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A Limnological Study of Three Lakes in Marquette County, Michigan

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A LIMNOLOGICAL STUDY OF THREE LAKES IN MARQUETTE COUNTY, MICHIGAN

by

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B.S., Northern Michigan University

A Thesis

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ABSTRACT

Physical, chemical and biological characteristics of Deer Lake, Lake Gribben and Section 2 Pond in Marquette County, Michigan, were assessed between June 1974 and July 1975. Temperature, dissolved oxygen, light, pH, non-filterable residue, alkalinity, several forms of phosphorus, total nitrate-nitrogen, total iron, specific conductance and plankton densities were determined for these three lakes.

Deer Lake was found to be a hypereutrophic, dimictic lake with a depletion of oxygen in the lower waters during periods of thermal stratification. Total phosphorus (0.18 to 1.66 mg P/1) and total nitrate-nitrogen (0.4 to 15.0 mg NO_3-N/1) were high in all strata of water throughout the year. Wastewater from three primary sewage treatment plants contributes to the high concentrations of these nutrients, although indirect evidence indicates that sediment-water interchange is also important in the loading of these nutrients. Large algal populations during the summer reflect these loadings.

Lake Gribben and Section 2 Pond were found to be dystrophic, 3rd order temperate lakes. Their water circulated on windy days during the ice free periods. Nutrient inflow from the drainage basins and their littoral communities, coupled with limited exchange from their sediments controlled their productivities.

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I wish to acknowledge the members of my graduate committee, Drs. Philip Doepke, William Robinson and Donald Macalady for their suggestions and criticisms which improved the presentation of results and readability of this manuscript.

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INTRODUCTION

The objective of this study was to determine the physical, chemical and biological characteristics of three bodies of water in Marquette County, Michigan. These bodies of water were prospective locations for testing the effects of the controlled addition of finely-divided particulates remaining after the separation of iron from iron ores (commonly known as tailings). The desired effect would be the limitation of available nutrients thereby controlling eutrophication. The bodies of water studied were Lake Gribben, Section 34 T47N, R26W; a pond located in Section 2 T46N, R26W; and Deer Lake located north of Ishpeming. Subsequent to this study, an area that includes Section 2 Pond and part of the Lake Gribben watershed was ditched, cleared of vegetation and diked to construct the Gribben tailings basin.

Deer Lake was studied as a site for possible treatment with tailings because it was identified as a problem lake with a serious algal bloom, deteriorating fish population and large amount of nutrient enrichment from primary sewage treatment plants (Kettele and Uttormark, 1971). Three primary sewage treatment facilities discharge their effluent into Carp Creek which enters Deer Lake. Lake Gribben and Section 2 Pond were studied as sites for possible treatment because they were located within the confines of the future Gribben tailings basin. It was hoped that if tests on Lake Gribben and Section 2 Pond showed promise of limiting nutrients, Deer Lake possibly might be a lake in which additions of tailings could show a beneficial effect.

Controlling human-stimulated eutrophication has become more of a problem as populations grow and less clean water is available for

drinking, industrial and recreational use. Many attempts have been made at lake restoration. Dunst, et al. (1974) have identified and described the present utility of various restoration techniques. Approximately 600 accounts of individual restoration experiences were evaluated. The methods employed either (1) limit fertility and/or sedimentation in lakes or (2) manage the consequences of lake aging. The former treats the underlying causes of lake problems while the latter tends to be cosmetic in nature, enhancing the usability of lakes but not controlling the source of degradation.

Fertility and sedimentation in lakes can be limited by reducing the amount of nutrients and sediment that flow into them, chiefly through wastewater treatment, diversion, land use practices and treatment of inflow. Other limitation techniques can be used within a lake to inhibit nutrient recycling or to accelerate nutrient outflows. Available methods include dredging, nutrient inactivation/precipitation, dilution/flushing, biotic harvesting, selective discharge, sediment exposure and desiccation, and lake bottom sealing.

To manage the consequences of lake aging various physical, chemical and biological approaches are available. These include aeration/circulation, manipulation of water levels, use of biocides and many others.

Lake restoration attempts are met with many difficulties. Lakes are extremely complicated ecosystems. Each lake has its own characteristics. What may work in one lake may or may not necessarily work in another. Before any effective attempts at restoration of a lake is undertaken it is imperative that pretreatment research be done to identify the important variables and quantify the cause and effect relationships within the lake (Dunst, et al., 1974).

This study was done in an effort to provide some of this information.

Temperature, dissolved oxygen, light, pH, non-filterable residue, alkalinity, several forms of phosphorus, total nitrate-nitrogen, total iron, specific conductance and plankton densities were determined for the three bodies of water between June 1974 and June 1975. There are many variables that affect water quality and productivity. These parameters were selected for analysis because they would yield the most amount of useful data given the time and laboratory equipment available.

METHODS AND MATERIALS

Sampling Locations and Frequency

Deer Lake was enlarged in 1912 as an impoundment of the Carp River. The reservoir was enlarged in 1942 to its present capacity of 1390 ft. above sea level (Figure 1). It has a controlled outlet regulated by the Cliffs Electric Service Company. Several creeks enter Deer Lake in addition to a seepage flow from several sides. Flow-through time has been estimated at 1 year (Ketelle and Uttormark, 1971).

A survey of the lake in June 1974 revealed two distinct basins, a North basin near the dam with a maximum depth of 8 meters and a South basin near the mouth of Carp Creek with a maximum depth of 10.5 meters. Vertical temperature profiles obtained during the survey showed a stable thermal stratification in the South basin. Therefore it was selected as the primary sampling location within the lake. Samples for general chemical characteristics were periodically taken from two depth regions - representing the upper waters and the lower waters - at the deepest location in the South basin. For reasons of brevity the upper waters will be referred to as the epilimnion and the lower waters will be referred to as the hypolimnion. The epilimnial samples were obtained by combining one liter samples taken from 2, 4 and 6 meters. The hypolimnial samples were taken from 1 meter above the bottom. The water was collected with a 1 liter, brass Kemmerer sampler and placed in glass bottles that had been acid washed with HCl and throughly rinsed with distilled water in the laboratory. Prior to filling, the bottles were rinsed with water from the region being sampled. At the South basin, water transparency measurements, zooplankton samples and phytoplankton

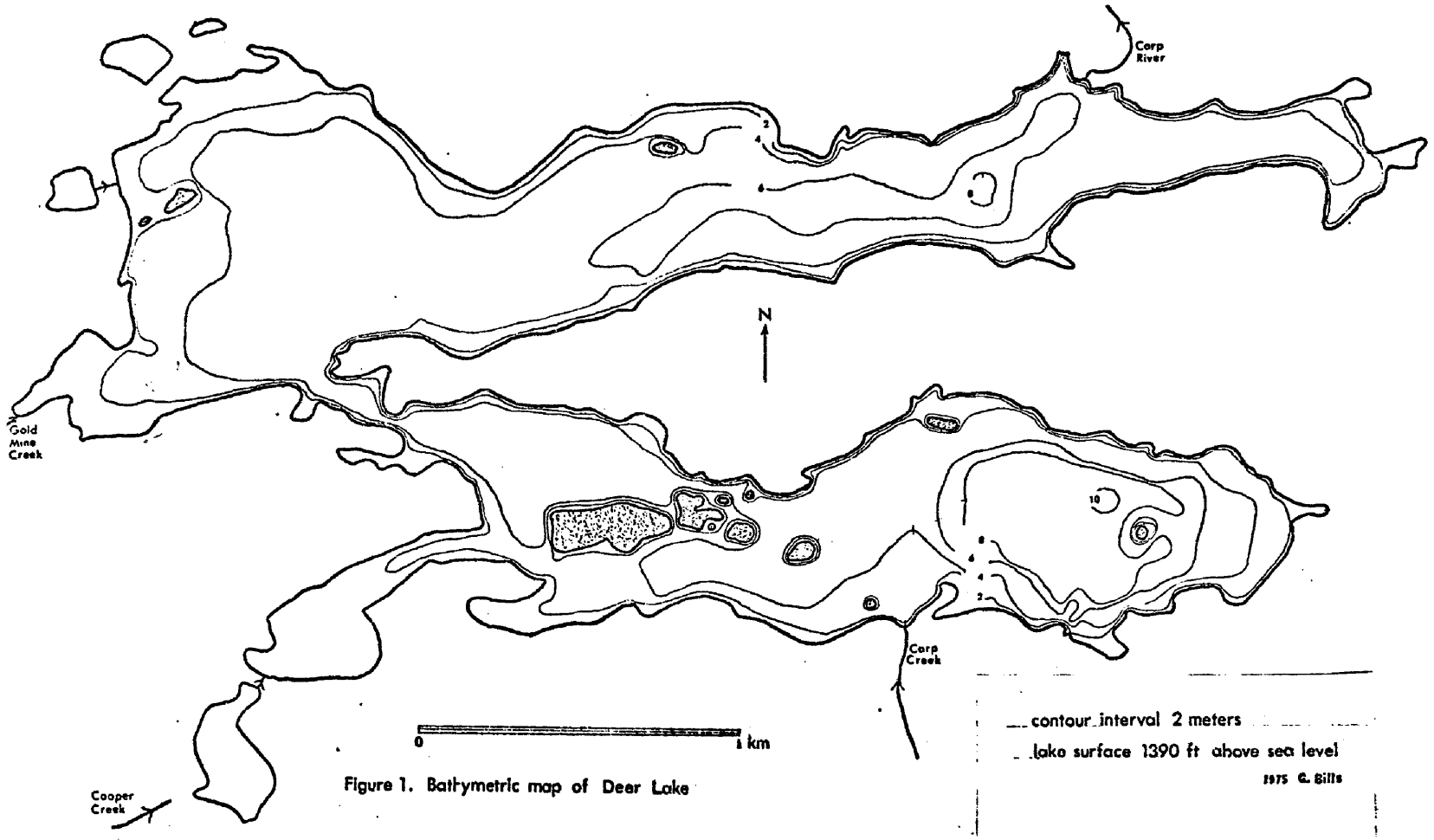

Figure 1. Bathymetric map of Deer Lake

samples were also taken. Vertical temperature and dissolved oxygen profiles were determined for both the North and South basins during 1974 and for the South basin in 1975.

Lake Gribben and Section 2 Pond were systems having seepage inflows and outflows. Inflow into Lake Gribben was primarily from the northwest with outflow to the southeast. Section 2 Pond had been created by beavers damming the seepage flow that courses largely from the west toward the south. Both bodies of water were shallow with maximum depths of 1.25 meters. Periodic water sampling for general chemical characteristics was dome at the 0.6 to 0.7 meter level with a Kemmerer sampler. The collected water was placed in glass bottles that were washed in the same manner as those used for Deer Lake. Additionally, plankton was sampled and vertical temperature and oxygen profiles were determined for both bodies of water. Lake Gribben and Section 2 Pond were not sampled as often as Deer Lake because of their shallowness and general inaccessibility at the time the study was being made. A summary of the dates of sampling for the various water bodies and parameters is given in Appendix 1.

Although fish were not sampled, yellow perch (Perca flavescens) were seen caught from Deer Lake. A bluntnose minnow (Pimephales notatus) was caught in Lake Gribben and a brook trout (Salvelinus fontinalis) was caught in Section 2 Pond.

Morphometric Characteristics

A bathymetric map (Figure 1) of Deer Lake was constructed from soundings obtained with a Lowrance Fish LoKaTor, Model LFP-300 along intersecting transects between prominent shoreline features while traveling at constant velocity (approximately 4 to 7 km/hr) between

shores. Depths were recorded at 30 second intervals. The depths were plotted at equal intervals for each transect on a shoreline map that was enlarged from a 7.5 minute series U.S. Geological Survey map. Contours were drawn by visual interpolation between the plotted depths.

Soundings revealed that Lake Gribben and Section 2 Pond had relatively constant depths of about 1 meter. Therefore, only the 1.0 meter contours were identified on their bathymetric maps (Figures 2 and 3). The locations of these depressions were established by intersections of transects between prominent shoreline features.

The watersheds (Figures 4, 5 and 6) for the three bodies of water were determined from topographic elevation changes shown on U.S. Geological Survey maps. The areas were found by using an Ott Disc Roller Planimeter, Model 131.

The volumes for the three bodies of water were determined by integrating a plot of area versus depth for the contours. The resultant volumes under the curve for each meter of depth were found by using the planimeter.

Appendix 2 contains the areas within bathymetric contours and volumes contained within depth intervals for Deer Lake.

Physicochemical Analysis

Temperature

Temperature was measured directly in degrees Celsius at each sampling site with a Yellow Springs Instrument Company, Model 54 battery powered oxygen-temperature meter. In Deer Lake the temperature was measured at each meter of depth from the surface to the

