TROPHIC CONDITIONS IN LAKE WINNISQUAM, NEW HAMPSHIRE

U.S. GEOLOGICAL SURVEY

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16. Abstracts Lake Winnisquam has received treated domestic sewage for approximately 50 years and since June 1961 has been treated with copper sulfate to control the growth of nuisance algae. The Laconia City secondary sewage-treatment plant was upgraded in 1975 to include phosphorus removal. Phosphorus was not removed effectively until early 1976, and, therefore, the 1976 data presented in this report are considered baseline or pre-phosphorus removal with respect to anticipated changes in the trophic condition of the lake. Effluent from the Laconia State School primary-treatment plant was diverted to the Laconia City plant in October 1976. Dissolved oxygen concentrations showed marked differences between the two basins comprising Lake Winnisquam. Phytoplankton samples showed similarities by algal group for all stations but algal genera varied between the upper and lower basins. Total phosphorus concentrations in the epilimnion ranged from 0.01 to 0.10 milligrams per liter, and accumulation of total phosphorus in the hypolimnion resulted in concentrations up to 0.59 milligrams per liter. Chemical states of nutrients varied among the stations corresponding to the degree of depletion of hypolimnetic dissolved oxygen. Dissolved oxygen profiles were used to illustrate zones of algal production, respiration, and bacterial decomposition. The rate of depletion of dissolved oxygen in the hypolimnion was linearly related to time. Because change in the rate of hypolimnetic dissolved oxygen depletion is more easily measured than change of nutrient load in the lake, it is suggested it be used as an indicator of the response of the lake to change in trophic condition.

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The following factors may be used to convert the International System of Units (SI) published herein to U. S. customary units:

Multiply SI Units	by	to obtain U. S. customary units
Length		
meter (m)	3.281	feet (ft)
kilometer (km)	.6214	mile (mi)
Area		
hectometer^2 (hm^2)	2.471	acre
kilometer^2 (km^2)	.3861	mile^2 (mi^2)
Volume		
meter^3 (m^3)	35.31	feet^3 (ft^3)
meter^3 per second (m^3/s)	35.31	feet^3 per second (ft^3/s)
meter^3 per second (m^3/s)	15,850	gallon per minute (gal/min)
Mass		
gram (g)	.03527	ounce avoirdupois (oz avdp)
kilogram (kg)	2.205	pounds avoirdupois (lb avdp)
Temperature		
degrees Celsius (°C)	1.8(°C) +32	degrees Fahrenheit (°F)

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ABSTRACT

Lake Winnisquam has received treated domestic sewage for approximately 50 years and since June 1961 has been treated with copper sulfate to control the growth of nuisance algae. The Laconia City secondary sewage-treatment plant was upgraded in 1975 to include phosphorus removal. Phosphorus was not removed effectively until early 1976, and, therefore, the 1976 data presented in this report are considered baseline or pre-phosphorus removal with respect to anticipated changes in the trophic condition of the lake. Effluent from the Laconia State School primary-treatment plant was diverted to the Laconia City plant in October 1976. Dissolved oxygen concentrations showed marked differences between the two basins comprising Lake Winnisquam. Phytoplankton samples showed similarities by algal group for all stations but algal genera varied between the upper and lower basins. Total phosphorus concentrations in the epilimnion ranged from 0.01 to 0.10 milligrams per liter, and accumulation of total phosphorus in the hypolimnion resulted in concentrations up to 0.59 milligrams per liter. Chemical states of nutrients varied among the stations corresponding to the degree of depletion of hypolimnetic dissolved oxygen. Dissolved oxygen profiles were used to illustrate zones of algal production, respiration, and bacterial decomposition. The rate of depletion of dissolved oxygen in the hypolimnion was linearly related to time. Because change in the rate of hypolimnetic dissolved oxygen depletion is more easily measured than change of nutrient load in the lake, it is suggested it be used as an indicator of the response of the lake to change in trophic condition.

INTRODUCTION

Lake Winnisquam, in south-central New Hampshire, has been a subject of great local interest for many years, principally due to its recreational value and the nearly annual appearance of large populations of nuisance forms of blue-green algae. Conditions resulting from algal blooms have detracted from the esthetic value of the lake and have generated many complaints to the New Hampshire Water Supply and Pollution Control Commission (NHWSPCC). In response, NHWSPCC has controlled algal growth with copper sulfate and planned upgrading of sewage treatment to reduce the inflow of nutrients that enhance algal growth. The use of copper sulfate has aroused concern due to reductions in the catch of fishes associated with deep, cold water, such as smelt, lake trout, and salmon.

A consultant's report (Metcalf and Eddy, 1961) indicated "...that Lake Winnisquam is being unduly fertilized by contributions of inorganic nitrogen and inorganic phosphorus contained in the sewage-plant effluents contributed by the Laconia State School and city of Laconia." After this report, the lake was studied more intensely by NHWSPCC, and plans were made to upgrade Laconia's sewage treatment and to connect the Laconia State School sewage-disposal system to Laconia's sewage-treatment plant. Phosphorus removal facilities were put on-line in late May 1975, and connection of the school system to the Laconia plant was completed and operational by mid-October 1976.

Purpose and Scope of Study

The study was conducted to provide a data base for identifying the changes in environmental conditions resulting from recent and planned modification of sewage-treatment and disposal facilities in the Lake Winnisquam lake basin. Chemical and phytoplankton sampling was planned to provide data comparable to those previously collected by NHWSPCC and to identify and enumerate organisms found in the most productive zones in the water column at each location.

Samples were taken for determining concentrations of nitrogen and phosphorus in tributary streams. Only the major tributary, the Winnipesaukee River, was sampled frequently because previous studies indicated that other tributaries were not significant contributors of plant nutrients.

Previous Studies

Since the Metcalf and Eddy report (1961) NHWSPCC has been actively studying Lake Winnisquam.

Several staff reports have been prepared by NHWSPCC describing lake conditions and attempts to control algal population. Staff Report 62 (1973) covers the period between the consultant's study and 1972. Included are a history of copper sulfate treatments, observations of physical conditions in the lake, and documentation of attempts at destratification of the lower lake basin. Nitrogen and phosphorus concentrations and identifications of algal genera were also included in that Staff report.

Staff Report 63 (1974) is a study of lake conditions before phosphorus removal by the Laconia sewage-treatment plant. It described chemical conditions of the lake, tributary inflows, and sewage-treatment plants more completely. Also included were measurements of flows in the tributaries at the time of sample collection. The relative contributions of phosphorus from the Winnipesaukee River, the sewage-treatment plants, and the tributary streams were identified. Staff Reports 70 and 72 document lake monitoring during 1974 and 1975, respectively.

Acknowledgments

Kenneth Warren, a biologist with NHWSPCC, helped organize and coordinate data collection for this study. His efforts in maintaining equipment and instruments for field use allowed for efficient data collection. His familiarity with Lake Winnisquam and his observations of past and current lake conditions were very useful to the author.

Steven Snell, of the NHWSPCC, was helpful in sample preparation and treatment, and his efforts often prevented delays in getting samples to the laboratories in a preserved state.

Others of the NHWSPCC staff provided valuable field and laboratory assistance.

LOCATION AND PHYSICAL FEATURES

Lake Winnisquam is located in the "Lakes Region" of central New Hampshire in the Towns of Tilton, Sanbornton, Meredith, Belmont, and the city of Laconia (fig. 1). It is a temperate lake of glacial origin, with a surface area of slightly more than 1,725 hm. The lake can be effectively divided into two basins by a shallow area in the vicinity of Winnisquam Bridge, which is known locally as "Mosquito Bridge", 3.2 km northeast of its outlet. The lake is 12.9 km long and 2.5 km wide, with the long axis lying nearly north and south.

The maximum depth in the north basin is 53 m near Pot Island. The maximum depth in the south basin is 19.8 m in the west-central part, south of Mohawk Island. Detailed information on the morphology of the the lake bottom has been gathered by NHWSPCC. A north-south profile of the lake, with sampling stations, is shown in figure 2.

Drainage areas of the tributaries, the intervening areas draining directly to the lake and the lake surface, are given in table 1.

