

Plankton - Passively floating or weakly swimming aquatic organisms of relatively small size that are at the mercy of the water currents.

Secchi-disk transparency - The mean depth of the point where a weighted white disk, 20 centimeters in diameter, disappears when viewed from the shaded side of a vessel, and that point where it reappears upon raising it after it has been lowered beyond visibility.

Seston - Total heterogeneous mixture of living and nonliving materials suspended in the water.

Shoreline configuration - A dimensionless ratio of the length of shoreline to the circumference of a circle having an area equal to that of the lake, given as:

$$\text{Shoreline configuration} = \frac{L}{2\sqrt{\pi A}}$$

where L = shoreline length, and
A = lake area

Supersaturation - The condition where a solvent contains more dissolved solute than it could take up at its temperature.

Thermocline - The plane of maximum rate of temperature increase in a thermally stratified lake, sometimes used as a synonym for metalimnion.

Trophic state index - Carlson's (1977) numerical representation of the nutrient content and productivity of water using any one of three variables, abbreviated TSI, given as:

$$TSI_{(SD)} = 10\left(6 - \frac{\ln SD}{\ln 2}\right)$$

$$TSI_{(chla)} = 10\left(6 - \frac{2.04-0.68\ \ln chla}{\ln 2}\right)$$

$$TSI_{(TP)} = 10\left(6 - \frac{\ln \frac{65}{TP}}{\ln 2}\right)$$

where: SD = secchi-disk transparency in meters,
chla = chlorophyll a concentration in micrograms per liter, and
TP = total phosphorus concentration in micrograms per liter.

Yellow-brown algae - Algae of the class Chrysophyceae, also called golden-brown algae, that are motile and frequently form a unique type of spore. Characteristic color due to predominance of certain pigments.

Zooplankton - Animal organisms of the plankton.

# WATER QUALITY OF FOUR LAKES IN LAKEVILLE, MINNESOTA

By Lan H. Tornes and Mark R. Have

## ABSTRACT

Water-quality characteristics were determined for four lakes (Marion, Orchard, Kingsley, and Lee) in the city of Lakeville to provide background data and evaluate changes in lake water quality that may occur with urbanization. Thirteen samplings were done from March 1976 to October 1978. Physical characteristics of the lakes were defined and selected chemical and biological constituents were determined. Calcium carbonate precipitation is suggested by pH values as high as 10 near the surface and a decrease in the calcium concentration when magnesium, sodium, and chloride concentrations increase. Pollution of part of Marion Lake is indicated by chloride concentrations that increased from 18 to 57 milligrams per liter between June and October 1978. The eutrophic state of the lakes is suggested by supersaturated dissolved oxygen near the surface and dissolved-oxygen concentrations less than 0.1 milligram per liter near the deepest parts of the lakes in summer. Total phosphorus and chlorophyll a concentrations and Secchi-disk transparencies were used to determine the trophic state of the lakes. Trophic state indices were as high as 69.2. Phosphorus concentrations were significantly higher in Lee and Kingsley Lakes than in the other lakes sampled. *Anacystis* and *Oscillatoria* were the dominant phytoplankton genera. Phytoplankton blooms occurred throughout the year with the highest sampled concentration yielding 890,000 cells per milliliter during September 1976 in Lee Lake.

## INTRODUCTION

The city of Lakeville, Minn., a suburb of the Twin Cities, is experiencing rapid growth and development. As with many of the suburbs, Lakeville was an agricultural community that now is becoming more residential with some light industry. The population increased from 924 in 1960 to 7,556 in 1970.

The city of Lakeville enlisted the help of the U.S. Geological Survey to establish baseline water-quality data for some of its lakes and to monitor for changes in water quality as the area becomes urbanized. A sampling program at seven sites on four major lakes (fig. 1) began in 1976.

Two of the lakes, Orchard and Marion, are used extensively for swimming, fishing, and boating. Lee and Kingsley Lakes are smaller and are used less for recreation.

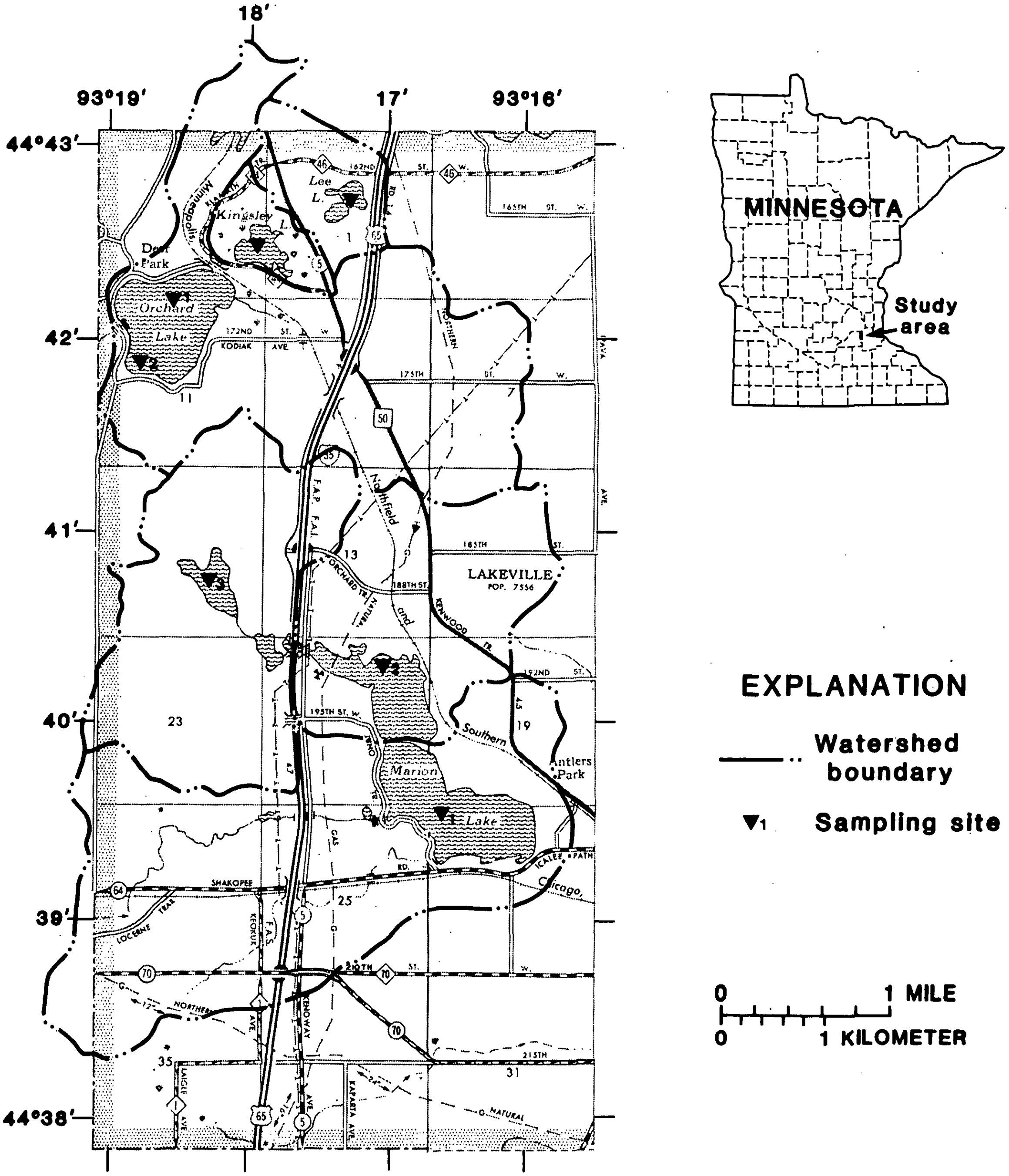



***Figure 1.--Location of sampling sites for lakes in the Lakeville area***

Marion and Orchard Lakes have had nuisance growths of algae for the past several years. This problem, and the suspected occurrence of swimmer's itch, have been reduced by annual applications of the algacide copper sulfate for at least the past 10 years (William Alich, Lakeville Public Works, oral commun., 1979).

## PHYSICAL CHARACTERISTICS AND MORPHOMETRY

The surficial materials around Lakeville are unconsolidated clay, sand, and gravel deposited as a moraine. The mean annual precipitation is 27.5 inches, most of which occurs between April and September. The recorded temperatures range from -40° to 112°F, with a mean annual temperature of about 45°F (Minnesota Conservation Department, 1965). All the lakes have internal drainage, except Orchard, which has surface-water outflow at higher stages.

Table 1 compares some of the physical features of the lakes and parts of lakes sampled for this program. Data shown were obtained from U.S. Geological Survey topographic maps, Bonestroo and others (1977) and field observations. Marion Lake is divided into three parts represented by the three sampling sites in this report. Sites 1 and 2 are separated by a shallow bar that bisects the lake. Sites 2 and 3 are divided by Interstate 35W, but are connected by concrete culverts. The direct connections maintain the same water level between all sites, but mixing between sites is not indicated.

Table 1.--Physical characteristics of the lakes

| Lake | Area, in acres | Shoreline length, in miles | Shoreline configuration | Bottom slope | Watershed area, in acres | Depth at deepest point, in feet | Remarks |
|---|---|---|---|---|---|---|---|
| Kingsley.... | 44.2 | 1.7 | 1.8 | 12.2 | 193 | 7.5 | Macrophytes abundant. |
| Lee......... | 20.5 | 1.0 | 1.6 | 40.3 | 313 | 17 | Very few macrophytes. |
| Marion, site 1.... | 257.9 | 3.3 | 1.5 | 15.4 | 2480 | 23 | Do. |
| Marion, site 2.... | 158.7 | 3.6 | 2.0 | 7.7 | 1150 | 9.0 | Macrophytes abundant. |
| Marion, site 3.... | 89.0 | 3.1 | 2.4 | 6.8 | 1460 | 6.0 | Do. |
| Orchard..... | 231.0 | 2.8 | 1.3 | 24.0 | 1930 | 34 | Few macrophytes. |

Lake-surface areas range from approximately 258 acres for Marion Lake site 1 to 20.5 acres for Lee Lake. Shoreline lengths range from 3.6 miles around Marion Lake site 2, to 1.0 mile around Lee Lake.

Shoreline configuration, a relationship between shoreline length and surface area of the lake, is an indication of the presence of protected bays and the amount of contact between land and water. High shoreline configuration values indirectly indicate the potential for growth of rooted aquatic plants and nutrient enrichment potential through near-shore development and runoff (Dion and others, 1976). Values for shoreline configuration range from 2.4 for Marion Lake site 3 to 1.3 for Orchard Lake.

Bottom slope, the ratio of maximum lake depth to mean lake diameter, indicates the amount of shallow sunlit water available for the growth of rooted aquatic plants (littoral zone). Marion Lake site 3 has the lowest bottom slope, indicating a large littoral zone. Lee Lake has the highest bottom slope and a much smaller littoral zone.

## CHEMICAL SAMPLES

Thirteen samplings were done from March 1976 to October 1978 with sampling frequency varying each year. The lakes were sampled each time for chloride, and three times for alkalinity, bicarbonate, dissolved sodium and calcium, suspended solids, and turbidity. Some of the samples were also analyzed for dissolved potassium and magnesium, and six samples were analyzed for dissolved solids.

All constituents were analyzed in accordance with methods of the American Public Health Association and others (1976), Skougstad and others (1979), or Greeson and others (1977).

Figure 2 is a trilinear diagram comparing the percent of milliequivalents per liter of the major cations in the September 1976 lake samples. The cations from the lake samples are about 30 percent calcium, with magnesium percentages ranging from 20 to 50 percent, and sodium and potassium ranging from 15 to 55 percent of the cations.

Figures 3a, 3b, and 3c show the results of analyses for calcium, magnesium, and sodium in lake samples collected in 1976. Figure 4 shows the chloride concentration throughout the sampling program. Marion Lake site 3 was frozen to the bottom in March 1978, so no sample was taken. A general increase in the concentrations of magnesium, sodium, and chloride through 1976 may be the result of concentration of dissolved constituents by evaporation of water or reduced dilution of inflowing ground water because of the drought during this period. Calcium concentrations generally decreased during 1976.

Dissolved-solids concentrations (fig. 5) varied but did not increase as did magnesium, sodium, and chloride.

Alkalinity (as calcium carbonate) was determined in the 1976 water year, and the concentrations for each site are shown in figure 6. Concentrations at the shallower sites in Marion Lake were greater in March during ice cover.

A large part of the dissolved solids is the constituents that contribute to alkalinity. Hence, there is good correlation between alkalinity (fig. 6) and dissolved solids (fig. 5).

Factors controlling calcium concentrations and alkalinity seem to be different from those affecting the magnesium, sodium, and chloride concentrations. Biological activity may have a major influence on calcium concentrations and alkalinity in highly productive lakes such as the Lakeville lakes.

During periods of high productivity, photosynthesis by phytoplankton and macrophytes utilizes carbon dioxide in the euphotic zone faster than it can be replaced by atmospheric or hypolimnetic carbon dioxide. Reduction of carbon dioxide raises the pH of the water and reduces the solubility of calcium carbonate. If the concentration of calcium carbonate was high enough before plant productivity raised the pH, excess calcium carbonate would precipitate from epilimnetic waters until saturation is achieved. The Lakeville lakes, situated in drift from the Des Moines lobe, could have sufficiently high concentrations of calcium carbonate to achieve saturation and precipitation during phytoplankton blooms (Kelts and Hsu, 1978; Reid and Wood, 1976).

In deep lakes, Marion site 1 and Orchard, precipitated calcium carbonate may redissolve in the hypolimnion due to the excessive carbon dioxide present from decompositional processes. Mixing of the lake can reintroduce calcium and bicarbonate to surface layers (Wetzel, 1975). Mixing by wind may explain the increase in alkalinity observed in Marion Lake site 1, and Orchard Lake sites 1 and 2 in June 1976. The remaining sites either are less affected by wind (Lee Lake) or are shallow enough to prevent dissolution of calcium carbonate until the winter period of reduced productivity.

The effects of calcium precipitation can be seen in the changing calcium concentrations shown in figure 3a. A comparison of these changes with changes in alkalinity shown in figure 6, indicates that the constituents follow remarkably similar seasonal patterns. The mean of the correlation coefficient between calcium concentrations and alkalinity for each of the sites is 0.958.

Magnesium compounds are generally more soluble than their calcium counterparts, showing significant precipitation, as carbonates and hydroxides of magnesium, only at pH values greater than 10 (Wetzel, 1975). The pH of the Lakeville lakes does approach 10 in many of the samples and may have surpassed 10 at other times (an August 1977 sample at Lee Lake had a pH of 10). The magnesium concentrations increased rather than decreased between June and September 1976 (fig. 3b). This increase implies that precipitation of magnesium in these lakes has a negligible effect on the cation ratios.