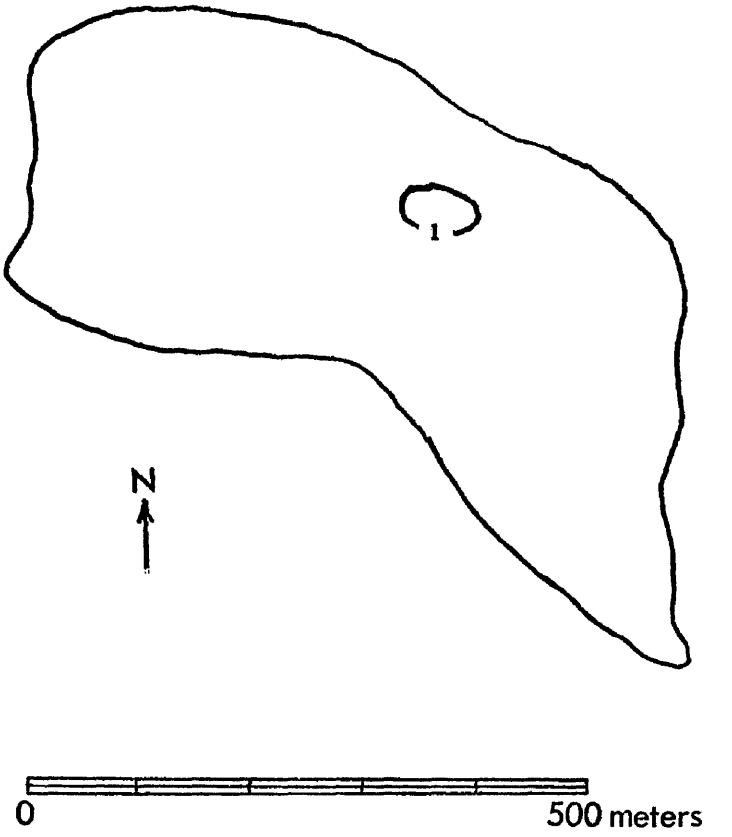

Figure 2. Bathymetric map of Lake Gribben

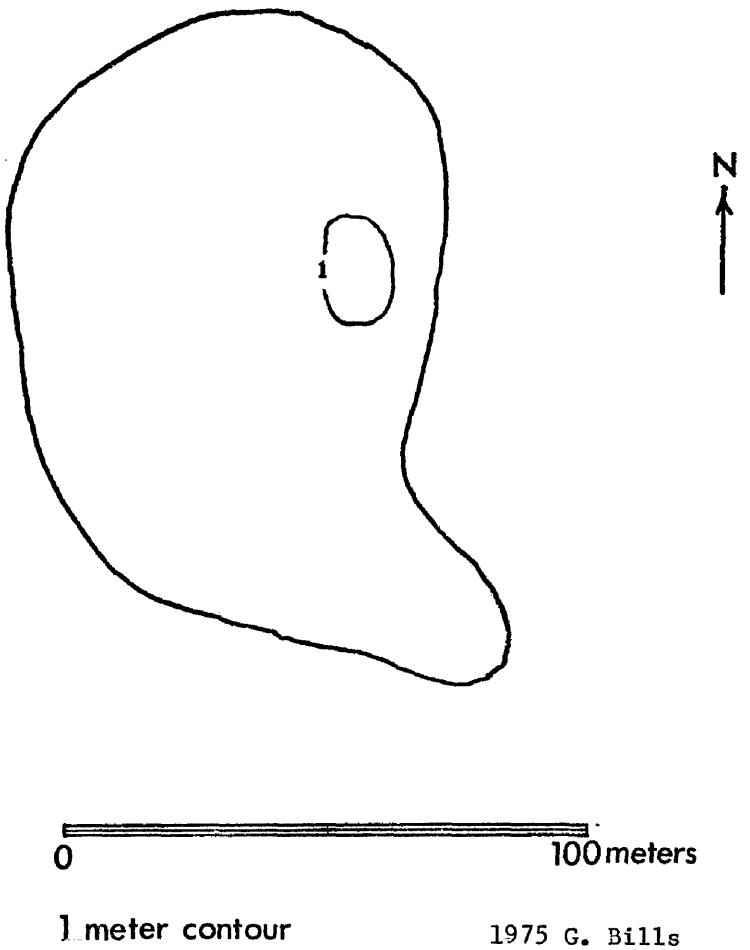

Figure 3. Bathymetric map of Section 2 Pond

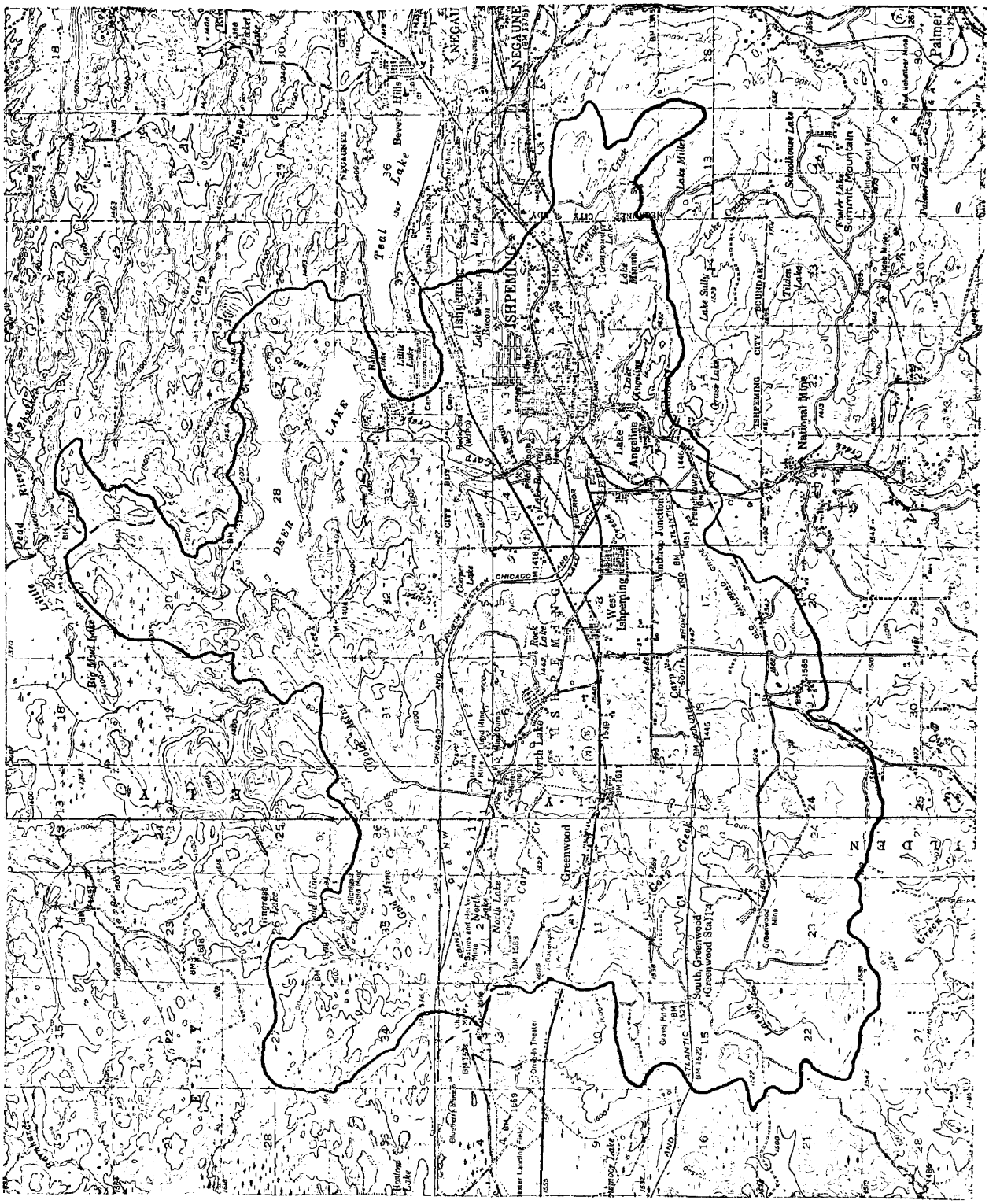

Figure 4. Deer Lake watershed

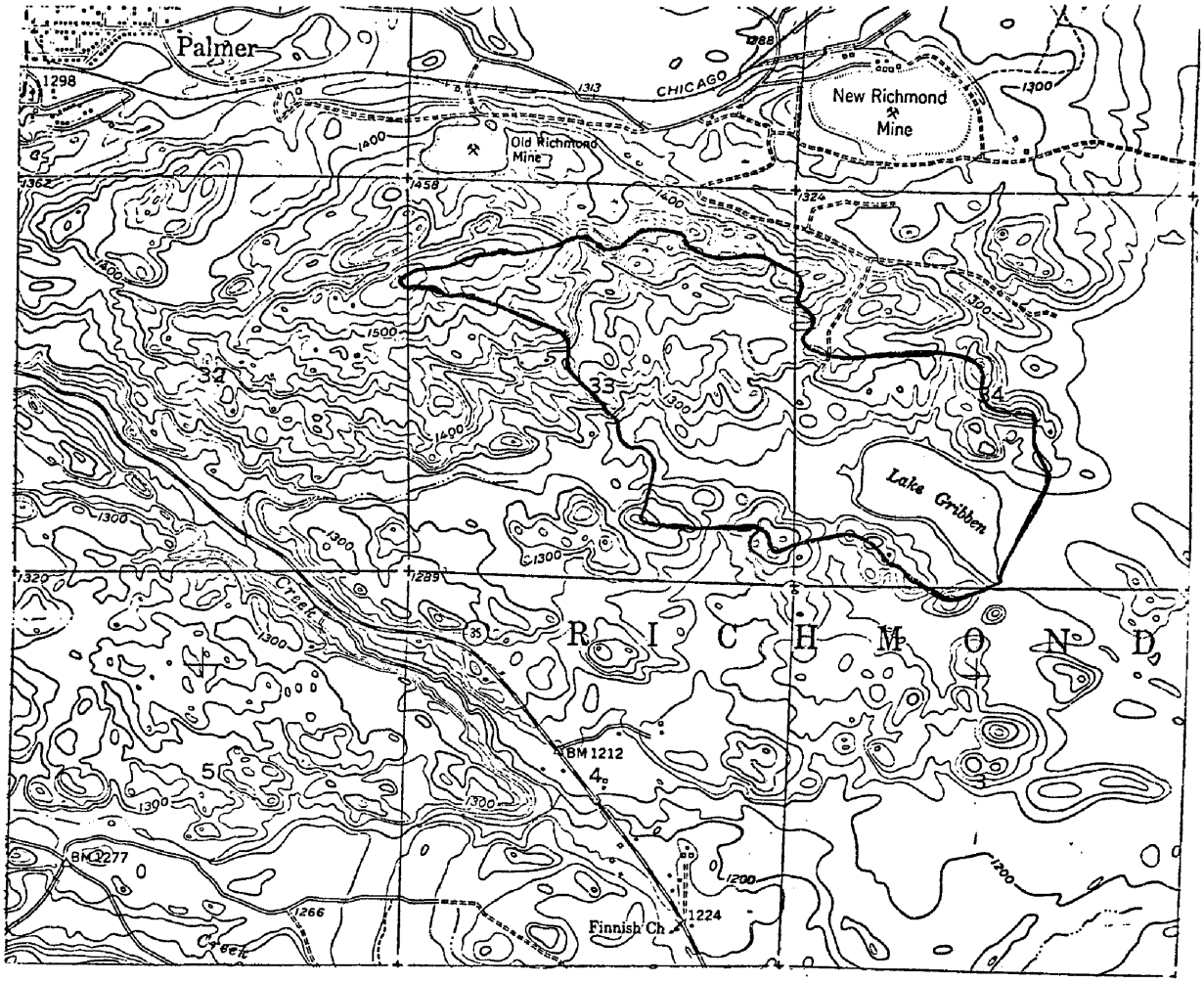

Figure 5. Lake Gribben watershed

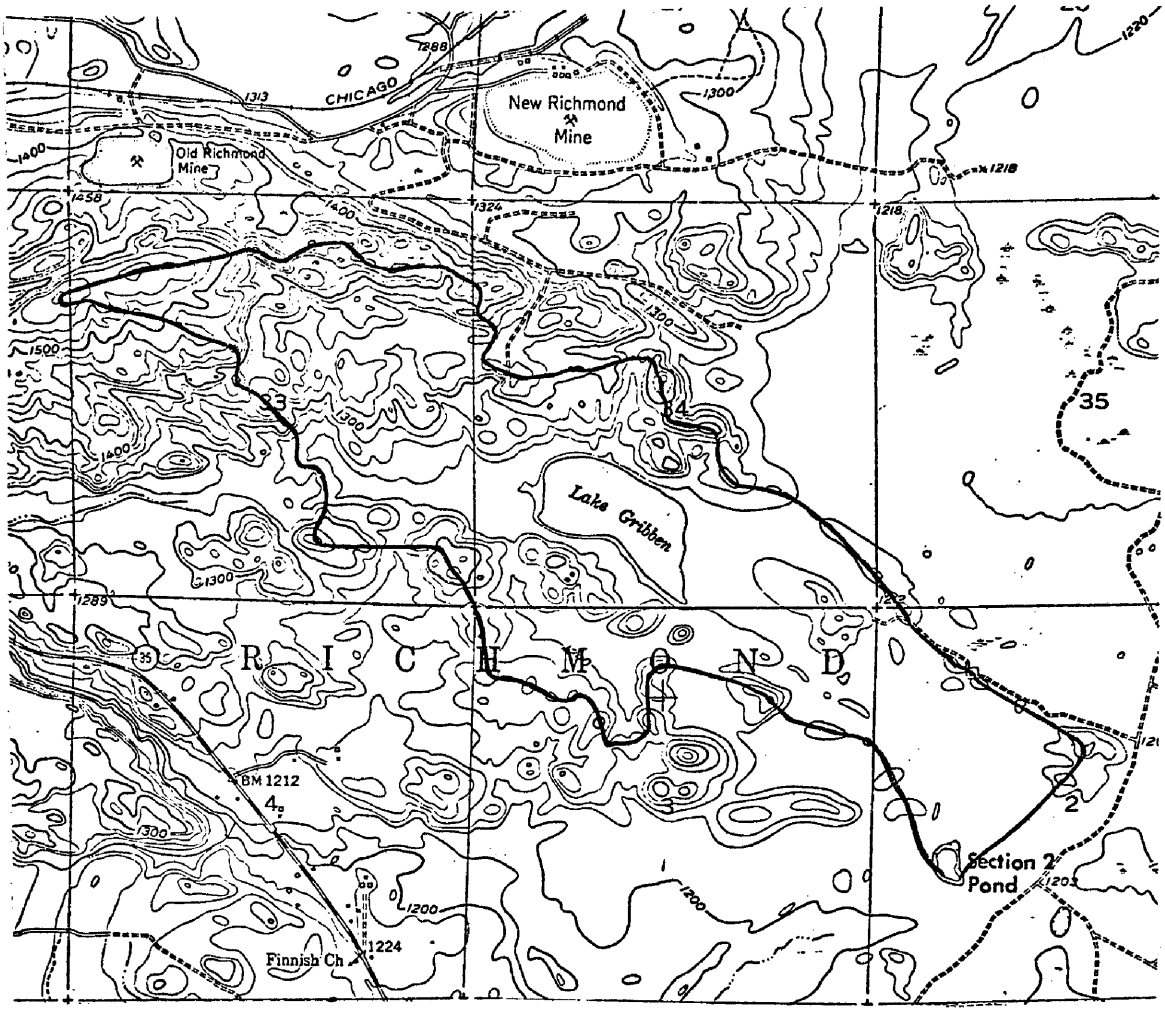

Figure 6. Section 2 Pond watershed

bottom In Lake Gribben and Section 2 Pond the temperature was measured at the surface, 0.5 meter, 1.0 meter and 1.25 meter (bottom) depths. All temperatures were determined to an accuracy of $\pm$ 0.5 degrees C.

Dissolved Oxygen

Dissolved oxygen concentrations were determined using the Azide Modification described in Standard Methods (APHA, 1971 p.477). Deer Lake samples were taken at each meter of depth from the surface to either the bottom or to a depth where upon adding concentrated H_2SO_4 the sample was completely colorless, indicating no oxygen present. Lake Gribben and Section 2 Pond samples were taken at the surface, 0.5 meters and 1.0 meters. The analysis procedure was carried out in the field except for the titration with standard sodium thiosulfate which was done upon returning to the laboratory. All dissolved oxygen concentrations were determined with a precision of $\pm$ 0.2 mg/l.

Specific Conductance and Salinity

Specific conductance was determined using a Yellow Springs Instrument Company, Model 31 conductivity bridge with a precision of $\pm$ 5%. All samples were held at 4° C until analysis (EPA, 1974) on 12-12-75. Samples were allowed to reach ambient temperature before analysis. All conductivities were corrected to 25° C (APHA, 1971 p.323).

There is a general similarity of bicarbonate waters wherever they are found such that specific conductance is closely proportional to the total salinity (Rodhe, 1949). Using the relationship estab-

lished by Rodhe, approximations of the salinities were obtained.

Hydrogen Ion Concentration

The pH measurements were made upon returning to the laboratory using a glass electrode with a Corning, Model 12 pH meter. The delay prior to measuring may have altered the accuracy of the pH measurements by making them lower than the actual value (Doepke, 1976). All pH measurements were determined with a precision of $\pm$ 0.02 standard units.

Alkalinity

Alkalinity was determined potentiometrically upon returning to the laboratory using a glass electrode with a Corning, Model 12 pH meter and titrating with 0.02 N H_2SO_4 to a pH of 8.3 for phenolphthalein alkalinity and to a pH of 4.5 for total alkalinity as described in Standard Methods (APHA, 1971 p.370). All alkalinity determinations were made with a precision of $\pm$ 1 mg $CaCO_3$/l.

Carbon Forms

Assuming all alkalinity is due to $CaCO_3$, approximations of the concentrations of HCO_3^-, $CO_3^=$, aqueous CO_2, total carbonic species (C_t), and total inorganic carbon can be determined. Using the measurements for total alkalinity and pH, these concentrations are calculated from the following equilibrium equations:

$$\left[HCO_3^-\right] = \frac{\text{Total Alkalinity} - \left[OH^-\right] + \left[H^+\right]}{\left(1 + 2K_2' / \left[H^+\right]\right)}$$

$$\left[CO_3^{=}\right] = \frac{\text{Total Alkalinity} - \left[OH^-\right] + \left[H^+\right]}{\left(\left[H^+\right] / K_2' + 2\right)}$$

$$\left[CO_2(aq)\right] = \frac{\text{Total Alkalinity} - \left[OH^-\right] + \left[H^+\right]}{\left(K_1' / \left[H^+\right] + 2K_2'K_1' / \left[H^+\right]^2 \right)}$$

$$\left[C_t\right] = \left[HCO_3^-\right] + \left[CO_3^{=}\right] + \left[CO_2(aq)\right]$$

$$\text{Total Inorganic Carbon (mg C/l)} = 12 \times \left[C_t\right]$$

where:

Total alkalinity is expressed in milliequivalents per liter

$$K_1' = \frac{\left[H^+\right]\left[HCO_3^-\right]}{\left[CO_2(aq)\right]} = \frac{K_1}{f_m^2}$$

$$K_2' = \frac{\left[H^+\right]\left[CO_3^{=}\right]}{\left[HCO_3^-\right]} = \frac{K_2}{f_d}$$

and

f_m = the activity coefficient for the monovalent ion

f_d = the activity coefficient for the divalent ion

$K_1 = 4.45 \times 10^{-7}$ at 25 °C and unit activity

$K_2 = 4.69 \times 10^{-11}$ at 25 °C and unit activity

A practical difficulty is determining the activity coefficients. Fortunately, at low salinities the activity coefficients do not vary significantly so that only an approximation or estimate of ionic strength is needed to estimate the activity coefficients (Loewenthal and Maris, 1976 p.87). Langelier (1936) established experimentally that in natural waters the ionic strength is closely estimated from the total inorganic solids concentration. Using the Langelier and Davies equation, Loewenthal and Maris plotted the activity coefficients for the mono- and divalent ions versus total inorganic dissolved solids. Since the salinity of inland waters

may be regarded as the concentration of all ionic constituents present (Hutchinson, 1957 p.553) salinity may be regarded as a close approximation to the total inorganic dissolved solids. Using these relationships the activity coefficients were found from the Loewenthal and Maris graph.

Transparency

Transparency was measured at Deer Lake using a Secchi disc with a diameter of 20 cm as outlined by Tyler (1968). Transparency was not measured in Lake Gribben and Section 2 Pond because the Secchi disc was visible on the bottom even though the water was stained brownish-yellow. The water in Lake Gribben was slightly brownish-yellow while the water in Section 2 Pond was a very dark brownish-yellow.

Nitrate-Nitrogen

Nitrate-nitrogen was determined using a Corning Nitrate Ion Electrode in conjunction with a Sargent Welch Model PBX pH meter. Samples were held by lowering the pH to less than 2 with concentrated H_2SO_4 and storing at 4° C (EPA, 1974). Analysis was done on 7-25-75 after samples were allowed to reach room temperature. All nitrate-nitrogen concentrations were determined with a precision of $\pm$ 0.2 mg NO_3-N/1.

Phosphorus Forms

Total phosphorus concentrations were determined following sulfuric acid - nitric acid digestion. After digestion the liberated

orthophosphate was determined using the Stannous Chloride Method (APHA, 1971 p.518).

Total orthophosphate was determined using the stannous chloride method without preliminary hydrolysis or digestion.

Total acid-hydrolyzable phosphate (condensed phosphate) was determined using the stannous chloride method following mild acid hydrolysis and then subtracting the total orthophosphate from the orthophosphate found after mild acid hydrolysis (APHA, 1971 p.521).

Total organic phosphate was determined by subtracting the sum of the total acid hydrolyzable phosphate and the total orthophosphate from the total phosphate (APHA, 1971 p.521). Of the total organic phosphate about 70% or more is within the particulate (sestonic) organic matter and the remainder is present as dissolved and colloidal organic phosphate (Wetzel, 1975 p.217).

Samples for total phosphate and orthophosphate analysis were held by cooling to 4° C. Samples for acid-hydrolyzable phosphate analysis were held by lowering the pH to less than 2 with H_2SO_4 and storing at 4° C (EPA, 1974).

All measurements were made in a Beckman Grating Spectrophotometer, Model DB-G, at 690 nm using a 1 cm cell. Analyses were performed on 8-5-75 after the samples were allowed to reach room temperature. All phosphate concentrations were determined with a precision of $\pm$ 25%.

Non-Filterable Residue and Total Residue

The non-filterable residue (total suspended solids) is matter of an undetermined composition that is retained by a 0.45 micron filter. The non-filterable residue was determined after filtering a volume of

water (200 to 500 ml) through a 0.45 micron filter and drying at 105° C according to Section 148 C in Standard Methods (APHA, 1971 p.291). Samples were held and stored at 4° C (EPA, 1974) prior to analysis on 12-4-75. All non-filterable residue concentrations were determined with a precision of ± 2 mg/l.

Using the salinity as a close approximation to the filterable residue (dissolved solids), an estimate was made for the total residue (total solids) according to Langelier (1936).

Total Iron

Total iron concentrations were determined using a Beckman Atomic Absorption Spectrophotometer, Model 440, at 248.8 nm. Samples were held by lowering the pH to less than 2 with concentrated HNO_3 and stored at 4° C (EPA, 1974). Analysis was done on 7-20-75. All total iron concentrations were determined with a precision of ± 1.8 mg Fe/l.

Phytoplankton (Deer Lake)

The phytoplankton samples from Deer Lake were collected by vertical hauls from a depth of 7 to 8 meters with a Wisconsin Plankton Net, #25 mesh, pore size 0.1 mm, and preserved in a 5% solution of formalin. The volume of water filtered was calculated by the formula $V = \pi r^2 h$ where: r = the radius of the net opening and h = the depth from which lifting occurred. The volumes of water filtered varied between 66.5 and 76 liters. Subsampling was done by taking a 1.0 ml aliquot with a Stempel pipette from a well mixed sample and placing the aliquot in a 50 mm X 20 mm X 1 mm Sedgwick-Rafter counting chamber. Phytoplankton were counted at 100 X magnification using

a strip count. This involved examining four strips the length of the cells. The concentration of each organism was calculated by using the formula Number per ml = $\frac{C \times 1000}{L \times D \times W \times S}$ where:

C = number of organisms counted

L = 50 mm (length of the strip)

D = 1.0 mm (depth of the strip)

W = 1.84 mm (width of the strip)

S = 4 (number of strips counted)

Phytoplankton were identified from keys (Prescott, 1970 and Needham and Needham, 1962) and tallied under the following categories: coccoid blue green, filamentous blue green, coccoid green, filamentous green, green flagellates, centric diatoms and pennate diatoms. Tallies of protozoans and rotifers were also made. The tallying procedure (EPA, 1973) was to consider colonies as single units, thus an isolated individual had equal numerical weight to that of a colony when figuring densities. Triplicate aliquots were counted and the results averaged. The number per ml in the sample was multiplied by the sample volume and divided by the volume of water filtered in order to estimate the density of each organism on the sample date.

Zooplankton (Deer Lake)

The zooplankton samples were collected on Deer Lake using a Clarke-Bumpus Plankton Sampler with a #2 net, pore size 0.5 mm. The epilimnial samples were collected by towing the sampler 210 seconds, 30 seconds at each meter of depth from 6 meters to the surface. The hypolimnial samples were collected by towing the sampler for 210 seconds at 8 meters of depth. All samples were preserved in a 5% solution of formalin. The volume of water filtered was calculated

by assuming filtration of 4 liters for each revolution of the impeller (manufacturer approximation).

Subsampling was done by taking a 1.0 ml aliquot with a Stempel pipette from a well-mixed sample and placing the sample in a 50 mm X 20 mm X 1 mm Sedgwick-Rafter counting chamber. All zooplankton were identified from keys (Eddy and Hodson, 1961 and Needham and Needham, 1962) and tallied under the following categories: Cladocera, Cyclopoidea copepods, Calanoidea copepods, nauplii, and Diptera larvae. Triplicate aliquots were counted and the results averaged (EPA, 1973). The mean count for each organism was multiplied by the sample volume and divided by the volume of water filtered in order to estimate the density of that organism in the lake on the sampling day.

Plankton (Lake Gribben and Section 2 Pond)

Because of the shallowness of Lake Gribben and Section 2 Pond, the conventional use of a Clarke-Bumpus Plankton Sampler and of a Wisconsin Plankton Net was not feasible. Therefore a Wisconsin Plankton Net, # 25 mesh, 0.1 mm pore size, was towed behind a canoe for 1 to 2 minutes in order to capture plankton. Subsampling and counting was done the same as for phytoplankton for Deer Lake. The plankton were identified, tallied and expressed as a percent of sample under the following categories: coccoid blue green, filamentous blue green, coccoid green, filamentous green, green flagellates, centric diatoms, pennate diatoms, flagellated protozoans, sarcodinian protozoans, rotifers, nauplii, cyclopoidea and Daphnia spp..

RESULTS

Deer Lake

Morphometry

Figure 7 is an aerial view of Deer Lake and the watershed area to the west south-west of the lake. The geology of the watershed area according to Wiitala, Newport and Skinner (1967) is characterized by bedrock and glacial till material. The bedrock formations consist of various kinds of igneous and metamorphic rocks which are Precambrian in origin.

The metamorphic rocks are mostly quartzites, schists, gneisses and metavolcanics. Igneous rocks which intrude the metamorphic rocks, are chiefly granite, diorite and basic igneous rocks. The Precambrian bedrock crops out in many places on ridges and knobs.

The glacial till is unsorted or poorly sorted, unstratified drift deposited directly from glacial ice without subsequent movement by wind or water. It is a very heterogeneous material ranging from clay to large boulders and from well rounded to sharply angular rock fragments. In the watershed the thickness of the till ranges from less than 0.3 meters to 15 meters.

The watershed area is 95 km^2. The surface area of Deer Lake is 366.7 ha. The perimeter of the basin is 22.3 km. A bathymetric map is shown in Figure 1 (p.5). The areas within the bathymetric contours and volumes contained within depth intervals are given in Appendix 2.

Temperature

Temperature data obtained for the North and South basins of Deer Lake are presented in Appendix 3. Vertical temperature profiles for five dates showing various stages of stratification and circulation

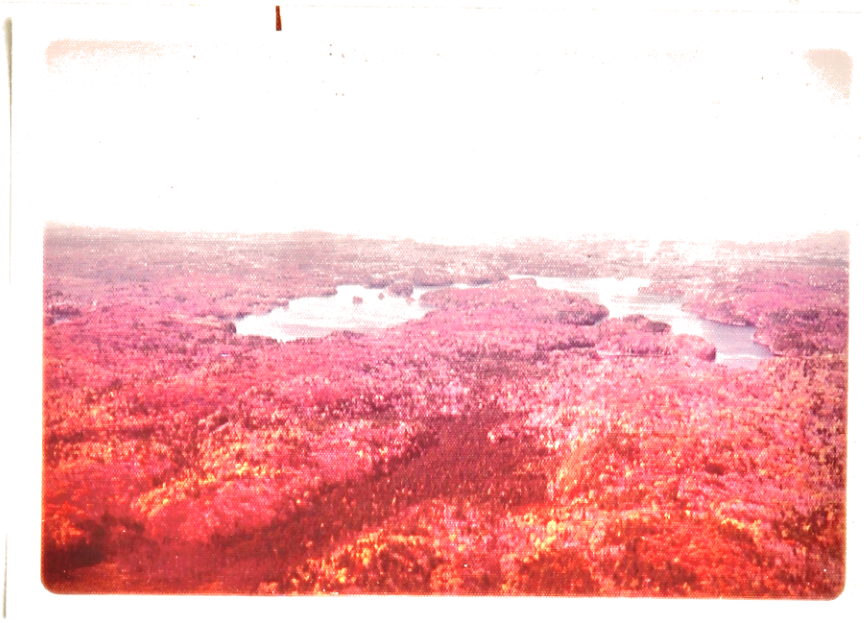

Figure 7. Aerial view of Deer Lake looking west south-west. The South Basin is on the left and the North Basin on the right. Photograph was taken on October 3, 1977.

for the South basin are presented in Figure 8. These profiles show that the South basin was stratified into an epilimnion (0-5 meters), metalimnion (5-9 meters) and a hypolimnion (9-10.5 meters) on 7-30-74. Profiles obtained on 9-25-74 and 10-15-74 reveal thermal conditions characteristic of the period of autumnal circulation present in a holomictic lake. The lake became ice bound in December and the profile for 2-23-75 was obtained during winter stagnation. The lake became free of ice about 4-15-75 and vernal holomictic circulation most likely occurred in late April. The profile for 5-20-75 shows that the lake is beginning to thermally stratify. This annual thermal pattern characterizes Deer Lake as a dimictic lake (Wetzel, 1975 p.78). The annual heat budget was calculated to be 8.196×10^3 cal/cm^2 by the method outlined by Hutchinson (1957 pp.492-495) using the data for the dates 8-24-74 and 2-23-75.

The temperature data for the North basin of Deer Lake show that thermal stratification was being established on 6-28-74 with the surface temperature at 21.0° C and the water at the bottom (8 meters) 12.0° C. Thermal stratification persisted through 8-25-74 with the surface water 21.2° C and the bottom water 11.4° C. Circulating conditions were present on 9-26-74 and 10-31-74.