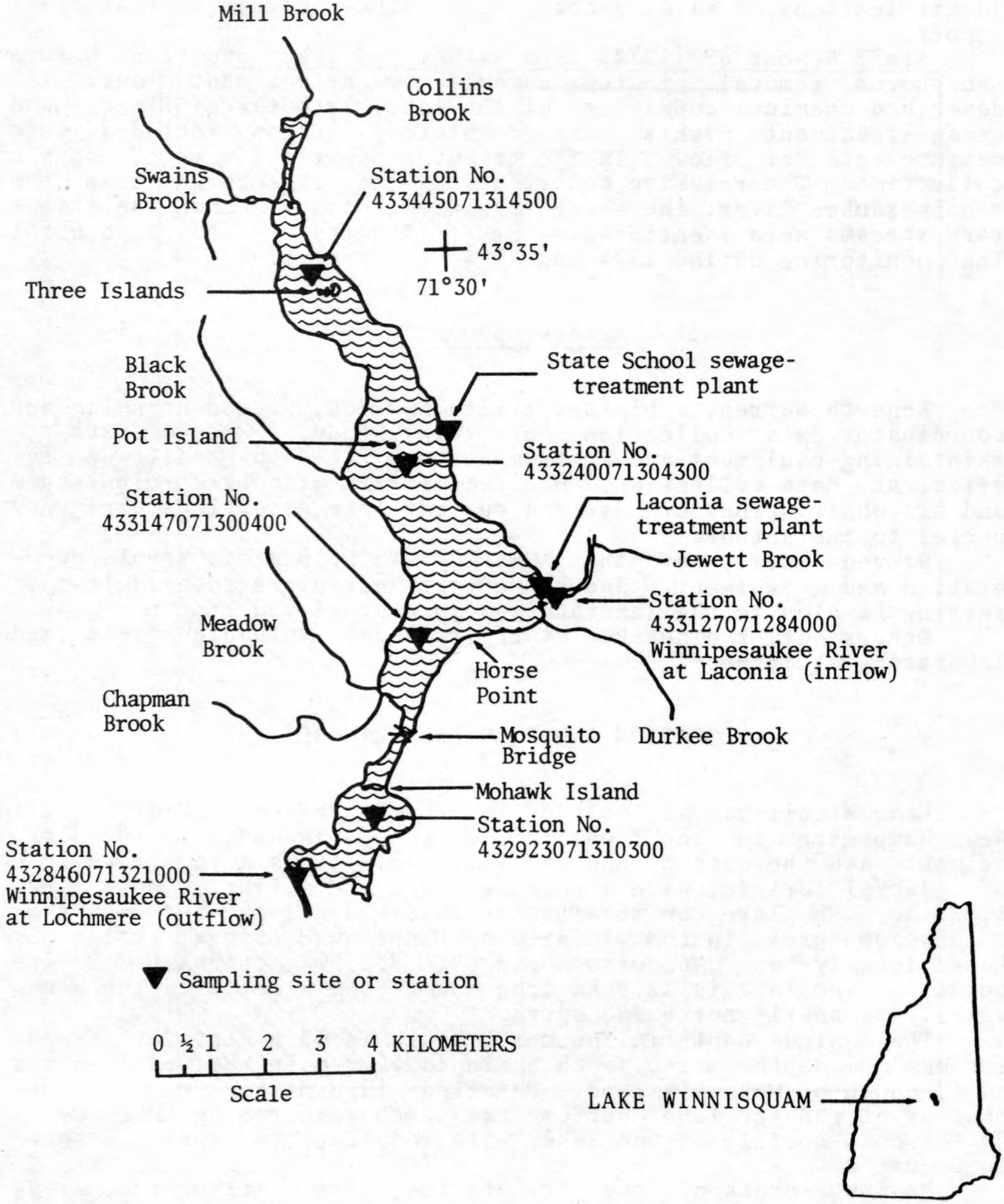


Figure 1.--Map showing Lake Winnisquam and location of sampling sites

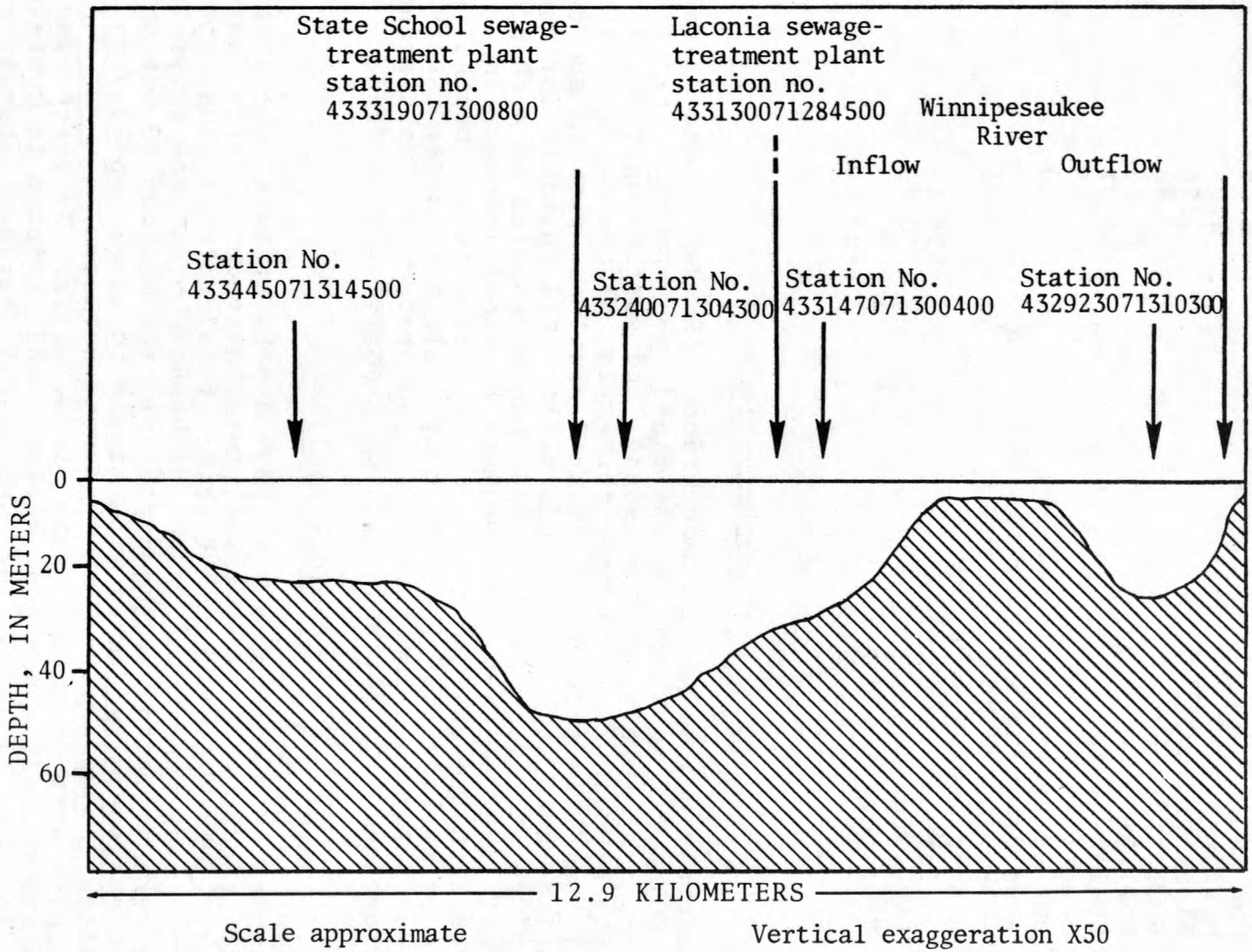


Figure 2.--North-south generalized cross section of Lake Winnisquam showing locations of sampling sites and the shallow area dividing the lake into two basins

Table 1.--Size of drainage areas tributary to Lake Winnisquam

Tributary	Drainage area (km^2)
Chapman Brook	6.94
Meadow Brook	2.64
Black Brook	7.58
Swains Brook	2.88
Mill Brook	19.55
Collins Brook	3.01
Jewett Brook	8.38
Durkee Brook	5.10
Area draining directly to lake excluding above basins	27.81
Winnipesaukee River at Laconia (inflow)	598.1
Lake Winnisquam surface	10.72
Winnipesaukee River at Lochmere (outflow)	693.0

METHODS

Field Observations

Temperature, specific conductance, pH, depth, and dissolved oxygen (DO) were measured in the field in a manner to facilitate profiling. A multiparameter sonde and surface unit with the capability of measuring all the above in place, was used at the start of the field season. Occasional problems with pH and depth observations and lack of a conductivity cell suitable for use in waters of very low specific conductance resulted in a change to individual instruments for measurement of specific conductance and DO, both with temperature measuring capabilities. Depths were measured by marking the 61-meter probe cable at 2-meter intervals. The pH was determined in the NHWSPCC laboratory. Transparencies were determined with a standard 20-cm diameter Secchi disc.

Chemical Analyses

Samples were collected at four depths at each lake station. Specific conductance, pH, color, total nitrogen, total ammonia nitrogen, total Kjeldahl nitrogen, total nitrite plus nitrate nitrogen, total phosphorus, and orthophosphorus were determined. Samples were collected at the depth of the maximum DO concentration, which generally ranged from middle to lower epilimnion, at midmetalimnion, midhypolimnion, and near bottom.

Samples were collected with a 2.2-liter Kemmerer sampler, chilled immediately upon collection, and shipped in containers cooled by dry ice to the Geological Survey laboratory in Albany, N.Y.