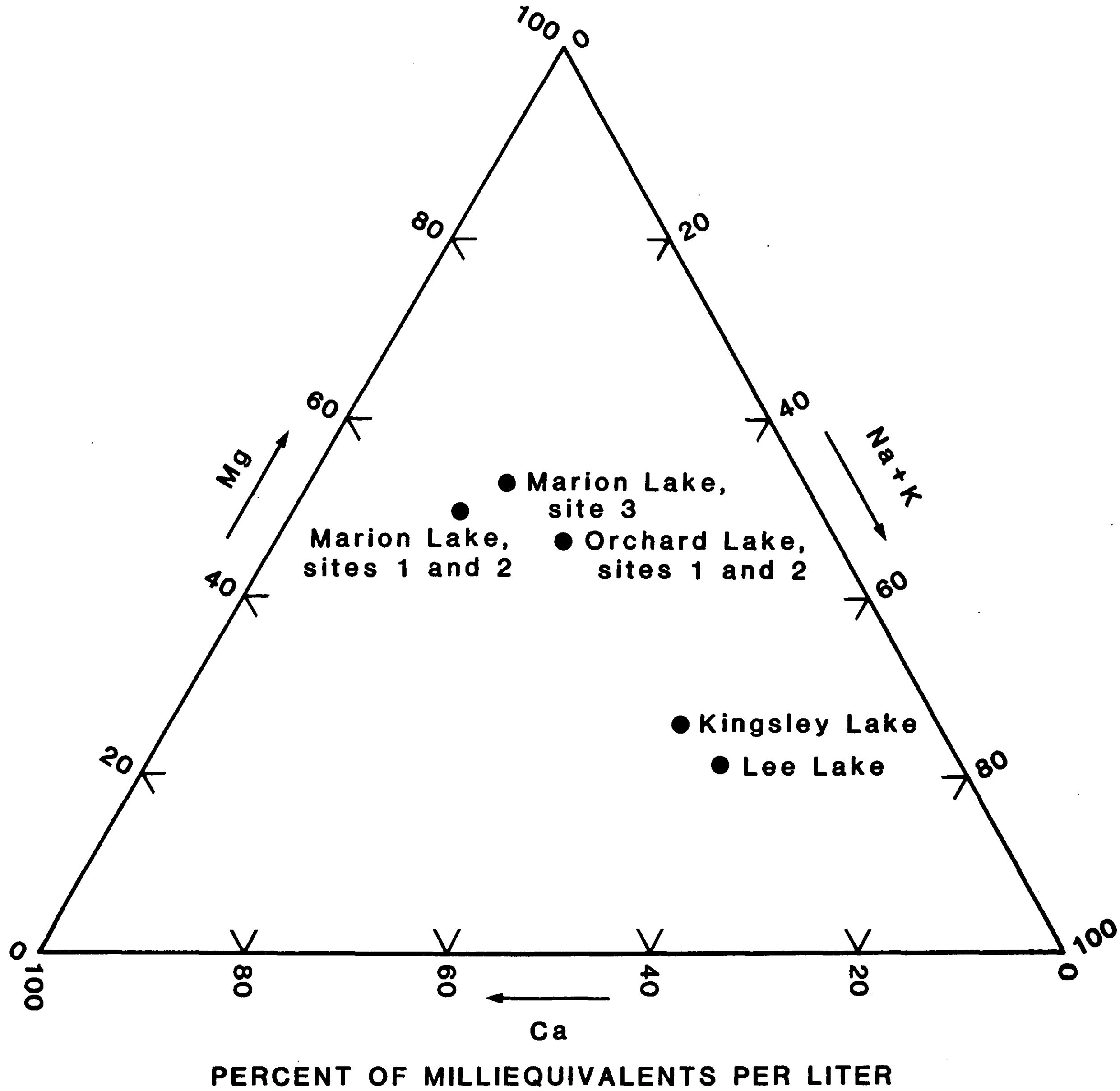



***Figure 2.--Major cations expressed as percentage of milliequivalents per liter***

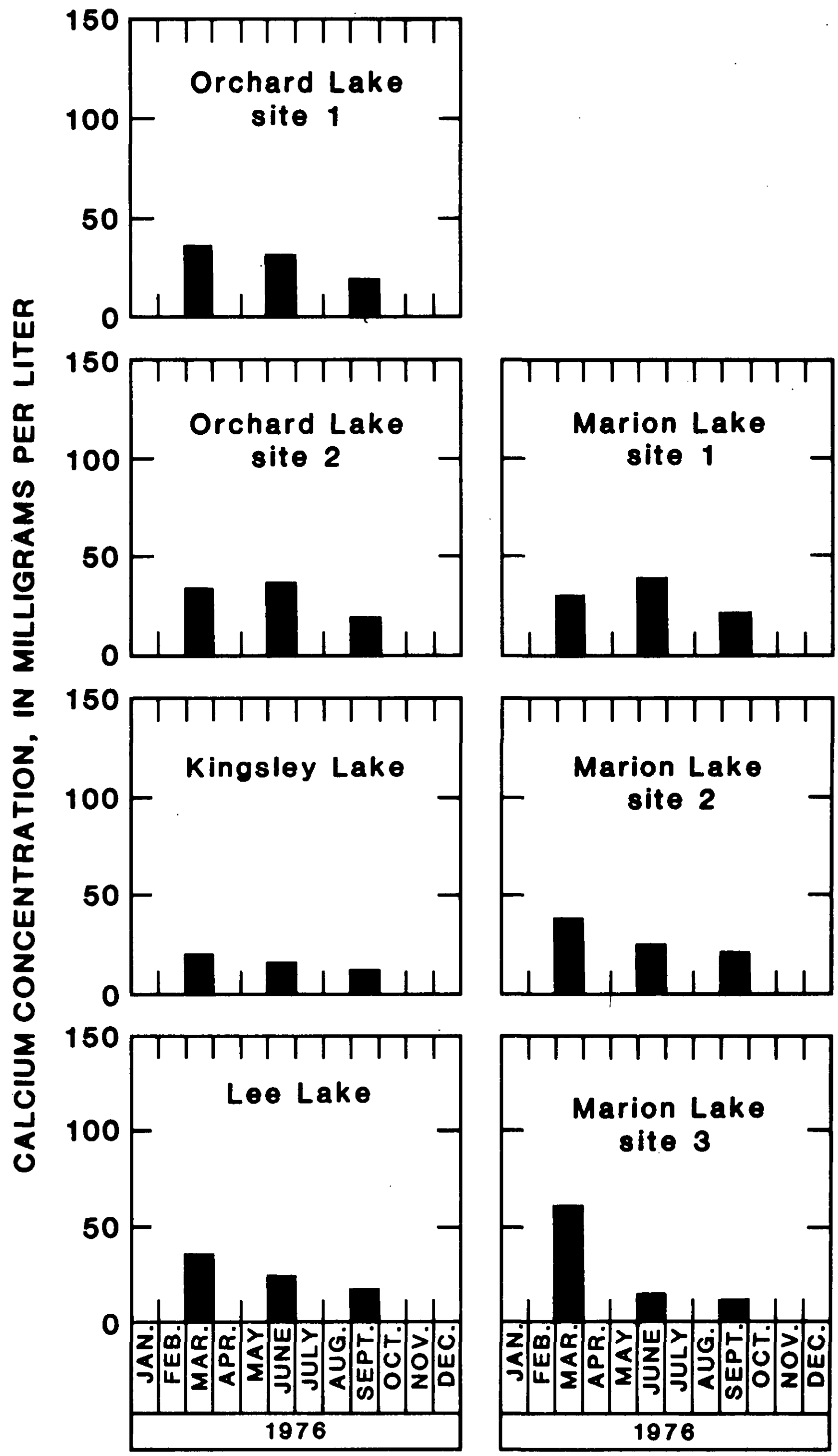



*Figure 3a.--Calcium concentrations in 1976*

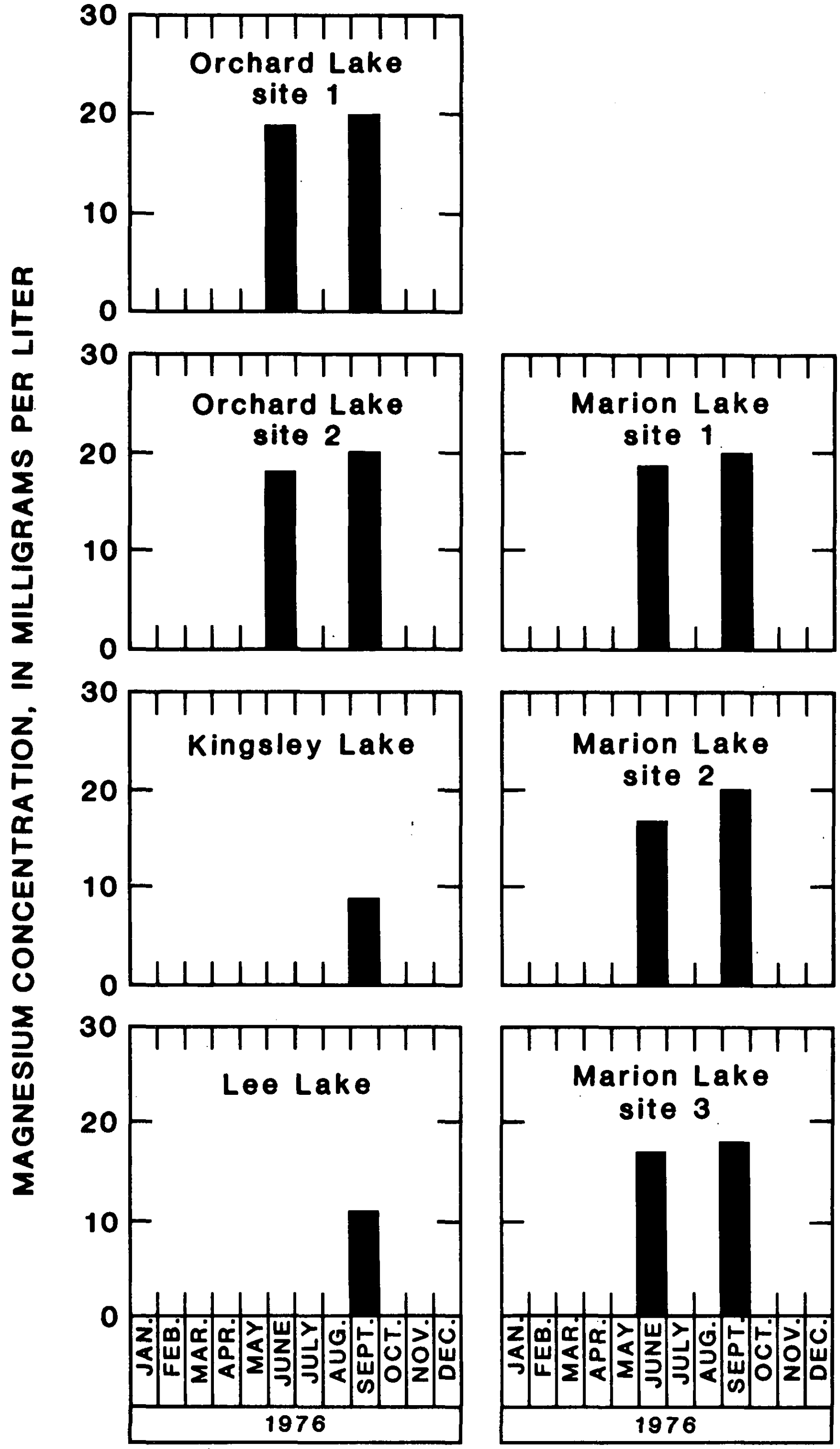



*Figure 3b.--Magnesium concentrations in 1976*

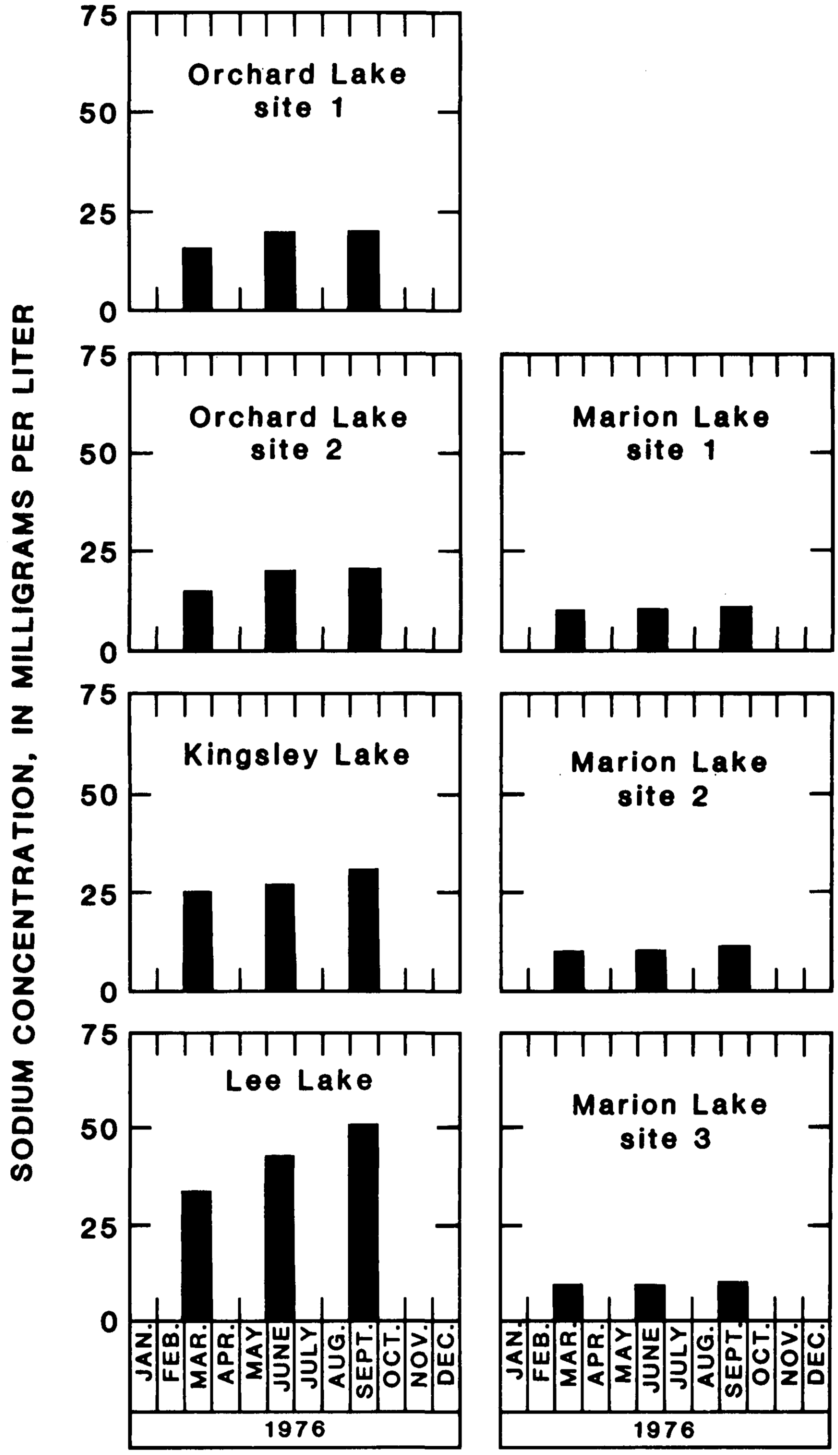



*Figure 3c.--Sodium concentrations in 1976*

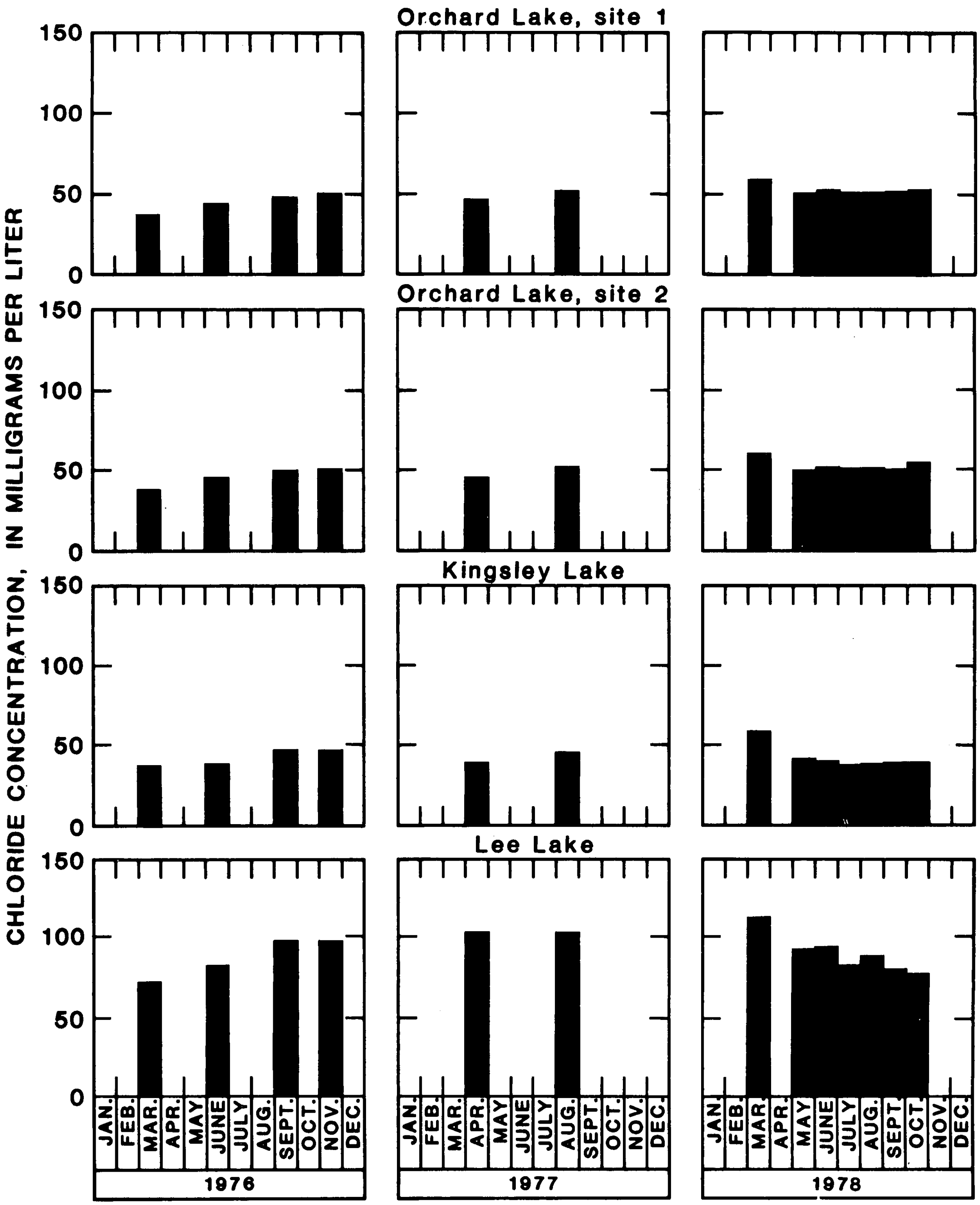
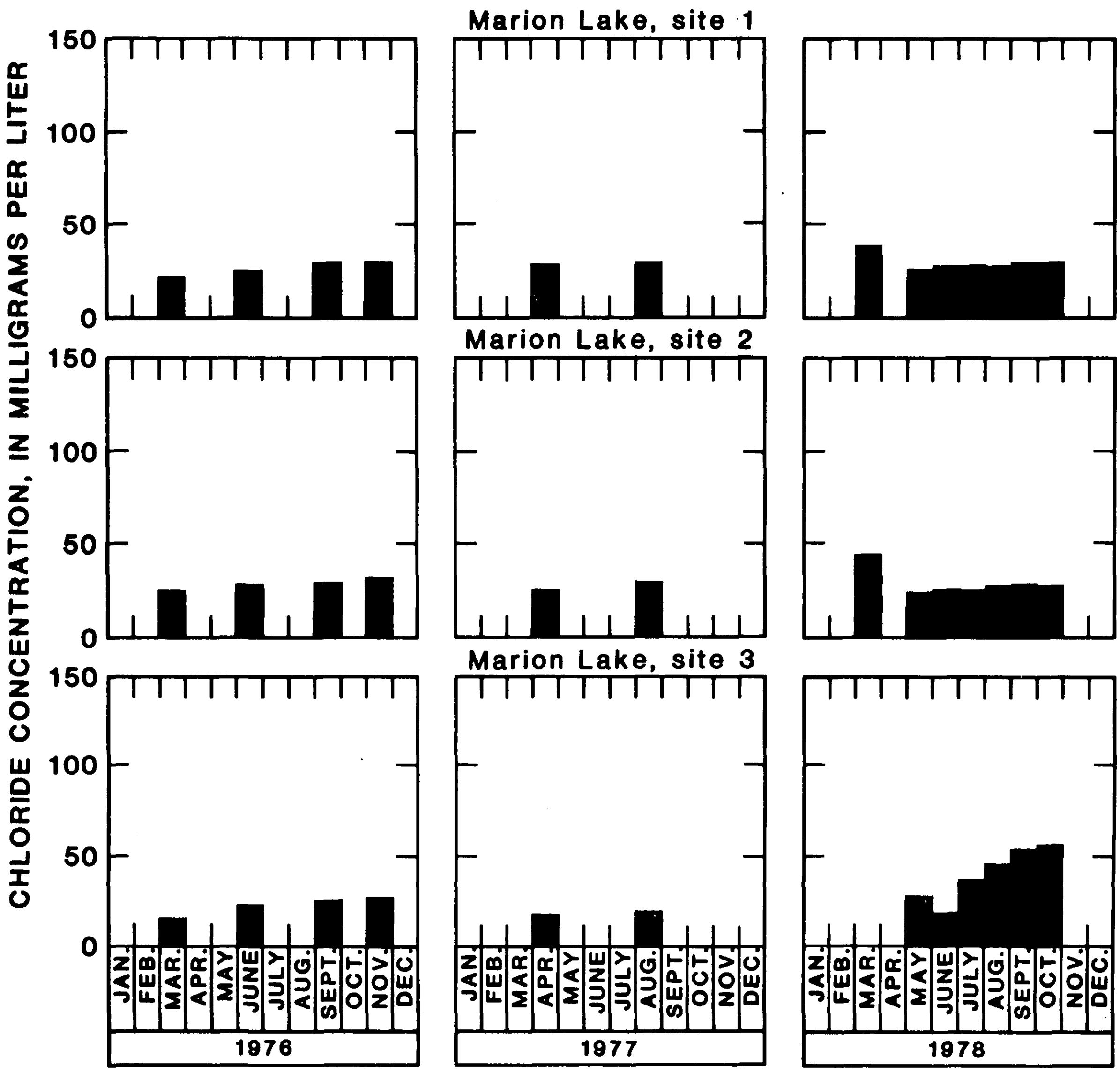