Dissolved Oxygen

Dissolved oxygen data for Deer Lake are presented in Appendix 4. Figure 9 illustrates dissolved oxygen concentrations for the same dates that were used to illustrate the annual temperature pattern for the South basin of Deer Lake. During summer stratification as depicted on 7-30-74, a clinograde oxygen profile was established with the lower metalimnion and hypolimnion being anoxic. The oxygen

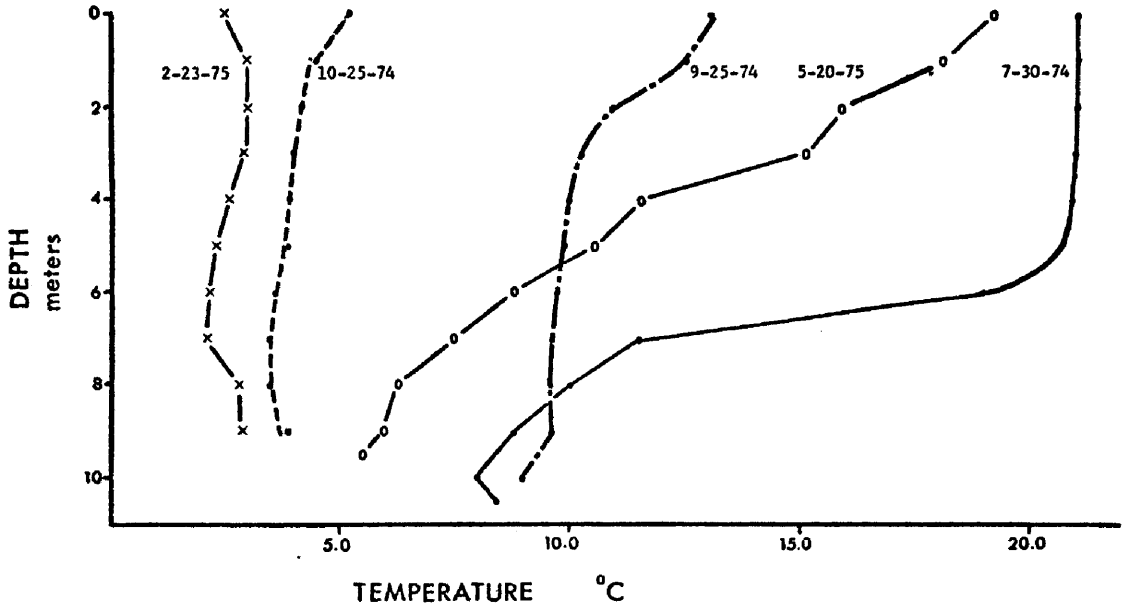

Figure 8. Thermal profiles of South Basin of Deer Lake on selected dates

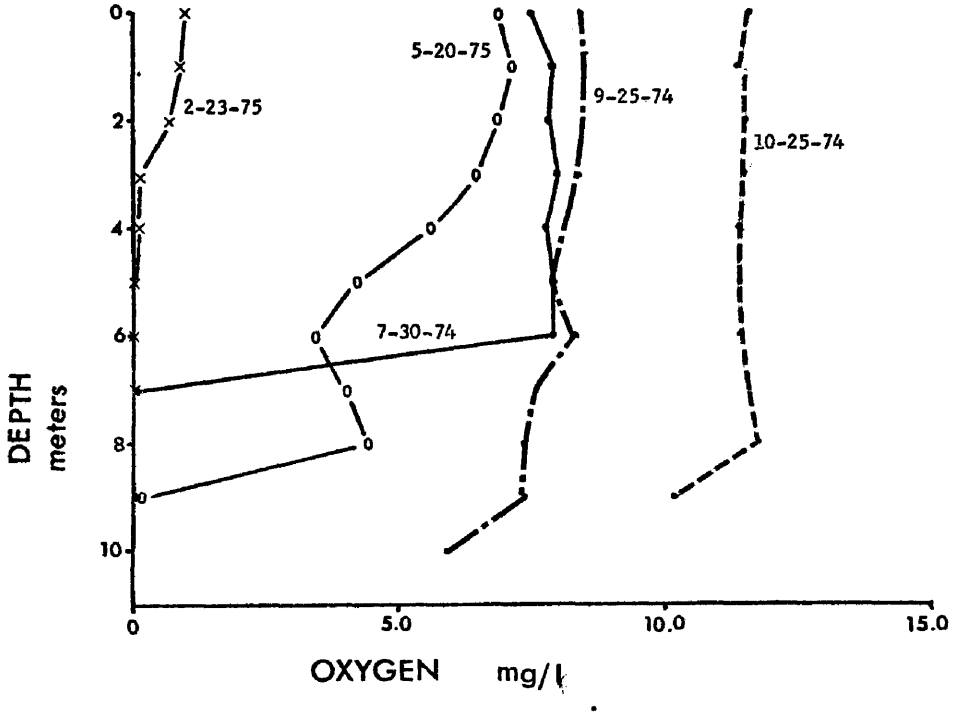

Figure 9. Dissolved oxygen profiles of South Basin of Deer Lake on selected dates

content of the hypolimnion of very productive or eutrophic (high in nutrients with high organic production) lakes is depleted often only a few weeks after summer stratification begins and the hypolimnion remains anoxic throughout this period (Wetzel, 1975 p.127). These conditions prevailed in Deer Lake until autumnal circulation produced an orthograde oxygen profile on 9-25-74 although slightly reduced oxygen concentrations were present near the bottom. This is probably due to the high concentration of organic matter on the bottom which causes a rapid loss of oxygen at the sediment-water interface where bacterial decompostion is often increased greatly over that occurring in the water (Wetzel, 1975 p.127). Similar approximately orthograde profiles were noted later in the autumnal holomixis (10-25-74) and at the end of vernal circulation and beginning of summer stratification (5-20-75). During winter stagnation the oxygen concentration is reduced at all depths. On 2-23-75 the water was anoxic at 5 meters.

Transparency

Secchi disc visibility readings (Appendix 5) made on the ice free sampling dates ranged from 1.0 meter in July and August to 2.0 meters in May.

Hydrogen Ion Concentration (pH)

Figure 10 shows the pH values obtained for the epilimnial and hypolimnial waters of Deer Lake. When holomictic circulation was occurring the pH values for the upper and lower water strata were nearly equal. However, during the periods of stagnation the pH in the hypolimnion was distinctly lower than that in the epilimnion.

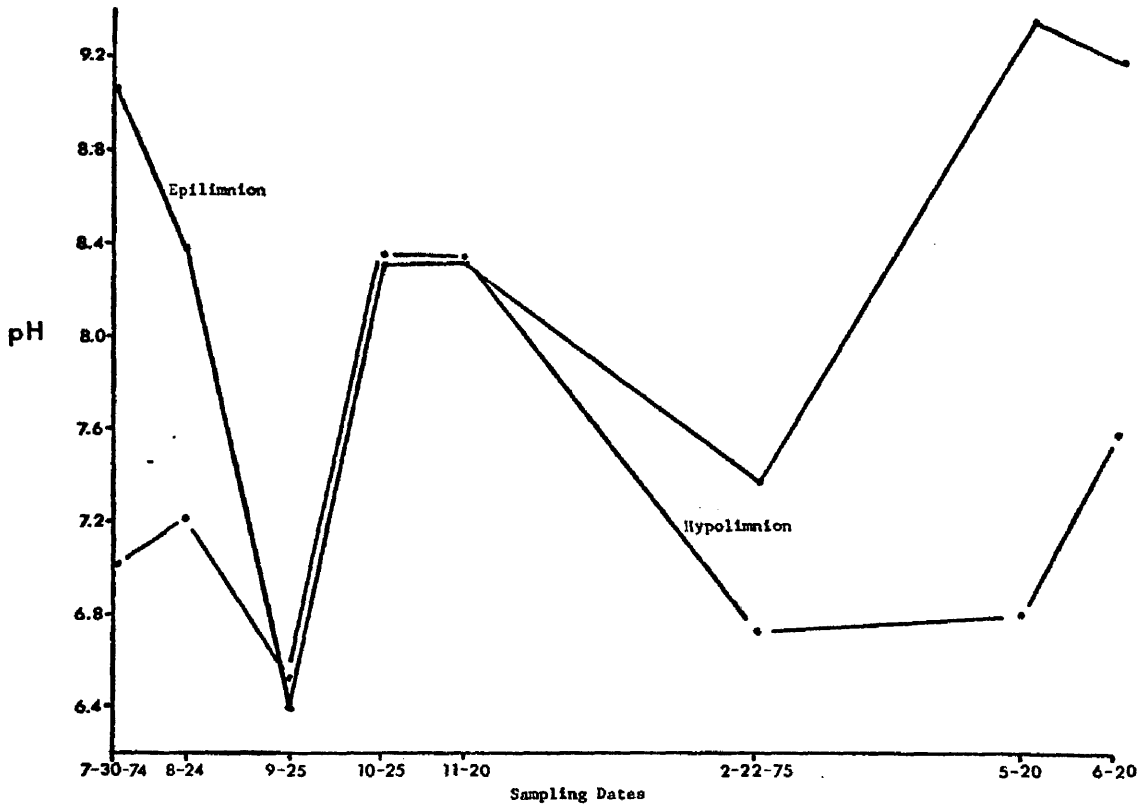

Figure 10. pH of Deer Lake

Specific Conductance and Salinity

The conductivity of Deer Lake is highest during the period of summer stagnation (Figure 11). The onset of autumnal circulation brings about a fall in conductivity which is followed by a rise during the period of stagnation under the ice. Vernal circulation produced a decrease in conductivity similar to that observed as a consequence of autumnal circulation. During the succeeding summer stagnation (6-20-75) the conductivity of Deer Lake rose.

The salinities (Appendix 5) calculated from the specific conductance values ranged between 167 and 253 mg/l for the epilimnial and hypolimnial waters, respectively. Their seasonal variation necessarily followed that of the specific conductance. Consistently, the values of conductivity and salinity for the lower water strata equalled or slightly exceeded those found in the upper water strata.

Alkalinity

Total alkalinity and phenolphthalein alkalinity data for Deer Lake are presented in Appendix 5.

The total alkalinity is generally higher during the periods of summer and winter stagnation and lowest during the periods of autumnal and vernal circulation (Figure 12). Usually the total alkalinity of the hypolimnion is higher than that of the epilimnion.

Phenolphthalein alkalinity was present only in the epilimnion and only during the establishment of (5-20-75) or during summer stagnation (7-30-74, 8-24-74 and 6-20-75). On these dates the phenolphthalein alkalinity ranged up to a high of 17 mg $CaCO_3$/l and never accounted for more than a quarter of the total alkalinity.

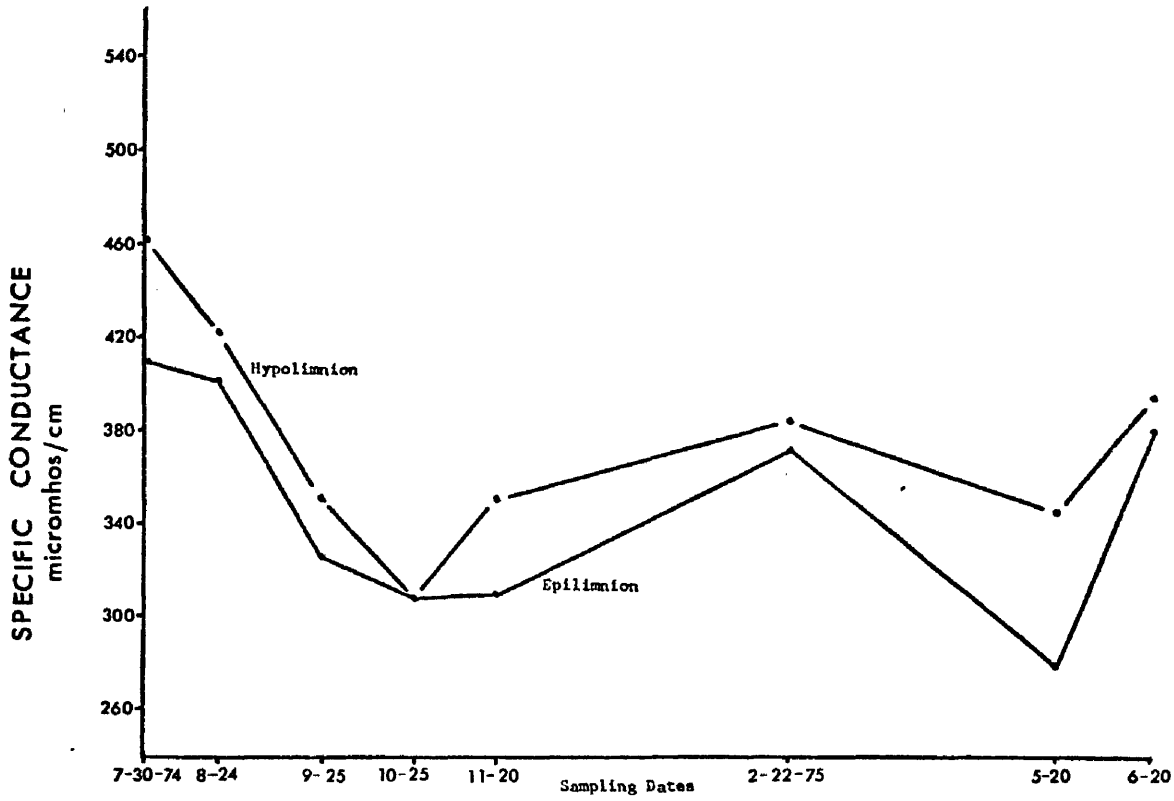

Figure 11. Specific Conductance of Deer Lake

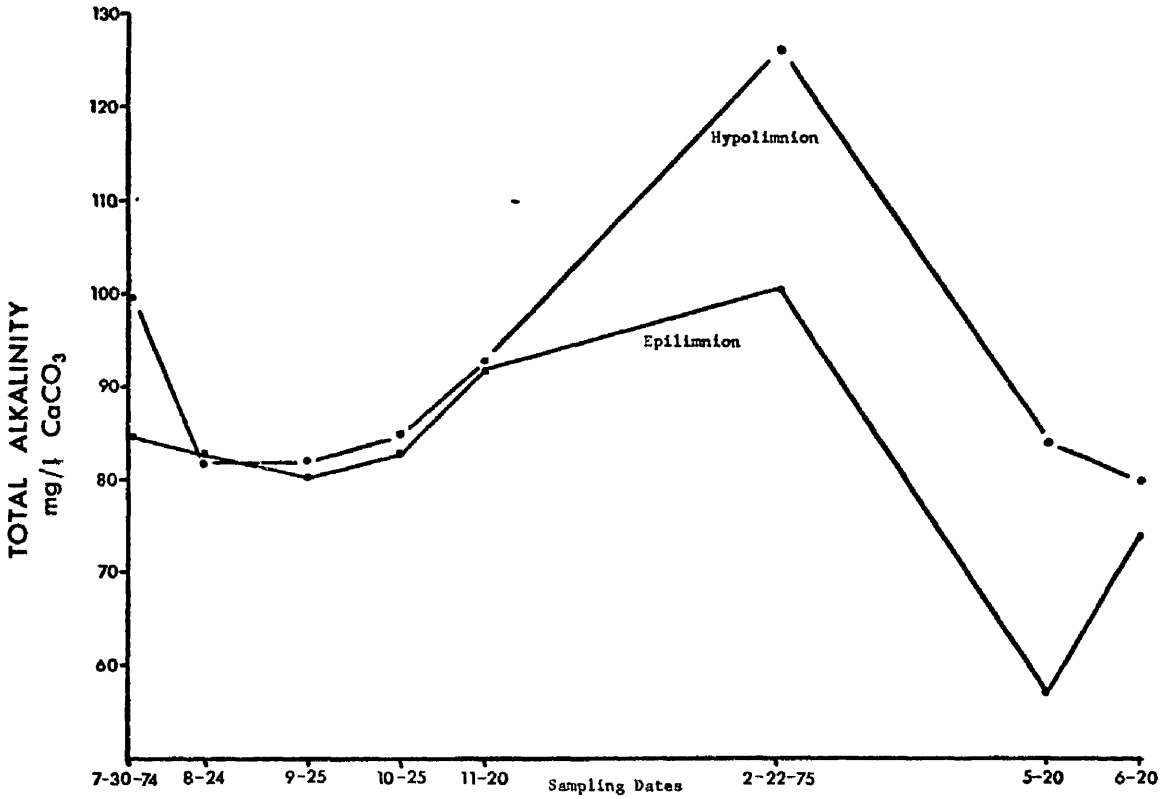

Figure 12. Total alkalinity of Deer Lake

Carbon Forms

The values calculated from the total alkalinity and pH for the carbonic species are presented in Appendix 5.

Table 1 gives the epilimnial and hypolimnial ranges of concentration for HCO_3^-, $CO_3^=$, $CO_2(aq)$, total carbonic species and total inorganic carbon in Deer Lake during the sampling period. The principal carbonic species present on all sampling dates in both the epilimnial and hypolimnial waters was HCO_3^-.

Non-filterable Residue and Total Residue

Non-filterable residue data for Deer Lake are presented in Appendix 5.

The non-filterable residue varied between 6.8 and 8.3 mg/1 in the epilimnion during summer stagnation and the overturn periods except for a concentration of 5.3 mg/1 on 11-20-74 (Figure 13). A concentration of 2.2 mg/1 was found in the upper waters during winter stagnation. In the hypolimnion the non-filterable residue reached its highest level (16.0 mg/1) during winter stagnation. Except for one sampling date which occurred during the autumnal overturn, the non-filterable residue of the lower water distinctly exceeded that of the upper water.

Estimates of the total residue ranged from 174 to 261 mg/1 and 193 to 298 mg/1 for the upper and lower layers respectively. Values for total residue peaked during summer stagnation. The total residue data are presented in Appendix 5.

Phosphorus

Figure 14 illustrates the fluctuations of phosphorus. The

TABLE 1. Ranges of carbonic species in South Basin of Deer Lake

	Epilimnion		Hypolimnion	
	Low	High	Low	High
HCO_3^- (moles/l)	8.54×10^{-4}	2.01×10^{-3}	1.59×10^{-3}	2.53×10^{-3}
$CO_3^=$ "	2.50×10^{-7}	1.26×10^{-4}	3.29×10^{-7}	4.13×10^{-4}
$CO_2(aq)$ "	2.06×10^{-7}	1.24×10^{-3}	1.40×10^{-5}	8.94×10^{-4}
C_t "	9.80×10^{-4}	2.87×10^{-3}	1.68×10^{-3}	3.42×10^{-3}
Total Inorganic Carbon mg/l	11.8	34.4	34.4	41.0

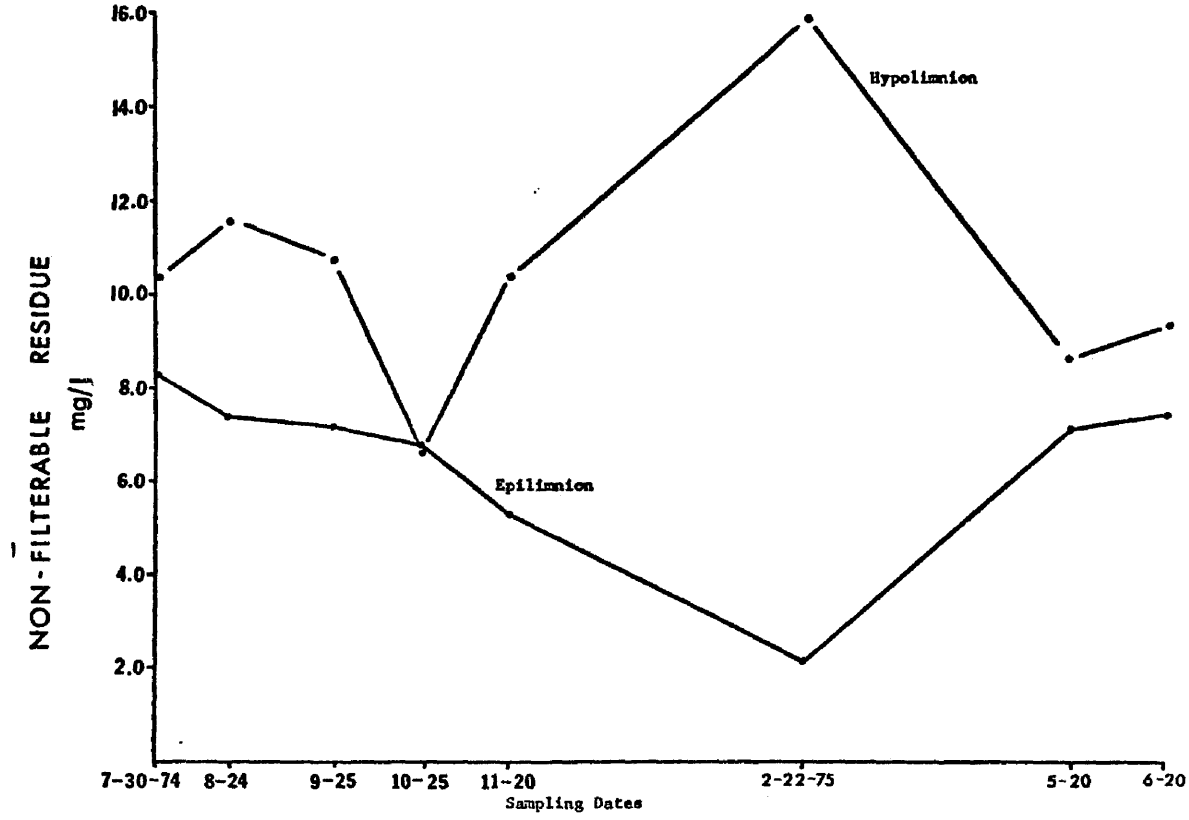

Figure 13. Non-filterable residue of Deer Lake

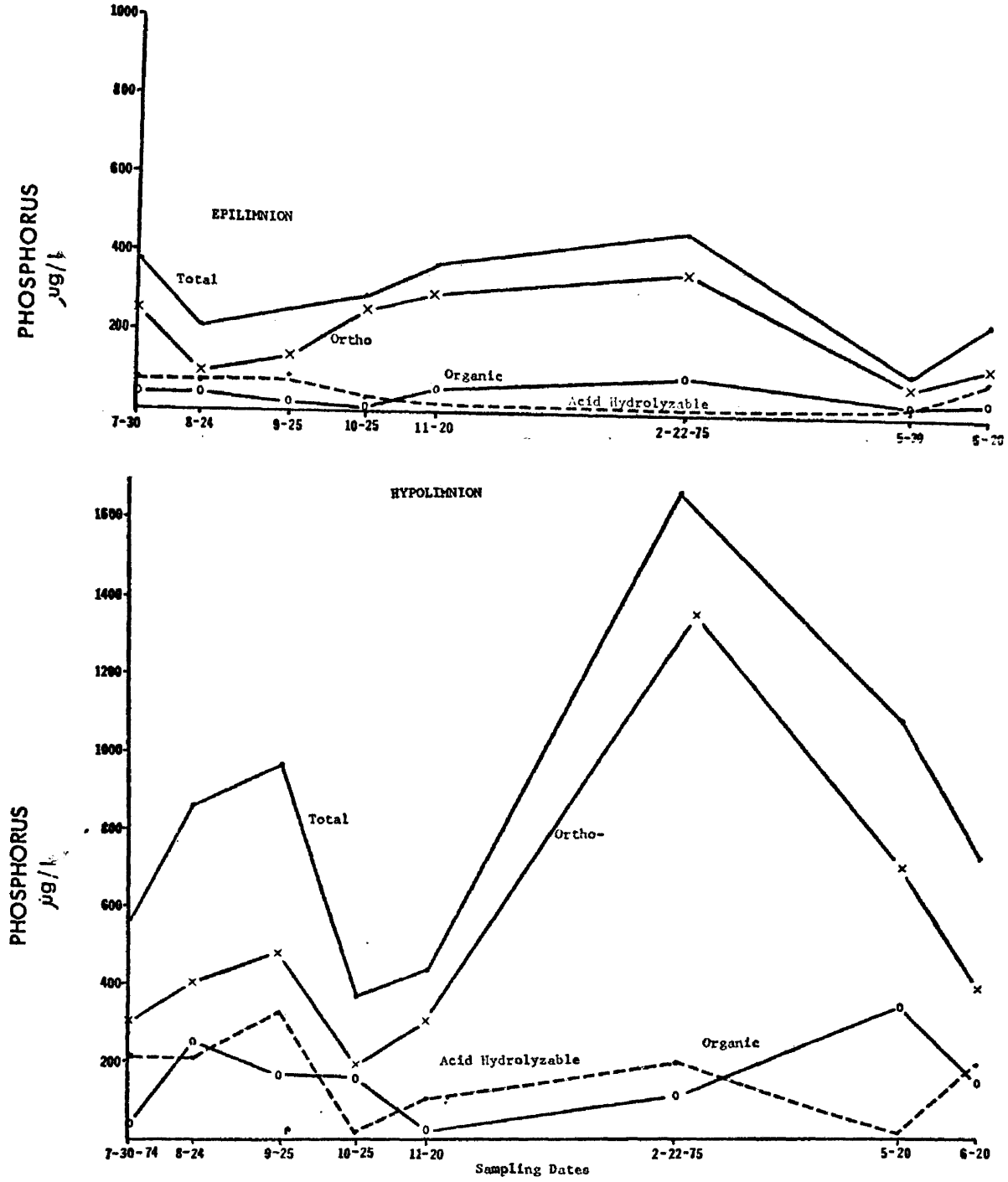

Figure 14. Forms of Phosphorus in Deer Lake

total phosphorus concentrations in the lower waters ranged between 365 and 1660 µg P/l and always exceeded the concentrations occurring on the same dates in the upper waters where a range between 108 and 406 µg P/l was observed. Late in the stagnation periods the lower waters showed marked elevations in total phosphorus. By contrast, the upper waters reached a peak in total phosphorus during winter stagnation but their concentrations of total phosphorus were somewhat reduced during the latter part of summer stagnation. In all instances the principal phosphorus component was orthophosphorus.