Analytical methods used are outlined by Brown and others (1970).

Phytoplankton Analyses

Phytoplankton were collected at the depth or zone of maximum DO concentration to obtain samples representative of the most productive organisms. A Kemmerer sampler was used when the zone spanned several meters, and a horizontal VanDorn water bottle was used when a definite peak in DO concentration was observed. One-liter raw water samples were preserved with 40 mL of 40 percent formalin solution upon collection and shipped in containers chilled with dry ice to the Geological Survey laboratory in Doraville, Ga., for analyses. Methods of analysis are described by Slack and others (1973).

Bottom-Sediment Samples

Samples for total organic carbon, total phosphorus, total nitrogen, and total copper were collected soon after the spring and autumn overturns using an Ekman grab. Subsamples not in contact with the sides of the sampler were then removed. Bottom-sediment samples were analyzed at the Survey laboratory in Albany, N.Y., using methods described by Brown and others (1970).

Rationale for Profiling Dissolved Oxygen

In natural surface water, the concentration of DO is influenced by physical, chemical and biological factors. In flowing water the physical factor is often more apparent than in standing or very slowly moving water. In lake water the short-term variations in DO are not commonly a result of physical forces except when turbulence results in the aeration of near-surface water. On the other hand, seasonal variations are greatly influenced by physical forces. Seasonal temperature changes result in unstable density relations between upper and lower lake water. The input of wind energy causes circulation of waters to occur resulting in a stable density relationship, reaeration, and a redistribution of DO.

Chemical influences on DO in lake water result from the tendency of the more abundant metals, usually iron and manganese, to exist in their most chemically stable forms, usually oxides.

Biological influences on DO are often the most significant in standing or slowly moving water. Often, however, it is difficult to make a distinction between physical, chemical, and biological factors. Few, if any, life processes are carried out in natural waters which do not involve all three factors.

DO was measured at many depths at each of the four sampling locations. Profiles were used to determine depths of maximum oxygen concentration. Samples were collected at these depths to indicate the genera and number of phytoplankton present. The DO profiles represent the net effect of the physical, chemical, and biological factors.

RESULTS

Temperature

Lake Winnisquam is a dimictic lake of the second class (Hutchinson, 1957)--it undergoes an inverse thermal stratification in the winter, a spring circulation, a direct thermal stratification in the summer with bottom-water temperatures above 4°C, and an autumn circulation. Figure 3 shows the temperature variations for conditions of spring circulation, summer stratification, and autumn circulation for the station near Three Islands. Data collection for this study was confined to the open-water (ice-free) period; therefore, the winter stratification is not illustrated.

The upper graph in figure 3 shows the isothermal conditions existing on April 27, 1976, and the increasing stratification which occurred through the summer period. The lower graph shows the decrease in stratification resulting from decling air temperatures in the early autumn and the eventual isothermal condition on Nov. 3, 1976, resulting from the completed mixing.

Transparency and Color

Secchi-disc transparencies averaged 5.3 m overall, with the upper basin averaging 5.5 m and the lower basin averaging 4.8 m. Minimum transparencies observed were 3.0 m in the upper basin and 2.4 m in the lower basin. Transparencies were generally equal to or greater than the depth of maximum DO concentration with the exception of the mid-July to mid-August period in the lower basin.

Units of color (Platinum-cobalt units) varied greatly between shallow and deep lake waters and between deep lake waters in the upper and lower lake basins. Color in the waters above the hypolimnion was 10 units or less in the upper basin and ranged from 1 to 35 in the lower basin. Color in the hypolimnion ranged from 1 to 30 units in the upper lake basin and 2 to 110 units in the lower lake basin.

Increased color in the hypolimnion is largely the result of reduction of organic matter from the trophogenic zone.

Dissolved Oxygen

Nearly homogeneous conditions existed with respect to DO at all four lake stations on April 27 (figs. 4-6). The spring circulation had occurred approximately 2 weeks prior to this sampling. At that time (April 27), no obvious zones of high photosynthetic activity were indicated by the DO profiles. Weather conditions were harsh with rough lake-surface conditions and the air temperature was low. These conditions, along with the homogeneity in water temperature throughout the vertical, maintained the lake waters in a circulated condition with DO concentrations near saturation. Although the diatom *Asterionella* was numerous on this date, it was assumed to have been dispersed throughout the upper waters so that oxygen produced through photosynthesis was also dispersed. As the summer progressed, marked increases in DO were observed at various locations in the vertical.

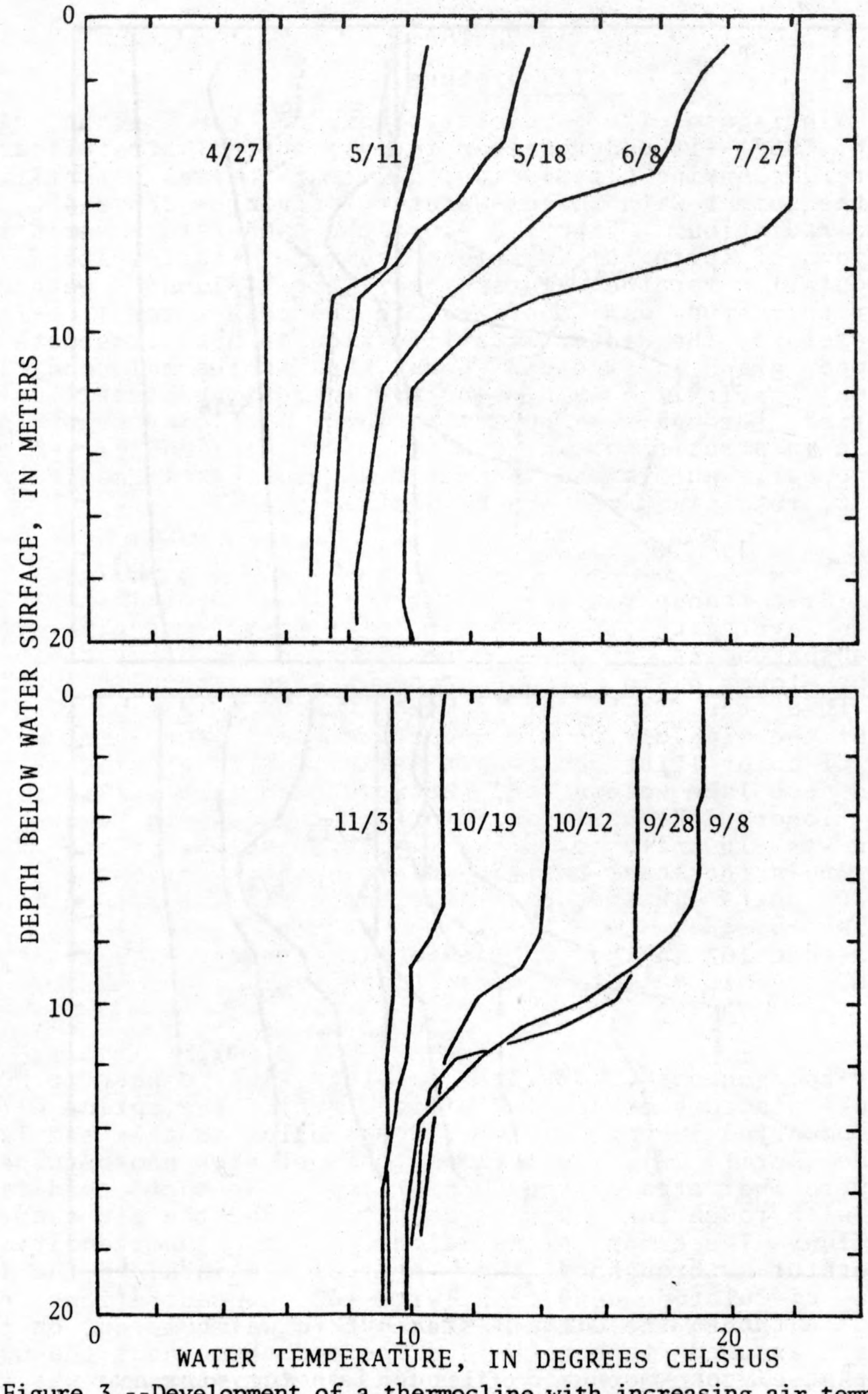


Figure 3.--Development of a thermocline with increasing air temperature and the disappearance of the thermocline with decreasing air temperature at Lake Winnisquam near Three Islands, 1976