*Figure 4.--Chloride concentrations*




*In the Lakeville lakes*

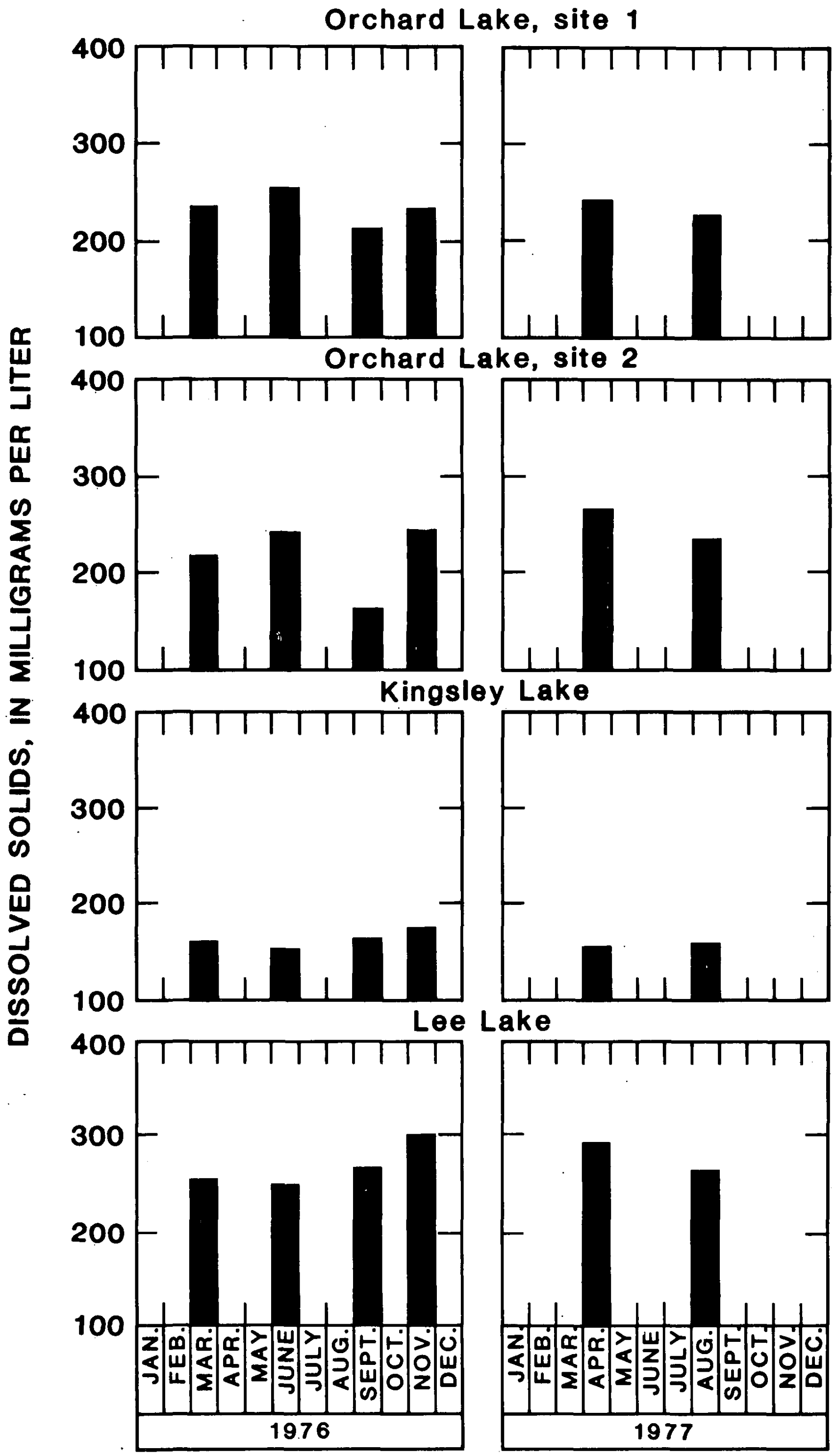
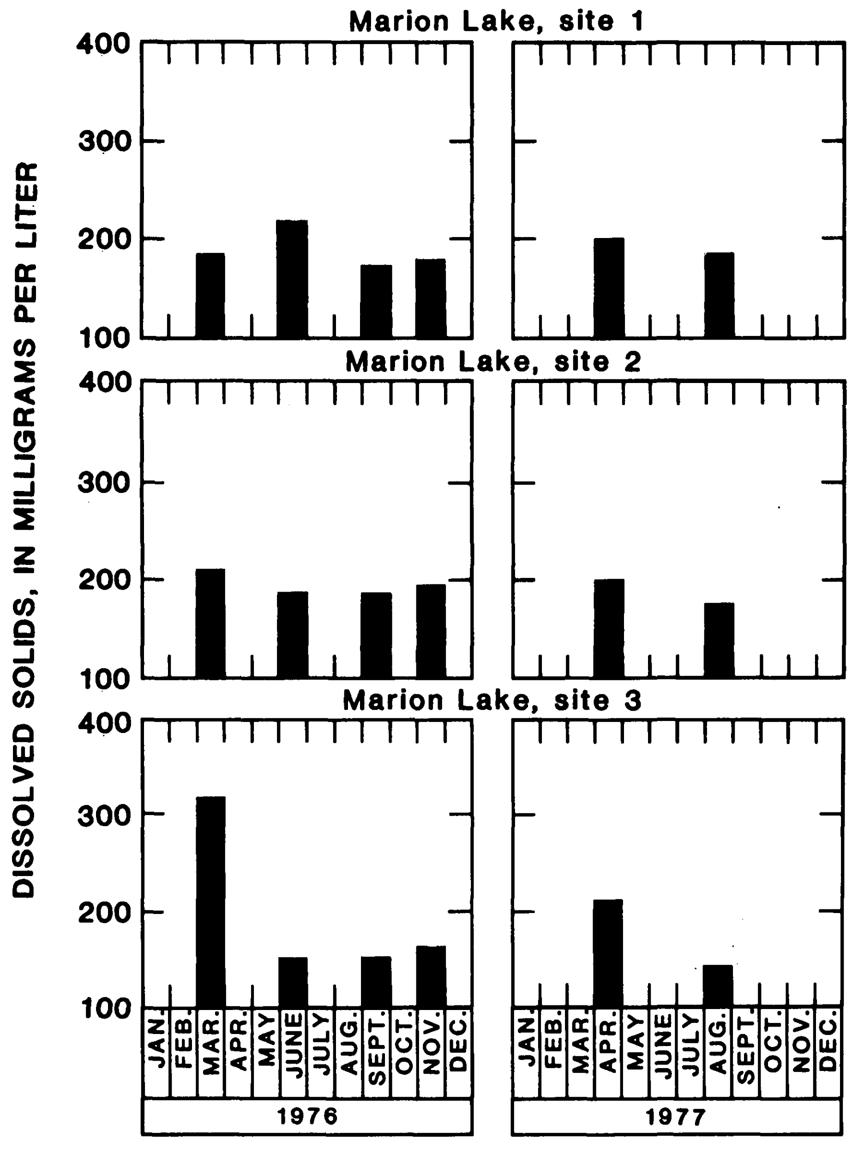



*Figure 5.--Dissolved-solids*




***concentrations for each lake***

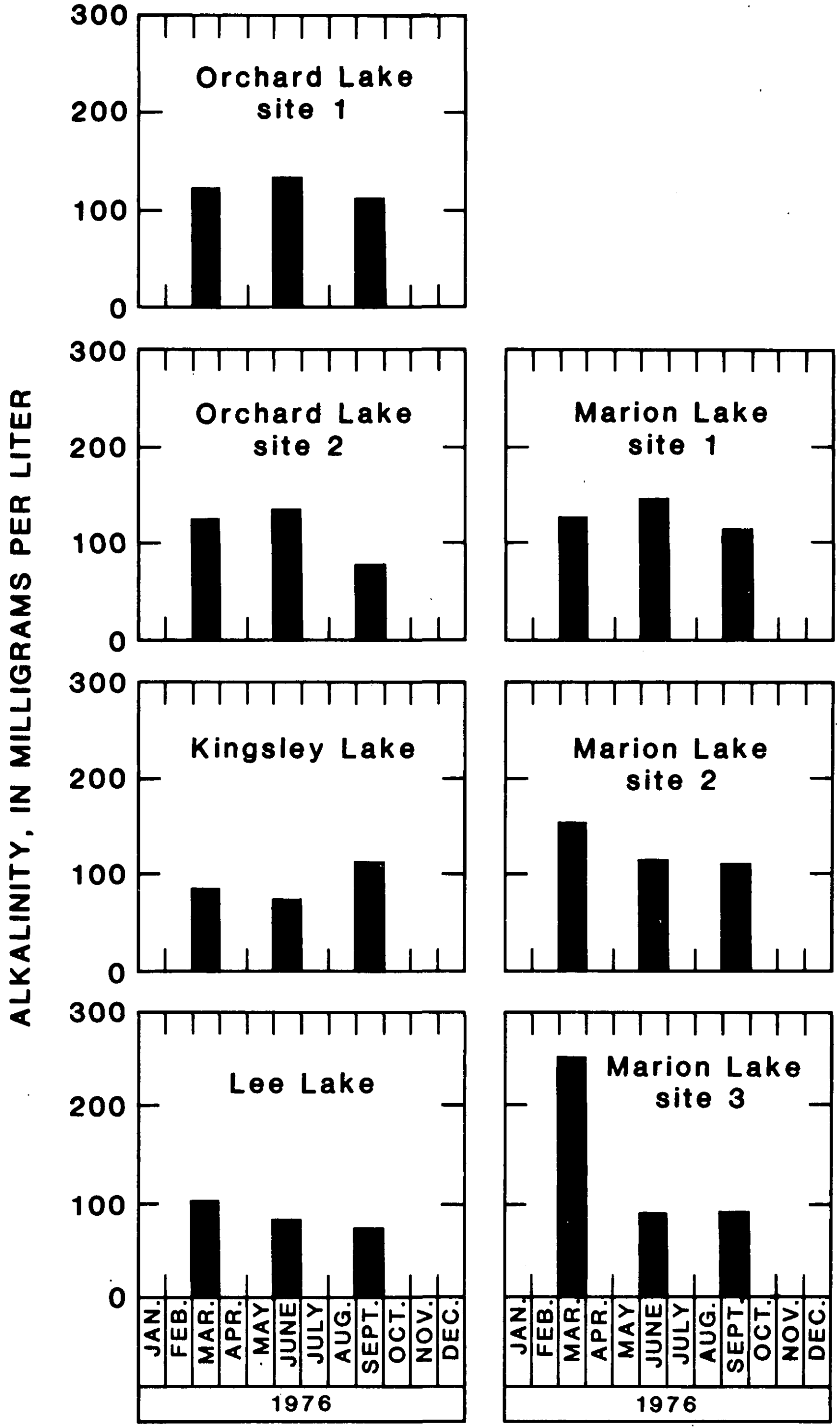



***Figure 6.--Alkalinity, as calcium carbonate, concentrations for each lake***

According to Wetzel (1975), sodium and potassium salts are abundant and readily soluble in natural waters, and alteration of the concentration in natural waters is uncommon. The trilinear diagram (fig. 2) shows that sodium and potassium comprise a high percentage of the equivalents for plots 4 and 5, Kingsley and Lee Lakes, respectively. The possibility of enrichment of sodium in these lakes is not indicated, as long-term data on the sodium content is currently lacking. Sewage and industrial wastes may add much sodium to the lakes (Hem, 1959), and runoff from applications of sodium chloride road salt may supply a significant amount of sodium to the lakes.

Chloride concentrations are virtually unaffected by metabolic utilization, with most input being derived from pollution (Wetzel, 1975). The increased chloride concentrations in 1976 continued throughout 1977 and peaked in March 1978. Much of the increased concentration of chloride and other ions can be attributed to effects of the drought, but pollution from sources such as road salt, though difficult to quantify, cannot be ruled out.

The concentration of chloride decreased in May 1978 as runoff from snowmelt diluted the lake water. The May 1978 chloride levels generally remained notably higher than the concentrations found in early 1976, probably due to extended effects of the drought. The plot of lake-surface elevations for Marion Lake (fig. 7), obtained from the Minnesota Department of Natural Resources, shows that by mid-1978 the lake had not returned to its early 1976 volume. Many ionic constituents could be expected to remain at relatively high concentrations because of the reduced volume.

Unlike that at the other sites, chloride concentrations in Marion Lake site 3 increased steadily from 18 to 57 mg/L between June and October 1978. Pollution of the lake is, thus, indicated. Sodium chloride and possibly calcium chloride applied to roads in the watershed could wash slowly into the lake during the summer in sufficient quantity to increase the chloride concentration in site 3. Chloride concentrations in Lee Lake show a general decline through 1978. The most probable cause of this decline is dilution by inflowing water low in chloride. Ground-water inflow, precipitation, domestic input, or a combination of these may be the source of this dilution water. The 30 percent drop in chloride concentration between May and October indicates that the volume of this dilution water could be large.

Evidence that animal wastes are affecting the water quality of Lee Lake is shown by the potassium concentrations determined in September 1976. Potassium concentrations in all lakes except Lee Lake ranged from 1.9 to 3.6 mg/L. In Lee Lake it was 9.0 mg/L. Potassium is a major constituent in animal wastes (Hodges, 1973, p. 174).

Continued periodic sampling of the Lakeville lakes for such stable inorganic constituents as chloride and sodium might further establish the relationship between these lakes and domestic influences around them. Increased sodium or chloride concentrations through time could indicate domestic inputs that could be controlled to prevent degradation of the lakes.

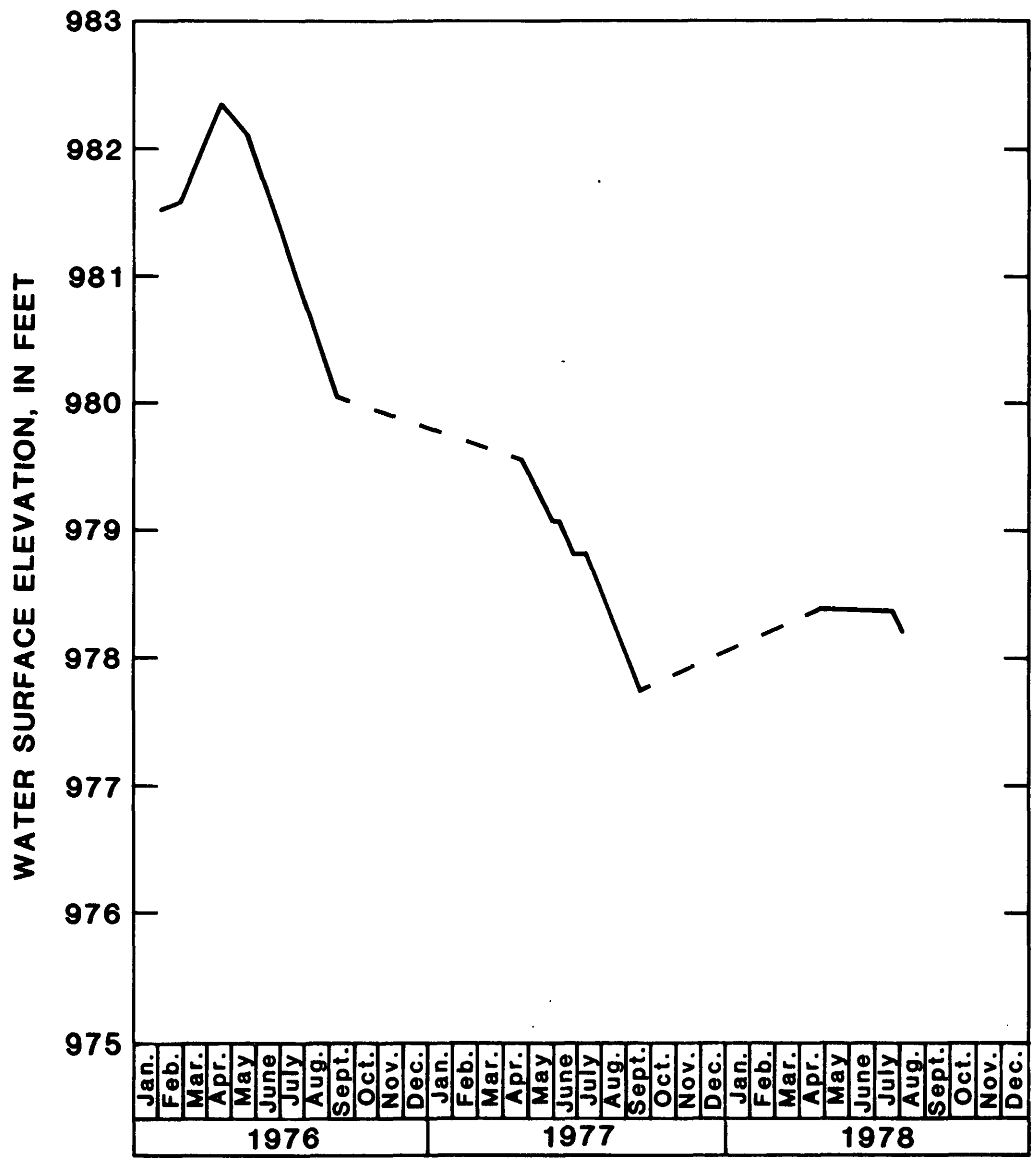



*Figure 7.--Lake surface elevations of Marion Lake (from Minnesota Department of Natural Resources)*

## Bottom Samples

Early in the program, one sample of bottom material was obtained at each site and analyzed for various constituents. The results of the analyses are shown in table 2. Due to the variability of bottom sediments and the drift, it is difficult to make generalized statements about the composition of bottom sediments.

Table 2.--Data from bottom material samples collected from each of the lake sampling sites in March 1976

[Values shown are total concentrations]

| | Orchard Lake | | Marion Lake | | | Kingsley Lake | Lee Lake |
|---|---|---|---|---|---|---|---|
| | Site 1 | Site 2 | Site 1 | Site 2 | Site 3 | | |
| Oil and grease, mg/kg........ | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1200 |
| Nitrogen, mg/kg........ | 2300 | 2600 | 16,400 | 42,400 | 30,300 | 3300 | 2800 |
| Phosphorus, mg/kg........ | 39 | --- | 140 | 68 | 62 | 510 | 250 |
| Organic carbon, g/kg......... | 171 | --- | 72 | 149 | 132 | 36 | 322 |
| Arsenic, ug/g......... | 51 | 38 | 12 | 9 | 8 | 10 | 9 |
| Cadmium, ug/g......... | 1 | 2 | 2 | 2 | 2 | 1 | 2 |
| Chromium, ug/g......... | 7 | 12 | 19 | 14 | 11 | 26 | 7 |
| Copper, ug/g......... | 80 | 22 | 53 | 41 | 12 | 37 | 12 |
| Lead, ug/g..... | 80 | 76 | 50 | 42 | 44 | 40 | 30 |
| Zinc, ug/g..... | 83 | 109 | 90 | 64 | 46 | 88 | 86 |
| Aluminum, ug/g......... | 3300 | 5700 | 8700 | 5200 | 4200 | 12,000 | 4000 |
| Mercury, ug/g......... | 0.4 | 0.6 | 0.4 | 0.1 | 0.3 | 0.1 | 0.1 |

Orchard Lake samples had relatively low concentrations of the potential plant nutrients nitrogen and phosphorus. A higher concentration of organic carbon indicates deposition of detritus. Most of the metals concentrations in the bottom sediment were similar to concentrations found in bottom samples from other lakes in the area (Payne, 1980). Arsenic concentrations in Orchard Lake were more than three times the concentrations sampled at the other sites. The arsenic may or may not be present naturally. High copper concentrations are probably caused by applications of the algacide copper sulfate. High lead concentrations could be the result of emissions from internal-combustion engines.

Marion Lake bottom samples had higher concentrations of nitrogen than samples from other lakes. This may be an indication of past runoff from agricultural land in the large gently sloping watershed of Marion Lake. High concentrations of organic carbon in Marion Lake sites 2 and 3 may be attributable to detritus observed at the sites.

Relatively high phosphorus concentrations found at Kingsley Lake are not easily explainable, although sampling may by chance have been in an area particularly high in phosphorus. In shallow lakes such as Kingsley, phosphorus in the bottom sediments is easily available for plant growth. The source of relatively high concentrations of the heavy metals, chromium and copper, is not known.

Oil and grease may have been introduced to Lee Lake through runoff from Interstate Highway 35. However, sampling error is possible, as oil and grease were not found in samples from other sites. Concentrations of other constituents in Lee Lake compare favorably with concentrations at the other sites. High organic-carbon concentrations again indicate the presence of detritus in Lee Lake.

## Dissolved-Oxygen Profiles

Vertical profiles of dissolved-oxygen concentration and temperature were obtained concurrent with the regular sample collection at each of the lake sites. Later in the sampling program, some of the profiles included measurements of pH. The profiles provided information concerning each lake's response to seasonal changes with respect to these field measurements.

The annual cycle of dimictic lakes has a period of summer stratification with warm, less-dense water at the surface and cold, denser (approaching maximum density temperature of 4°C) water at the bottom. The upper layer, or epilimnion, is subject to frequent mixing by wind action. The lower layer, or hypolimnion, is generally isolated and becomes stagnated during the summer. These layers are commonly separated by a thermocline, or metalimnion, where the temperature changes rapidly with depth.