Nitrate-Nitrogen

Nitrate-nitrogen data for Deer Lake are illustrated in Figure 15. Concentrations of 15 and 13 mg NO_3-N/l were present in the epilimnion and hypolimnion respectively on 5-20-75 near the beginning of summer stagnation. Nitrate levels dropped during late summer stagnation to less than 1 mg NO_3-N/l in both levels. During autumnal circulation the nitrate concentrations generally rise and approach 2 mg NO_3-N/l prior to winter stagnation. However, it should be noted that on 10-25-74 the nitrate in the hypolimnion had a singularly high concentration. On 2-22-75 the nitrate levels were at 2.9 and 3.4 mg NO_3-N/l in the upper and lower water respectively.

Iron

The concentration of total iron in Deer Lake is depicted in Figure 16. Values of approximately 1 mg Fe/l were found during the circulation periods and in the upper water during the stagnation periods. Elevated concentrations that approached 4 mg Fe/l were found during the stagnation periods in water just above the bottom.

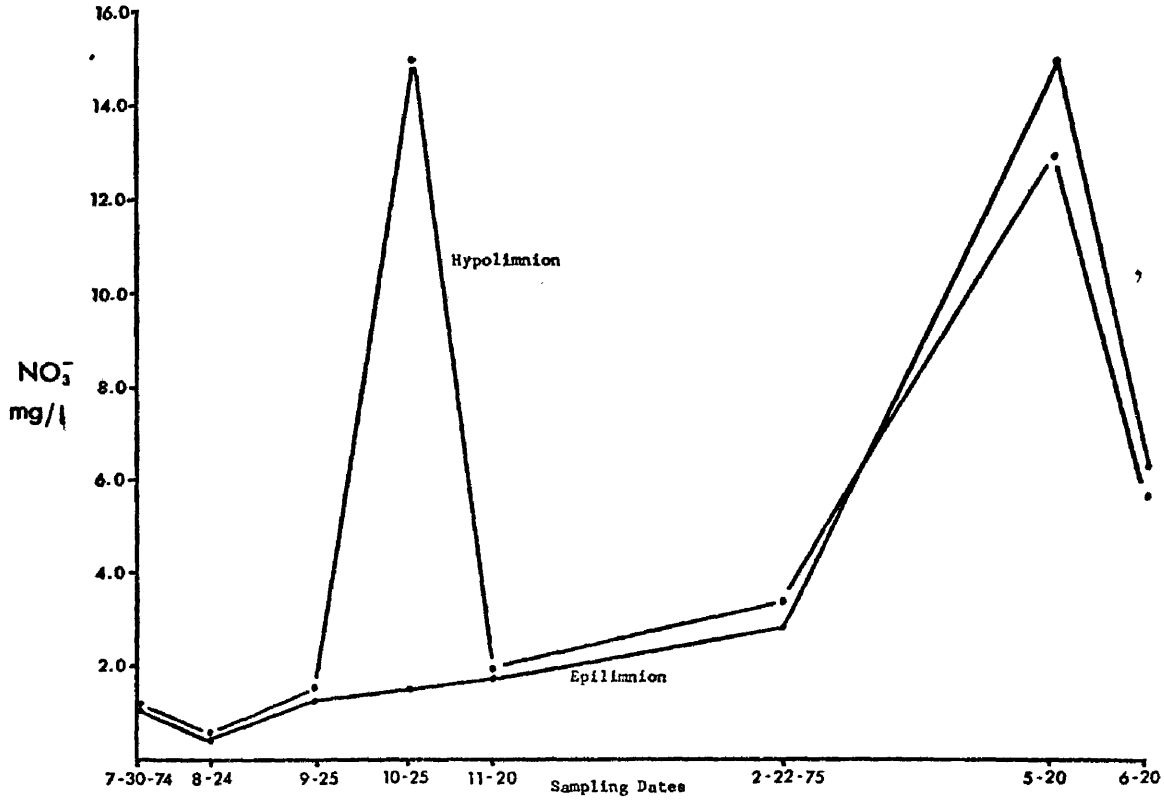

Figure 15. Nitrate-nitrogen concentrations in Deer Lake

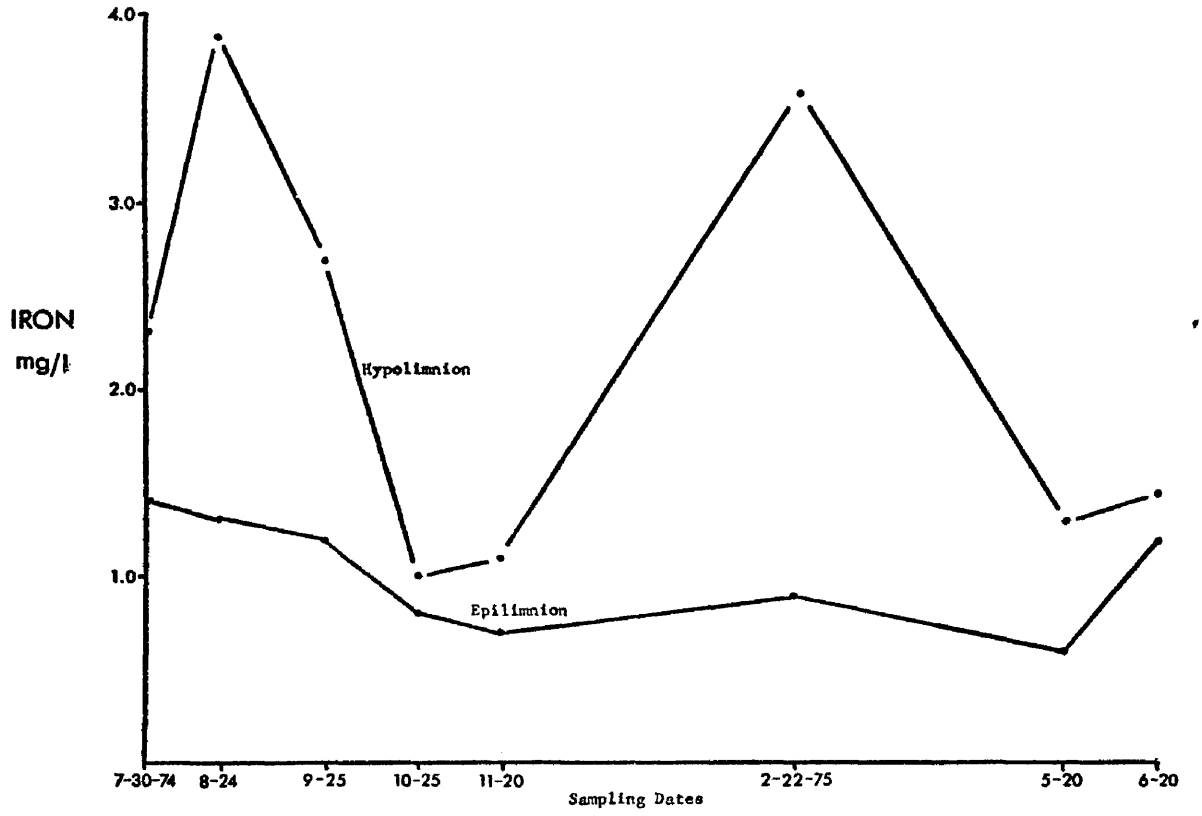

Figure 16. Total iron concentrations of Deer Lake

Plankton Analysis

Vertical Haul Plankton

The tabulations of the vertical haul plankton for Deer Lake are presented in Appendix 8.

The vertical haul zooplankton consisted of protozoans (Ceratium spp. and Difflugia spp.) and rotifers (Keratella spp. and Kellicottia spp.). The protozoans (primarily Ceratium spp.) numbered in the thousands per liter during the months of July through October and were the predominant vertical haul plankters during summer stagnation in 1974. The rotifer populations were always at a low level.

The vertical haul phytoplankton contained coccoid blue green algae, filamentous blue green algae, coccoid green algae, filamentous green algae, green flagellates, centric diatoms and pennate diatoms. The phytoplankton reached abundance maxima at the beginning of summer stagnation in both 1974 and 1975. Their number fell slightly during summer stagnation in 1974, remained high through the autumnal circulation, and declined to a minimum during winter stagnation. The various groups of phytoplankton that made up the total showed dramatic variation in numbers throughout the sampling period.

The coccoid blue green algae comprised a minor percent of the total phytoplankton present at the beginning of summer stagnation in both 1974 and 1975 (Figure 17) even though their number was high (Figure 18). During summer stagnation they were the predominant group with their numbers reaching a maximum on 9-25-74. At the autumnal circulation they dropped in number and comprised a minor percent of the total. Their number reached a minimum during winter stagnation even though they were the most numerous group.

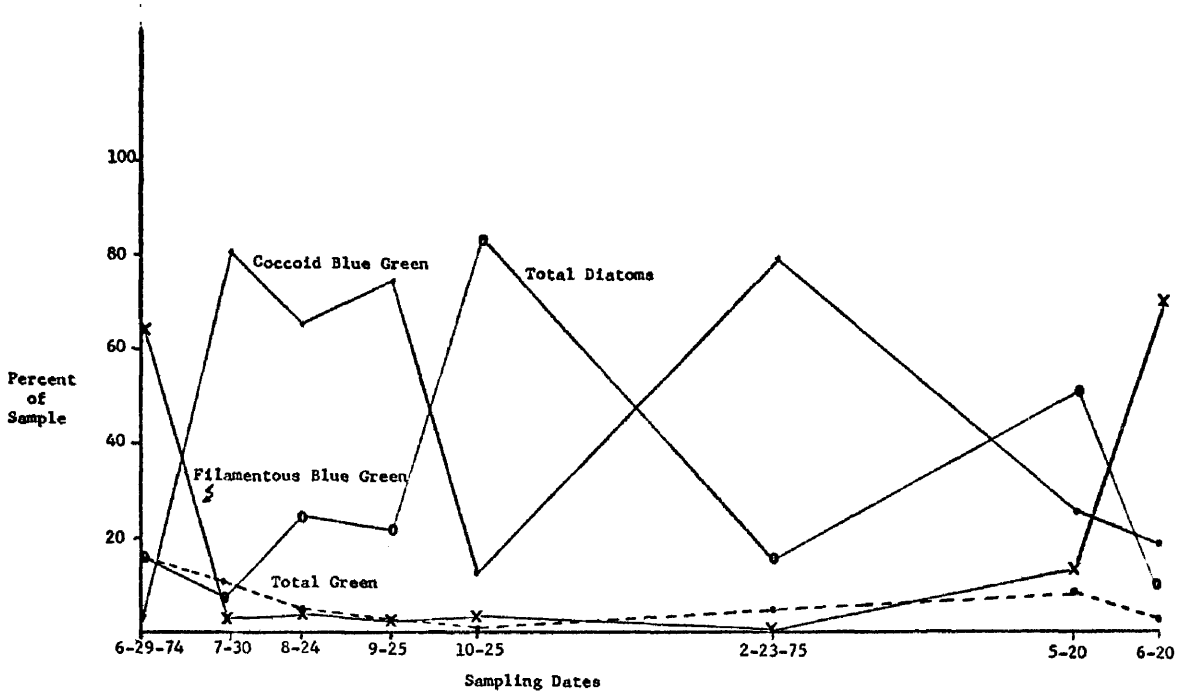

Figure 17. Percent of various phytoplankton groups of total phytoplankton in Deer Lake

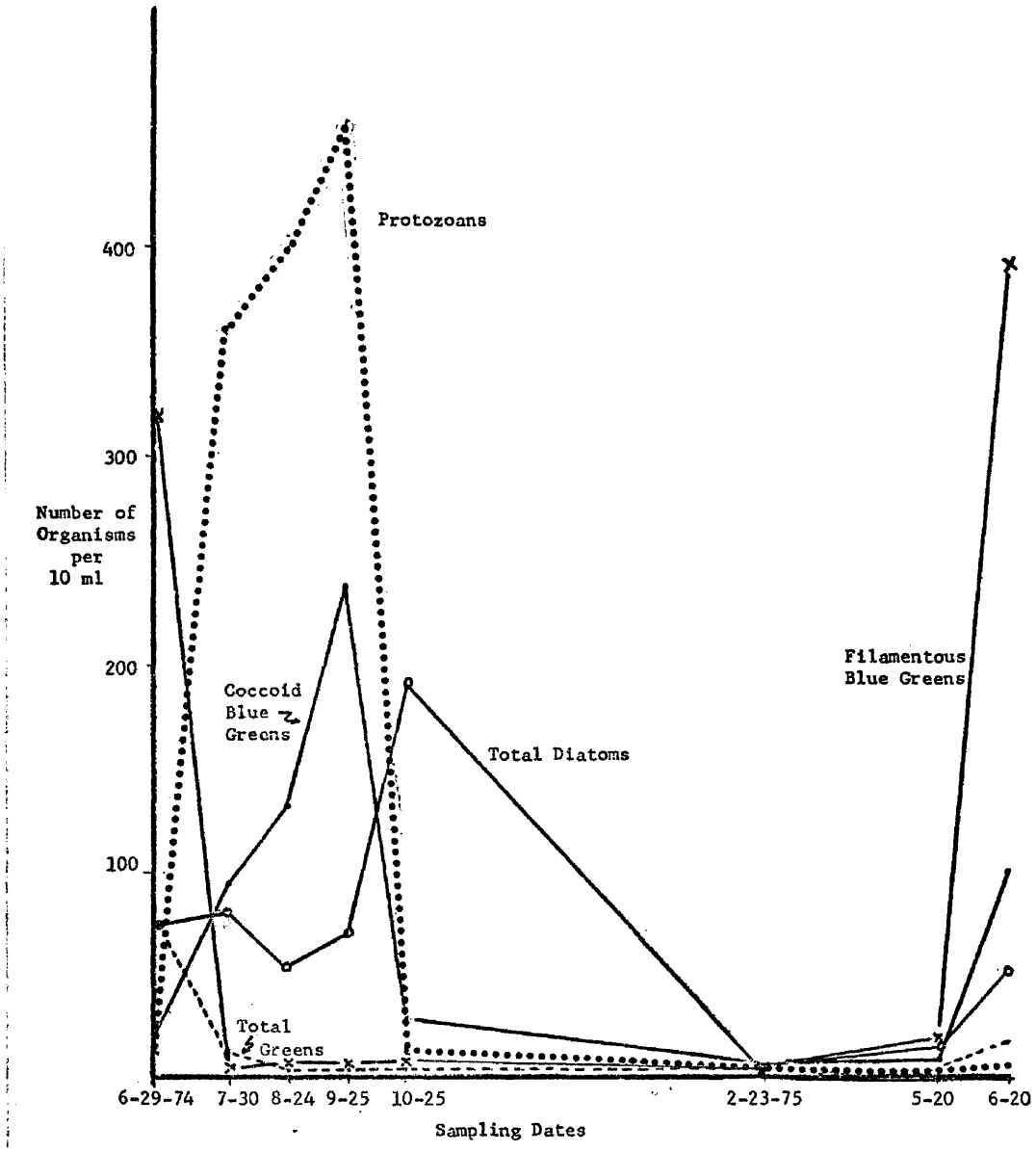

Figure 18. Abundance of various phytoplankton in South Basin of Deer Lake

The filamentous blue green algae attained maxima at the beginning of summer stagnation in both 1974 and 1975 when they were the predominant phytoplankton (Figures 17 and 18). During summer stagnation the population was low and comprised a minor percent of the total phytoplankton present. They were not found during the period of winter stagnation. The coccoid green, filamentous green, and green flagellated algae were always less abundant than the blue green algae populations and always comprised a minor percent of the total phytoplankton.

The diatoms were most abundant during autumnal circulation when they were the predominant group. They were also the predominant group immediately after vernal circulation. The centric diatoms (primarily Stephanodiscus spp.) were always more abundant than the pennate diatoms. Pennate diatoms never comprised more than 26% of the total diatoms present on a sampling date.

Clarke-Bumpus Zooplankton

The zooplankton collected with the Clarke-Bumpus plankton sampler were cladocerans (mainly Daphnia spp.), cyclopoidea copepods, calanoidea copepods and dipterans belonging to the genus Chaoborus. The cladocerans and copepods showed peak abundances in both the epilimnion and hypolimnion during summer stagnation with greater numbers occurring in the epilimnion (Table 2). In the epilimnion during summer stagnation the cladoceran populations were large and predominated. Very few zooplankters were present after vernal circulation in May, 1975. However, by late June their numbers increased to a level similar to that found in 1974.

TABLE 2. Densities (Number/1) of Zooplankters in South Basin of Deer Lake based on Clarke-Bumpus sampling

Organism	6-29-74	7-30-74	8-24-74	9-25-74	10-25-74	5-20-75	6-20-75
Epilimnion, 0 to 6 meters Composite							
Cladocera	346.0	389.4	220.0	54.8	31.7	0.03	243.0
Cyclopoidea	7.8	21.3	18.3	16.9	10.0	____	6.5
Calanoidea	____	18.7	12.4	14.5	8.2	____	2.1
Nauplii	____	____	____	____	____	0.03	____
Hypolimnion, 1 meter above Bottom							
Cladocera	6.7	24.1	18.4	16.8	8.2	____	5.3
Cyclopoidea	1.1	5.2	1.7	0.6	1.0	____	2.1
Calanoidea	____	3.4	2.3	0.6	1.0	____	1.0
Diptera (Chaoborus)	____	1.1	____	0.1	0.2	0.3	0.2

Lake Gribben and Section 2 Pond

Morphometry

Figure 19 is an aerial view, looking northwest, of Lake Gribben in May, 1974. The seepage outlet is in the lower right portion of the lake. Aquatic macrophytes that reach the surface are visible in the foreground and in the western part of the lake. The geology of the watershed is similar to that of Deer Lake except that in addition to bedrock and glacial till, swamp deposits adjacent to the west side of the lake make up a part of the watershed. Swamp deposits consist of decayed or decaying organic matter (peat and muck) mixed in places with silt and fine sand.

Figure 20 is an aerial view looking northwest of Section 2 Pond in May, 1974. The seepage outlet to the left is hindered by a beaver dam. The Sphagnum bog is visible to the right of the pond. Lake Gribben is visible at the top of the photograph. A cedar and tamarack swamp, with Sphagnum covering the ground, extends to Lake Gribben. The geology of the watershed is similar to Lake Gribben except that swamp deposits make up a greater proportion of the watershed area.

Watershed maps of Lake Gribben and Section 2 Pond are presented in Figures 5 (p.11) and 6 (p.12), respectively. The morphometric data for Lake Gribben and Section 2 Pond are summarized in Appendix 10.

Temperature

The temperature profiles for Lake Gribben (Figure 21) show that summer thermal stratification does not occur. During the ice free seasons the water circulates completely on windy days. Stagnation conditions become established during the ice cover period.

Figure 19. Aerial view of Lake Gribben looking northwest

Figure 20. Aerial view of Section 2 Pond looking northwest. Lake Gribben is at the top of the photograph.

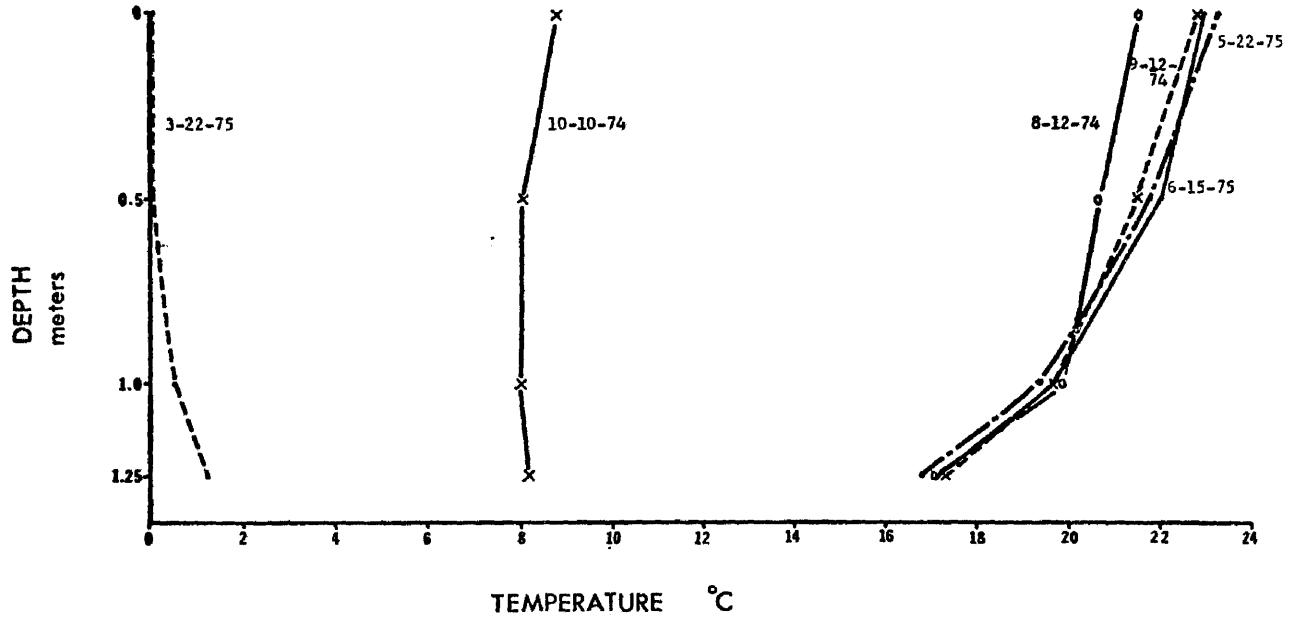

Figure 21. Thermal profiles of Lake Gribben

Accordingly, Lake Gribben is a 3rd order temperate lake (Welch, 1952 p.62). The annual heat budget was calculated to be 2000 cal/cm^2.

The temperature profiles for Section 2 Pond (Figure 22) show that a steep thermal gradient occurs during the warm period of the year. Steep thermal gradients were present on 7-12-74, 8-11-74, 5-11-75 and 6-15-75 with temperature differences between the surface and the bottom for those dates being 11.5, 13.8, 12.9 and 8.5 ^{o}C respectively. During winter the temperature is reduced to nearly $0^{o}C$ throughout the water column. The annual heat budget was calculated to be 1500 cal/cm^2.

Dissolved Oxygen

Figure 23 illustrates the dissolved oxygen concentration for the six dates that Lake Gribben was sampled. Lake Gribben exhibited an approximately orthograde oxygen curve for all the dates sampled except 3-22-75. During winter stagnation a high oxygen demand probably was created at the sediment-water interface causing a depletion of oxygen near the bottom.

Figure 24 illustrates the dissolved oxygen concentration on the six dates Section 2 Pond was sampled. Generally the Section 2 Pond had an orthograde oxygen profile for all dates except on 7-12-74. On that date there was an absence of oxygen at 1 meter.

Hydrogen Ion Concentration (pH)

The hydrogen ion concentration in Lake Gribben varied little throughout the year with a low pH of 6.0 on 10-10-74 and a high of 7.0 on 5-22-75 (Figure 25).

The water of Section 2 Pond was acidic, ranging in pH from 3.9 on 10-10-74 to 5.7 on 3-23-75.