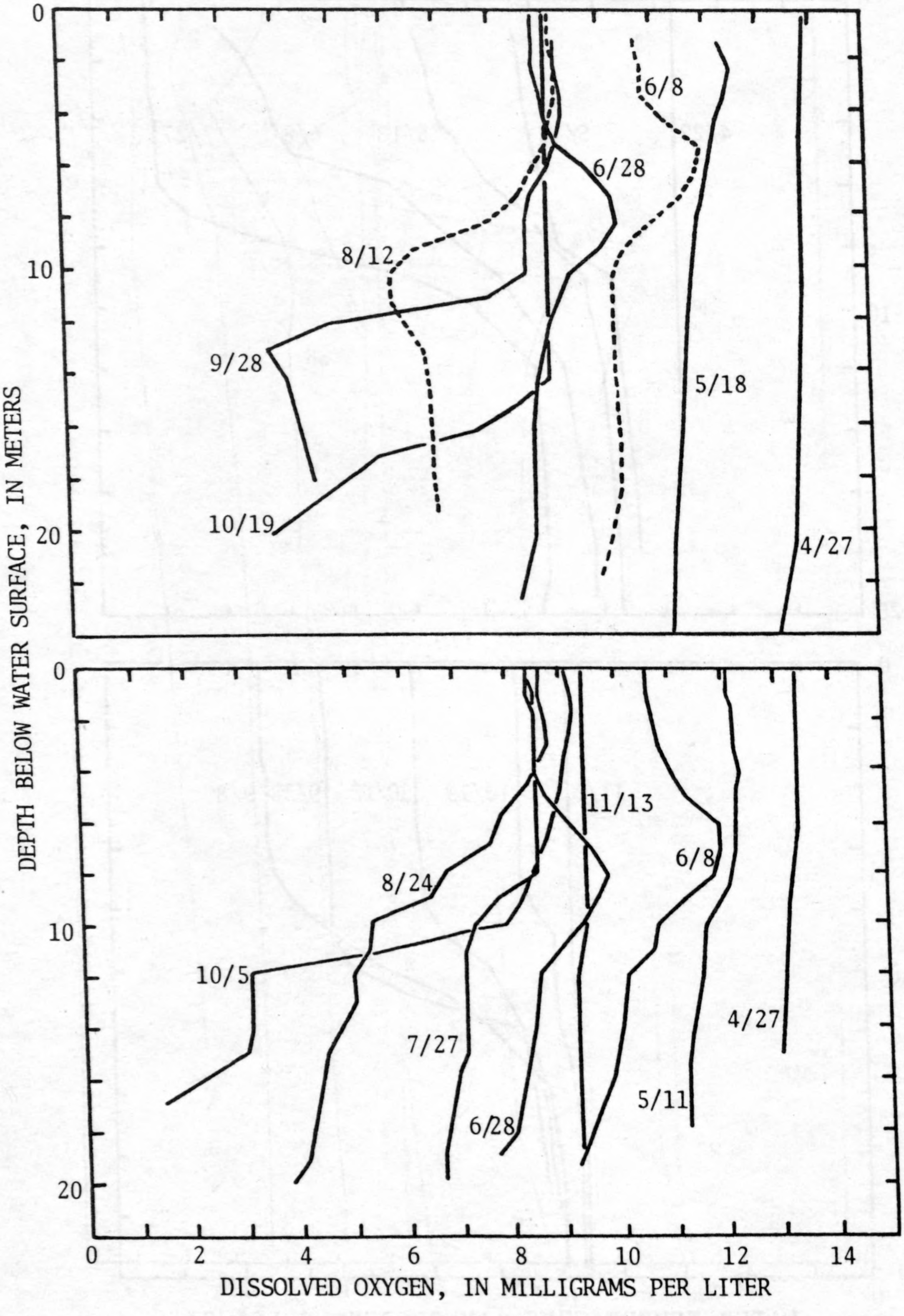


Figure 4.--Dissolved-oxygen profiles for Lake Winnisquam near Horse Point (top) and near Three Islands (bottom), 1976