In the fall, surface water cools and mixes with other layers as vertical density currents are set up. Breakdown of stratification encourages almost complete mixing of the lake by wind action.

As the water cools below the maximum density temperature of 4°C, the lake becomes inversely stratified, with the warmest water near the bottom and cooler water above. The small density gradient at this temperature allows the lake waters to mix frequently by wind action until ice cover prevents mixing. Lake temperatures during winter inverse stratification will range from 0°C near the surface to 4°C or less near the bottom.

The warm temperatures of spring break down the winter inverse stratification and allow wind action to mix the water. The mixing may continue until a few days of warm, calm weather again establishes summer stratification.

Shallow lakes, such as Kingsley, Marion sites 1 and 2, and Orchard site 2, exhibit only winter inverse stratification. Summer stratification is rare and unstable, with the whole lake behaving as the epilimnion of deeper lakes. When sampled during the ice-free seasons, the shallow lakes showed only minor variations in vertical profiles of temperature, dissolved oxygen, pH, and specific conductance.

Selected vertical profiles at Orchard Lake site 1 are shown in figure 8. The profile for March 8, 1976, was obtained under ice cover and shows the inverse temperature stratification described earlier. The temperatures warmer than 4°C found near the bottom were probably caused by heat released by decomposition of detritus accumulated at the bottom. The profile of dissolved-oxygen concentrations showed oxygen enrichment, due to photosynthetic activity of phytoplankton, in the upper 5 feet of the water. Oxygen depletion was apparent below 10 feet in depth, probably caused by biological decomposition.

The profile obtained April 11, 1977, shows the lake water to be well mixed during the period of spring turnover. The lake essentially had a constant temperature throughout its depth. The dissolved-oxygen concentrations were also constant, with some minor oxygen depletion observed near the bottom.

A summer profile of pH, water temperature, and dissolved-oxygen was done on August 9, 1978. It is considered typical of other profiles obtained during the summer. The lack of stratification in the upper 12 feet of the water column defines the epilimnion, with good mixing by wind action. The hypolimnion was found below 27 feet, though almost total oxygen depletion (less than 0.1 mg/L) occurred below 24 feet in depth, indicating a higher hypolimnetic boundary. The thermocline is indistinct between the epilimnion and hypolimnion. The lack of definite boundaries and the relatively small temperature range from top to bottom (approximately 9°C) could subject this lake to substantial mixing by wind. Mixing can reintroduce nutrients trapped near the bottom to surface layers, where they may be utilized by phytoplankton and cause algal blooms.

The pH profile of August 1978 shows the characteristic vertical distribution found in productive lakes in summer. The pH was high at the surface, owing primarily to depletion of carbon dioxide by photosynthesis. The pH values less than 7.0 at and near the bottom were the result of decompositional processes that increase the concentration of carbon dioxide (Wetzel, 1975).

Photosynthesis can raise the concentration of dissolved oxygen near the surface beyond the point of saturation. Orchard Lake was supersaturated to a depth of 12 feet in the August 1978 profile.

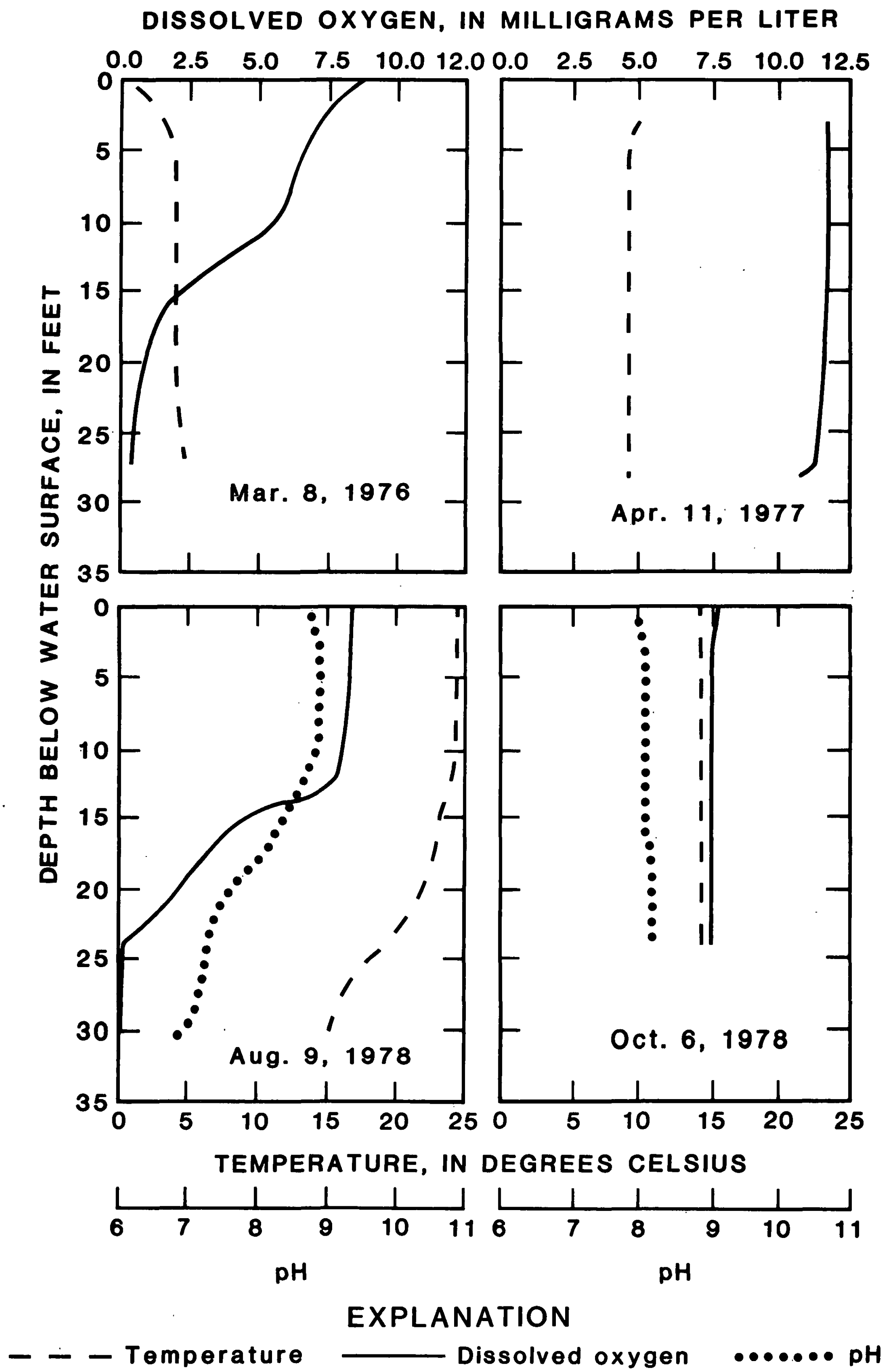



*Figure 8.--Selected temperature, dissolved oxygen, and pH vertical profiles for Orchard Lake, site 1*

The homogeneity of Orchard Lake during fall turnover is indicated by the profile obtained October 6, 1978. The water temperature was constant throughout the vertical, the dissolved-oxygen concentration varied only 0.1 mg/L, and the pH varied only 0.2 unit.

Figure 9 shows the results of profiles from site 1 on Marion Lake. Fall, winter, and spring profiles (fig. 9) are similar to those obtained at site 1 on Orchard Lake. A profile on March 20, 1978, under ice cover, showed water temperatures ranging from 0°C near the surface to 4°C near the bottom and dissolved-oxygen concentrations ranging from 3.3 mg/L near the surface to 0.4 mg/L near the bottom.

The temperature and dissolved-oxygen conditions shown on the Marion Lake profile for June 6, 1978, in figure 9, are potentially good for maintaining high productivity. The dissolved-oxygen concentrations ranged from supersaturation near the surface to nearly zero (anoxic) at the bottom, where soluble phosphate could be released to the water. The temperature ranged only 2.3°C from top to bottom, with no thermocline present. The 1-mile fetch at site 1 and the lack of stratification can subject this lake to frequent mixing by wind action and reintroduction of nutrients from bottom sediment to surface layers.

The profile obtained August 9, 1978, showed characteristics similar to those seen in the June 6 profile. The dissolved oxygen declined rapidly from supersaturation to anoxia, no thermocline was present, and, in addition, the pH was high near the top and declined rapidly near the bottom. Comparison of the 17-foot bottom temperatures between the June 6 and August 9 samplings showed an increase of 3.3°C at that depth. This was probably evidence of mixing between the warm surface waters and the cooler bottom waters induced by wind action.

Profiles are shown for Lee Lake in figure 10. The June 6, 1978, profile shows no thermocline. A drop in pH, and a rapid decline in the concentration of dissolved oxygen was observed below 7 feet.

The Lee Lake profile from August 9, 1978, is similar to the June profile, though the temperatures were warmer from top to bottom and the dissolved oxygen and pH had a greater range of values in August. The percentage of saturation for dissolved oxygen at 1-foot depth was 153, which is high, but not unusual in productive lakes. The drop in pH and dissolved oxygen in August was less distinct and occurred at a shallower depth than in June. These data indicate high phytoplankton productivity in only about the top 3 feet of the lake.

Profiles from the Lakeville lakes indicate that all may be classified as eutrophic on the basis of their profiles. High productivity at the surface is combined with rapid decomposition near the bottom to produce a characteristically wide range in dissolved-oxygen concentration. The limited degree of thermal stratification allows frequent mixing of the waters, maintaining a supply of nutrients from the bottom sediments adequate for continued high productivity through the summer.

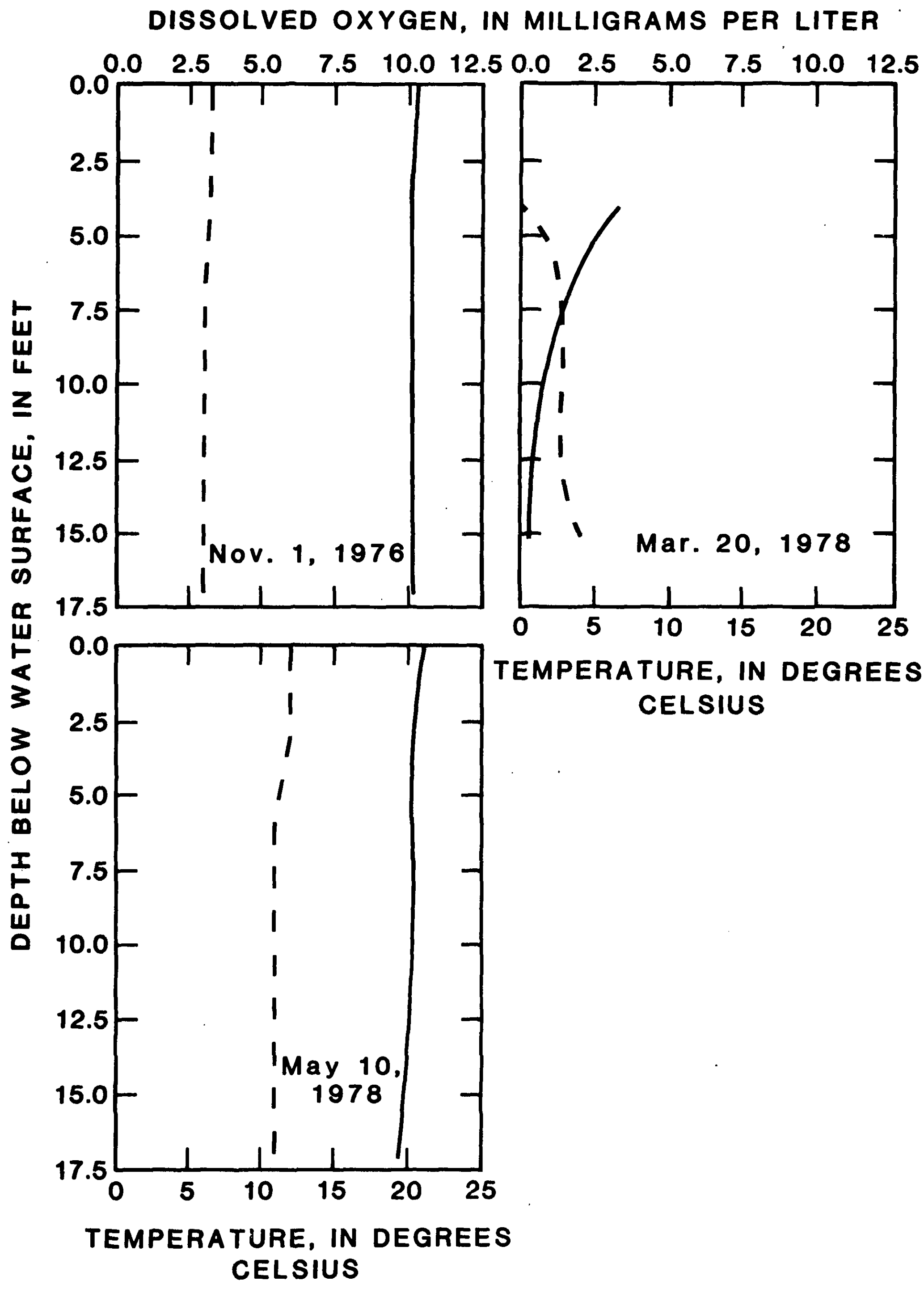
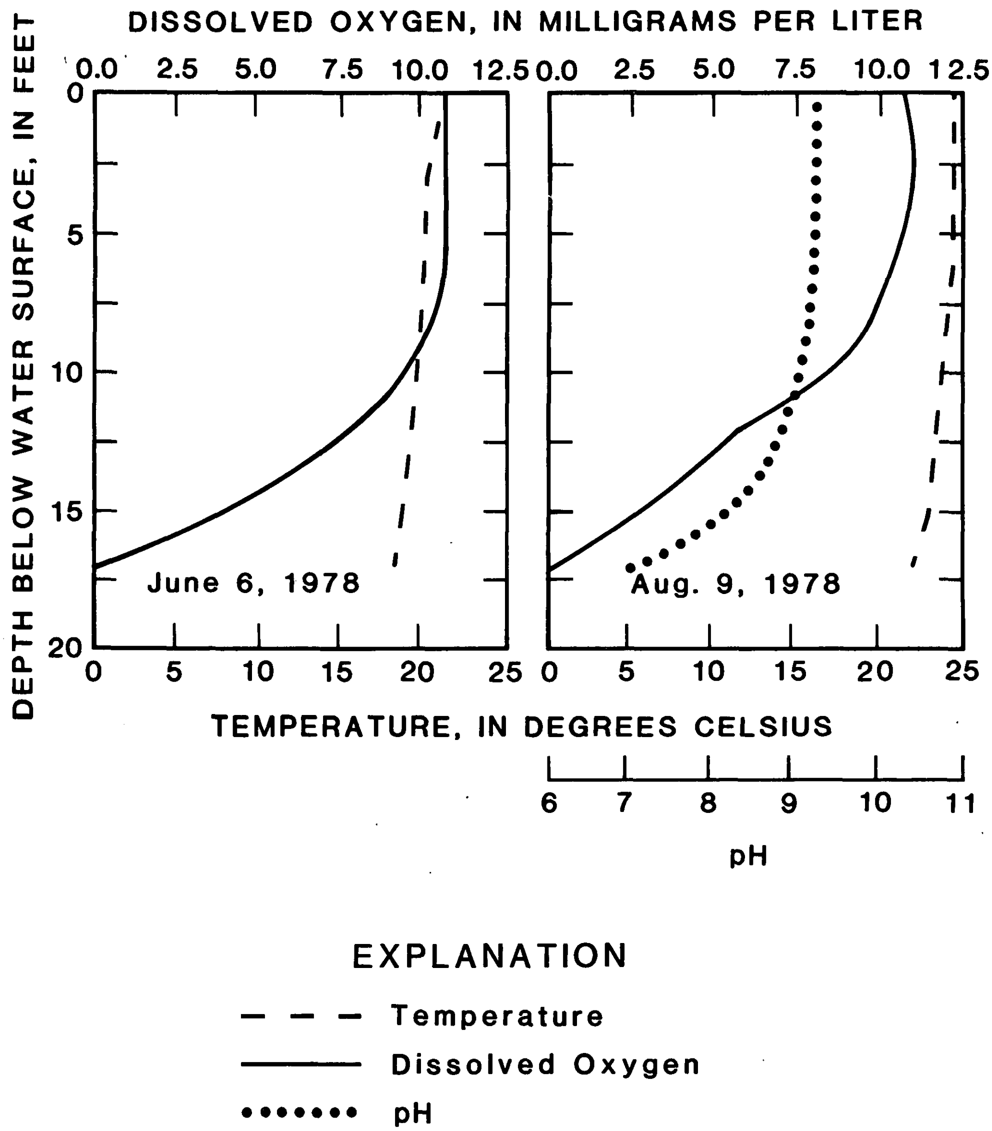



*Figure 9.--Selected temperature, dissolved oxygen, and pH*




***vertical profiles for Marion Lake, site 1***

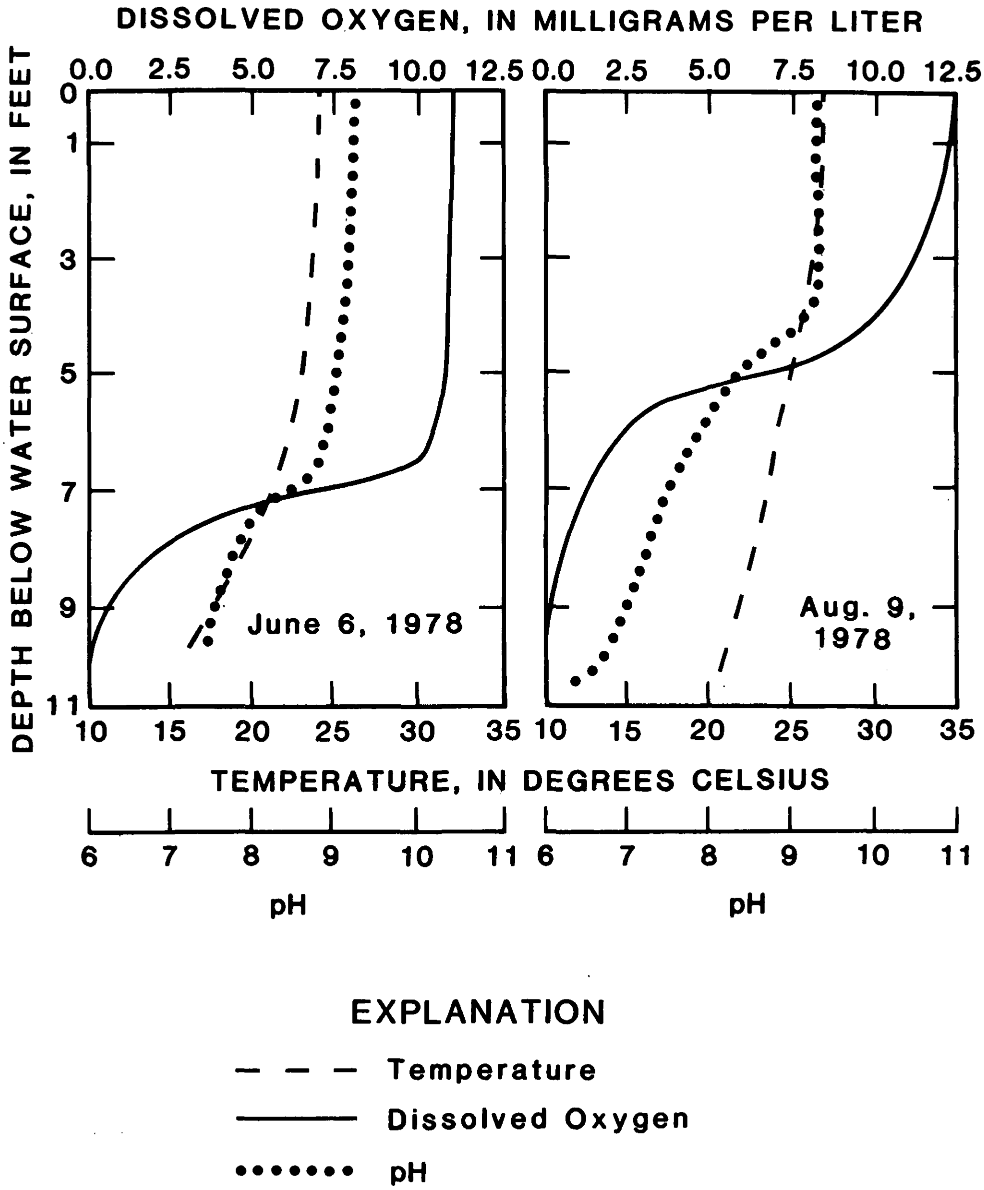



*Figure 10.--Selected temperature, dissolved oxygen, and pH vertical profiles for Lee Lake*

## Nitrogen, Phosphorus, Silica, and Total Organic Carbon

Figures 11-14 show the concentrations of nitrogen, total organic carbon, total and dissolved phosphorus, and silica at all sites. Samples for nitrogen, total organic carbon, dissolved phosphorus, and silica were collected only in 1976, which was the beginning of the drought that extended into 1977. One year of sampling obviously is not sufficient for long-term trend analysis, but concentrations of these constituents can be compared between lakes.