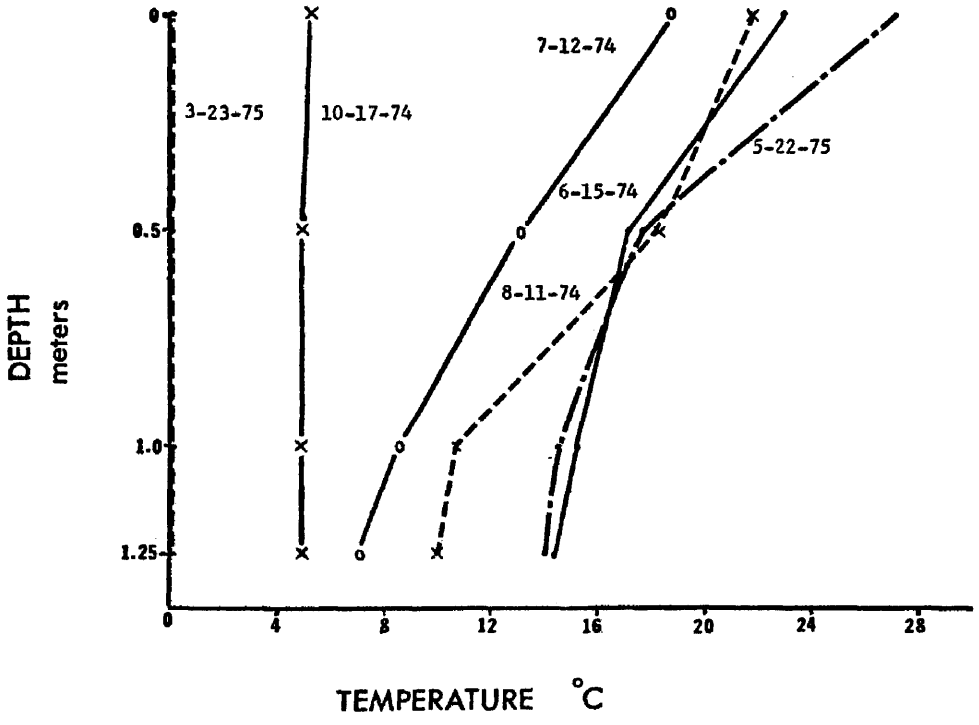

Figure 22. Thermal profiles of Section 2 Pond

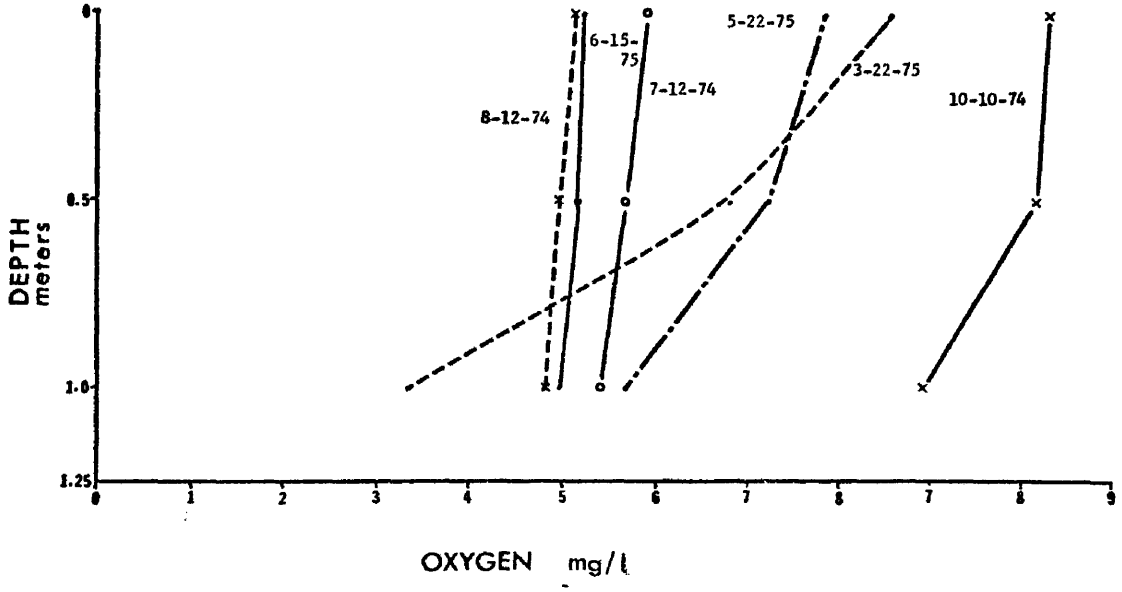

Figure 23. Dissolved oxygen profiles of Lake Gribben

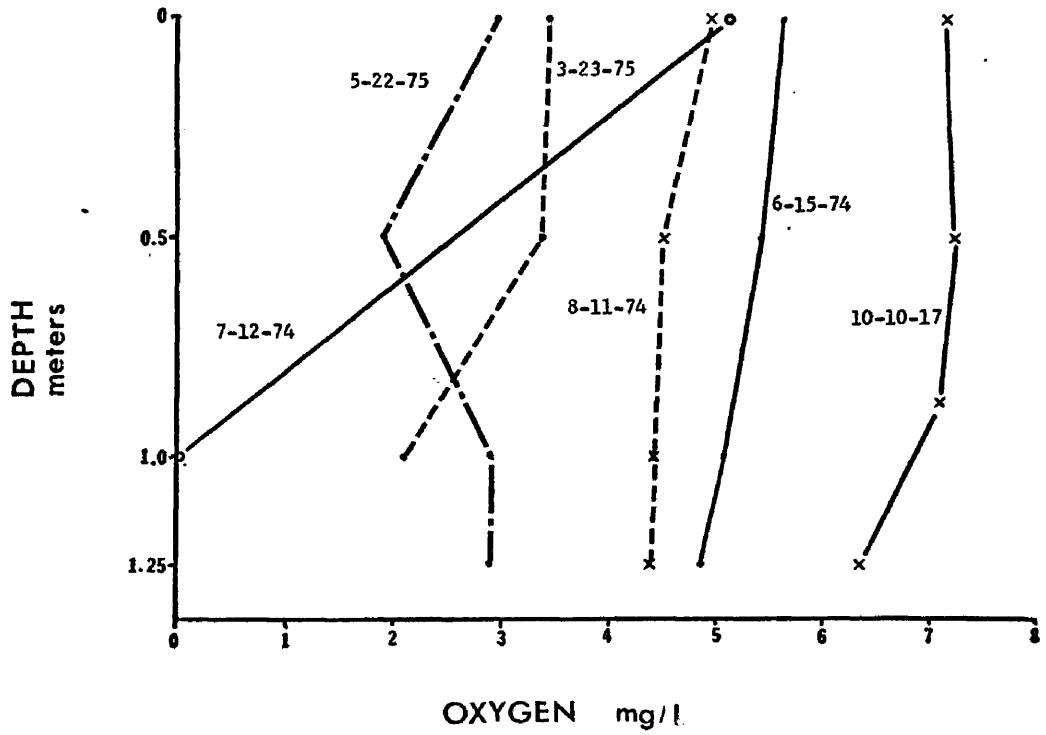

Figure 24. Dissolved oxygen profiles of Section 2 Pond

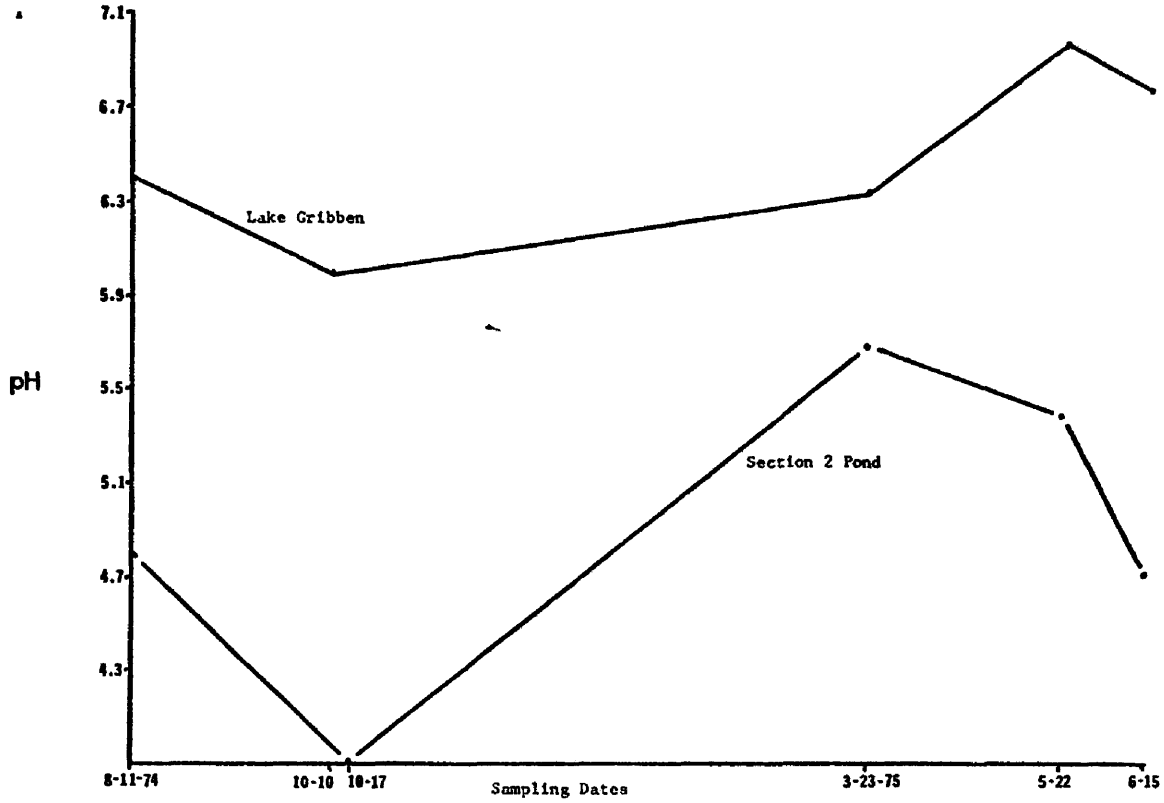

Figure 25. pH of Lake Gribben and Section 2 Pond

Specific Conductance and Salinity

Specific conductance data for Lake Gribben and Section 2 Pond are presented in Appendix 13. The conductivity of both bodies of water (Figure 26) was nearly constant and similar throughout the period of sampling, except during the winter when there was a sharp rise in conductivity.

Salinities calculated from the specific conductance values are presented in Appendix 13. The salinities varied between 23 and 45 mg/l in Lake Gribben and between 20 and 50 mg/l in Section 2 Pond.

Alkalinity

Total alkalinity and phenolphthalein alkalinity data for Lake Gribben and Section 2 Pond are presented in Appendix 13.

There was no phenolphthalein alkalinity found in Lake Gribben or Section 2 Pond. Figure 27 illustrates the values obtained for total alkalinity in both bodies of water during the sampling period.

Carbon Forms

Values calculated for the carbonic species and total inorganic carbon from the total alkalinity and pH are presented in Appendix 14.

Table 3 gives the ranges of concentration for HCO_3^-, $CO_3^=$, $CO_2(aq)$, total carbonic species and total inorganic carbon in Lake Gribben and Section 2 Pond during the sampling period.

Non-Filterable Residue and Total Residue

The fluctuations of non-filterable residue for Lake Gribben and Section 2 Pond are displayed in Figure 28. The non-filterable residue

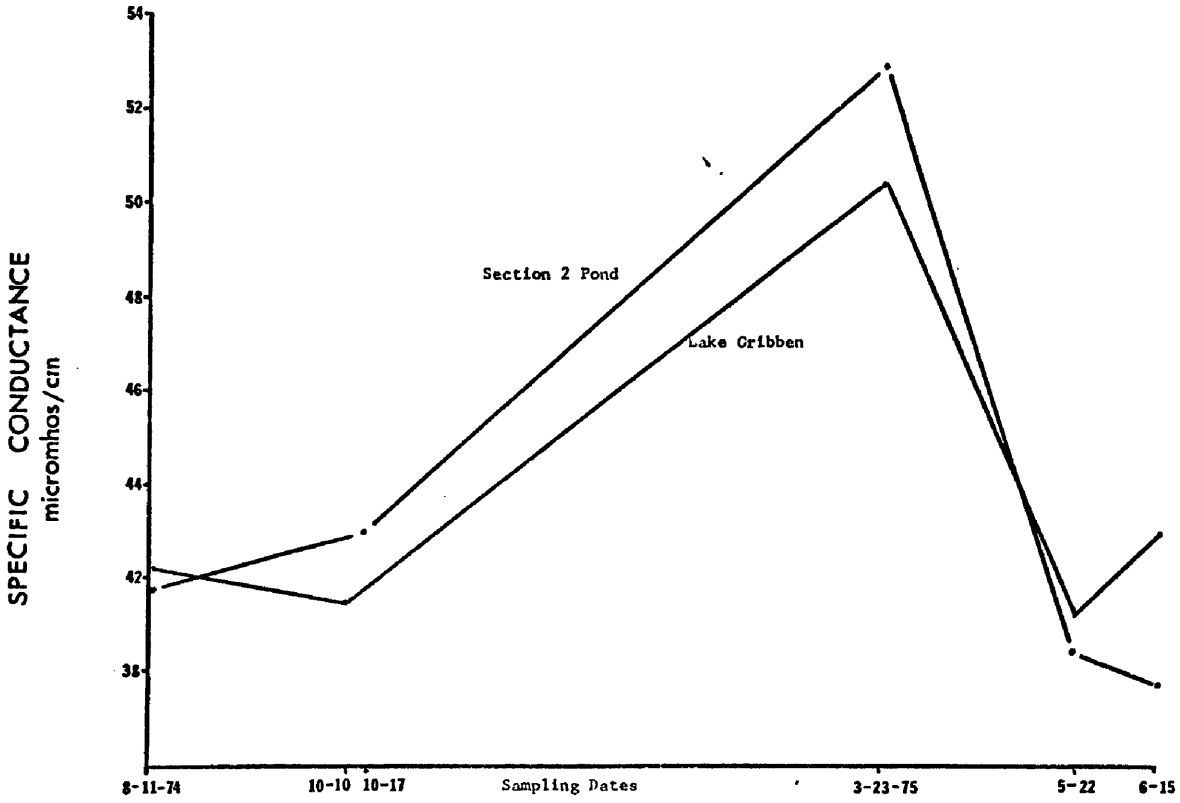

Figure 28. Specific conductance of Lake Gribben and Section 2 Pond

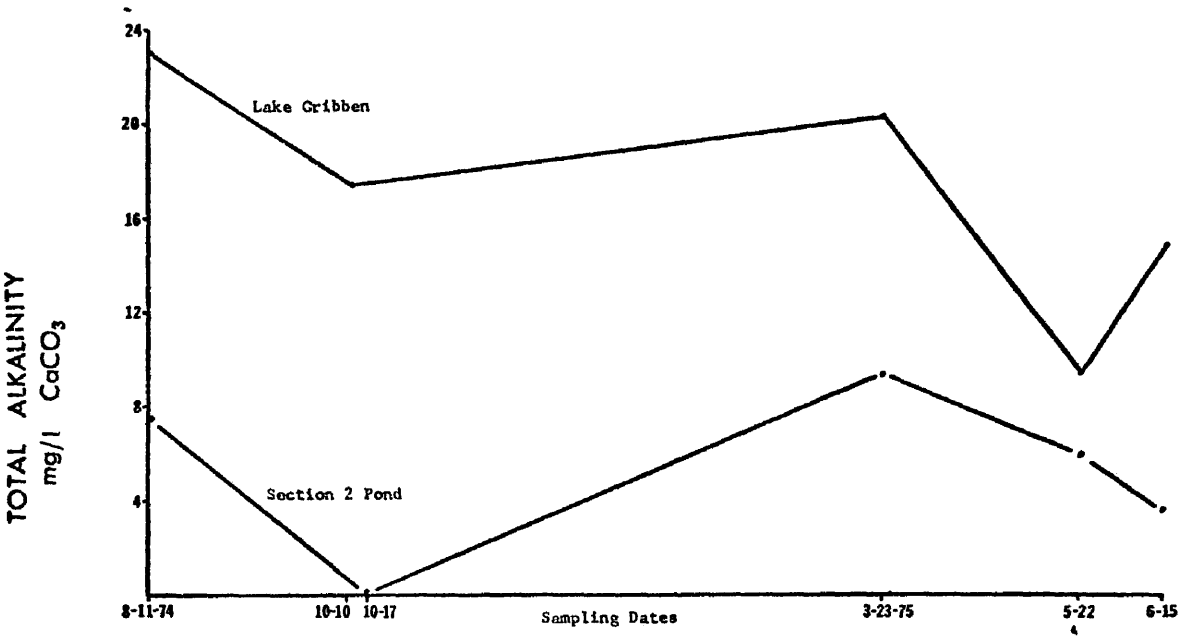

Figure 27. Total Alkalinity of Lake Gribben and Section 2 Pond

TABLE 3. Ranges of Carbonic Species in Lake Gribben and Section 2 Pond

	Epilimnion		Hypolimnion	
	Low	High	Low	High
HCO_3^- (moles/l)	1.90×10^{-4}	4.60×10^{-4}	8.91×10^{-5}	1.92×10^{-4}
$CO_3^=$ "	1.83×10^{-8}	6.01×10^{-7}	5.21×10^{-10}	1.65×10^{-8}
CO_2(aq.) "	4.19×10^{-5}	7.58×10^{-4}	8.10×10^{-4}	3.43×10^{-2}
C_t "	2.32×10^{-4}	11.09×10^{-4}	1.00×10^{-3}	3.44×10^{-2}
Total Inorganic Carbon (mg/l)	2.8	13.3	12.0	412.8

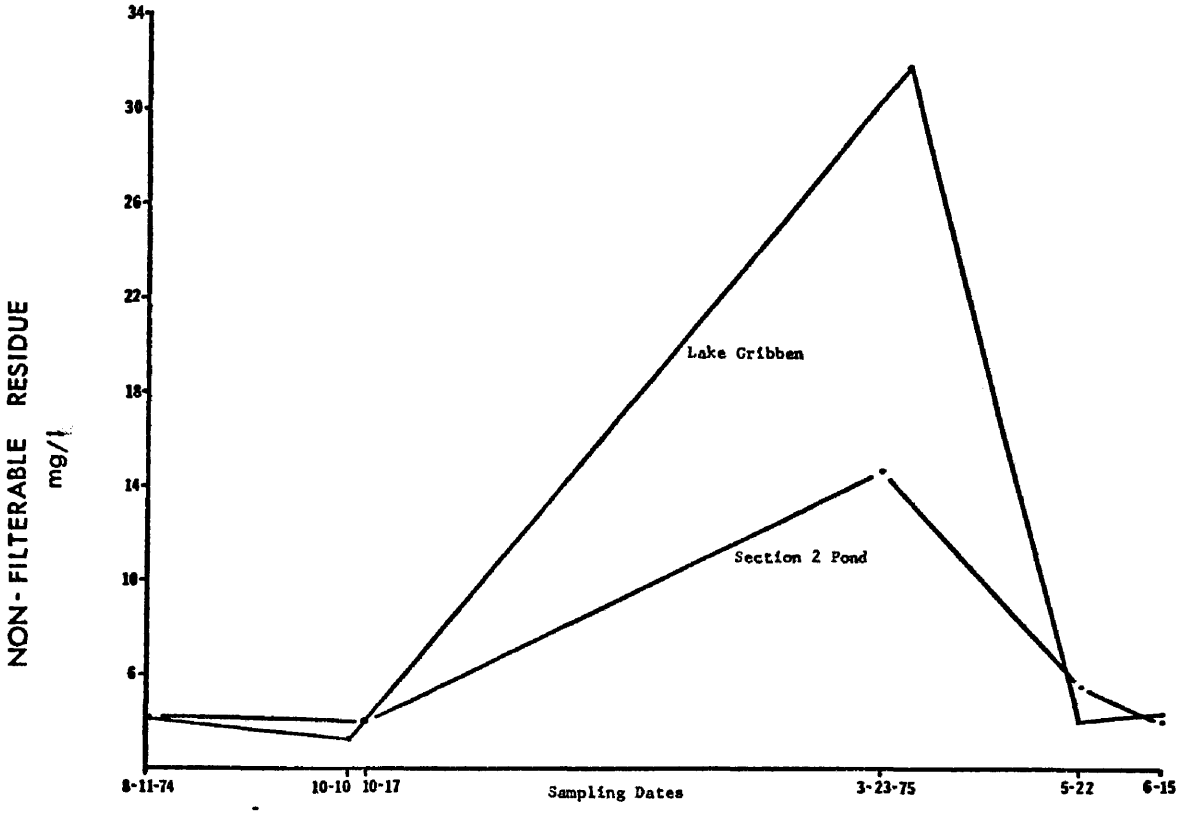

Figure 28. Non-filterable residue of Lake Gribben and Section 2 Pond

concentrations were similar and relatively low (from 3.2 to 5.6 mg/1) in both bodies of water except for the determination made during the ice cover period when 32 mg/1 was found in Lake Gribben.

The estimates of total residue for the various sampling dates are presented in Appendix 13. Total residue ranged between 29.4 mg/1 and 77.0 mg/1 for Lake Gribben and between 24.0 mg/1 and 54.8 mg/1 for Section 2 Pond.

Phosphorus

The data obtained for the forms of phosphorus in Lake Gribben and Section 2 Pond are presented in Appendix 15. The total phosphorus concentrations of most uncontaminated surface waters are between 10 to 50 µg/1 (Wetzel, 1975 p.217). Both bodies of water fall within this range (Figures 29 and 30). Section 2 Pond generally had higher levels of total phosphorus than Lake Gribben.

Nitrate-Nitrogen

The data for nitrate-nitrogen for Lake Gribben and Section 2 Pond are presented in Appendix 15. Lake Gribben had 2 to 3 mg NO_3-N/1 throughout the sampling period except for a concentration of 7.5 mg NO_3-N/1 after the spring break-up of ice in 1975 (Figure 31).

Section 2 Pond had less than 1 mg NO_3-N/1 on 8-11-74 and 10-17-74. Beneath the ice on 3-23-75 nitrate-nitrogen concentration was 8.1 mg NO_3-N/1. Values determined after the pond became ice-free in 1975 were lower and declining although not as low as the 1974 levels.