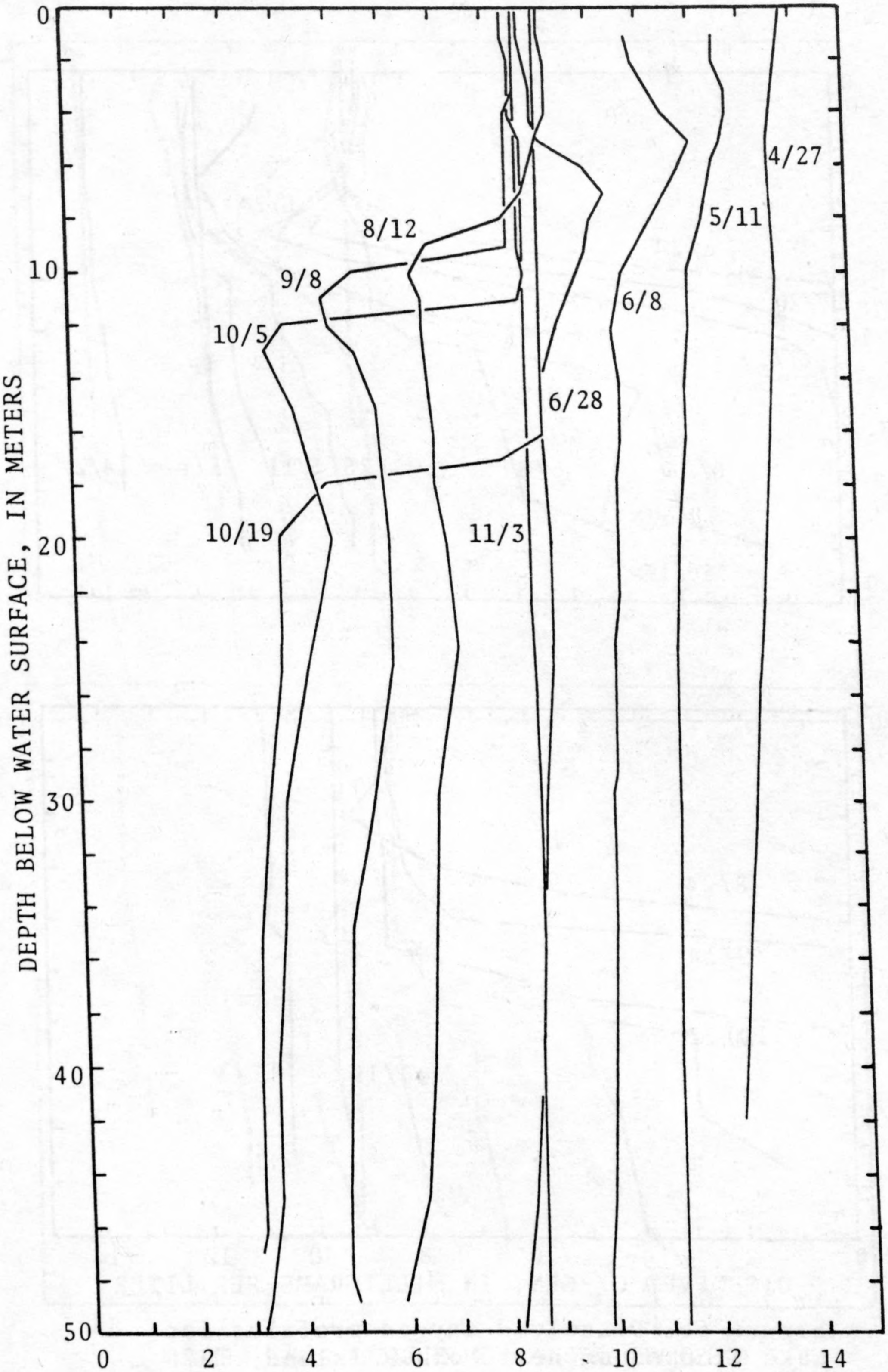


Figure 5.--Dissolved-oxygen profiles for Lake Winnisquam near Pot Island, 1976

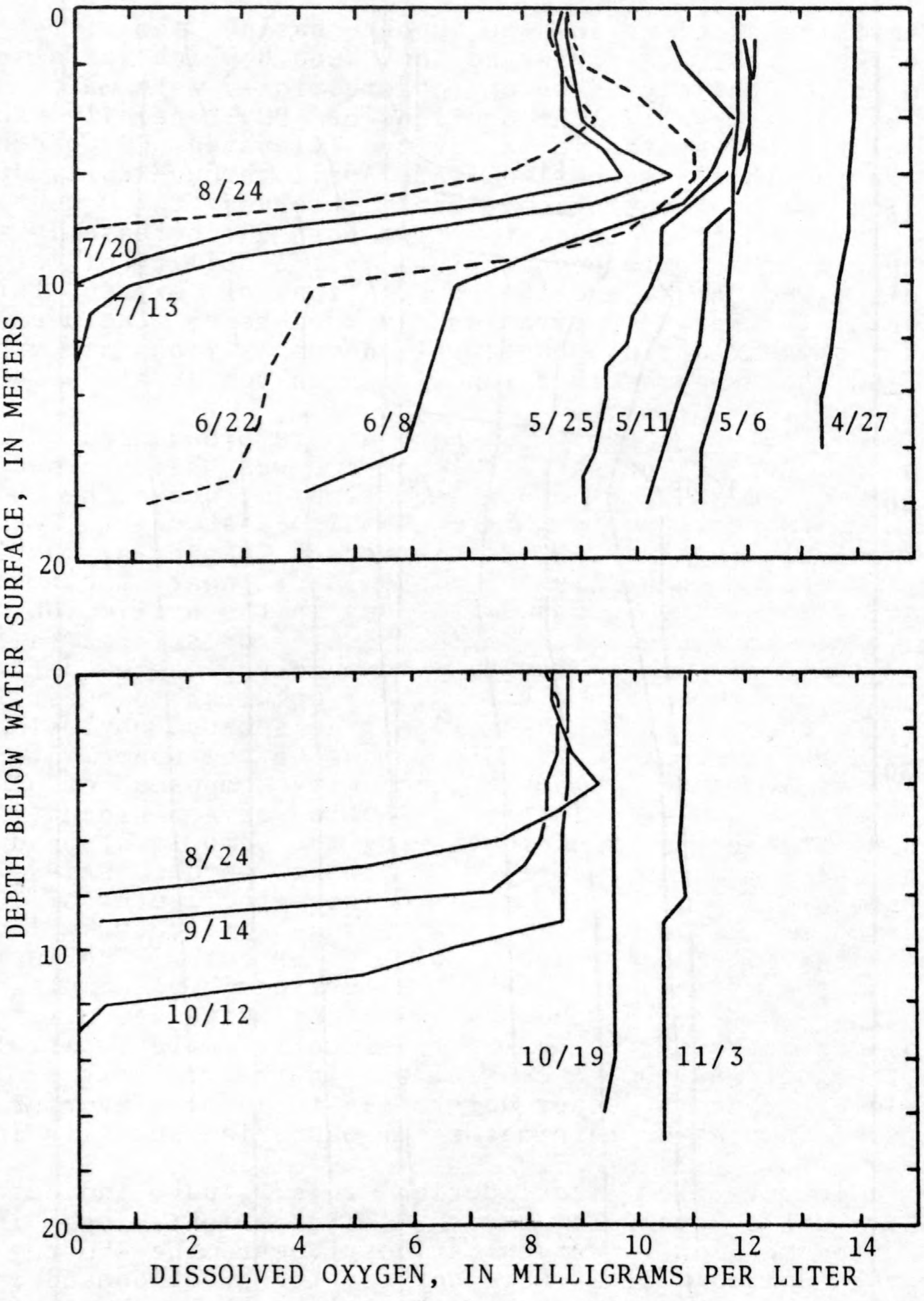


Figure 6.--Dissolved-oxygen profiles for Lake Winnisquam near Mohawk Island, 1976

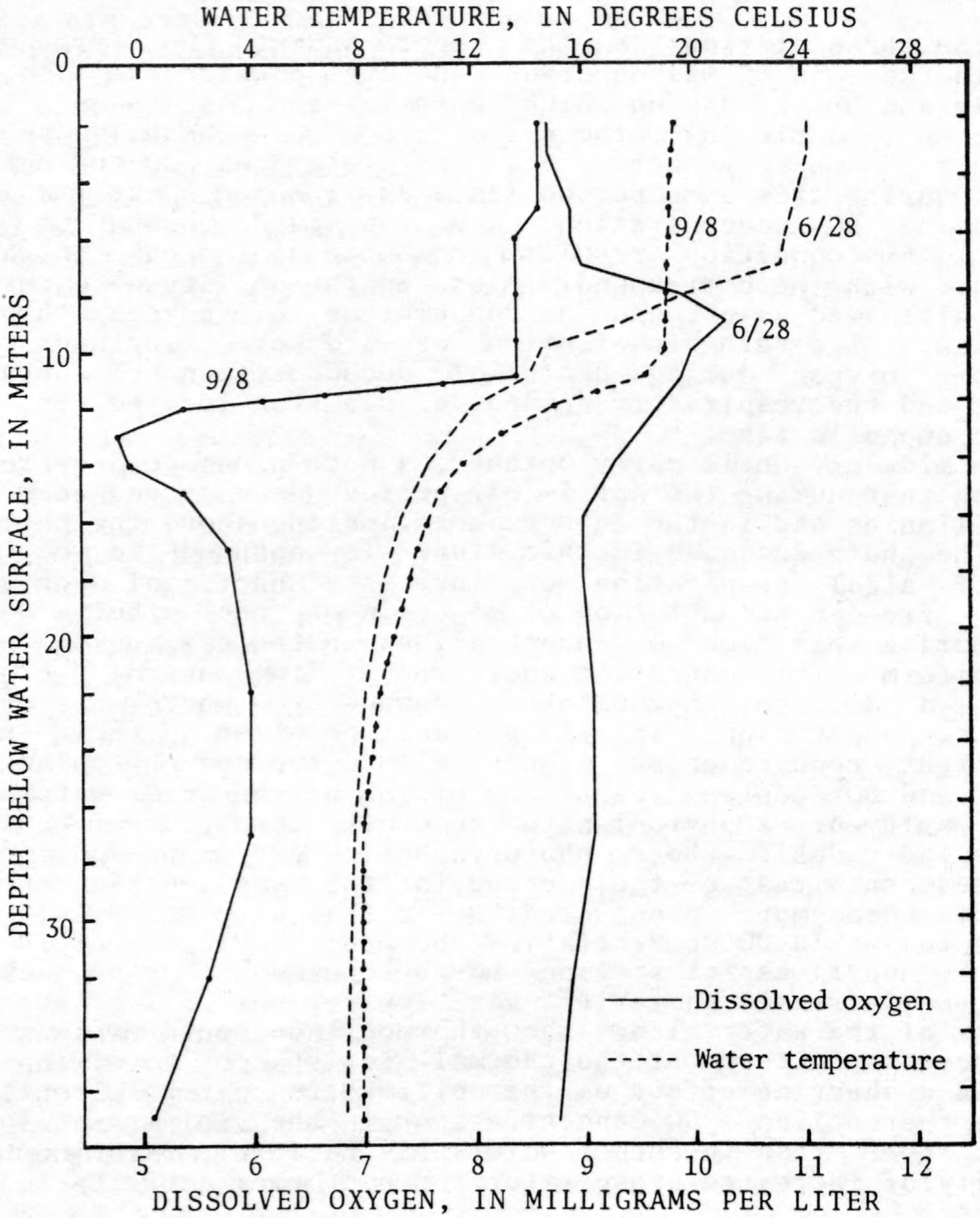
Upper Lake Basin Stations

At the three stations in the upper basin, the first pronounced increase in DO was observed on June 8 which was also the first calm and bright day on which observations were made. From this date until early July, the profiles of DO generally showed zones of high photosynthetic activity (elevated DO concentrations). During this same period (late April through early July). a decreasing DO concentration was observed throughout the vertical. This condition results from both an increase in water temperature with the corresponding loss in the ability of water to contain dissolved gases, and the consumption of oxygen through respiration. The term "respiration" as used here, includes the uptake of oxygen during bacterial decomposition of organic materials and the respiratory demands of plankton located in and below the euphotic zone.

From mid-July until early October, a more pronounced decrease in DO than that during the April-July period was observed near the lower epilimnion and in the upper metalimnion, above the thermocline. The sharp decrease in this zone is assumed to be the result of algal respiration or increased bacterial activity resulting from an accumulation of algae in or near their death phase. During this time DO concentrations in the epilimnion were fairly uniform. This condition could result from several factors, including a diverse phytoplankton community where different species occupy positions in the vertical peculiar to their individual light requirements, a physically dispersed phytoplankton community and DO content caused by mixing of the upper waters of similar density or, a phytoplankton community composed of populations of individuals whose photosynthetic oxygen production is less intense than that of those occupying the same location during the period when more pronounced DO peaks were observed. The abrupt decreases in DO concentrations between the depths of 10 and 12 m at the upper basin stations may be caused either by lack of mixing or by increased bacterial activity or both. The increase in density of the water along the thermocline could explain the abrupt decrease in terms of the thermal resistance to mixing resulting in a shearing effect as the epilimnetic water circulates above the thermocline. DO concentrations in the vicinity of 10 to 12 m were lower than in deeper waters (14 to 16 m) favoring the possibility of increased respiratory or bacterial activity in the 10-12 m zone.

Only a few profiles made during this study indicated a discernible benthic demand for oxygen. The slight jogs in the profiles, toward lower concentrations, near the bottom may represent this demand. If it were not for the great demand in the hypolimnion, the demand from the benthos might be more noticeable.

The relative effects of physical and biological factors on summer DO concentrations is illustrated by profiles of temperature and DO for June 28 and Sept. 8 (fig. 7). The temperature difference, 5°C, in the epilimnion would, by physical consideration alone, result in a much greater difference in DO than was



(NOTE: September profiles are dotted for ease in relating dissolved oxygen and temperature by date.)