Most of the nitrogen (fig. 11) was in the form of dissolved ammonia plus organic nitrogen, with the highest concentrations occurring under ice in March 1976. Ammonia products from decay and decomposition processes could be the main cause of these higher dissolved-nitrogen concentrations. Lee Lake had the highest concentration of dissolved ammonia plus organic nitrogen, which may be due to decomposition of organic material in Lee Lake from plankton and agricultural-related inputs from the surrounding watershed.

Dissolved nitrite plus nitrate nitrogen concentrations were low in all the lakes. This is common in eutrophic lakes where available nitrate is quickly utilized by phytoplankton.

The particulate ammonia plus organic nitrogen is that part of total nitrogen that is contained in the plankton. Concentrations varied greatly among the lakes, but Lee Lake had the highest concentration of particulate ammonia plus organic nitrogen (fig. 11). Particulate ammonia plus organic nitrogen does not correlate strictly with phytoplankton cell counts because there are many other factors that affect particulate concentrations. However, the highest particulate ammonia plus organic nitrogen concentration at Lee Lake in September 1976 (fig. 11) coincides with the highest phytoplankton cell count. The only time that particulate ammonia was higher than the dissolved was in September 1976.

Like the ammonia and organic nitrogen, the total organic carbon (fig. 12) is probably mostly in the dissolved state (Wetzel, 1975, p. 540). There is a great variability between lakes, with some being highest in the winter and some being lowest. The carbon concentrations at all sites were similar to what was found in other eutrophic lakes in the metropolitan area (Have, 1975; 1980; Payne, 1977; 1980).

Total and dissolved phosphorus concentrations are shown in figure 13. There seems to have been an increase in dissolved phosphorus in the June 1976 samples at all sites. This may have been lingering effects from spring runoff and spring mixing. However, the major part of the phosphorus was generally particulate or that which is contained in plankton and seston.

Kingsley and Lee Lakes were significantly higher statistically than Orchard and Marion Lakes in total phosphorus concentrations, but the reason for this is uncertain. It seems that agricultural land use would be a primary source of phosphorus in Lee Lake and that release of phosphorus from macrophytes may be a primary source in Kingsley Lake. Also, both Kingsley

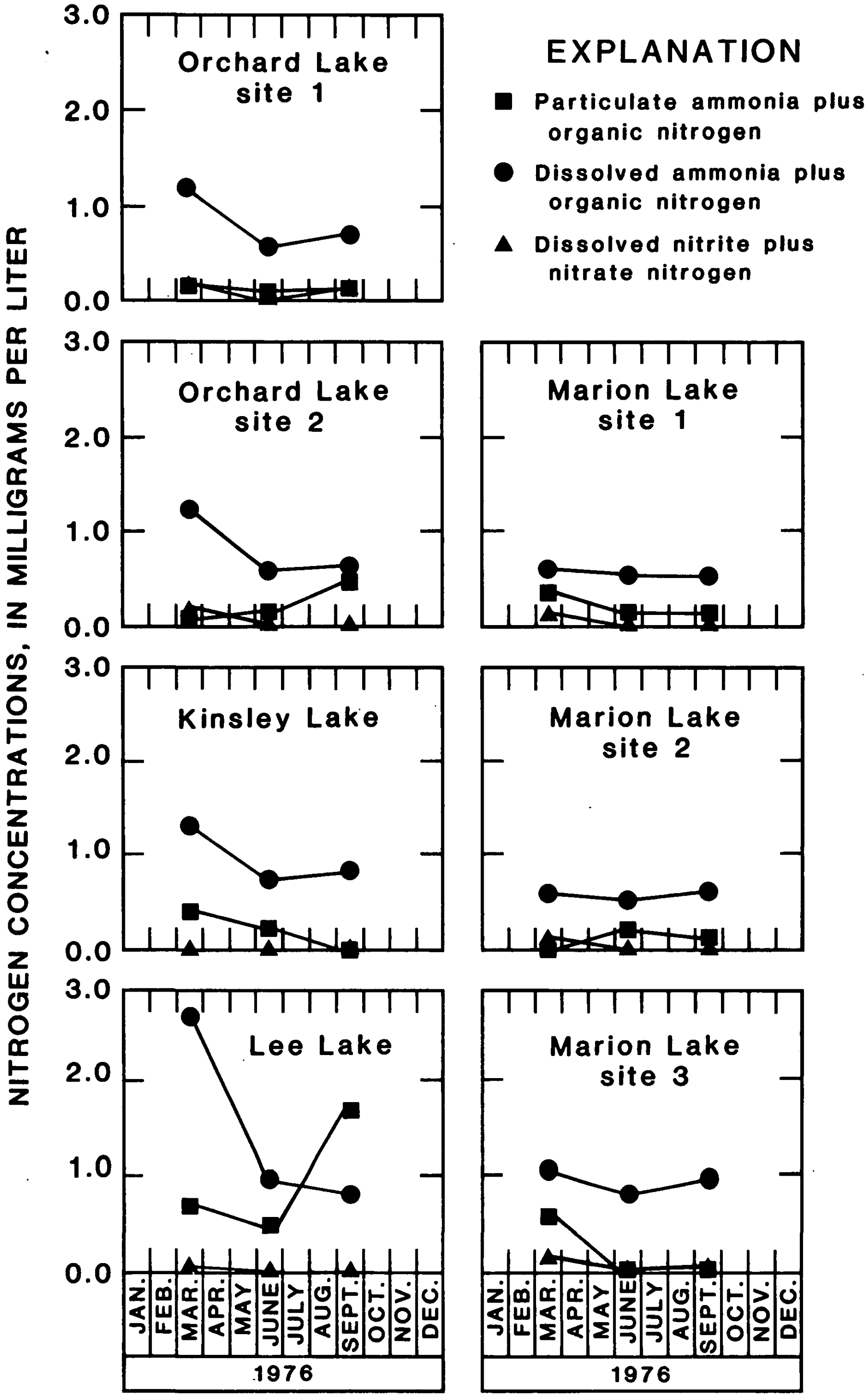



*Figure 11.--Concentrations of nitrogen for each lake*

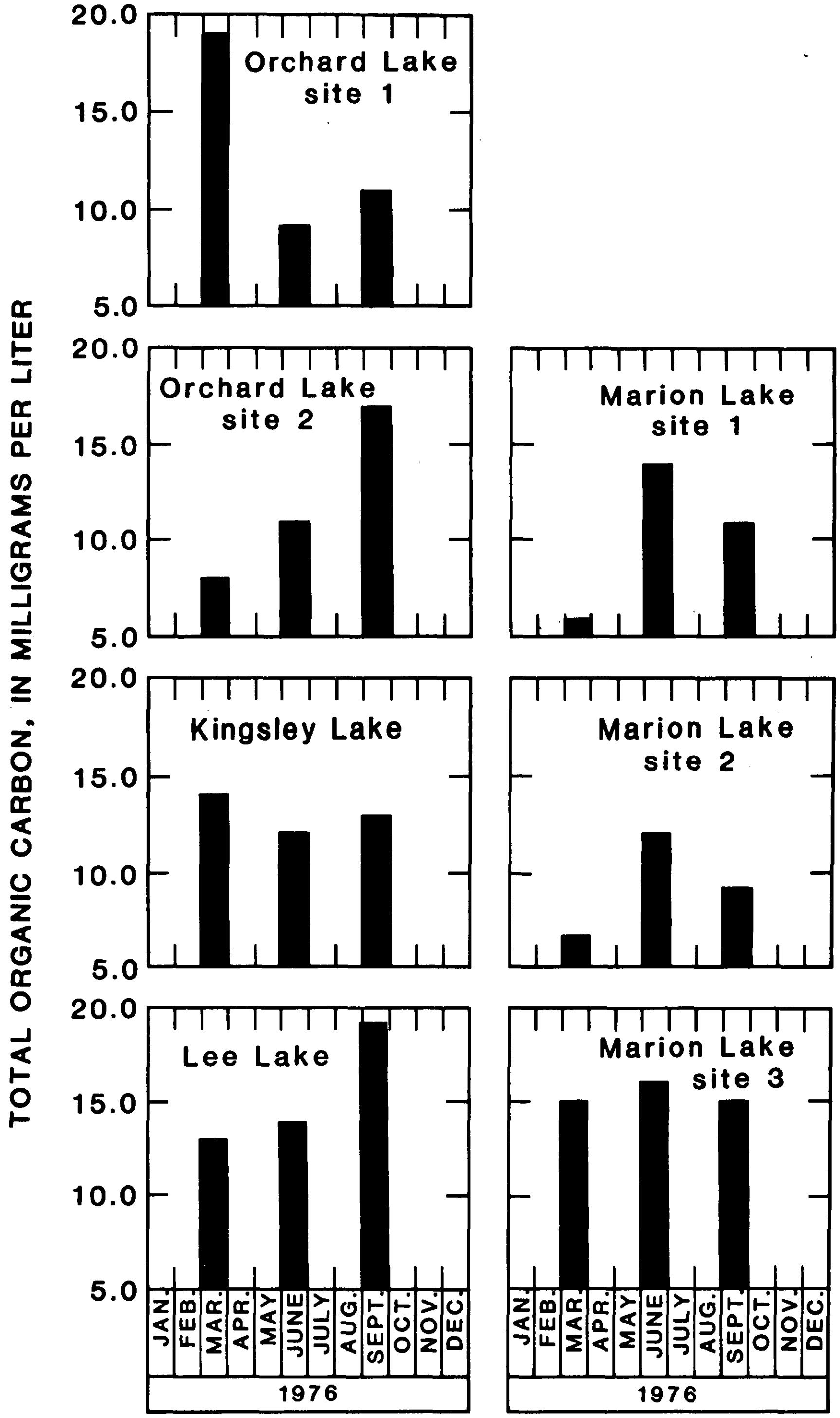



*Figure 12.--Concentration of total organic carbon for each lake*

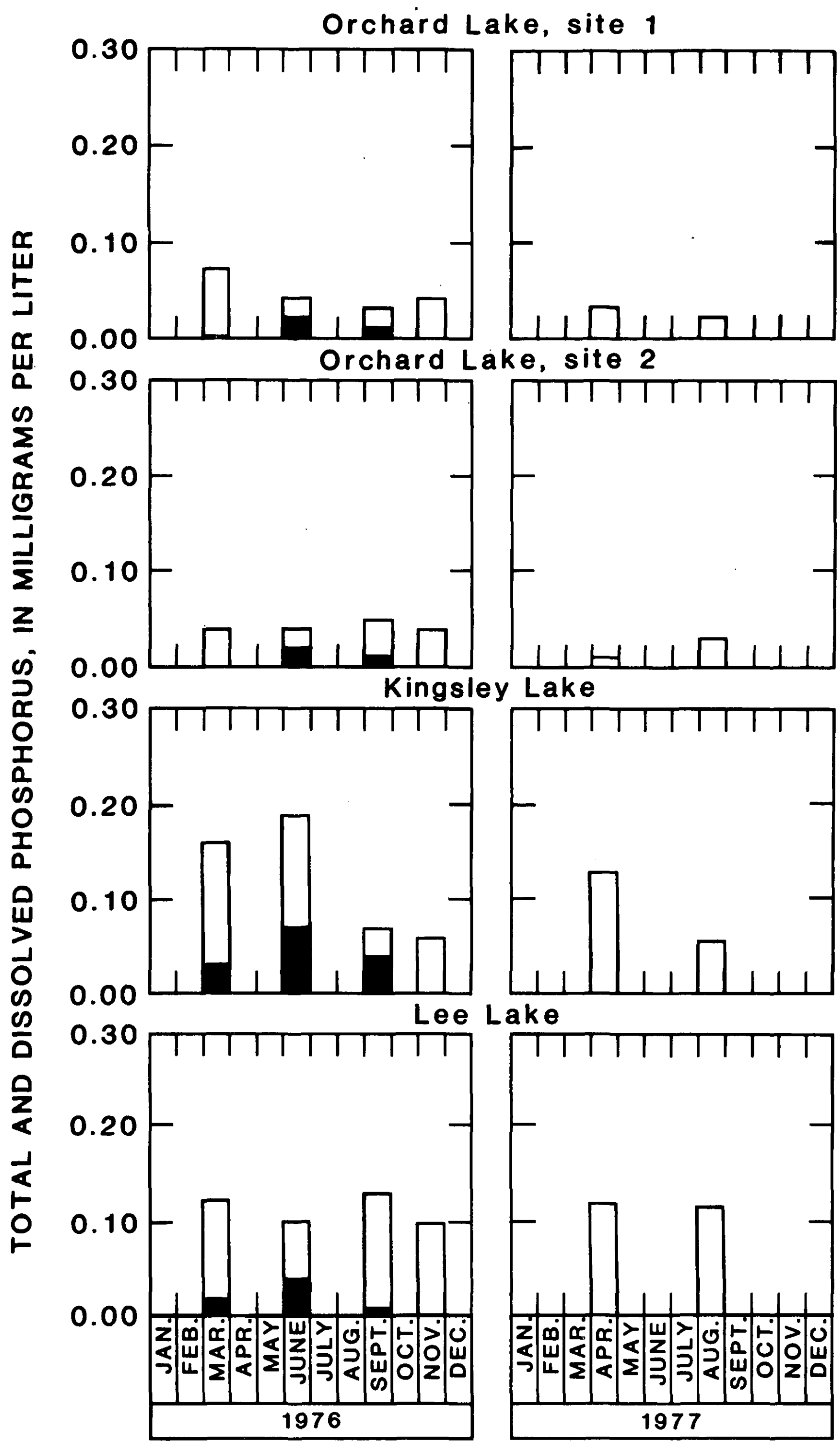
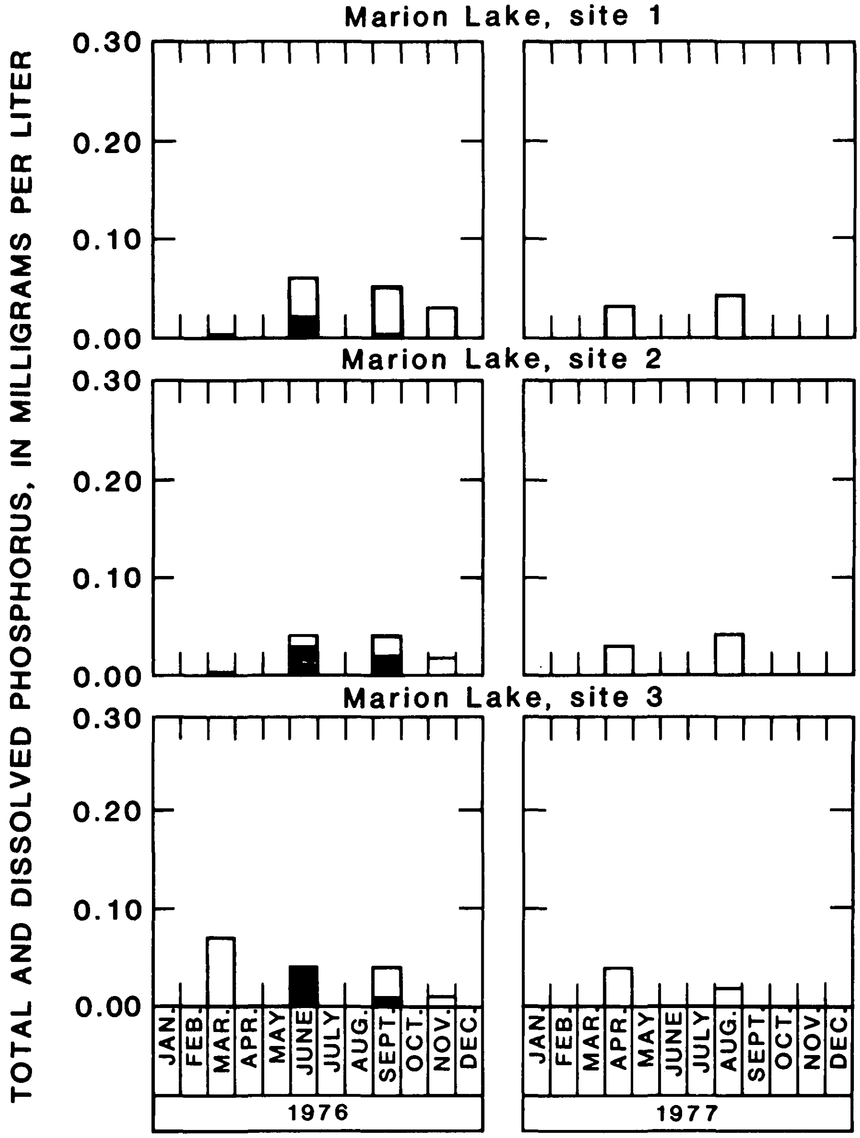



*Figure 13.--Total and dissolved phosphorous*




EXPLANATION

Dissolved phosphorous

The dissolved portion of the total phosphorus was only collected for the first three samples.