Iron

Iron concentrations for Lake Gribben and Section 2 Pond are

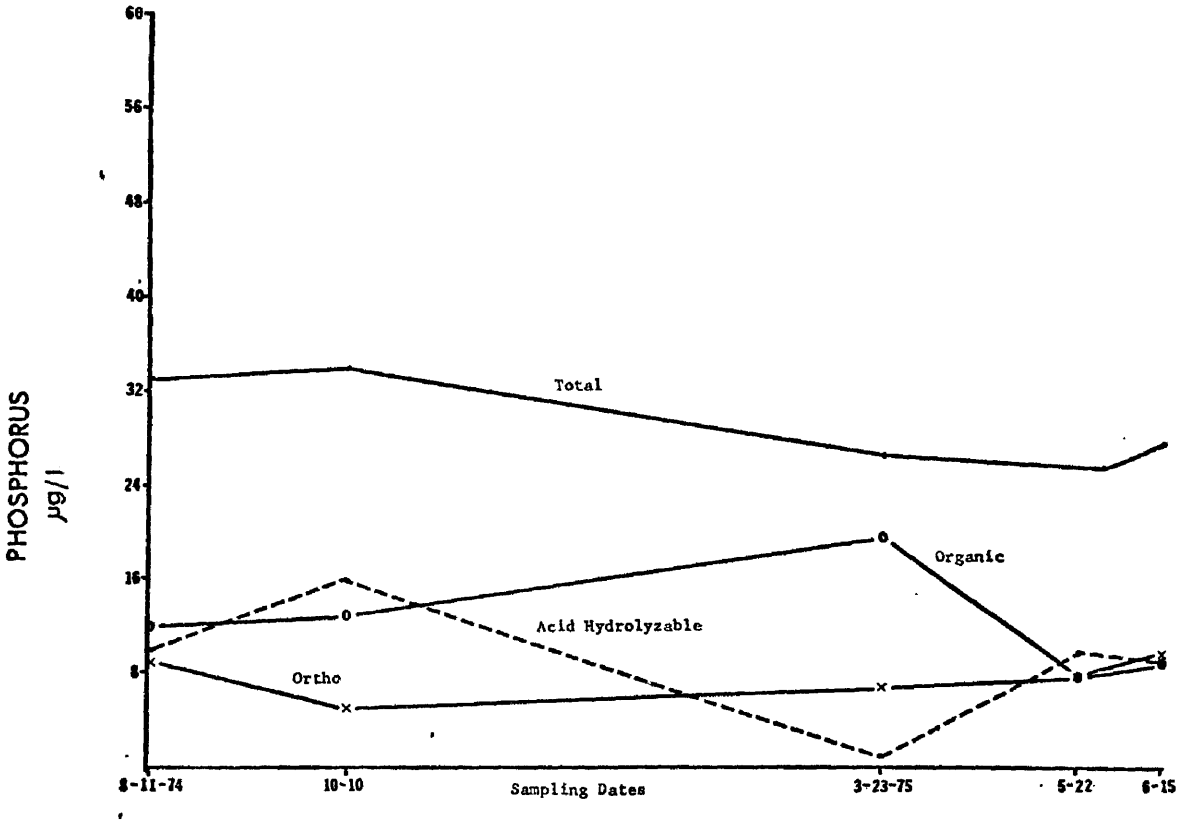

Figure 29. Forms of Phosphorus in Lake Gribben

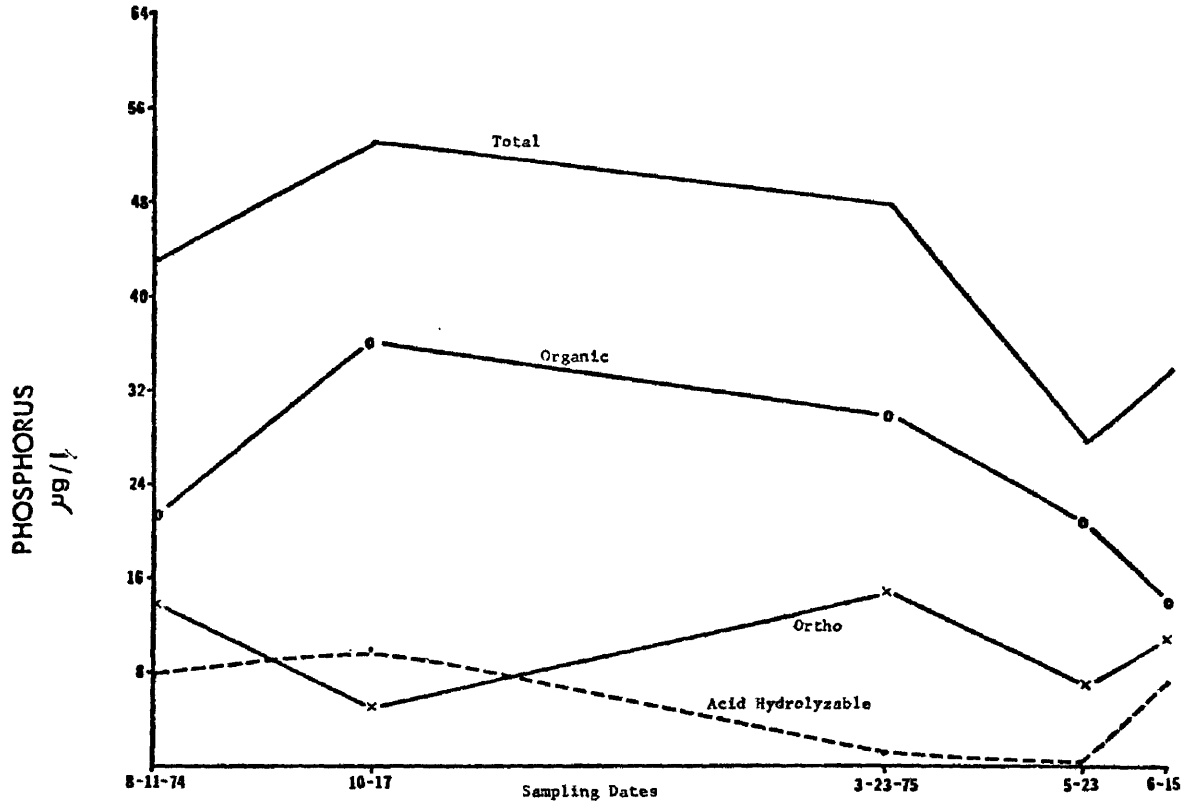

Figure 30. Forms of Phosphorus in Section 2 Pond

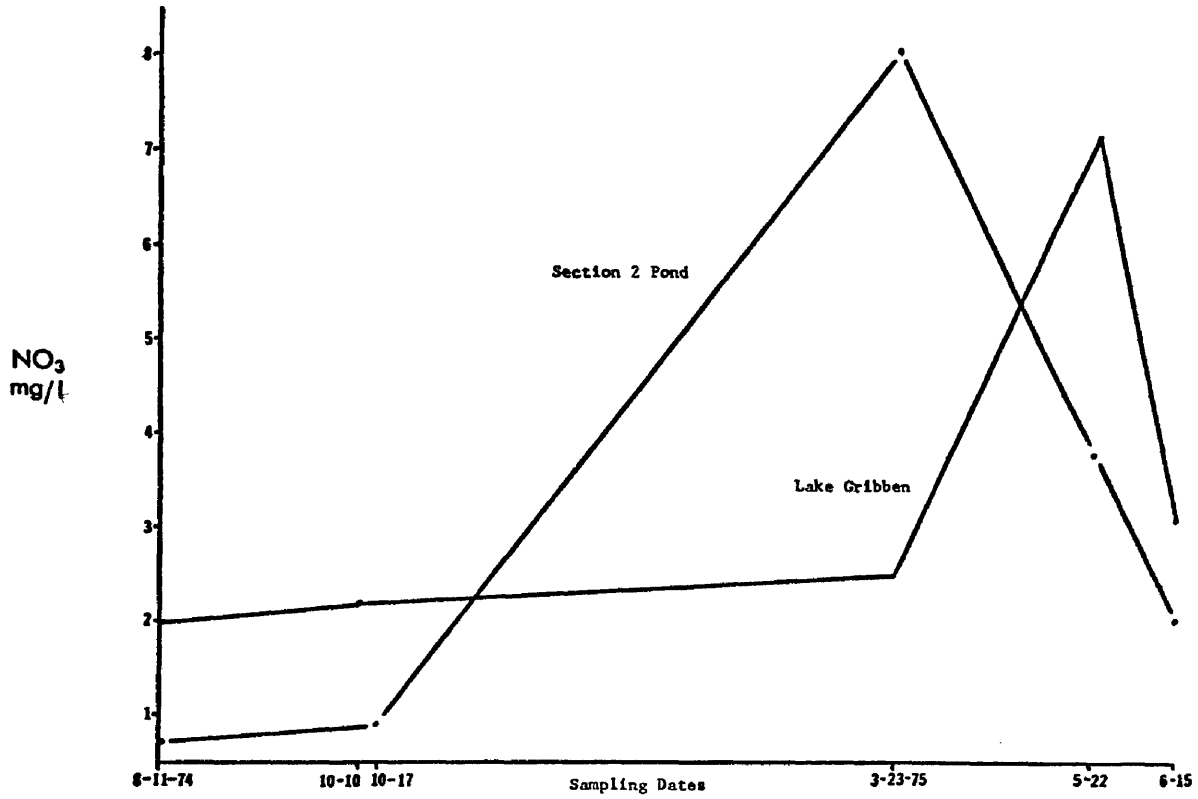

Figure 31. Nitrate-nitrogen in Lake Gribben and Section 2 Pond

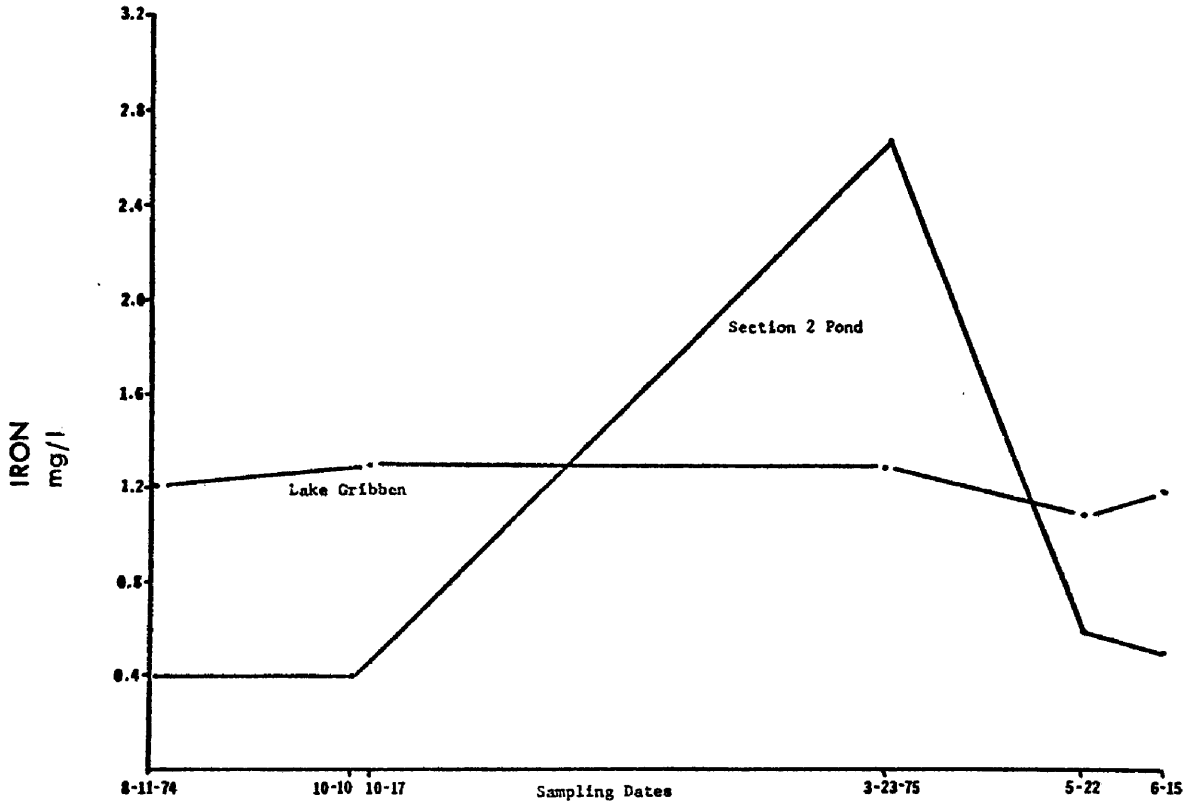

Figure 32. Total iron in Lake Gribben and Section 2 Pond

presented in Figure 32 and Appendix 13.

Lake Gribben had an iron concentration of approximately 0.4 mg/l except for the sampling made through the ice when iron measured 2.7 mg/l. The iron concentration of Section 2 Pond was relatively constant at about 1.2 mg/l during the study period.

Plankton

Lake Gribben

The percentages of the various groups of plankters collected in Lake Gribben are presented in Appendix 16.

The phytoplankton consisted of coccoid blue green algae (Microcystis spp.), filamentous blue green algae (Anabaena spp. and Oscillatoria spp.), coccoid green algae (Pediastrum spp.), filamentous green algae (Spirogyra spp.), green flagellates (Eudorina spp. and Pandorina spp.), centric diatoms (Stephanodiscus spp. and Melosira spp.), and pennate diatoms (Fragilaria spp. and Asterionella spp.).

During the summer of 1974 and the spring of 1975, diatoms were the most abundant (Figure 33). In the autumn of 1974 blue green algae predominated. Because the net had to be towed for 1 to 2 minutes in order to collect enough organisms to count, the phytoplankton density was considered sparse.

The zooplankton consisted of dinoflagellates (Ceratium spp.), rotifers (Kellicottia spp., Keratella spp. and Polyarthra spp.), sarcodinans (Difflugia spp.), Daphnia spp., and nauplii. Dinoflagellates and rotifers were the dominate zooplankton during the sampling period. Zooplankton always comprised a minor percent of the total plankton collected except on 10-10-74 when rotifers made up 32.6% of the sample.

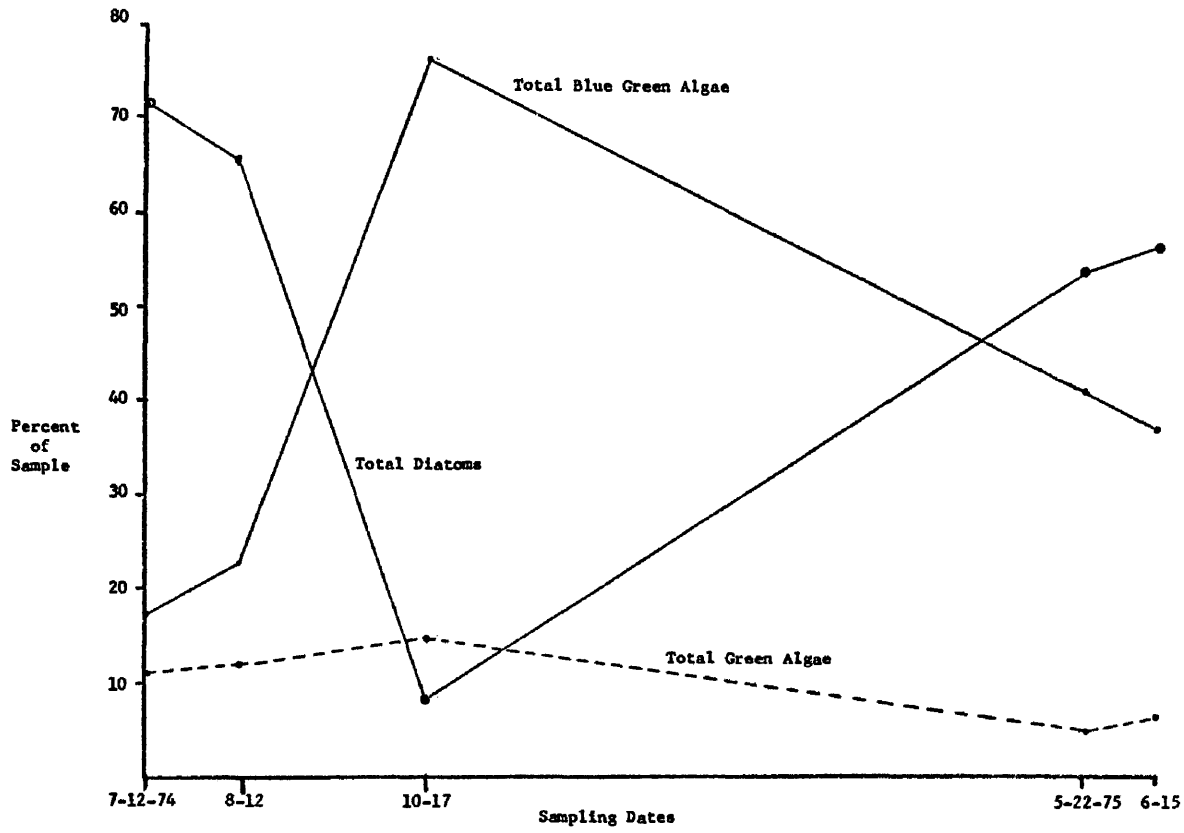

Figure 33. Percent of various phytoplankton groups of total phytoplankton in Lake Gribben

Section 2 Pond

The percent of the various plankters found in Section 2 Pond are presented in Appendix 17.

The phytoplankton collected consisted of coccoid blue green algae (Microcystis spp.), filamentous blue green algae (Anabaena spp.), coccoid green algae (Pediastrum spp.), filamentous green algae (Spirogyra spp.), green flagellates (Pandorina spp.), centric diatoms (Stephanodiscus spp. and Cyclotella spp.) and pennate diatoms (Tabellaria spp., Fragilaria spp. and Asterionella spp.). During the course of the study diatoms predominated (between 64.4% and 68.2% of the phytoplankton) except on 7-12-74 when they constituted 29.7% of the sample (Figure 34). On that date blue green algae predominated with 31.9% and 23.9% consisting of filamentous blue green and coccoid blue green algae, respectively.

The zooplankton collected consisted of dinoflagellates (Ceratium spp.), sarcodinians (Difflugia spp.), rotifers (Kellicottia spp., Keratella spp. and Polyarthra spp.), cyclopoidea copepods (Cyclops spp.), nauplii and Daphnia spp. The zooplankton comprised a minor percent of the total plankton except on 7-12-74 when the dinoflagellates were the most numerous plankton present, representing 58.2% of the sample.

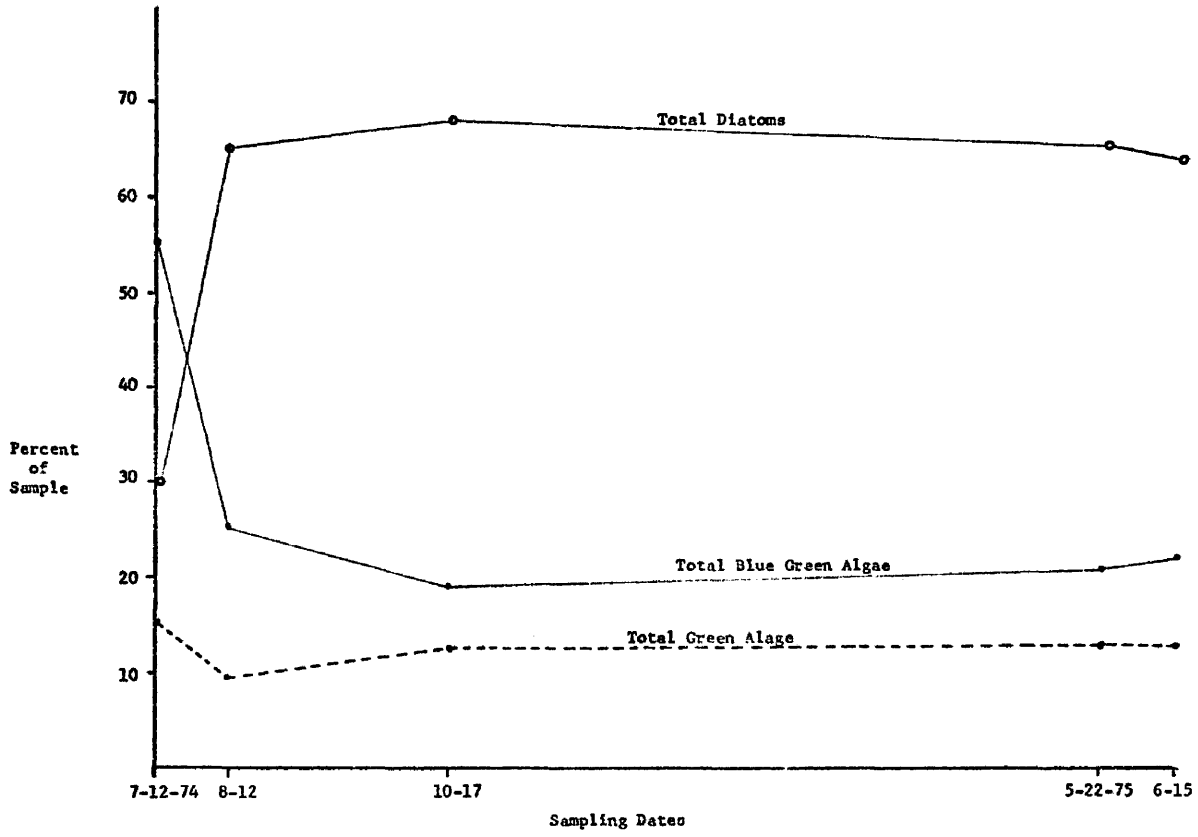

Figure 34. Percent of various phytoplankton groups of total phytoplankton in Section 2 Pond

DISCUSSION

Deer Lake

The seasonal changes in temperature are dominant regulators of nearly all physicochemical cycling and consequently of lake metabolism and productivity (Wetzel, 1977 p. 83). As spring progressed in 1974 the surface water was heated and a vertical thermal gradient was formed which could not be disrupted by the existing winds and allow further mixing of the entire water column. As the surface water became less dense greater thermal resistance to mixing was realized to the point where only the upper water was circulating and thermal stratification occurred. During stratification in the very productive water of Deer Lake, consumption of dissolved oxygen by catabolic processes exceeded agumentation by photosynthesis and led to total anoxia in the hypolimnion. With the approach of autumn and declining air temperatures the loss of heat from the water exceeded solar input. The surface water cooled and became more dense, thus causing a breakdown of thermal stratification. The upper water mixed with the lower water by a combination of convection currents and wind induced epilimnetic circulation. The column of water had become isothermal by 9-25-74 and the water circulated from the surface to the bottom. The circulating water brought oxygen into the lower water and instituted a uniform character to all the strata of water.

Declining air temperatures in early winter lowered the temperature of the surface water until ice formed. The ice cover sealed off the effects of the wind which led to winter stagnation. As the snow cover on the ice deepened, solar radiation entering the lake was decreased and oxygen produced by photosynthesis was reduced. Catabolic metabolism caused the lake to become anoxic below 5 meters

by 2-23-75.

When the ice cover deteriorated in the spring there was little thermal resistance to mixing by the wind. Consequently the lake water circulated again shortly after the ice melted. Oxygen was introduced into all depths of water and a uniform character of all strata of water was again realized.

The difference in pH between the hypolimnion and the epilimnion during the stagnation periods is probably determined by the utilization of CO_2 in the trophogenic zone, the liberation of CO_2 in the tropholytic zone, and by the buffer capacities of solution bases as the CO_2 accumulates. Where geochemical buffer capacities of solutions are limited, as they are to some extent in Deer Lake, water will be poorly buffered and a quantity of CO_2 liberated into the hypolimnetic water will produce a lowering of the pH (Hutchinson, 1957 p.685).

The range of pH indicates that Deer Lake is regulated by the CO_2-HCO_3-CO_3 system of buffering and is therefore of the "bicarbonate type" (Wetzel, 1975 p.174).

The reasons for the higher specific conductance and salinity values during the stagnation periods are complex and not well understood. There is generally a positive correlation between conductance and pH. However, the expected relationship between conductance and pH does not exist for Deer Lake. This is probably because of the high amount of organic matter present (Strøm, 1947). In many lakes chemical reactions in the sediment appear to contribute to the rise and fall of the conductivity and salinity. Mortimer (1942) found a considerable increase in the conductivity and in the concentration of solutes in the water over the mud after the mud surface had been reduced. He suggested that the increase resulted from reduction of

absorbing ferric complexes in the mud surface. The converse explanation may apply to the general fall in conductivity and salinity at the overturns. It cannot be known if this occurs in Deer Lake without knowing the concentrations of ferrous iron in the complex and ionic forms. Groundwater inflow into the basin could also have had an effect upon the conductivity and salinity. Crumrine and Beeton (1975) found in the lakes in the Sylvania Recreation Area, Ottawa National Forest, that conductivities decreased during spring runoff and later increased in summer when groundwater inputs were proportionally greater. Without data on groundwater influx and flow patterns it is impossible to judge what influence it may have had on conductivity and salinity.