Figure 7.--Dissolved-oxygen and temperature profiles for June 28, 1976, and September 8, 1976, at Lake Winnisquam near Pot Island

observed. The production of oxygen through photosynthesis, although not as localized on the later date, accounts for the approximately equal DO concentrations. Windy conditions prevailed on the later date causing the upper waters to be in a mixed condition. The drastic decrease in DO shown at 9-11 m on Sept. 8 is due to intense algal respiration, decomposition of dead algal cells by bacteria, or both. The general decrease in DO in the hypolimnion is due to the decomposition of dead algal cells which are settling downward through the water column. The similarity in temperature in the hypolimnion illustrates that the difference in DO cannot be related to the ability of the water to contain DO.

Lower Lake Basin Stations

The station in the lower basin yielded more variable profiles than did the stations in the upper basin. Increases in DO in the epilimnion were generally more pronounced than in the upper basin indicating greater photosynthetic activity, whereas the decreases in DO below the epilimnion were more pronounced. The lower 10 meters became anaerobic by the end of June. A substantial benthic demand was indicated at this station particularly during the month of June (fig. 6). However, because the hypolimnetic DO concentrations decreased fairly uniformly with no indication of the benthic demand being exerted above approximately 16 m it does not appear that the benthic demand was the principal cause of oxygen depletion in the hypolimnion. The autumn mixing is graphically shown in figure 6. Sometime between October 12 and 19, the water column became homogeneous with respect to DO. Further mixing and exposure to cooler air resulted in the high concentrations of DO observed on November 3.

Rate of Dissolved Oxygen Depletion

As an indicator of lake conditions, the concentration of DO is an easily obtainable measure of the general stress placed on the lake by both autochthonous and allochthonous organic loading.

Although an estimate of an areal hypolimnetic deficit of dissolved oxygen is considered to be debased by the presence of oxidizable allochthonous materials (Hutchinson, 1957), it does remain reasonable that the rate at which hypolimnetic dissolved oxygen diminishes following spring overturn is indicative of the condition of the lake. Such rates, however peculiar to a given lake, should change in response to changes in nutrient loading and (or) plankton growth rates. The rates calculated for Lake Winnisquam from 1976 data are expressed in terms of equations of lines of least squares fit as follows:

$$\text{Dissolved oxygen, in milligrams per liter} = \text{Intercept} + \text{Slope} \times \text{Number of days since spring overturn}$$

Intercepts and slopes obtained for the four lake stations are as follows:

Station location and number	Intercept	Slope
Near Three Islands 433445071314500	+12.5	-0.058
Near Pot Island 433240071304300	+12.9	-.051
Near Horse Point 43314707130400	+13.0	-.056
Near Mohawk Island 432923071310300	+14.7	-.178

The equations are based on DO concentrations observed at a depth of 15 m with an estimated date (April 20) for spring overturn. The date for the overturn is somewhat arbitrary which may result in some variation in the intercept due to date selected, however, the slope is not so influenced and provides an indication of the rate of decline in hypolimnetic DO concentration. The rates of DO depletion at stations in the upper lake basin are similar.

The Mohawk Island station (lower basin) rate is greater than the other station rates by three to four times. The greater rate at this station may be due to several factors including morphology of the lower basin, its location downstream of the larger upper basin which might allow accumulation of seston (suspended particulate matter) transported from the upper basin, and the septic system effluent from a large number of summer residences around the perimeter of the lower basin. The second factor mentioned has not been investigated in this study, but may be of some importance. Seston, with a small positive buoyancy, may be transported through the somewhat shallow and restricted passage between basins before they are degraded sufficiently to lose their positive buoyancy. Seston, with a small negative buoyancy, may be kept from settling until velocities of transport decline in the lower basin. The impact of septic systems at the summer residences has not been investigated, but may also be of some importance.

Phytoplankton

Samples of phytoplankton for identification and enumeration were collected at the depth of the greatest observed value of DO to provide identification and enumeration of the most productive (photosynthetically active) organisms. It was recognized at the outset that some organisms might be systematically excluded from the sample; however, the dominant, most photosynthetically active organisms were those of greatest interest.

Tables 2 through 5 list, by station and date, the composition of the phytoplankton samples collected at the depth of the DO maximum. The organisms which were present in numbers equaling or exceeding 10 percent (less when second most numerous was less than 10 percent) of the total cell count are listed. In addition, total cell counts are included to show changes in density.

Caution must be taken in comparing phytoplankton data in this report to data in reports published by the NHWSPCC. They made 3 m vertical hauls with a Wisconsin-type plankton net which frequently obtained a sample from above the zones of maximum DO observed in this study. At times, the observed DO maximum appeared at depths as great as 9 m. Samples collected at this depth using a point-sampler should not be expected to be of the same composition as those from a 3 m vertical haul.

When DO profiles began to show a zone of fairly rapid decrease in DO, usually within 2 m below the location of maximum DO, additional samples were collected to identify the phytoplankton in this zone of assumed intense algal and bacterial respiration.

The results of the additional samples are shown in tables 6 through 9, along with the results of the "DO maximum" sample taken on the same day. The tables are structured to emphasize the difference in composition of samples with respect to depth.

Algal Succession

The appearance, rate of growth, decline, and disappearance of a particular organism or group of organisms is controlled by many factors, light intensity, nutrient supply, and temperature probably being the most important. These three factors are apparently closely interrelated as each organism, or each group of organisms, requires different levels of each to thrive. *Asterionella*, for example, seems to prefer low temperature, ample light, and, in addition to the nutrients required by most other phytoplankton, an adequate supply of silica. The spring increase in numbers of *Asterionella*, and often to a lesser extent other diatoms, is possibly controlled by antecedent conditions. If, for example, heavy snow cover on the ice limited light more than it did in other years, then a greater nutrient supply would be available to support the vernal increase when the ice cover thinned and light penetration increased. The above conditions may result in two diatom peaks in the spring--one before mixing occurs, which locally depletes either silica or another essential element or compound, and one following the spring mixing, when nutrient conditions are again favorable. The early summer decline of the diatoms has been attributed to the possibly lethal effects of increased temperature and irradiation, at a time when the cells are at less than their physiological optimum due to a stress caused by declining availability of silica (Golterman, 1960). At least two pulses of diatoms, principally *Asterionella* were observed at each of the four lake stations sampled, particularly at the Three Islands station. The trend of cell counts, however, was rapidly declining prior to the minor secondary pulse.

Table 2.--Composition of phytoplankton samples for Lake Winnisquam near Three Islands, 1976

Date	Genera (Percentage of total cells in sample)	Total cells in sample
4-27	Asterionella (98)	3,200
5-6	Asterionella (84) Fragilaria (5)	4,700
5-11	Asterionella (65) Tabellaria (10)	2,800
5-18	Sample spilled during shipment.	--
5-25	Asterionella (44) Crucigenia (18) Tabellaria (17)	3,300
6-1	Sample spilled during shipment.	--
6-8	Asterionella (58) Tabellaria (19) Dinobryon (17)	2,900
6-15	Anabaena (48) Asterionella (35) Tabellaria (12)	7,900
6-22	Anabaena (37) Aphanizomenon (26) Asterionella (16)	3,000
6-25	This section of lake treated with 2,400 lbs $CuSO_4$.	--
6-28	Aphanizomenon (19) Anacystis (16) Tabellaria (16) Schroederia (13)	290
7-6	Anacystis (29) Oocystis (24) Chlamydomonas (24) Ankistrodesmus (10) Dictyoshaerium (10)	1,100
7-13	Anacystis (85) Ochromonas (9)	4,700
7-20	Aphanizomenon (33) Anacystis (28) Anabaena (15) Gomphosphaeria (14)	6,000
7-27	Anacystis (68) Gomphosphaeria (20) Aphanizomenon (5)	9,400
8-3	Aphanizomenon (37) Schroederia (17) Tabellaria (13) Chroomonas (10) Scenedesmus (10)	2,100
8-12	Anabaena (31) Gomphosphaeria (22) Anacystis (13) Tabellaria (12) Gloeocystis (12)	2,400
8-17	Gomphosphaeria (44) Tabellaria (16) Aphanizomenon (11)	2,700
8-24	Dictyosphaerium (46) Gomphosphaeria (34)	12,000
8-31	Dictyosphaerium (53) Sphaerocystis (20) Synura (14)	2,200
9-3	Dictyosphaerium (52) Eudorina (26) Anacystis (12)	2,300
9-14	Dictyosphaerium (58) Anabaena (21) Anacystis (11)	4,100
9-23	Anabaena (50) Anacystis (32)	1,600
10-5	Anacystis (57) Anabaena (20)	1,400
10-19	Spondylosium (63) Anabaena (11) Aphanizomenon (11)	250
11-5	Aphanizomenon (67) Dinobryon (11) Asterionella (10)	2,400