***concentrations for each lake***

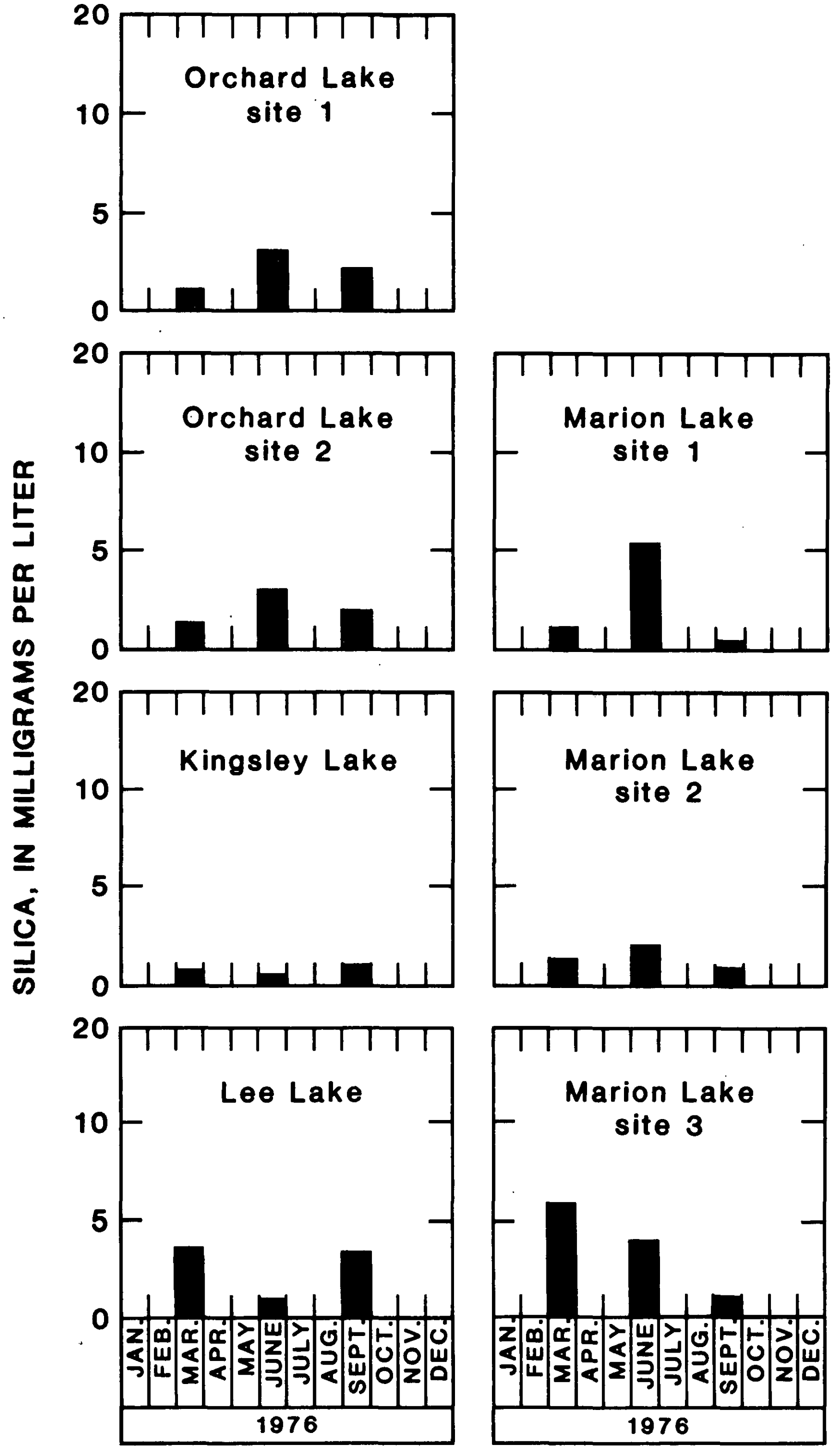



*Figure 14.--Silica concentrations for each lake*

and Lee Lakes had the highest concentrations of phosphorus in the bottom sediments. The phosphorus can be introduced into the overlying water layer by mixing.

As with carbon, silica concentrations were variable (fig. 14). Concentrations in Kingsley Lake were the lowest overall and those in Marion site 3 were the highest. Concentrations ranged from 0.3 mg/L at Kingsley to 6.8 mg/L at site 3 on Marion Lake. This range is above the 0.1 mg/L limit for phytoplankton growth suggested by Wallen and Tuppling (1977).

The most important factor controlling silica concentrations in these lakes is intensive assimilation of silica by diatoms. Between the June and September sampling, a decline in silica concentrations was observed at all sites except Kingsley and Lee Lakes, where utilization of silica by diatoms may decrease for some unknown reason.

## TROPHIC STATES

Lakes can be classified by physical characteristics, nutrient concentration, and productivity of algae. Generally, these classifications are oligotrophic, mesotrophic, and eutrophic, indicating extremely clear, nutrient poor lakes to highly enriched lakes with very high production, respectively. A more specific lake-classification scheme has been devised by Carlson (1977) called the trophic state index (TSI). Carlson arbitrarily assigned a scale of 0 to 100 to the three trophic variables, surface concentration of chlorophyll a, surface concentration of total phosphorus, and Secchi-disk transparency. Although the numerical breaks for each trophic state are slightly different for each trophic variable, lakes with a TSI less than about 40 are oligotrophic, lakes with a TSI greater than about 50 are eutrophic, and lakes with an intermediate TSI are mesotrophic (Reckhow, 1979).

The bar graphs in figures 15-21 show the TSI for each of the variables, when sampled, at each of the sites. The TSI's for the Secchi-disk transparency are not given where the transparency was greater than the depth of the water at the site. Carlson's trophic state delineations for each variable also are shown on each graph for comparison (Reckhow, 1979).

Chlorophyll a, a pigment common to all phytoplankton, is used herein as an indicator of phytoplankton biomass. As a true representation of biomass, the chlorophyll a concentration is considered less than reliable. The content of chlorophyll a in individual cells is subject to variability depending on cell size and environmental conditions, even though total cell biomass may be unaffected (Wetzel, 1975). Other factors affecting the reliability of chlorophyll a data include interference from sediments and exposure to light or acids during storage (Greeson and others, 1977).

Total phosphorus may be a good indicator of the productivity of a lake, so long as it is the limiting nutrient controlling plant growth, as is the case most often. The analysis for total phosphorus is considered reliable and provides a representative estimation of the total phosphorus concentration in the water.