The larger concentration of total inorganic carbon in the hypolimnion during the stagnation periods is probably from decomposition and bacterial production of ammonium bicarbonate in the sediments (Ohle, 1952) and bicarbonates released from $FeCO_3$ and $MnCO_3$ in the sediments (Wetzel, 1975 p176).

The higher non-filterable residues found during the stagnation periods are most likely a result of the "rain" of dead plankton and detritus from the epilimnion to the hypolimnion.

The marked increase in total phosphorus and iron in the hypolimnion during the stagnation periods is probably due to the high biological production in the lake and high organic pollution which contribute to the lowering of the dissolved oxygen to near zero at the sediment interface. This caused a reduction in the redox potential in the upper few millimeters of sediment. Under these conditions there is a release of ferrous iron and substantial quantities of phosphate previously held in complex form (Mortimer, 1971).

The decrease of total phosphorus and iron in the hypolimnion

during the autumnal and vernal circulation periods might be traced to the introduction of oxygen. This caused an increase in the redox potential of the water which allowed the ferrous iron compounds to form ferric precipitates including ferric phosphate, thus producing a decrease in both total phosphorus and iron. The decrease of total phosphorus during the autumnal circulation period may also be a consequence to some extent of dilution with the overlying epilimnial waters.

In most natural waters the orthophosphate is usually a low percentage, about 10%, of the total phosphorus (Wetzel, 1975 p.218). However in Deer Lake the percentage of orthophosphate ranged between 46% and 82%. This indicates that phosphorus probably is not a limiting nutrient for the growth of phytoplankton. The source of these high concentrations of phosphorus is most likely the effluents from the sewage treatment plants on Carp Creek.

The total iron concentrations found in the epilimnial waters were higher than the typical range of total iron found in oxygenated surface waters of pH 5 to 8. These higher concentrations are probably due to the input of organic matter from the sewage treatment plants. Organic matter can combine with iron to form soluble iron complexes (Singer, 1973).

During summer stagnation and the subsequent oxygen deficiency of the hypolimnion, nitrification stops and denitrification takes place, thereby causing the nitrate-nitrogen concentration to become depressed. The nitrate-nitrogen concentration in the epilimnion during summer stagnation is also low, presumably due to assimilation by phytoplankton.

The water in the hypolimnion had become oxygenated with the beginning of autumnal circulation by 9-25-74. This allowed nitrification to occur and, with the breakdown of stratification, an increase in

nitrate-nitrogen was also realized in the epilimnion.

It is probable that on 9-25-74 there was still a microzone of unoxygenated water at the sediment interface which had not yet allowed ammonia in the sediments to become nitrified. Mortimer (1941) found that there was a lag time between when oxygen was introduced into the hypolimnion and when the sediments were oxygenated. This would allow only water above the sediments to become nitrified.

On 10-25-74 it is possible that the microzone of unoxygenated water had dissipated shortly before the sample was taken and the newly nitrified nitrogen had not had time to mix with the upper water. This might be the reason for the unusually high concentration of nitrate-nitrogen in the hypolimnion on that date.

It should be recognized that the volume of water around the sampling point that comprised the hypolimnion was less than 1% of the whole lake volume. Therefore it is not surprising that the nitrate-nitrogen concentrations in the hypolimnion had dropped on 11-20-74 to a concentration similar to that in the epilimnion.

The higher concentration of nitrate-nitrogen found in both the epilimnion and hypolimnion during winter stagnation is probably tracable to a high input of nitrogenous compounds from the sewage treatment plants and low assimilation by plankton during the winter. However, it is probable that much of the nitrogen input during winter stagnation was denitrified due to the anoxic, or near anoxic, conditions that prevailed.

The oxygenation of the lake during vernal circulation caused nitrification of reduced nitrogenous compounds which had accumulated during winter stagnation. As a result there were high nitrate-nitrogen concentrations.

At various times of the year one group of plankton dominated the other groups in Deer Lake. At different times the blue green algae (Microcystis spp. or Anabena spp.) and the diatoms Stephanodiscus spp. were dominant.

Hutchinson (1967 p.387) described some of the commonly observed characteristic phytoplanktonic algal associations that occur repeatedly in lakes that can be classified according to trophic status. Lakes where plankton is dominated by blooms of Microcystis spp. or Anabena spp. and, at least at certain seasons by others, among them Stephanodiscus spp. are usual in the more highly productive lakes of temperate regions. The data clearly indicate that Deer Lake fits into this category.

Understanding the seasonal succession of plankton appears to be a monumental problem. The chemical complexity of aquatic systems coupled with the effects of light, temperature and the interelationships among the plankters themselves has made study extremely difficult.

The predominantly diatom population at autumnal and vernal circulation in Deer Lake is typical of temperate fresh waters and has been reported by many researchers (Hutchinson, 1967, Chapter 23). Wetzel (1975 p.328) reports that silica concentrations appear to be the major regulatory factor involving diatom populations. So distinct is the correlation between the observed decline of the diatom minimum with regressing silica concentration and experimental results of bioassays that the relationship appears to be predominantly causal. Factors of light intensity, temperature, nitrogen, phosphorus, zooplankton grazing, and fungal parasitism do not appear to be instrumental in the decline. However, much more complex interactions of both physicochemical and biotic factors undoubtedly exist in the seasonal succession of diatom

populations when silica concentrations are not reduced to limiting levels for exponential growth. It is probable that silica is the main regulating factor for diatom populations in Deer Lake, but this is speculative and needs further study to be confirmed.

Several complex interacting variables seem to contribute to the population rise and decline of blue green and green algae during an annual cycle in Deer Lake.

The green algae reach their highest levels in the spring when nitrate-nitrogen concentrations are elevated and temperatures are lower. As summer stagnation progressed the epilimnetic temperature increased, nitrate-nitrogen concentrations dropped, phosphorus was abundant, the pH was alkaline and bicarbonate was the principal source of available carbon. These conditions favor a rise in abundance of blue green algae (Shapiro, 1973). While temperature increase contributes to the rise of blue green algae (Hutchinson, 1967 p.482), it is not the major factor in controlling their population numbers.

If there is heavy loading of phosphorus, blue green algae become dominant as the nitrate-nitrogen concentration is reduced because they have efficient capacities for fixing molecular nitrogen (Moss, 1973). Wastewater from the sewage treatment plants provides the phosphorus loading. Also facilitating their high population density is a high pH and large amount of bicarbonate. Blue green algae are more efficient at using bicarbonate as a source of carbon than green algae which best use carbon dioxide as a source of carbon (Moss, 1973 and Shapiro, 1973).

During the autumnal circulation when temperature, pH, alkalinity and nitrate-nitrogen concentrations are no longer favorable, the population of blue green algae declines. While these conditions would generally be favorable for the green algae, their population declines

also. It is probable that substances liberated by the dead or dying cells of blue green algae and Ceratium inhibit the growth of green algae. These substances appear, at least in part, to be fatty acids or their soaps. At present their role in seasonal succession is uncertain (Hutchinson, 1967 p.488). It appears that these algal antibiotics may exist in Deer Lake and have an effect on the green algae, however, further investigation would be required to confirm or disprove this hypothesis.

During winter stagnation the low temperature and reduced light conditions are most likely responsible for keeping the populations of all species low.

After vernal circulation conditions conducive for growth of all species were present and, as a result, all groups of plankton present had relatively high populations. Filamentous blue greens dominated probably because of the high pH and bicarbonate concentration and low availability of carbon dioxide. Also it has been found that Anabena is algistatic to green algae (Hutchinson, 1967 p.470).

Lake Gribben

During winter stagnation conditions decay occurs in the sediment. This is evidenced by the lowering of the dissolved oxygen concentration at the bottom.

Throughout the year continuous production of ions must have been taking place. However, concentration in the water was little affected, as precipitation and adsorption in the oxidized mud surface had immobilized a large part of these products. During winter stagnation a decrease in the thickness of the oxidized layer probably took place. This would have caused a liberation of adsorbed ions and a corresponding

decrease in capacity of the surface layer to adsorb products of continuous mud processes. The result of these changes in the mud probably produced the higher specific conductance, higher non-filterable residue and higher total iron concentration observed during winter stagnation.

The pH falls within the range of pH 6 to 9 which is characteristic of the majority of most lakes within the area. Lakes of the "bicarbonate type" contain varying amounts of carbonate and are regulated by the CO_2-HCO_3-CO_3 system of buffering capacity (Wetzel, 1975 p.174). Lake Gribben is a lake of this type.

The total phosphorus concentrations showed little variation throughout the sampling period. However, there was a rise in the organic phosphorus during stagnation. The reason for this rise is unclear; possibly it may have been an accumulation of dead algal cells.

The higher nitrate-nitrogen concentration on 5-22-75 is probably a result of churning of the mud after the spring breakup.

Without knowing the concentration of the plankton it is difficult to interpret the plankton data. For example, is the decline in the percent of diatoms in the sample a rise in the percent of blue greens in the sample on 10-17-74 or a result of a higher concentration of blue green algae and the same concentration of diatoms? Or was it a result of the same concentration of blue green algae and a lower concentration of diatoms, or because there was a higher concentration of blue green algae and a lower concentration of diatoms? Interpretation of the physicochemical data to help explain the variation in plankton data produces conflicting conclusions. For example, there is a decline in the percent of blue greens in the sample between 5-22-75 and 6-15-75. However, the change in pH and concentration of

nitrate-nitrogen would favor the growth of blue green algae. Therefore a sound hypothesis cannot be made to explain the planktonic composition.

Section 2 Pond

It is unusual for a body of water as shallow as Section 2 Pond to exhibit a stable summer thermal stratification. However, the large trees and emergent vegetation (Figure 20, p.45) surrounding the small pond reduce wind effects sufficiently so that marked thermal gradients can occur. However, when the wind is strong enough the pond circulates as evidenced by the presence of oxygen near the bottom on 7-12-74.

The pond bottom was largely organic matter originating from beaver activity and emergent and nearby terrestrial vegetation. These organic depositions probably had a high oxygen demand which caused the oxygen depletion on 7-12-74.

Low pH values are found in natural waters rich in dissolved organic matter, especially in bogs and bog lakes that are dominated in the littoral mat by the moss Sphagnum. The pH of Sphagnum bogs is usually in the range of 3.3 to 4.5 (Wetzel, 1975 p.174). The sources of the H^+ activity are primarily due to cation exchange in the walls of Sphagnum during which H^+ are released and, to a lesser degree, secretion by live Sphagnum of whole organic molecules (Clymo, 1964). In addition the color of the water characteristically was a yellow-brown, similar to that described by Shapiro (1957). He concluded that the yellow-brown color was the result of humo-limnetic acids that originate as a result of decomposition in soil and possibly in sediments as well. These factors may have caused the low pH in

Section 2 Pond. The higher pH found in Section 2 Pond during the ice cover period possibly resulted from reduced production and flow of H^+ from the frozen Sphagnum mat.

The increase in specific conductance in the winter is probably caused by the same processes as in Lake Gribben, namely a decrease in the depth of the oxidized strata in the sediments.

The higher levels of phosphorus found in Section 2 Pond as compared with Lake Gribben are probably due to the rich organic matter seeping in from the Sphagnum bog adjacent to it (Wetzel, 1975 p.217).

Nitrification is reduced severely in acidic waters and nitrate produced in such waters is probably utilized as rapidly as it is produced, so that most of the time only very low quantities are found (Wetzel, 1975 p.200). This would explain the low nitrate-nitrogen levels usually found in Section 2 Pond. The high nitrate-nitrogen concentration on 3-23-75 is probably a result of low plankton concentrations and consequently low uptake of nitrate.

The relatively high iron concentration in Section 2 Pond is normal for bodies of water such as Section 2 Pond that are heavily stained with dissolved limnohumic compounds and are acid bog waters (Wetzel, 1975 p.253).

The high percentage of diatoms in Section 2 Pond is unusual in that in bog lakes the percent of diatoms, as compared with other waters, is very small (Welch, 1952 p.394). The reasons for the apparent dominance of diatoms in Section 2 Pond is unknown. An attempt to explain the seasonal variation in planktonic composition was not done for the same reasons given for Lake Gribben.

Trophic Levels

Wetzel (1975 p.626) reports that the old concept that lakes progress from oligotrophy to eutrophy is not necessarily true. After an initial oligotrophic phase (little phytoplankton due to low nutrient availability) the ontogeny of a lake usually follows one of three pathways. It can become an eutrophic lake (contain much phytoplankton due to high nutrient availability), a marl lake (low productivity due to excessive buffered bicarbonate conditions) or a dystrophic lake (high content of humic organic matter and low planktonic productivity).

Though there are a number of exceptions, Vollenweider (1968) demonstrated a direct correlation between high sustained productivity of algal populations and average concentration of epilimnetic total phosphorus and epilimnetic total inorganic nitrogen. Using these data, lakes may be classified to trophic level (Table 4). The average epilimnetic concentrations of total phosphorus and nitrate-nitrogen for Deer Lake are given in Table 5. It should be noted that only nitrate-nitrogen was sampled. The total would also include nitrite-nitrogen and ammonia and thus would be higher if these two forms of nitrogen were included.

According to Vollenweider (1968) on the basis of these two parameters, Deer Lake would be classified as hypereutrophic.

The cause of Deer Lake's accelerated growth is probably a consequence of loading of nutrients from the primary sewage treatment plants discharging into Carp Creek. Although inorganic nutrient loading, particularly of phosphorus and nitrogen, is fundamental to initial eutrophication and to maintaining high productivity of phytoplankton, the recycling of nutrients from the sediments are also important in maintaining high plankton productivity.

TABLE 4. Classification of lake trophy according to average epilimnetic nutrient concentration (after Vollenweider, 1968)

General Level of Lake Productivity	Total Phosphorus µg/l	Total Inorganic N mg/l
Ultra-oligotrophic	less than 5	less than 0.2
Oligo-mesotrophic	5 to 10	0.2 to 0.4
Meso-eutrophic	10 to 30	0.3 to 0.65
Eutrophic	30 to 100	0.5 to 1.5
Hypereutrophic	greater than 100	greater than 1.5

TABLE 5. Average epilimnetic nutrient concentrations in Deer Lake

Lake	Average Total Epilimnetic Phosphorus µg/l	Average Total Epilimnetic Inorganic N mg/l
Deer Lake	278	2.6

In dystrophic lakes the humic organic matter comes from allochthonous and littoral sources. Productivity has classically been defined as low. However, this refers to planktonic productivity and ignores the littoral plant community of the lake system. The littoral plant community dominates the metabolism of these lake systems and serves as the principal source of dissolved and particulate organic matter. Lake Gribben and Section 2 Pond are best classified as being dystrophic. Although the littoral community was not studied, "Conceptually it is easy to place the littoral productivity within such trophic schemes, quantitative evaluations of its contributions are meager. Sufficient information is available, however, to indicate that it cannot be ignored in most cases," (Wetzel, 1975 pp.649-650).

CONCLUSIONS AND RECOMMENDATIONS

Deer Lake

Deer Lake is a temperate dimictic lake. During thermal stratification there is a depletion of oxygen in the hypolimnion which leads to anoxic conditions in the lower water. Phosphorus and nitrogen exist at high levels throughout the year. Although primary sewage treatment wastewater contributes to the high concentration of these nutrients, indirect evidence indicates that the sediment-water interchange is also important in the loading of these nutrients. The large algal populations reflect the availability of these nutrients.

Future studies should be undertaken to determine phosphorus and nitrogen residence times, silica concentrations, algal antibiotics and groundwater influx and flow patterns. Nutrient exchange

reactions should be investigated in order to fully understand nutrient pathways, rates and degree of exchange throughout the ecosystem.

Before any lake treatment program is begun, secondary treatment of the sewage wastewater that is discharged into the lake is necessary. After this is accomplished, further evaluation will indicate which rehabilitation techniques, if any, will yield the best results.

Lake Gribben and Section 2 Pond

Lake Gribben and Section 2 Pond were 3rd order temperate lakes. The water circulated on windy days during the ice free periods. Nutrient inflow from the drainage basins and littoral community coupled with limited exchange from their sediments controlled their productivities. On the basis of their high loading from allochthonous and littoral sources; moderate iron, phosphorus and nitrate-nitrogen concentrations; and low planktonic productivity, Lake Gribben and Section 2 Pond were classified as dystrophic lakes.

Owing to their location within or near the future Gribben Tailings Basin and construction activity associated with developing this basin, conditions in Lake Gribben and Section 2 Pond have been altered. Ditch construction has drained Section 2 Pond and significantly lowered the water level in Lake Gribben for an indefinite period of time.

REFRENCES CITED

APHA. 1971. Standard methods for the examination of water and waste water, 13th ed. APHA, New York.

Crumrine, J.P., and A.M. Beeton. 1975. Limnology of lakes of the Sylvania Recreation Area, Ottawa National Forest. Spec. Rep. No. 24. Univ. Wis., Milwaukee.

Doepke, P.S. Personal communication. Dept. Biol., NMU., Marquette, Mi. 49855.

Dunst, R.C., S.M. Born, P.D. Uttormark, S.A. Smith, S.A. Nichols, J.O. Peterson, D.R. Knauer, S.L. Smith, D.R. Winter, T.L. Wirth. 1974. Survey of lake rehabilitation techniques and experiences. Bull. No. 75. Wis. Dept. Natur. Resour., Madison.

Eddy, S. and A.C. Hodson. 1961. Taxonomic keys to the common animals of the North Central states. Burgens, Minneapolis. 162p.

EPA. 1973. Biological field and laboratory methods for measuring the quality of surface waters and effluents. Off. of Res. and Devel., U.S. Environmental Protection Agency, EPA-670-4-73-001. Cincinnati. 298p.

EPA. 1974. Methods for chemical analysis of water and wastes. Nat. Environ. Res. Center, U.S. Environmental Protection Agency, EPA-625-16-74-003. Cincinnati.

Hutchinson, G.E. 1957. A treatise on limnology, vol. I. John Wiley and Sons, Inc., New York. 1015p.

_____ 1967. A treatise on limnology, vol. II. John Wiley and Sons, Inc., New York. 1115p.

Kettelle, N.J., and P.D. Uttormark. 1971. Problem lakes in the United States. Univ. Wis. Water Resour. Center, Tech. Rep. 16010 EHR. 282p.

Langelier, N.P. 1936. "The analytical control of anticorrosion water treatment." Jour. A.W.W.P. 28:1500.

Loewenthal, R.E., and G.U.R. Marais. 1976. Carbonate chemistry of aquatic systems: theory and application. Ann Arbor Sci., Ann Arbor. 433p.

Mortimer, C.H. 1941. The exchange of dissolved substances between mud and water in lakes. (Parts I and II). Jour. of Ecol. 29:280-329.

_____ 1942. The exchange of dissolved substances between mud and water in lakes. (Part III, IV, summary, and references). Jour. of Ecol. 30:147-201.

Needham, J.G., and P.R. Needham. 1962. A guide to the study of fresh-water biology. Holden-Day, Inc. San Francisco. 180p.

Ohle, W. 1952. Die hypolimnische kohlendioxyd-akkumulation als produktions-biologischer indikator. Arch. Hydrobio. 46:153-285. contained in Wetzel, R.G. 1975. Limnology. W.B. Saunders Co., Philadelphia. 743p.

Prescott, G.W. 1970. The freshwater algae. Wm. C. Brown Co., Debuque. 342p.

Rodhe, W. 1949. The ionic composition of lake waters. Werh. Int. Ver. Limnol., 10:377-386. contained in Hutchinson, G.E. 1957. A treatise on limnology, vol. I. John Wiley and Sons, Inc., New York.

Shapiro, J. 1957. Chemical and biological studies on yellow organic acids of lake color. Limnol. Oceanogr. 2:161-179.

_____ 1973. Blue green algae: why they become dominant. Science 179:382-384.

Strøm, K.M. 1947. Correlation between X^{18} and pH in lakes. Nature 159:782-783.

Singer, P.C. 1973. Trace metals and metal-organic interactions in natural waters. Ann Arbor Science. Ann Arbor. 303-321p.

Tyler, J.E. 1968. The Secchi disc. Limnol. Oceanogr. 13:1-6.

Vollenweider, R.A. 1968. Scientific fundamentals of eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors in eutrophication. Paris Rep. Organisation Economic Cooperation Development. DAS/CSI/68.27. Annex, 21p. Bibliography 61p. contained in Wetzel, R.G.

Welch, P.S. 1953. Limnology. McGraw-Hill, New York. 538p.

Wetzel, R.G. 1975. Limnology. W.B. Saunders Co., Philadelphia 743p.

Wiitala, S.W., Newport, T.G., and E.L. Skinner. 1967. Water resources of the Marquette iron range area, Michigan. Geol. Surv. Water-supply Pap. No. 1842. U.S. Gov. Print. Off., Washington.