Table 3.--Composition of phytoplankton samples for Lake Winnisquam near Pot Island, 1976

Date	Genera (Percentage of total cells in sample)	Total cells in sample
4-27	Asterionella (84)	4,200
5-6	Asterionella (85)	5,200
5-11	Asterionella (67) Tabellaria (12)	4,800
5-18	Dinobryon (53) Asterionella (34)	2,500
5-25	Asterionella (29) Dinobryon (27) Tabellaria (14)	2,500
6-1	Sample spilled during shipment.	--
6-8	Sample spilled during shipment.	--
6-15	Asterionella (59) Anabaena (33)	3,000
6-22	Elakatothrix (55) Chroomonas (14) Crucigenia (13)	1,800
6-28	Aphanizomenon (48) Schroederia (15) Dinobryon (10) Cryptomonas (10)	960
7-6	Dictyosphaerium (32) Oocystis (23) Ochromonas (14)	4,500
7-13	Anacystis (40) Aphanizomenon (36) Oocystis (18)	1,300
7-20	Anacystis (63) Anabaena (26) Aphanizomenon (10	7,600
7-27	Anacystis (73) Aphanizomenon (15)	11,000
8-3	Aphanizomenon (70) Anacystis (14) Tube sample	2,000
8-12	Anacystis (25) Eudorina (23) Tabellaria (18) Aphanizomenon (14) Gomphosphaeria (12)	2,500
8-17	Anacystis (67) Dictyosphaerium (11)	2,500
8-24	Anacystis (31) Tabellaria (22) Sphaerocystis (11) Crucigenia (11) Schroederia (10)	1,700
8-31	Sphaerocystis (30) Aphanizomenon (21) Oocystis (21) Synura (15)	1,500
9-8	Dictyosphaerium (59) Sphaerocystis (18)	5,200
9-14	Anacystis (43) Eudorina (25) Anabaena (11)	2,200
9-28	Anacystis (48) Aphanizomenon (29)	2,100
10-5	Anacystis (93)	1,800
10-19	Spondylosium (86)	4,800
11-3	Asterionella (35) Fragilaria (23) Anacystis (20)	940

Table 4.--Composition of phytoplankton samples for Lake Winnisquam near Horse Point, 1976

Date	Genera (Percentage of total cells in sample)	Total cells in sample
4-27	Asterionella (93)	7,700
5-6	Asterionella (98)	3,300
5-11	Asterionella (56) Dinobryon (21) Tabellaria (11)	4,500
5-18	Asterionella (33)	3,500
5-25	Asterionella (29) Tabellaria (10)	2,500
6-1	Asterionella (44) Tabellaria (28) Dinobryon (24)	4,000
6-8	Asterionella (71) Tabellaria (18) Dinobryon (11)	1,500
6-15	Sample spilled during shipment.	--
6-22	Elakatothrix (27) Asterionella (20) Dinobryon (17) Chroomonas (12) Anacystis (15)	1,100
6-28	Chroomonas (44) Dinobryon (17) Cloeocystis (12) Cryptomonas (11)	890
7-6	Anacystis (70) Chroomonas (10)	3,100
7-13	Anacystis (81) Anabaena (10)	5,200
7-20	Anacystis (47) Anabaena (29) Aphanizomenon (19)	6,100
7-27	Anacystis (44) Aphanizomenon (42)	6,200
8-3	Sample lost.	--
8-12	Gomphosphaeria (49) Aphanizomenon (16) Oscillatoria (11) Tabellaria (11)	2,000
8-17	Aphanizomenon (23) Melosira (23) Anacystis (18) Tabellaria (17) Schroederia (10)	2,200
8-24	Dictyosphaerium (43) Eudorina (32) Anabaena (12)	5,200
8-31	Dictyosphaerium (42) Sphaerocystis (24) Anabaena (10)	2,900
9-8	Dictyosphaerium (64)	3,900
10-19	Spondylosium (52) Oscillatoria (14) Anacystis (13) Anabaena (11)	3,800

Table 5.--Composition of phytoplankton samples for Lake Winnisquam near Mohawk Island, 1976

Date	Genera (Percentage of total cells in sample)	Total cells in sample
4-27	Asterionella (93)	14,000
5-6	Asterionella (78) Anacystis (10	11,000
5-11	Asterionella (39) Anacystis (36) Dinobryon (17)	5,400
5-18	Asterionella (46) Fragilaria (21)	3,100
5-25	Dinobryon (38) Tabellaria (30) Asterionella (21)	2,300
6-1	Asterionella (52) Dinobryon (27) Nitzschia (11)	1,400
6-8	Sample spilled during shipment.	--
6-15	Asterionella (94)	3,000
6-22	Asterionella (41) Dinobryon (20) Uroglena (17) Quadrigula (11)	3,500
6-28	Asterionella (63) Dinobryon (20) Acenedesmus (10)	2,100
7-6	Dictyosphaerium (42) Anacystis (42)	2,400
7-13	Dinobryon (29) Ochromonas (25) Anacystis (13) Schroederia (10)	1,500
7-20	Anacystis (42) Aphanizomenon (32) Anabaena (19)	3,800
7-27	Dinobryon (43) Aphanizomenon (17) Anacystis (14)	2,100
8-3	Anacystis (25) Aphanizomenon (22) Ulothrix (20)	5,000
8-12	Anacystis (49) Oocystis (20) Schroederia (13)	1,000
8-17	Gloeocystis (52) Tabellaria (28) Schroederia (10)	1,600
8-24	Dictyosphaerium (84) Eudorina (16)	29,000
8-31	Dictyosphaerium (48) Gomphosphaeria (21)	4,400
9-8	Eudorina (34) Dictyosphaerium (30) Melosira (14) Oscillatoria (10)	3,100
9-14	Anacystis (57) Dinobryon (19) Eudorina (17)	190,000
9-28	Gomphosphaeria (59) Anacystis (31)	5,100
10-5	Spondylosium (76)	9,700
10-19	Spondylosium (60) Anacystis (20)	6,900
11-3	Asterionella (27) Dinobryon (15) Spondylosium (15) Chroomonas (13) Schroederia (10)	610

Table 6.--Multiple phytoplankton samples collected at Lake Winnisquam near Three Islands, 1976

(Values in the body of the table are cells per milliliter, and values in parentheses are DO concentrations at indicated depth.)

Date	Genera	Depth, in meters, and (DO, in milligrams per liter)		
8-12		1 (9.2)	2 (9.2)	9 (7.3)
	Chroomonas	300	--	--
	Anacystis	62	310	--
	Schroederia	50	69	--
	Gloeocystis	50	300	77
	Tabellaria	520	290	330
	Anabaena	--	740	--
	Melosira	--	88	--
	Gomphosphaeria	--	530	--
	Aphanizomenon	--	--	1,400
10-5		3 (8.6)	7 (8.6)	11 (5.8)
	Anabaena	270	--	--
	Oscillatoria	110	--	--
	Anacystis	770	1,450	1,600
	Gomphosphaeria	--	120	4,400
	Aphanizomenon	--	73	110
11-3		2 (9.4)	8 (9.4)	
	Dinobryon	270	--	
	Melosira	120	--	
	Aphanizomenon	1,600	1,800	
	Asterionella	250	450	
	Schroderia	120	210	
	Spondylosium	--	94	

Table 7.--Multiple phytoplankton samples collected at Lake Winnisquam near Pot Island, 1976

(Values in the body of the table are cells per milliliter, and values in parentheses are DO concentrations at indicated depth.)

Date	Genera	Depth, in meters, and (DO, in milligrams per liter)		
8-12		1.5 (9.1)	3 (9.2)	9 (6.8)
	Chroomonas	74	--	--
	Dinybryon	32	--	--
	Ochromonas	74	37	--
	Tabellaria	180	460	--
	Schroederia	120	37	--
	Eudorina	95	580	92
	Anacystis	--	630	--
	Oscillatoria	--	90	--
	Gomphosphaeria	--	300	410
	Aphanizomenon	--	340	960
8-24		7 (8.8)	11 (5.6)	
	Anacystis	520	--	
	Crucigenia	180	--	
	Tabellaria	360	180	
	Spaerocystis	180	50	
	Schroederia	170	19	
	Chroomonas	76	25	
	Anabaena	--	81	
	Aphanizomenon	--	220	
	Dictyosphaerium	--	410	
9-8		5 (8.4)	11 (4.8)	
	Sphaerocystis	950	--	
	Melosira	390	--	
	Dictyosphaerium	3,100	320	
	Eudorina	380	100	
	Anabaena	240	230	
	Gomphosphaeria	--	650	
10-5		5 (8.6)	10 (8.7)	12.5 (3.9)
	Schroederia	75	--	--
	Dinobryon	130	43	--
	Chroomonas	90	87	--
	Tabellaria	100	--	70
	Anacystis	2,550	1,600	2,000
	Aphanizomenon	780	--	100

Table 8.--Multiple phytoplankton samples collected at Lake Winnisquam near Horse Point, 1976
(Values in the body of the table are cells per milliliter, and values in parentheses are DO concentrations at indicated depth.)