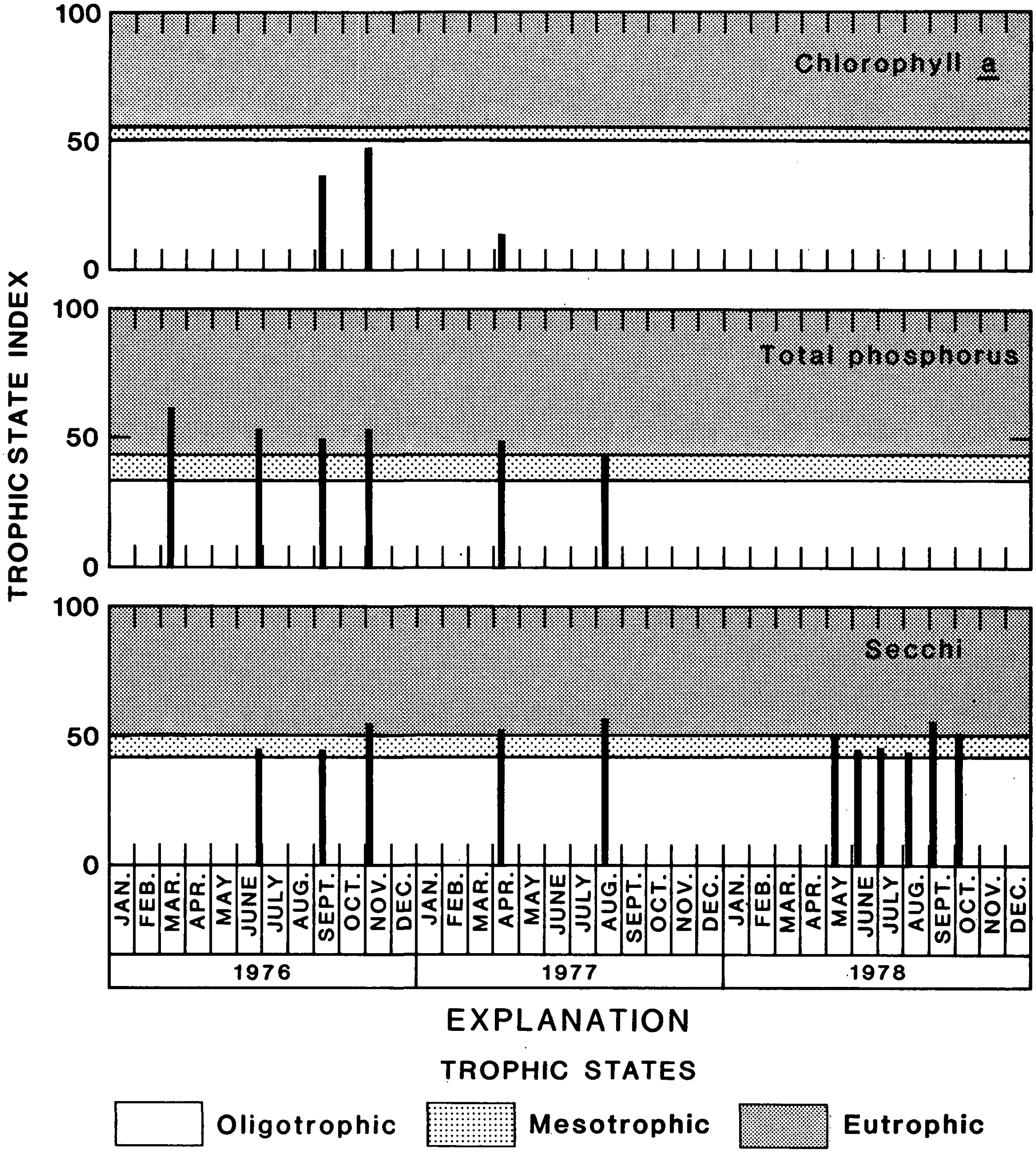



*Figure 15.--Trophic state indices for Orchard Lake, site 1*

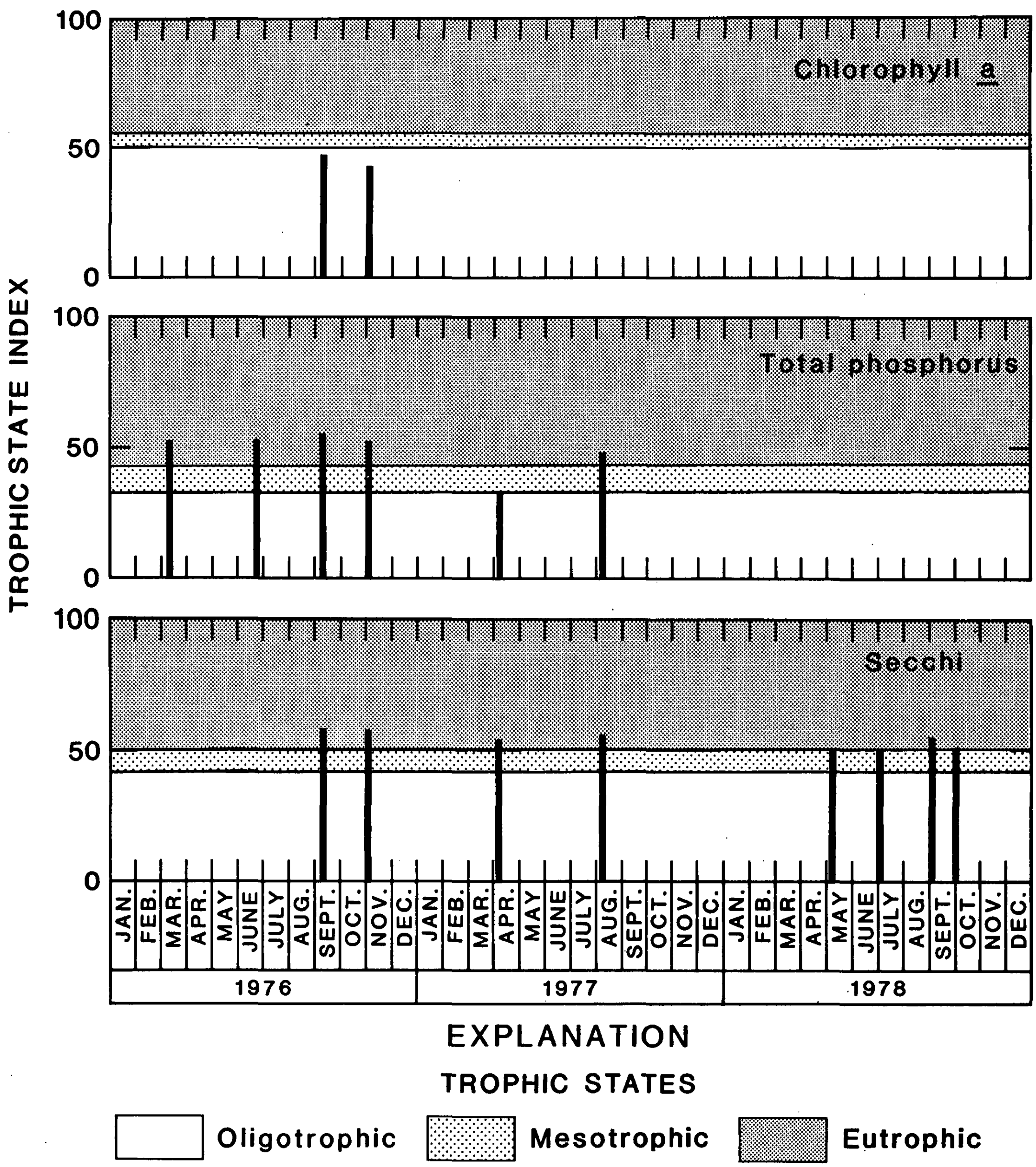



*Figure 16.--Trophic state indices for Orchard Lake, site 2*

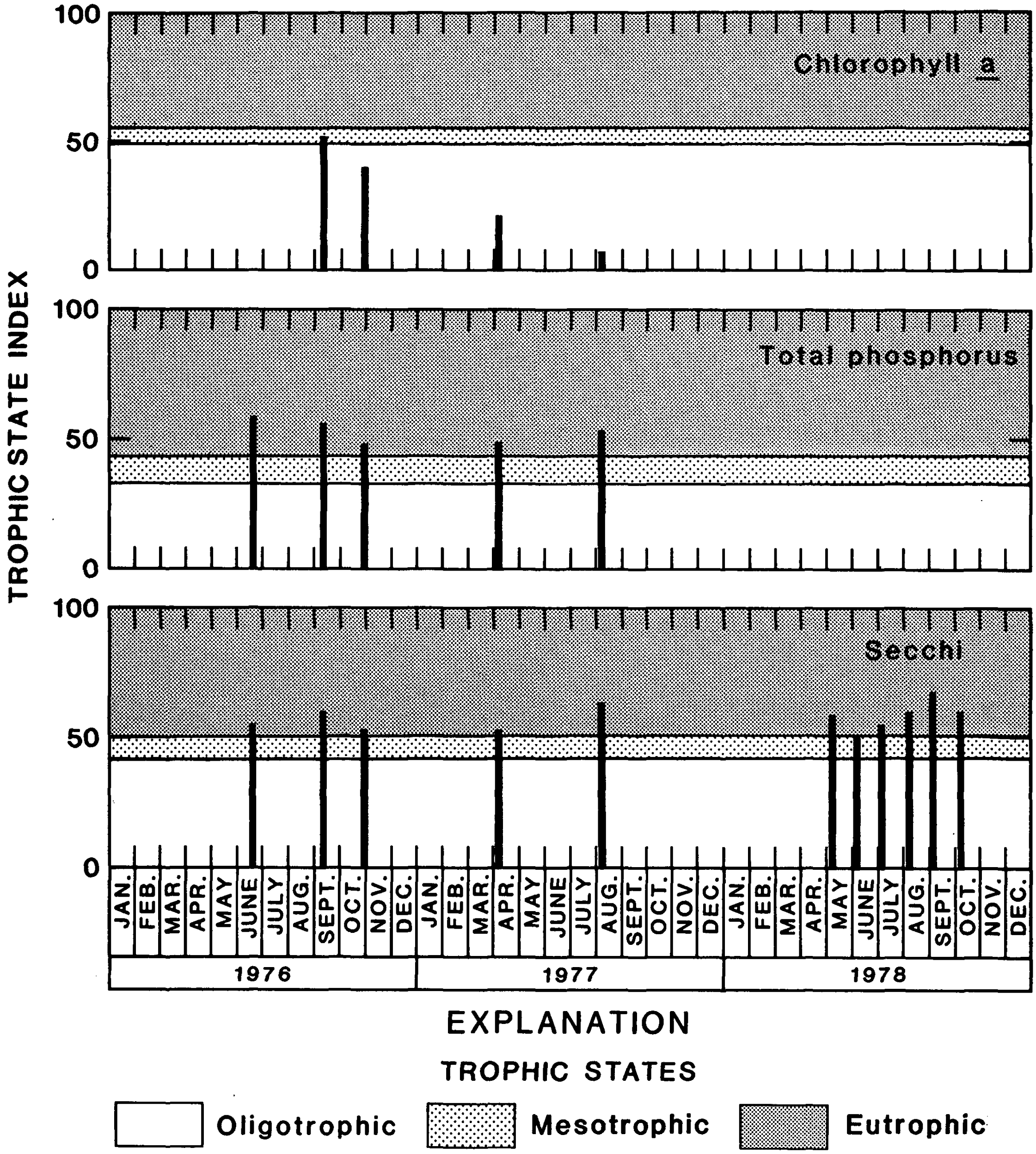



***Figure 17.--Trophic state indices for Marion Lake, site 1***

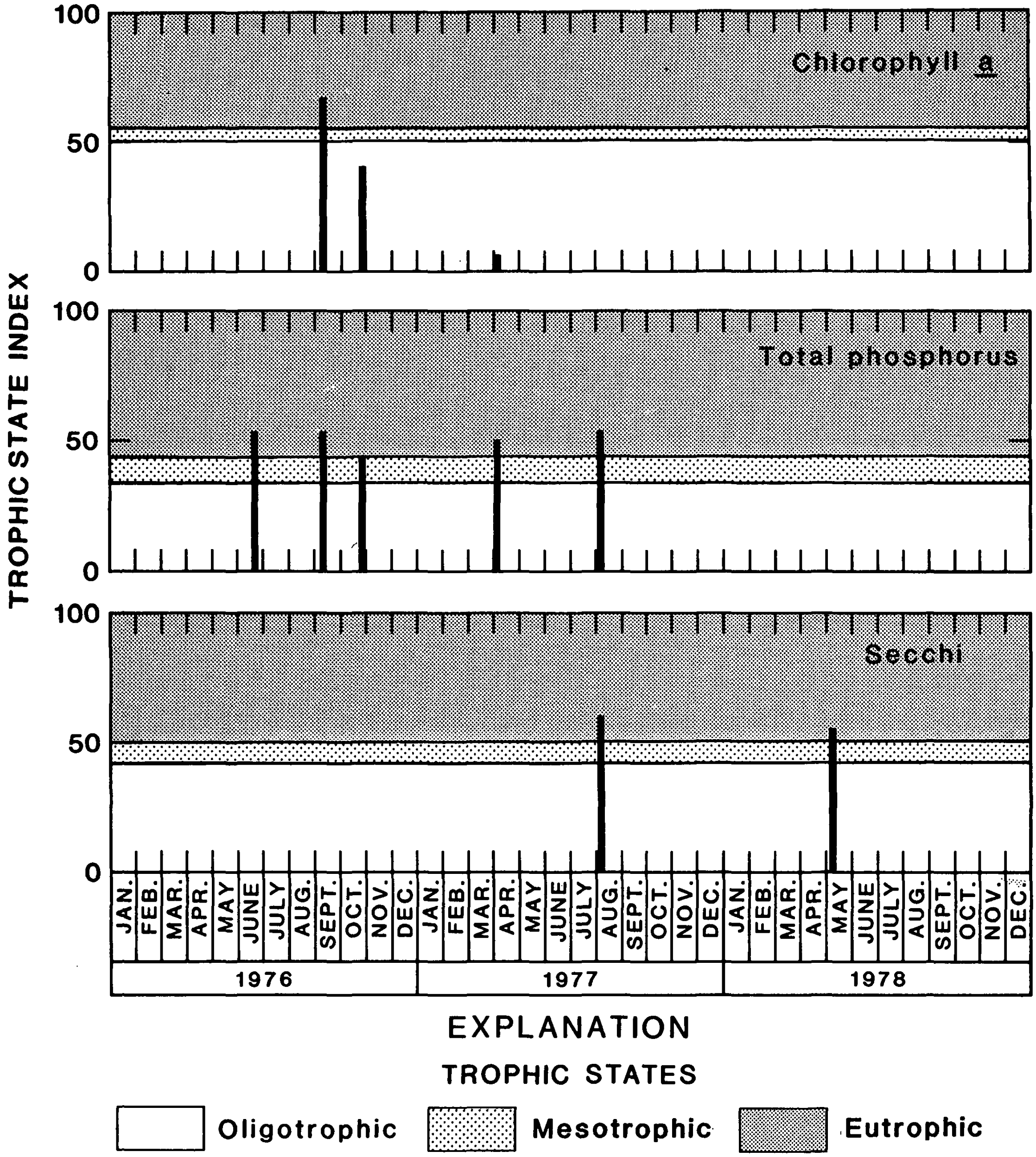



*Figure 18.--Trophic state indices for Marion Lake, site 2*

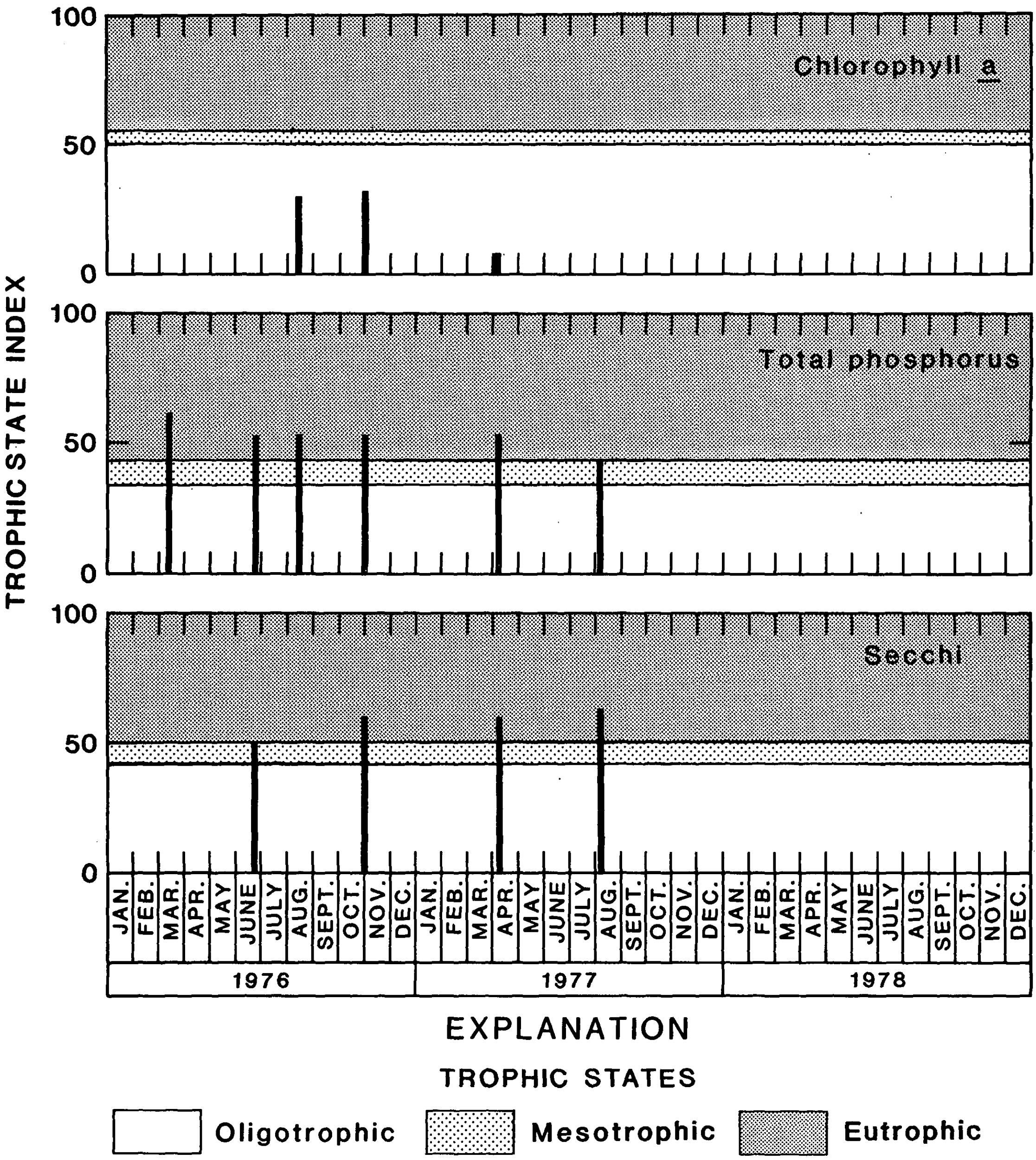



*Figure 19.--Trophic state indices for Marion Lake, site 3*

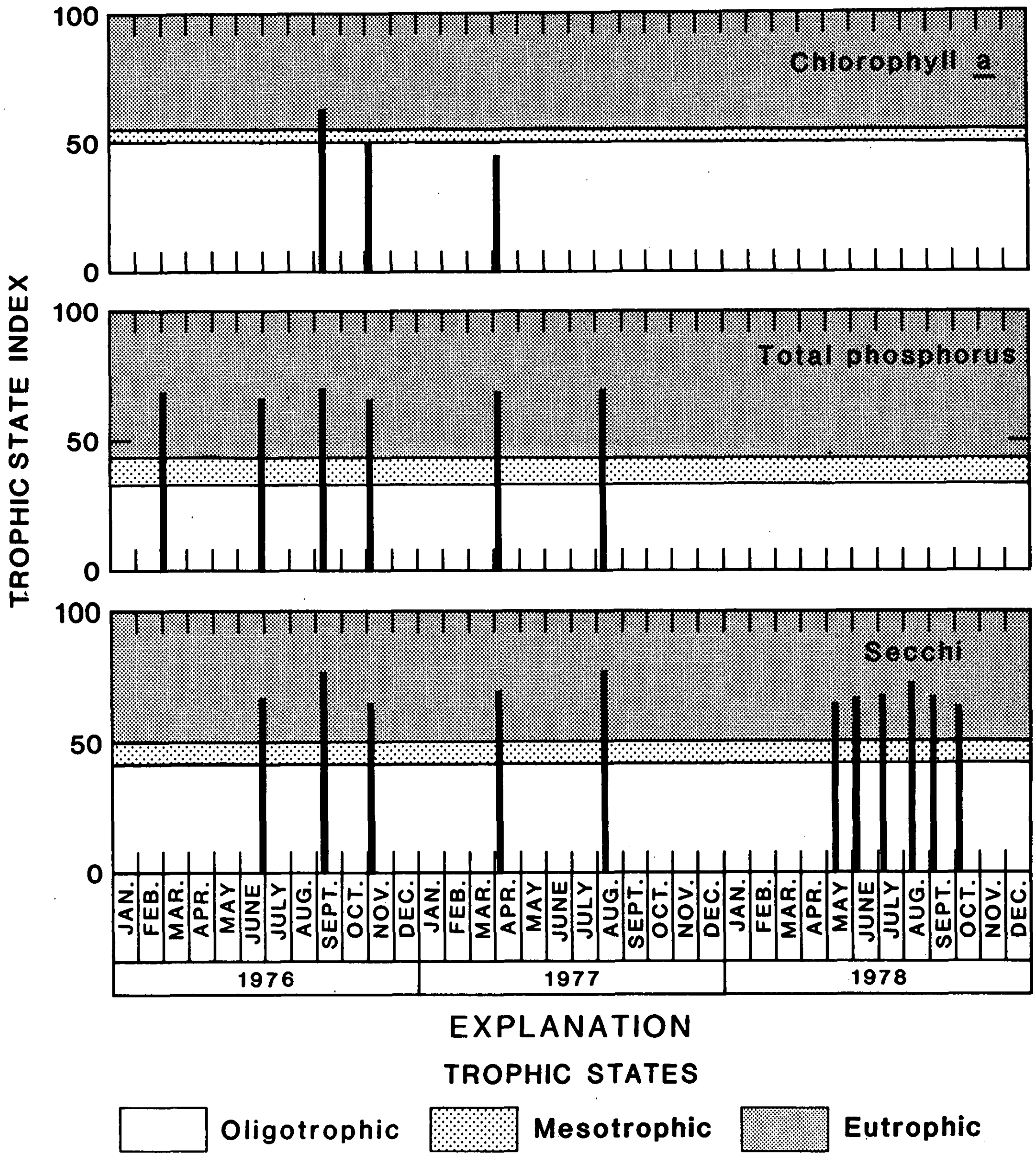



*Figure 20.--Trophic state indices for Lee Lake*

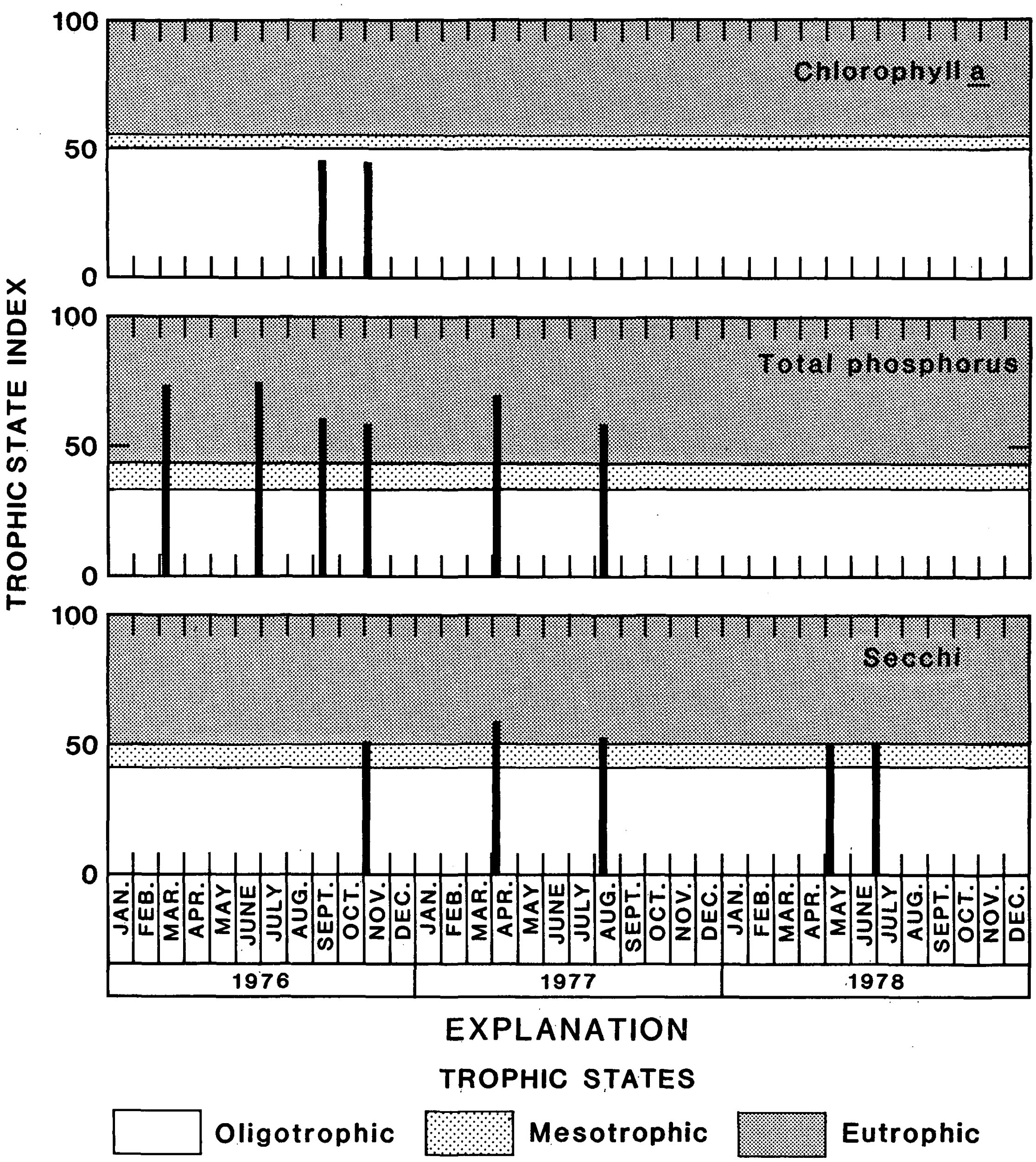



*Figure 21.--Trophic state indices for Kingsley Lake*

Secchi-disk transparencies are influenced both by the attenuation characteristics of the water and its dissolved and particulate matter and in a very generalized way have been used to estimate the approximate density of phytoplankton populations in productive lakes (Wetzel, 1975). These transparencies may be misleading as a trophic state indicator in colored lakes or highly turbid (nonalgal) lakes.

Figures 15 and 16 are the TSI graphs for Orchard Lake sites 1 and 2, respectively. The chlorophyll a graphs indicate an oligotrophic lake according to the EPA delineations shown. Carlson (1977) recommends the use of summer values of chlorophyll a as a basis for determination of the TSI for a lake. The September sample could be representative of the summer chlorophyll a concentrations at site 1, providing a TSI of 36.5. The November chlorophyll a TSI at site 1 was higher at 47.5. At site 2, which generally had coincidental constituent concentrations to site 1, the chlorophyll a concentration and TSI declined between September and November. Reduced insolation should reduce phytoplankton biomass from September to November, and figure 22 shows a drop in phytoplankton cell numbers. These factors should lead to a reduced chlorophyll a concentration and a decline in the TSI from September to November at site 1. Though an algal bloom at site 1 during the November sampling was possible, the chlorophyll a data seem unreliable.

Total phosphorus TSI's indicate that Orchard Lake is eutrophic. The low standard deviations from the means shown in table 3 indicate that this constituent may be reliable as an indicator of the trophic status of Orchard Lake.

Table 3.--Mean trophic-state indexes and standard deviations for each sampling site

[N = number of samples]

| Lake | Secchi-disk transparency | N | Standard deviation | Total phosphorus | N | Standard deviation | Chlorophyll a | N | Standard deviation |
|---|---|---|---|---|---|---|---|---|---|
| Orchard Lake, site 1......... | 49.3 | 11 | 4.7 | 51.3 | 6 | 6.1 | 32.7 | 3 | 17.1 |
| Orchard Lake, site 2......... | 54.2 | 8 | 2.9 | 49.5 | 6 | 8.5 | 45.2 | 2 | 3.0 |
| Marion Lake, site 1......... | 57.8 | 11 | 4.8 | 53.1 | 5 | 4.4 | 29.8 | 4 | 20.8 |
| Marion Lake, site 2......... | 57.6 | 2 | 3.5 | 50.1 | 5 | 4.4 | 37.9 | 3 | 30.4 |
| Marion Lake, site 3......... | 58.6 | 4 | 5.2 | 52.6 | 5 | 6.4 | 17.4 | 4 | 16.4 |
| Lee Lake......... | 69.2 | 11 | 4.8 | 68.2 | 6 | 1.6 | 52.0 | 3 | 9.5 |
| Kingsley Lake.... | 53.1 | 4 | 4.4 | 66.2 | 6 | 7.5 | 45.6 | 2 | 0.8 |

Secchi-disk TSI's for Orchard Lake seem reliable as a trophic state indicator because of their uniformity and low standard deviations. Table 3 shows that site 2 of Orchard Lake has a greater mean Secchi TSI than site 1. This may be due to increased turbidity in the shallow water at site 2, but probably because Secchi-disk transparencies greater than the depth at the site can only be estimated and were not used to compute TSI's.

Chlorophyll _a_ TSI's for Marion Lake site 1 (fig. 17) seem unreliable, with a mean of 29.8 and a high standard deviation. Total phosphorus and Secchi-disk transparency both indicate a eutrophic lake, with mean TSI's of 53.1 and 57.8, respectively.

In site 2 of Marion Lake, the chlorophyll _a_ TSI's (fig. 18) conform more closely with the other variables than those for the previous sites considered. The September 1976 chlorophyll _a_ TSI of 66.4 is higher than any of the other TSI's for that site. Total phosphorus TSI's, with a mean value of 50.1, classify the lake as eutrophic. Secchi-disk measurements, limited in number by the shallow water depth of the site, also classify the lake as eutrophic.

Site 3 of Marion Lake (fig. 19) can be classified as eutrophic according to the EPA standards shown. Total phosphorus and Secchi-disk measurements give mean TSI's of 52.6 and 58.6, respectively, though some Secchi-disk readings were not used because of the shallow water depth at this site.

Lee Lake (table 3) has the highest average trophic state indexes of any of the sites sampled. The September chlorophyll _a_ sample (fig. 20) classifies the lake as eutrophic and the mean of all three samples, though not all are from the representative season, classify the lake as mesotrophic. Secchi-disk measurements (none affected by lake depth) and total phosphorus concentrations both classify the lake as eutrophic, with mean TSI's of 69.2 and 68.2, respectively.

Kingsley Lake (fig. 21) shows some variations from the other sites. It can be seen that the TSI's for total phosphorus are consistently higher than the Secchi-disk TSI's. Algal biomass production is usually dependent on the total phosphorus available. Secchi-disk transparency is used as a trophic state indicator because it is affected, in part, by the algal biomass present. If phytoplankton are not present or reduced in numbers, a high Secchi-disk reading will be obtained, producing a lower TSI. The possible excretion by macrophytes of organic compounds that inhibit the growth of phytoplankton (Wetzel, 1975, p. 402) and successful competition by macrophytes for sunlight and nutrients seems to have a noticeable effect on the concentration of phytoplankton in Kingsley Lake. A lower concentration of phytoplankton would allow increased transparency of the water. If the aquatic macrophytes are also removing phosphorus from bottom sediments and releasing it to the water, a path suggested by Wetzel (1975, p. 228), the TSI for phosphorus would be high relative to the TSI for the Secchi-disk transparency. This would seem to be the case in Kingsley Lake.

The mean TSI's (table 3) for each of the sites and each of the methods are a good basis for identifying changes that may result from development of the shoreline or from increased control of inputs to the lakes.

## BIOLOGICAL CHARACTERISTICS

Phytoplankton are essential in lakes for aquatic animal life to exist; however, when they become too numerous, some uses of the water can be adversely affected. An overabundance of phytoplankton is called an algal bloom. Lee (1970) proposed that a concentration of 500 to 1,000 cells/mL of water indicates a bloom, and most other investigators have also used this concentration for defining blooms.

Algal populations were generally higher than 500 cells/mL at all sites (fig. 22 and table 4). Most of the samples had blue-green algal concentrations of 15 percent or higher in the total sample. These concentrations are common for eutrophic lakes and are similar to concentrations in lakes in Eagan and Apple Valley, Minn., (Have, 1975). However, the upper end of the concentration ranges for the Eagan and Apple Valley lakes were generally higher.

The two most common genera of blue-green algae that were found in the four lakes were *Anacystis* and *Oscillatoria* (fig. 23). *Anacystis* was found in 19 of 39 samples and *Oscillatoria* was found in 17 samples. Palmer (1968) assigned a pollution-tolerant rating to each alga reported by 165 authors in 269 reports. *Anacystis* and *Oscillatoria* are rated 19th and 2nd, respectively, in his list of 60 mostpollution-tolerant genera. *Anacystis* is infamous because of the many records of acute and often fatal poisoning of livestock that drank from ponds containing *Anacystis* (Palmer, 1962, p. 53).