APPENDIX 1. Dates of sampling for the various parameters on the various study waters

Study Area and Dates of Sampling	Temperature	DO	Transmittance	pH	Non-filterable Residue	Alkalinity	P	N	Fe	Plankton	Specific Conductance
Deer Lake South Basin											
6-15-74	x*	x									
6-28-74	x	x									
7-30-74	x	x	x	x	x	x	x	x	x	x	x
8-24-74	x	x	x	x	x	x	x	x	x	x	x
9-25-74	x	x	x	x	x	x	x	x	x	x	x
10-25-74	x	x	x	x	x	x	x	x	x	x	x
11-20-74	x	x	x	x	x	x	x	x	x	x	x
2-22-75	x	x	x	x	x	x	x	x	x	x	x
5-20-75	x	x	x	x	x	x	x	x	x	x	x
6-15-75	x	x	x	x	x	x	x	x	x	x	x
Deer Lake North Basin											
6-15-74	x										
6-28-74	x	x									
7-30-74	x	x									
8-25-74	x	x									
9-26-74	x	x									
10-31-74	x	x									
Lake Gribben											
7-12-74	x	x		x	x	x	x	x	x	x	x
8-12-74	x	x		x	x	x	x	x	x	x	x
10-10-74	x	x		x	x	x	x	x	x	x	x
3-23-75	x	x		x	x	x	x	x	x	x	x
5-22-75	x	x		x	x	x	x	x	x	x	x
6-15-75	x	x		x	x	x	x	x	x	x	x

* x indicates parameter was measured or sampled

APPENDIX 1. continued

Study Area and Dates of Sampling	Temperature	DO	Transmittance	pH	Non-filterable Residue	Alkalinity	P	N	Fe	Plankton	Specific Conductance
Section 2 Pond											
7-12-74	x	x		x	x	x	x	x	x	x	x
8-11-74	x	x		x	x	x	x	x	x	x	x
10-17-74	x	x		x	x	x	x	x	x	x	x
3-23-75	x	x		x	x	x	x	x	x	x	x
5-22-75	x	x		x	x	x	x	x	x	x	x
6-15-75	x	x		x	x	x	x	x	x	x	x

APPENDIX 2. Areas within bathymetric contours and volumes contained within depth intervals for Deer Lake

Depth Contour	Area (ha)
Surface	366.70
0 - 2 meters	48.04
2 - 4 "	130.85
4 - 6 "	162.84
6 - 8 "	29.06
10 - 10.5 "	.48

Depth (meters)	Volume (M^3)
0 - 1	355.85×10^4
1 - 2	331.98 " "
2 - 3	300.08 " "
3 - 4	246.66 " "
4 - 5	152.85 " "
5 - 6	71.43 " "
6 - 7	41.09 " "
7 - 8	26.55 " "
8 - 9	14.71 " "
9 - 10	4.99 " "
10 - 10.5	0.29 " "
0 - 10.5 or total volume	1546.43 " "

APPENDIX 3. Temperature data (°C) for the South and North Basins of Deer Lake

South Basin of Deer Lake

Depth (meters)	6-15-74	6-28	7-30	8-24	9-25	10-25	11-20	2-23-75	5-20	6-20
0	16.5	21.0	21.0	22.0	13.0	5.2	3.5	2.5	19.2	20.7
1	16.5	20.5	21.0	21.8	12.5	4.5	3.9	3.0	18.1	20.7
2	16.4	19.5	21.0	21.5	10.9	4.2	3.3	3.0	15.9	20.0
3	15.9	17.1	21.0	21.5	10.2	4.0	3.3	2.9	15.1	20.0
4	15.8	15.0	20.9	21.0	10.0	3.9	3.1	2.6	12.5	19.5
5	15.6	14.0	20.7	20.9	9.9	3.9	3.0	2.3	10.5	18.8
6	15.0	14.0	19.0	19.5	9.7	3.6	3.1	2.2	8.5	18.0
7	13.8	11.5	11.5	15.0	9.6	3.5	2.7	2.1	7.5	13.2
8	10.5	10.1	10.0	11.2	9.6	3.5	2.7	2.8	6.3	11.0
8.5								2.9		
9	9.8	9.0	8.8	9.5	9.6	3.9	2.7		5.9	10.0
9.5									5.5	
10		8.9	8.0	8.8	9.0					9.0
10.5		8.0	8.4	8.5						

APPENDIX 3. continued

North Basin of Deer Lake						
Depth (meters)	6-15-74	6-28-74	7-30-74	8-25-74	9-26-74	10-31-74
Surface	17.1	21.0	21.0	21.2	13.0	3.1
1	17.1	20.0	21.0	22.0	12.5	3.1
2	17.0	18.7	21.0	21.5	11.0	3.1
3	16.9	17.5	20.5	21.5	10.0	3.0
4	16.8	16.0	20.2	21.0	10.0	2.5
5	16.5	13.9	19.0	20.5	9.5	2.1
6	16.0	12.6	18.8	19.2	9.3	2.0
7	15.8	12.2	12.1	16.0	9.1	___
7.5	15.2	___	___	___	9.1	___
8	___	12.0	10.5	11.4	___	___

APPENDIX 4. Dissolved oxygen data (mg O_2/L) for the South and North Basins of Deer Lake

	South Basin of Deer Lake									
Depth (meters)	6-15-74	6-28	7-30	8-24	9-25	10-25	11-20	2-23-75	5-20	6-20
Surface	8.93	10.96	7.46	7.45	8.33	11.52	12.20	0.97	6.85	10.65
1	10.56	12.02	7.82	7.72	8.42	11.32	12.31	0.91	7.10	11.92
2	9.34	12.38	7.76	7.63	8.42	11.47	12.02	0.72	6.86	11.32
3	9.44	12.59	7.97	7.61	8.37	11.43	11.85	0.13	6.45	11.05
4	10.05	11.06	7.72	7.61	8.07	11.38	11.72	0.11	5.58	10.59
5	9.34	____	7.87	7.56	7.82	11.37	11.05	0.00	4.22	8.28
6	6.70	4.92	7.87	7.52	8.32	11.38	10.91	0.00	3.45	5.13
7	5.38	____	0.00	0.00	7.36	11.57	10.01	0.00	4.07	4.89
8	4.77	0.91	____	0.00	7.36	11.78	9.47	____	4.47	2.02
9	1.62	____	0.00	0.00	7.36	10.15	9.00	____	0.15	0.23
10	____	0.14	____	____	5.94	____	____	____	____	0.97

APPENDIX 4. continued

North Basin of Deer Lake					
Depth (meters)	6-28-74	7-30-74	8-25-74	9-26-74	10-31-74
Surface	10.74	7.25	7.10	8.32	12.23
1	11.21	7.30	7.20	8.42	12.54
2	11.24	7.30	7.20	8.42	11.98
3	11.23	7.31	7.20	8.10	11.98
4	10.30	7.31	7.20	8.00	12.00
5	8.96	7.29	7.14	7.85	9.75
6	4.82	7.20	7.05	7.54	12.00
7	———	———	———	7.50	———
7.5	———	———	———	7.50	———
8	———	———	———	———	———

APPENDIX 5. Physical and chemical characteristics of water in South Basin of Deer Lake

Sampling Dates and Water Strata	Pheno Alkalinity mg $CaCO_3$/l	Total Alkalinity mg $CaCO_3$/l	pH	Specific Conductance micromhos/cm, 25°C	Non-filterable Residue mg/l	Total Iron mg/l	Secchi Disc Visibility, m	Total Residue mg/l
7-30-74								
Epilimnion	17.0	86.0	9.10	410	8.3	1.4	1.0	261.3
Hypolimnion	0	100.0	7.00	463	10.4	2.3	___	298.4
8-24-74								
Epilimnion	10.0	83.0	8.40	402	7.4	1.3	1.0	254.4
Hypolimnion	0	82.2	7.24	423	11.6	3.9	___	272.6
9-25-74								
Epilimnion	0	86.0	6.4	327	7.2	1.2	1.5	204.2
Hypolimnion	0	82.0	6.5	352	10.8	2.7	___	224.8
10-25-74								
Epilimnion	0	85.0	8.33	308	6.8	.8	1.5	192.8
Hypolimnion	0	85.0	8.37	308	6.6	1.0	___	192.6
11-20-74								
Epilimnion	0	92.0	8.32	310	5.3	.7	1.5	192.3
Hypolimnion	0	93.0	8.34	352	10.4	1.1	___	224.4
2-22-75								
Epilimnion	0	100.8	7.40	373	2.2	.9	___	230.3
Hypolimnion	0	126.5	6.74	386	16.0	3.6	___	247.4
5-20-75								
Epilimnion	14.0	56.5	9.38	279	7.2	.6	2.0	174.2
Hypolimnion	0	84.0	6.82	346	8.7	1.3	___	218.7
6-20-75								
Epilimnion	15.0	74.0	9.21	381	7.5	1.2	1.5	241.5
Hypolimnion	0	80.0	7.6	395	9.4	1.4	___	252.4

APPENDIX 6. Salinity and forms of carbon in South Basin of Deer Lake

Sampling Dates	Calculated Salinity mg/l	$/\overline{HCO_3^-}/$ moles/l	$/\overline{CO_3^=}/$ moles/l	$/\overline{CO_2}/_{(aq.)}$ moles/l	$/\overline{C_t}/$ moles/l	Total Inorganic Carbon mg/l
7-30-74						
Epilimnion	253	1.43×10^{-3}	1.25×10^{-4}	2.06×10^{-6}	1.55×10^{-3}	18.6
Hypolimnion	288	2.00×10^{-3}	1.34×10^{-6}	3.72×10^{-4}	2.37×10^{-3}	28.4
8-24-74						
Epilimnion	247	1.61×10^{-3}	2.63×10^{-5}	1.22×10^{-5}	1.63×10^{-3}	19.6
Hypolimnion	261	1.64×10^{-3}	1.88×10^{-6}	1.79×10^{-4}	1.82×10^{-3}	21.8
9-25-74						
Epilimnion	197	1.63×10^{-3}	2.50×10^{-7}	1.24×10^{-3}	2.87×10^{-3}	34.4
Hypolimnion	214	1.63×10^{-3}	3.29×10^{-7}	1.01×10^{-3}	2.64×10^{-3}	31.7
10-25-74						
Epilimnion	186	1.65×10^{-3}	2.21×10^{-5}	1.54×10^{-5}	1.67×10^{-3}	20.0
Hypolimnion	186	1.65×10^{-3}	2.24×10^{-5}	1.40×10^{-5}	1.68×10^{-3}	20.2
11-20-74						
Epilimnion	187	1.79×10^{-3}	2.34×10^{-5}	1.70×10^{-5}	1.83×10^{-3}	22.0
Hypolmnion	214	1.81×10^{-3}	2.54×10^{-5}	1.58×10^{-5}	1.86×10^{-3}	22.3
2-22-75						
Epilimnion	228	2.01×10^{-3}	3.21×10^{-6}	1.56×10^{-4}	2.17×10^{-3}	26.0
Hypolimnion	237	2.53×10^{-3}	8.92×10^{-7}	8.94×10^{-4}	3.42×10^{-3}	41.0
5-20-75						
Epilimnion	167	8.54×10^{-4}	1.26×10^{-4}	9.05×10^{-7}	9.80×10^{-4}	11.8
Hypolimnion	210	1.67×10^{-3}	7.05×10^{-7}	4.93×10^{-4}	2.16×10^{-3}	25.9
6-20-75						
Epilimnion	234	1.21×10^{-3}	1.26×10^{-4}	1.73×10^{-7}	1.34×10^{-3}	16.1
Hypolimnion	243	1.59×10^{-3}	4.13×10^{-4}	7.60×10^{-5}	2.08×10^{-3}	25.0

APPENDIX 7. Nitrate-nitrogen and forms of phosphorus in South Basin of Deer Lake

Sampling Dates	Nitrate-Nitrogen mg NO_3-N/l	Total Phosphorus µg P/l	Total Acid Hydrolyzable Phosphorus µg P/l	Total Ortho-Phosphorus µg P/l	Total Organic Phosphorus µg P/l
7-30-74					
Epilimnion	1.0	381	79	253	49
Hypolimnion	1.1	560	218	306	36
8-24-74					
Epilimnion	0.5	210	69	98	43
Hypolimnion	0.4	863	212	403	248
9-25-74					
Epilimnion	1.3	241	84	138	19
Hypolimnion	1.5	968	324	480	164
10-25-74					
Epilimnion	1.5	293	29	255	9
Hypolimnion	15.0	365	11	191	163
11-20-74					
Epilimnion	1.8	372	19	297	56
Hypolimnion	1.9	436	102	314	20
2-22-75					
Epilimnion	2.9	460	10	356	94
Hypolimnion	3.4	1660	196	1354	110
5-20-75					
Epilimnion	15.0	180	10	73	25
Hypolimnion	13.0	1080	12	723	345
6-20-75					
Epilimnion	6.3	242	91	120	31
Hypolimnion	5.6	724	190	390	144

APPENDIX 8. Number of plankters/10 ml in vertical haul samples from Deer Lake

Organism	6-29-74	7-30-74	8-24-74	9-25-74	10-25-74	2-23-75	5-20-75	6-20-75
Coccoid Blue Green	18.8 (3.6%)*	97.2 (20.3%)	130.0 (21.6%)	240.0 (30.5%)	28.0 (12.0%)	4.7 (71.4%)	7.1 (19.9%)	100.0 (17.7%)
Filamentous Blue Green	327.0 (61.9%)	2.9 (0.5%)	7.4 (1.2%)	6.3 (8.0%)	8.3 (3.6%)	——— ———	3.8 (10.6%)	390.0 (68.9%)
Coccoid Green	18.9 (3.6%)	80.1 (1.7%)	4.6 (0.8%)	2.3 (0.3%)	——— ———	0.2 (2.7%)	0.9 (2.6%)	16.0 (2.8%)
Filamentous Green	——— ———	0.6 (0.1%)	1.1 (0.2%)	——— ———	——— ———	——— ———	0.8 (2.1%)	——— ———
Green Flagellates	64.6 (12.2%)	4.0 (0.8%)	2.8 (0.5%)	3.4 (0.6%)	0.1 (0.1%)	0.1 (0.1%)	0.6 (0.1%)	——— ———
Centric Diatoms	69.9 (13.2%)	6.3 (1.3%)	50.3 (8.4%)	67.0 (8.5%)	190.0 (81.5%)	0.8 (11.4%)	12.0 (33.6%)	44.0 (7.8%)
Pennate Diatoms	8.6 (1.6%)	2.3 (0.5%)	2.9 (0.5%)	1.7 (0.2%)	3.1 (1.3%)	0.2 (2.9%)	2.1 (5.8%)	6.3 (1.9%)
Protozoans	12.0 (2.3%)	360.0 (75.3%)	401.1 (66.6%)	460.0 (58.6%)	17.0 (7.3%)	0.4 (5.8%)	7.0 (19.5%)	3.4 (0.6%)
Rotifers	8.6 (1.6%)	1.7 (0.3%)	2.3 (0.4%)	4.0 (0.5%)	2.3 (1.0%)	0.1 (1.4%)	0.8 (2.1%)	6.3 (1.1%)
(Total)	528.4	555.1	602.4	784.7	248.7	6.5	35.1	179.9

* Percent of sample consisting of each group is included in the parenthesis.

APPENDIX 9. Percent of various phytoplankton groups of total phytoplankton in Deer Lake

Organism	6-29-74	7-30-74	8-24-74	9-25-74	10-25-74	2-23-75	5-20-75	6-20-75
Coccoid Blue Green	3.7%	80.3%	65.3%	74.8%	12.2%	79.4%	26.1%	18.0%
Filamentous Blue Green	64.5%	2.4%	3.7%	2.0%	3.6%	____	14.0%	70.1%
Total Green Algae	16.4%	10.4%	4.3%	1.8%	0.1%	4.7%	8.4%	2.9%
Total Diatoms	15.5%	7.1%	26.8%	21.4%	83.9%	15.9%	51.7%	9.0%

APPENDIX 10. Morphometric characteristics of Lake Gribben and Section 2 Pond

Lake Gribben	
Maximum Depth	1.25 meters
Mean Depth (Approx.)	1.00 meters
Area	9.1 ha
Watershed Area (includes Lake)	3.4 km^2
Volume (Approx.)	19.0 X 10^4 m^3
Section 2 Pond	
Maximum Depth	1.25 meters
Mean Depth (Approx.)	1.0 meters
Area	.85 ha
Watershed Area (includes lake)	3.4 km^2
Volume (Approx.)	8.5 X 10^3 m^3

APPENDIX 11. Temperature (^{o}C) data for Lake Gribben and Section 2 Pond

Lake Gribben

Depth (meters)	7-12-74	8-12-74	10-10-74	3-22-75	5-22-75	6-15-75
Surface	21.5	22.8	8.7	0.0	23.2	22.9
0.5	20.6	21.5	8.0	0.0	21.8	22.0
1.0	19.9	19.7	8.0	0.5	19.4	19.7
1.25 (Bottom)	17.1	17.3	8.2	1.2	16.8	17.2

Section 2 Pond

Depth (meters)	7-12-74	8-11-74	10-17-74	3-22-75	5-22-75	6-15-75
Surface	18.5	23.7	5.2	0.0	27.0	22.8
0.5	13.0	18.2	4.9	0.0	17.6	17.1
1.0	8.5	10.6	4.9	0.0	14.5	15.2
1.25 (Bottom)	7.0	9.9	4.9	0.0	14.1	14.3

APPENDIX 12. Dissolved oxygen data (mg/1) for Lake Gribben and Section 2 Pond

Lake Gribben

Depth (meters)	7-12-74	8-12-74	10-10-74	3-22-75	5-22-75	6-15-75
Surface	5.89	5.12	10.25	8.53	7.81	5.37
0.5	5.68	4.96	10.16	6.80	7.21	5.26
1.0	5.43	4.82	8.93	3.35	5.68	4.97

Section 2 Pond

Depth (meters)	7-12-74	8-11-74	10-17-74	3-22-75	5-22-75	6-15-75
Surface	5.12	4.97	7.12	3.46	2.95	5.62
0.5	____	4.51	7.21	3.40	1.94	5.41
1.0	0	4.46	7.11	2.13	2.90	5.19
1.25	____	4.40	6.39	____	2.89	4.87

APPENDIX 13. Chemical characteristics of water in Lake Gribben and Section 2 Pond

Lake Gribben

Sampling Dates	Pheno Alkalinity mg $CaCO_3$/1	Total Alkalinity mg $CaCO_3$/1	pH	Specific Conductance micromhos/cm, 25°C	Calculated Salinity mg/1	Non Filterable Residue mg/1	Total Residue mg/1	Total Iron mg/1
8-12-74	0	23.0	6.40	47	25	4.1	29.4	0.4
10-10-74	0	17.5	6.00	44	28	4.1	27.2	0.4
3-23-75	0	20.5	6.35	80	45	32.0	77.0	2.7
5-22-75	0	9.5	7.00	43	23	4.0	27.0	0.6
6-15-75	0	15.0	6.80	50	27	4.3	31.3	0.5
Section 2 Pond								
8-11-74	0	7.5	4.80	45	24	4.2	28.2	1.2
10-17-74	0	0	3.90	50	27	4.0	31.0	1.3
3-23-75	0	9.5	5.70	90	50	4.8	54.8	1.3
5-22-75	0	6.2	5.41	40	22	5.6	57.6	1.1
6-15-75	0	3.5	4.72	37	20	4.0	24.0	1.2

APPENDIX 14. Carbonic species in Lake Gribben and Section 2 Pond

Sampling Dates	$[HCO_3^-]$ moles/l	$[CO_3^=]$ moles/l	$[CO_2]$ (aq.) moles/l	$[C_t]$ moles/l	Total Inorganic Carbon mg/l
Lake Gribben					
8-12-74	4.60×10^{-4}	6.01×10^{-7}	3.96×10^{-4}	8.56×10^{-4}	10.8
10-10-74	3.51×10^{-4}	1.83×10^{-8}	7.58×10^{-4}	11.09×10^{-4}	13.3
3-23-75	4.10×10^{-4}	5.01×10^{-8}	3.89×10^{-4}	7.96×10^{-4}	9.6
5-22-75	1.90×10^{-4}	9.78×10^{-8}	4.19×10^{-5}	2.32×10^{-4}	4.8
6-15-75	3.00×10^{-4}	9.83×10^{-8}	1.03×10^{-4}	4.03×10^{-4}	4.8
Section 2 Pond					
8-11-74	1.50×10^{-4}	4.90×10^{-10}	5.15×10^{-3}	5.30×10^{-3}	63.6
10-17-74	1.26×10^{-4}	5.21×10^{-10}	3.43×10^{-2}	3.44×10^{-2}	412.8
3-23-75	1.92×10^{-4}	5.23×10^{-9}	8.10×10^{-4}	1.00×10^{-3}	12.0
5-22-75	1.24×10^{-4}	1.65×10^{-8}	1.05×10^{-3}	1.17×10^{-3}	14.0
6-15-75	8.91×10^{-5}	2.35×10^{-10}	3.74×10^{-3}	3.82×10^{-3}	45.8

APPENDIX 15. Nitrate-nitrogen and forms of phosphorus in Lake Gribben and Section 2 Pond

Sampling Sites and Dates	Total Nitrate-Nitrogen mg NO_3-N/l	Total Phosphorus µg P/l	Total Acid Hydrolyzable Phosphorus µg P/l	Total Ortho-Phosphorus µg P/l	Total Organic Phosphorus µg P/l
Lake Gribben					
8-12-74	2.0	31	10	9	12
10-10-74	2.2	34	16	5	13
3-23-74	2.5	27	1	7	20
5-22-75	7.5	26	10	8	8
6-15-75	3.1	28	9	10	9
Section 2 Pond					
8-11-74	0.7	43	8	14	21
10-17-74	0.9	51	10	5	36
3-23-74	8.1	46	1	15	30
5-22-75	3.8	28	0	7	21
6-15-75	2.0	34	9	11	14

APPENDIX 16. Percent of phytoplankton and zooplankton per sample in Lake Gribben

	Sampling Dates				
Phytoplankton	7-12-74	8-12-74	10-10-74	5-22-75	6-15-75
Coccoid Blue Green	11.7% (10.3%)*	14.8% (12.6%)	63.9% (33.7%)	20.0% (18.3%)	19.9% (18.3%)
Filamentous Blue Green	5.3% (4.7%)	8.0% (6.8%)	12.7% (6.7%)	21.2% (19.4%)	17.6% (16.2%)
Coccoid Green	10.5% (9.3%)	10.0% (8.5%)	15.0% (7.9%)	2.4% (2.2%)	3.9% (3.6%)
Filamentous Green	1.1% (1.0%)	1.8% (1.5%)	_____	2.4% (2.2%)	2.1% (1.9%)
Green Flagellates	less than 1.0%	less than 1.0%	_____	_____	less than 1.0%
Centric Diatoms	13.6% (12.0%)	8.6% (7.3%)	4.2% (2.2%)	5.9% (5.4%)	7.8% (7.2%)
Pennate Diatoms	57.7% (50.9%)	56.9% (48.5%)	4.2% (2.2%)	48.1% (44.1%)	48.6% (44.6%)
Zooplankton					
Protozoans	38.3% (4.4%)	42.0 (6.0%)	9.5% (4.5%)	62.8% (5.4%)	46.1% (4.1%)
Rotifers	42.6% (4.9%)	31.5% (4.5%)	69.1% (32.6%)	37.2% (3.2%)	33.7% (3.0%)
Sarcodina	_____	_____	9.5% (4.5%)	_____	_____
Daphnia	8.7% (1.0%)	14.0% (2.0%)	_____	_____	_____
Nauplius	10.4% (1.2%)	12.6% (1.8%)	11.9% (5.6%)	_____	20.2% (1.8%)

* Number in parenthesis is percent of total plankton per sample.

APPENDIX 17. Percent of phytoplankton or zooplankton per sample in Section 2 Pond

	Sampling Dates				
Phytoplankton	7-12-74	8-11-74	10-17-74	5-22-75	6-15-74
Coccoid Blue Green	23.9% (6.6%)*	12.4% (8.9%)	15.0% (14.7%)	11.9% (11.1%)	13.1% (9.7%)
Filamentous Blue Green	31.9% (8.8%)	12.8% (9.2%)	4.0% (3.9%)	9.1% (8.5%)	9.6% (7.1%)
Coccoid Green	12.0% (3.3%)	4.9% (3.5%)	2.4% (2.3%)	5.8% (5.4%)	7.8% (5.8%)
Filamentous Green	———	3.2% (2.3%)	8.7% (8.5%)	6.3% (5.9%)	1.7% (1.3%)
Green Flagellates	3.6% (1.0%)	1.4% (1.0%)	1.6% (1.6%)	1.1% (1.0%)	3.4% (2.5%)
Centric Diatoms	———	4.7% (3.4%)	1.6% (1.6%)	2.3% (2.1%)	6.0% (5.1%)
Pennate Diatoms	29.7% (8.2%)	60.6% (43.6%)	66.6% (65.1%)	64.0% (59.5%)	57.6% (42.8%)
Zooplankton					
Dinoflagellates	79.8% (58.2%)	76.7% (22.1%)	———	14.3% (1.0%)	77.9% (20.4%)
Sarcodina	7.5% (5.5%)	7.3% (2.1%)	61.5% (1.6%)	62.9% (4.4%)	8.4% (2.2%)
Rotifers	7.5% (5.5%)	4.5% (1.3%)	38.5% (1.0%)	22.9% (1.6%)	9.9% (2.6%)
Cyclopoidea	1.4% (1.0%)	———	———	———	———
Nauplius	3.7% (2.7%)	6.9% (2.0%)	———	———	3.8% (1.0%)
Daphnia	———	4.5% (1.3%)	———	———	———

* Number in parenthesis is percent of total plankton per sample.