### Lee Lake

Lee Lake had the highest phytoplankton counts of the four lakes. The September 1976 sample had a concentration of 890,000 cells/mL. One major cause of the high counts is the type of land use around Lee Lake. There is a farming operation northeast of the lake that consists of a feedlot and pasture for cattle. Cattle have been observed wading in the lake during some sampling visits. Domestic waterfowl were also observed on other lakefront properties.

The two key nutrients, nitrogen and phosphorus, promote phytoplankton growth when they are excreted in or near the water. The nutrients are contained in both liquid and solid animal wastes. Nutrients contained in liquid wastes are dissolved and, therefore, are readily available for utilization by phytoplankton.

Another factor contributing to phytoplankton growth is the lack of submerged macrophytes like those in the other lakes studied. If macrophytes were more prevalent, they would be competing for the same nutrients that phytoplankton need and, therefore, would tend to depress the growth of phytoplankton. Organic compounds excreted by some macrophytes tend to inhibit the growth of phytoplankton (Wetzel, 1975, p. 402). An early onset of algal blooms because of nutrient loading and the relatively steep bottom slope in Lee Lake (table 1) are probably reasons for very little observed macrophytic plant life.

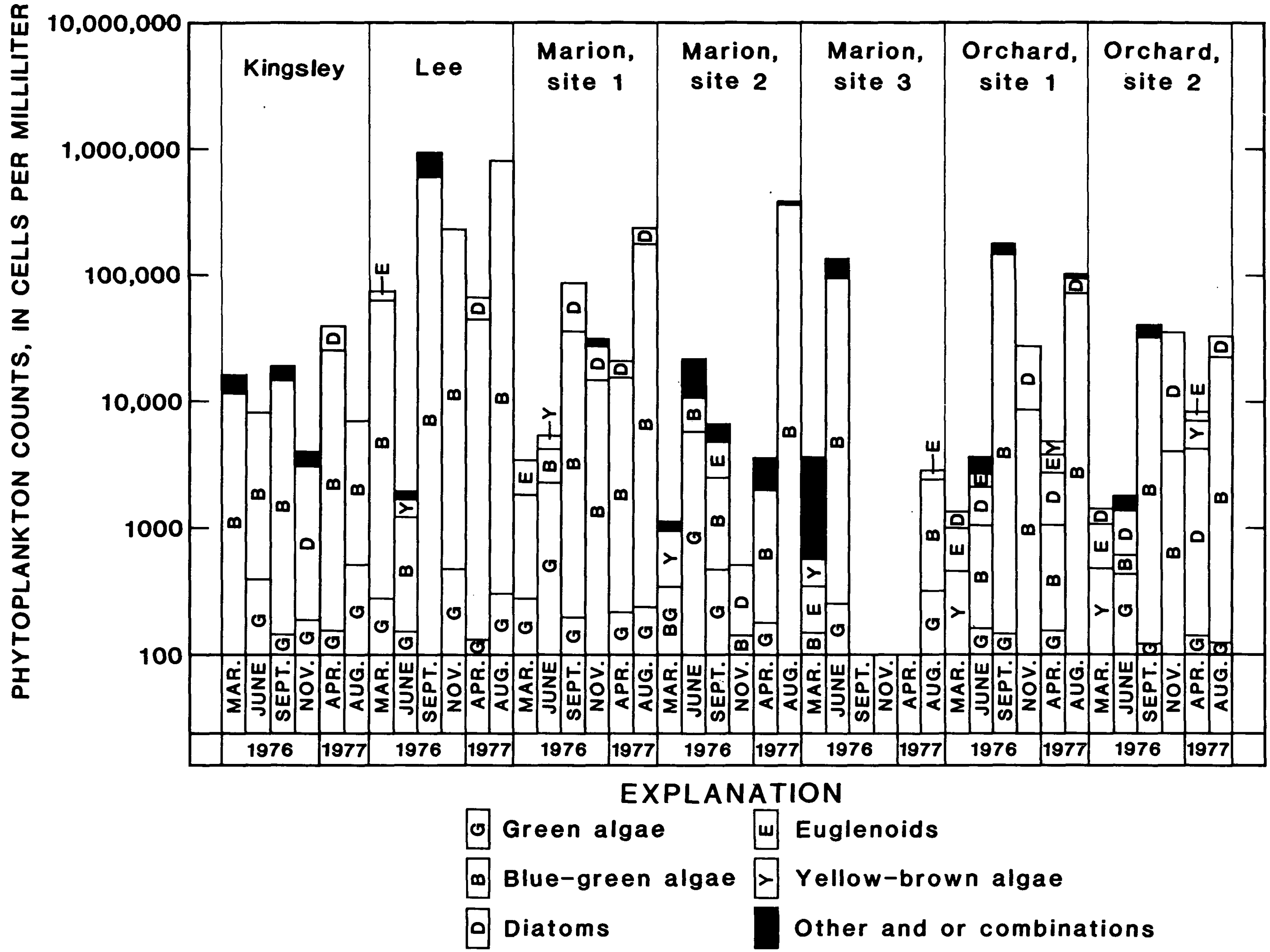



*Figure 22.--Phytoplankton-cell counts for each lake*

Table 4.—Phytoplankton cell counts for each sampling site

[Symbols used for types: BG, blue-green algae; D, diatoms; E, euglenoids; F, fire algae; G, green algae; YB, yellow-brown algae]

| Date of collection | Total number of cells per milliliter | Dominant genera | | | Codominant genera | | | Codominant genera | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Genus | Type | Percent of total cells | Genus | Type | Percent of total cells | Genus | Type | Percent of total cells |
| ORCHARD LAKE, SITE 1 | | | | | | | | | | |
| 3- 8-76.... | 1200 | Ochromonas | YB | 61 | Chroomonas | E | 22 | — | — | — |
| 6-25-76.... | 3600 | Oscillatoria | BG | 48 | Nitzschia | D | 16 | — | — | — |
| 9-10-76.... | 180,000 | Anacystis | BG | 87 | — | — | — | — | — | — |
| 11- 2-76.... | 27,000 | Aphanizomenon | BG | 63 | Cyclotella | D | 17 | Anacystis inserta | BG | 15 |
| 4-11-77.... | 5200 | Oscillatoria | BG | 30 | Cyclotella | D | 22 | — | — | — |
| 8-10-77.... | 96,000 | Anacystis | BG | 54 | Anabaena | BG | 18 | — | — | — |
| ORCHARD LAKE, SITE 2 | | | | | | | | | | |
| 6-25-76.... | 1700 | Oocystis | G | 24 | Fragilaria | D | 15 | — | — | — |
| 9-10-76.... | 41,000 | Anacystis | BG | 68 | Aphanizomenon | BG | 22 | — | — | — |
| 11- 2-76.... | 35,000 | Aphanizomenon | BG | 64 | Melosira | D | 22 | — | — | — |
| 4-11-77.... | 8500 | Cyclotella | D | 60 | — | — | — | — | — | — |
| 8-10-77.... | 33,000 | Anabaena | BG | 54 | Gomphosphaeria | BG | 16 | — | — | — |

Table 4.--Phytoplankton cell counts for each sampling site--Continued

| Date of collection | Total number of cells per milliliter | Dominant genera | | | Codominant genera | | | Codominant genera | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Genus | Type | Percent of total cells | Genus | Type | Percent of total cells | Genus | Type | Percent of total cells |
| | | | | MARION LAKE, SITE 1 | | | | | | |
| 3-11-76.... | 3400 | Anacystis | BG | 52 | Chlamydomonas | G | 29 | — | — | — |
| 6-25-76.... | 5200 | Scenedesmus | G | 66 | — | — | — | — | — | — |
| 9-15-76.... | 80,000 | Oscillatoria | BG | 68 | — | — | — | — | — | — |
| 11- 2-76.... | 30,000 | Oscillatoria | BG | 44 | Gomphosphaeria | BG | 43 | — | — | — |
| 4- 7-77.... | 21,000 | Anacystis | BG | 79 | — | — | — | — | — | — |
| 8- 9-77.... | 240,000 | Anabaena | BG | 27 | Oscillatoria | BG | 26 | Aphanizomenon | BG | 22 |
| | | | | MARION LAKE, SITE 2 | | | | | | |
| 3-11-76.... | 1100 | Chromulina | YB | 46 | Oscillatoria | BG | 36 | — | — | — |
| 6-25-76.... | 13,000 | Pleodorina | G | 59 | Pandorina | G | 20 | — | — | — |
| 9-15-76.... | 6600 | Anacystis inserta | BG | 34 | Sphaerocystis | G | 27 | Chroomonas | E | 17 |
| 11- 1-76.... | 470 | Cocconeis | D | 46 | Oscillatoria | BG | 25 | Achnanthes | D | 20 |
| 4- 7-77.... | 3700 | Anacystis | BG | 64 | — | — | — | — | — | — |
| 8- 8-77.... | 400,000 | Anacystis | BG | 85 | — | — | — | — | — | — |

Table 4.--Phytoplankton cell counts for each sampling site--Continued

| Date of collection | Total number of cells per milli-liter | Dominant genera | | | Codominant genera | | | Codominant genera | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Genus | Type | Percent of total cells | Genus | Type | Percent of total cells | Genus | Type | Percent of total cells |
| MARION LAKE, SITE 3 | | | | | | | | | | |
| 3-11-76.... | 4200 | Dinobryon | YB | 22 | Trachelomonas | E | 20 | Gyrodinium | F | 15 |
| 6-25-76.... | 140,000 | Oscillatoria | BG | 57 | — | — | — | — | — | — |
| 11- 2-76.... | 59 | Oscillatoria | BG | 31 | Achnanthes | D | 31 | Cocconeis | D | 15 |
| 8- 8-77.... | 3000 | Gomphosphaeria | BG | 38 | Sphaerocystis | G | 28 | Anacystis | BG | 16 |
| KINGSLEY LAKE | | | | | | | | | | |
| 3- 5-76.... | 16,000 | Raphidiopsis | BG | 91 | — | — | — | — | — | — |
| 6-24-76.... | 7900 | Oscillatoria | BG | 26 | Anabaena | BG | 15 | Anacystis | BG | 15 |
| 9- 9-76.... | 16,000 | Anacystis | BG | 71 | — | — | — | — | — | — |
| 11- 2-76.... | 3900 | Cyclotella | D | 77 | — | — | — | — | — | — |
| 4- 3-77.... | 44,000 | Anacystis | BG | 38 | Oscillatoria | BG | 23 | Lyngbya | BG | 21 |
| 8-10-77.... | 7200 | Sphaerocystis | G | 29 | Anacystis | BG | 26 | Oscillatoria | BG | 16 |
| LEE LAKE | | | | | | | | | | |
| 3- 5-76.... | 70,000 | Oscillatoria | BG | 80 | — | — | — | — | — | — |
| 6-30-76.... | 1900 | Anacystis | BG | 61 | — | — | — | — | — | — |
| 9- 9-76.... | 890,000 | Anacystis | BG | 32 | Oscillatoria | BG | 31 | Raphidiopsis | BG | 17 |
| 11- 3-76.... | 400,000 | Oscillatoria | BG | 77 | Dictyosphaerium | G | 19 | — | — | — |
| 4- 3-77.... | 65,000 | Oscillatoria | BG | 58 | Anacystis | BG | 27 | — | — | — |
| 8- 8-77.... | 790,000 | Oscillatoria | BG | 35 | Aphanizomenon | BG | 24 | Anacystis | BG | 19 |

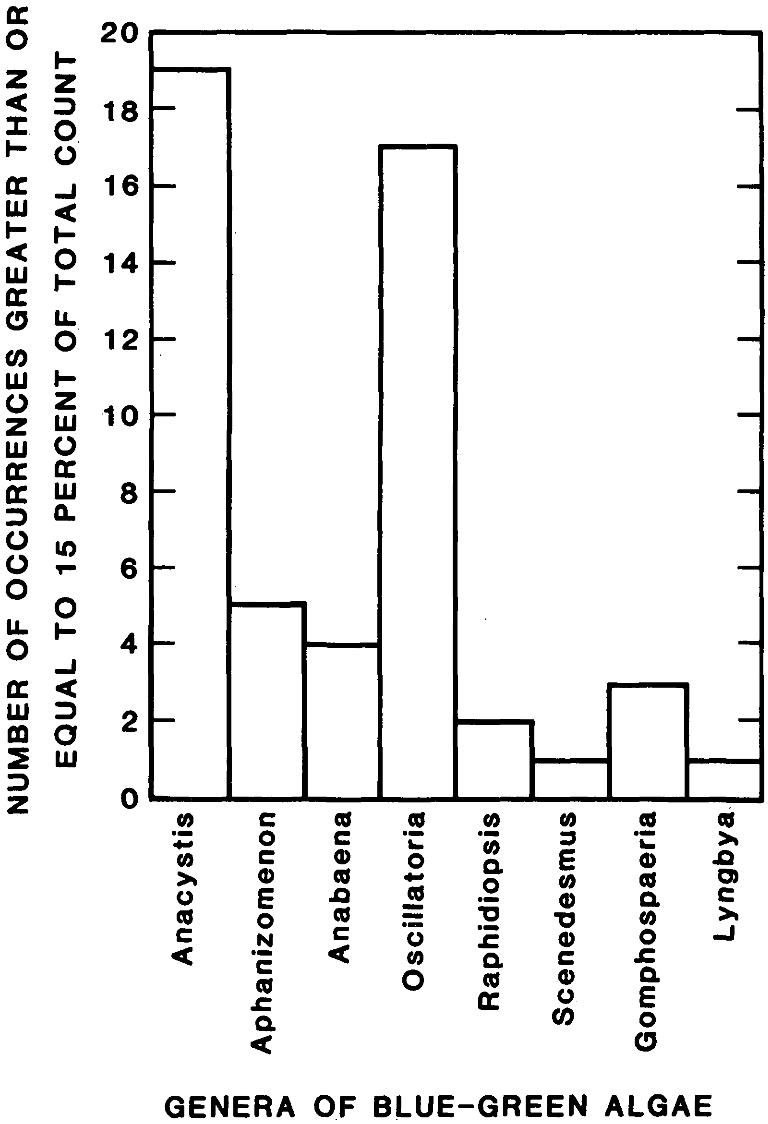



*Figure 23.--Occurrence of blue-green algae genera in the Lakeville lakes*

Zooplankton grazing is another control of phytoplankton growth. Zooplankton concentrations were not measured, but it may be that their concentrations were not high enough to control phytoplankton growth significantly.

## Kingsley Lake

Phytoplankton counts in Kingsley Lake ranged from 3,900 cells/mL in November 1976 to 44,000 cells/mL in April 1977 (table 4). This was the most narrow cell-count range of all four lakes. Zooplankton grazing may control phytoplankton populations, allowing macrophytes to dominate the waters. Macrophytes, which were found virtually across the entire bottom of Kingsley Lake, probably dampen extreme fluctuations of phytoplankton.

The highest phytoplankton count, which occurred in April 1977, consisted of over 80 percent blue-green algae. Large algal blooms occur often in the spring, after the ice has melted, because of buildup of ammonia during the winter.

The lowest phytoplankton count was found in samples collected in November 1976, which were the only samples not dominated by blue-green algae. Cyclotella, a diatom, made up 77 percent of the phytoplankton population. If diatom blooms occur, it is usually in spring or fall when the water is cool. Cyclotella is rated 15th out of 60 by Palmer (1968) in his list of most pollution tolerant genera.

Most of the phytoplankton identified in samples from Kingsley Lake are on Palmer's list of pollution-tolerant genera. Therefore, even though there is less development around Kingsley Lake than around the other three Lakeville lakes, the type of phytoplankton found makes it possible that Kingsley is an eutrophic or nutrient-enriched lake.

## Marion Lake

Figure 22 and table 4 show that the three sites on Marion Lake are dissimilar in phytoplankton activity. Virtually each set of samples taken at Marion Lake for any one time differs in genera and in population density between sites. Water depth, influence of macrophytes, and character of the surrounding watershed are probably the more important causes of the differences in phytoplankton activity. As seen in table 1, there is considerable difference in depth, macrophytic activity, and land use between sites. Site 3 is isolated by the freeway, except for a box culvert, from the rest of the lake, and it has little residential development compared with sites 1 and 2.

Looking specifically at sets of samples (table 4) one can notice how different the sites are in both genera and population density. Phytoplankton pulses at sites 1 and 2 occurred fairly simultaneously, although there were differences in genera. This synchronism indicates that similar influences affect phytoplankton activity at sites 1 and 2, which can be expected as both sites are in the same large part of the lake. Phytoplankton activity at site 3, on the other hand, is different from that at the other two sites.

Phytoplankton populations at site 3 were less dense than at sites 1 and 2. The largest bloom sampled at site 3 was 140,000 cells/mL, which was much less than the maximums at sites 1 and 2. Zooplankton and macrophytes, which are abundant, probably control phytoplankton growth at site 3 as they do in Kingsley Lake.

City of Lakeville personnel normally apply the algacide, copper sulfate, to Marion Lake during late spring or early summer. The frequency of sampling, however, was not enough to detect any effect from this application.

### Orchard Lake

The phytoplankton data for Orchard Lake indicate that similar bloom conditions were present at both sites (table 4). Except for the June 1976 samples, most genera identified were common to both sites, and changes in populations occurred in unison. As was the case at the other Lakeville lakes, blue-green algae were the most common types.

The similarities in phytoplankton populations between the Orchard Lake sites may be due to the shape of the lake. As seen in figure 1, the shoreline of Orchard Lake does not contain bays that are commonly the location of phytoplankton blooms.

The algacide, copper sulfate, is generally applied to Orchard Lake during late spring or early summer. The frequency of sampling, however, was not enough to detect effects of this application.

## SUMMARY

The city of Lakeville enlisted the help of the U.S. Geological Survey to establish baseline water-quality data for some of its lakes and to monitor for changes in water quality as the area becomes urbanized. A sampling program at seven sites on four major lakes began in 1976 and continued through 1978.

The four lakes, Orchard, Marion, Lee, and Kingsley, are closed lakes with a wide range of physical characteristics. Lake-surface areas range from 20.5 to 258 acres, depths range from 6 to 34 feet, and bottom slopes range from 6.8 to 40.3 percent. These factors affect the availability of littoral zones for the growth of aquatic macrophytes.

Results of chemical analyses indicate that biological activity may modify, during the growing season, the chemical content of the lake water. Photosynthetic utilization of carbon dioxide can raise the pH and cause precipitation of calcium carbonate in the lakes. Chloride concentrations at all sites increased during the drought of 1976. In Marion Lake site 3, chloride concentrations increased throughout the 1978 sampling.

The trophic state of the lakes classifies them as eutrophic, with TSI's averaging as high as 69.2 in Lee Lake. The high availability of nutrients is seen in water samples collected in spring and in the samples of bottom sediment.

Cell counts were as high as 890,000 cells per milliliter, and the blooms were commonly dominated by pollution-tolerant genera, such as Anacystis and Oscillatoria. Nutrient availability produces frequent algal blooms in the lakes that are not limited to the summer. Both phytoplankton cell counts and trophic state indexes provide evidence that aquatic macrophytes are successfully competing with phytoplankton for available nutrients in Kingsley Lake.

Profiles of temperature, dissolved oxygen, and pH at the deeper lake sites confirm the high biological activity expected in these eutrophic lakes. High productivity in the surface layers often produces supersaturated dissolved-oxygen conditions and alkaline pH's. Rapid decomposition near the bottom severely reduces oxygen content and lowers the pH below 7.0.

Continued monitoring of chloride may provide evidence of domestic influences in the lake watersheds that could be controlled to prevent degradation of the lakes. Periodic Secchi-disk readings and sampling of phosphorus might indicate whether accelerated eutrophication is a problem in the lakes.

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