Date	Genera	Depth, in meters, and (DO, in milligrams per liter)		
8-12		2.3 (8.6)	7.3 (9.0)	10.4 (5.7)
	Gomphosphaeria	980	--	--
	Oscillatoria	230	--	--
	Melosira	96	--	--
	Aphanizomenon	310	3,200	--
	Tabellaria	210	470	5
	Eudorina	--	810	--
	Anacystis	--	520	--
	Anabaena	--	--	270
	Pandorina	--	--	39

Table 9.--Multiple phytoplankton samples collected at Lake Winnisquam near Mohawk Island, 1976
(Values in the body of the table are cells per milliliter, and values in parentheses are DO concentrations at indicated depth.)

Date	Genera	Depth, in meters, and (DO, in milligrams per liter)			
8-12		2.3 (8.9)	4.4 (8.7)	6.6 (7.1)	
	Schroederia	140	--	--	
	Oocystis	210	--	--	
	Anacystis	500	340	--	
	Tabellaria	69	350	370	
	Anabaena	--	160	--	
	Melosira	--	630	320	
	Eudorina	--	480	360	
	Oscillatoria	--	--	1,100	
	Dinobryon	--	--	910	
	Cryptomonas	--	--	120	
8-24		4.0 (9.3)	6.1 (7.6)		
	Dictyosphaerium	24,000	8,200		
	Eudorina	4,600	1,200		
	Gomphosphaeria	--	3,600		
	Sphaerocystis	--	2,100		
	Anabaena	--	890		
	Tabellaria	--	840		
	Schroederia	--	760		
10-5		2.1 (9.2)	6.1 (8.4)	9.1 (7.1)	10 (0.0)
	Spondylosium	7,300	--	--	--
	Gonium	860	--	--	--
	Dictyosphaerium	720	--	--	--
	Dinobryon	290	--	--	--
	Aphanizomenon	470	480	670	--
	Anacystis	--	85	1,800	2,400
	Melosira	--	--	130	--
	Agmenellum	--	--	--	4,300

The appearance of other genera or groups of organisms is related to environmental factors not as yet well understood. Temperature, light, and nutrient availability probably are again the most important, although grazing by zooplankton is probably also involved.

Figures 8 and 9 show the composition of the phytoplankton samples by algal groups, and may be used in conjunction with tables 2 through 6 to show the succession by group and by genera. The composition shows a uniformity, by group, among the four stations. However, some notable differences do exist. The yellow-brown algae are slightly more in evidence at Pot Island and Mohawk Island, and the *Euglenoids* are slightly more numerous (late June-early July) at Horse Point than at the other stations. The mid-June increase in blue-greens *Anabaena* near Three Islands was the only occasion on which treatment of the lake with copper sulfate was deemed necessary by the NHWSPCC (June 25, 1976). The number of cells declined from 3,000 per milliliter to 290 per milliliter as a result of the treatment, and the principal offender, *Anabaena*, was not observed in subsequent samples until July 20th.

The late April to mid-June period was dominated by *Asterionella* at all lake stations. Early (May-June) appearances of blue-greens in relatively low numbers differed somewhat with station. At the two northern stations, Three Islands, and Pot Island, *Anabaena* was the first of this group to show up in the samples. At Horse Point and Mohawk Island, nearer the southern end of the lake, *Anacystis* was the first of the group to appear.

During July and most of August, several genera of bluegreens, either individually or as a group, dominated the algal community sampled.

From mid-late August through early September, the green algae became dominant, the most frequently observed being *Dictyosphaerium*.

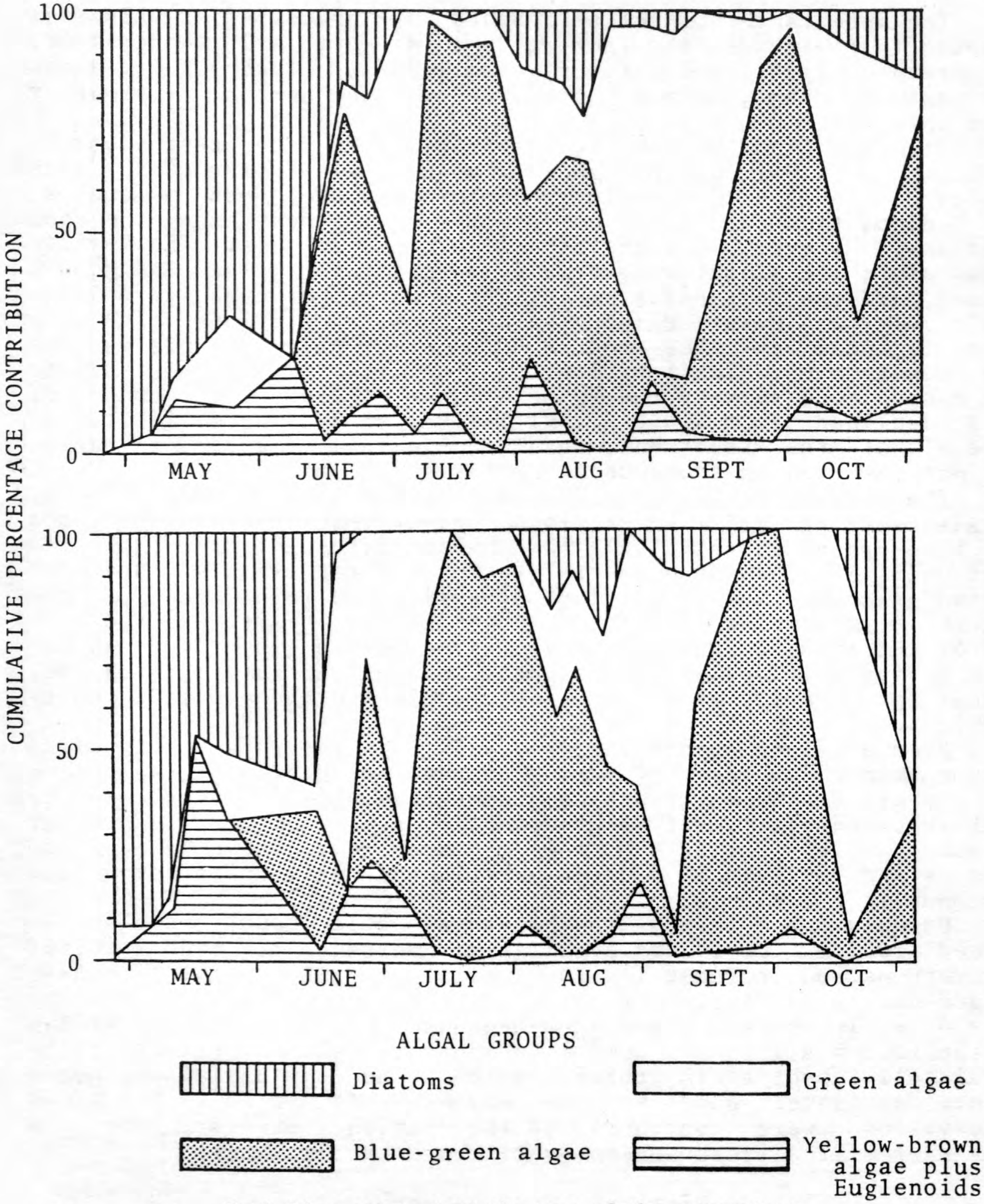
In mid-September, the blue-greens regained dominance, mostly *Anabaena*, *Anacystis*, and *Gomphosphaeria*. *Aphanizomenon* was present in many samples collected from mid-July on, but only at Three Islands and Pot Island did it attain the position of being most numerous in the sample.

On only one occasion did the total cell count in a sample exceed 100,000 cells per milliliter when *Anacystis* made a brief but very marked increase (190,000 cells per milliliter) at Mohawk Island during mid-September.

By early November, *Asterionella* was again in dominance at two of the four stations and comprised approximately 10 percent of the total cell count at the third station. The fourth station, Horse Point, was discontinued at the end of September in 1976. Field observations were continued at the station, however, for the remainder of the field season (until November 3).

Nitrogen and Phosphorus

Since the Metcalf and Eddy report of 1961, the input of nitrogen and phosphorus, particularly phosphorus, has generally been considered to be the cause of the apparent eutrophic state of



Each line represents the sum of the percentage contribution of all algal groups plotted below it.

Figure 8.--Composition of phytoplankton samples, by algal groups, for Lake Winnisquam near Three Islands (top) and near Pot Island (bottom), 1976

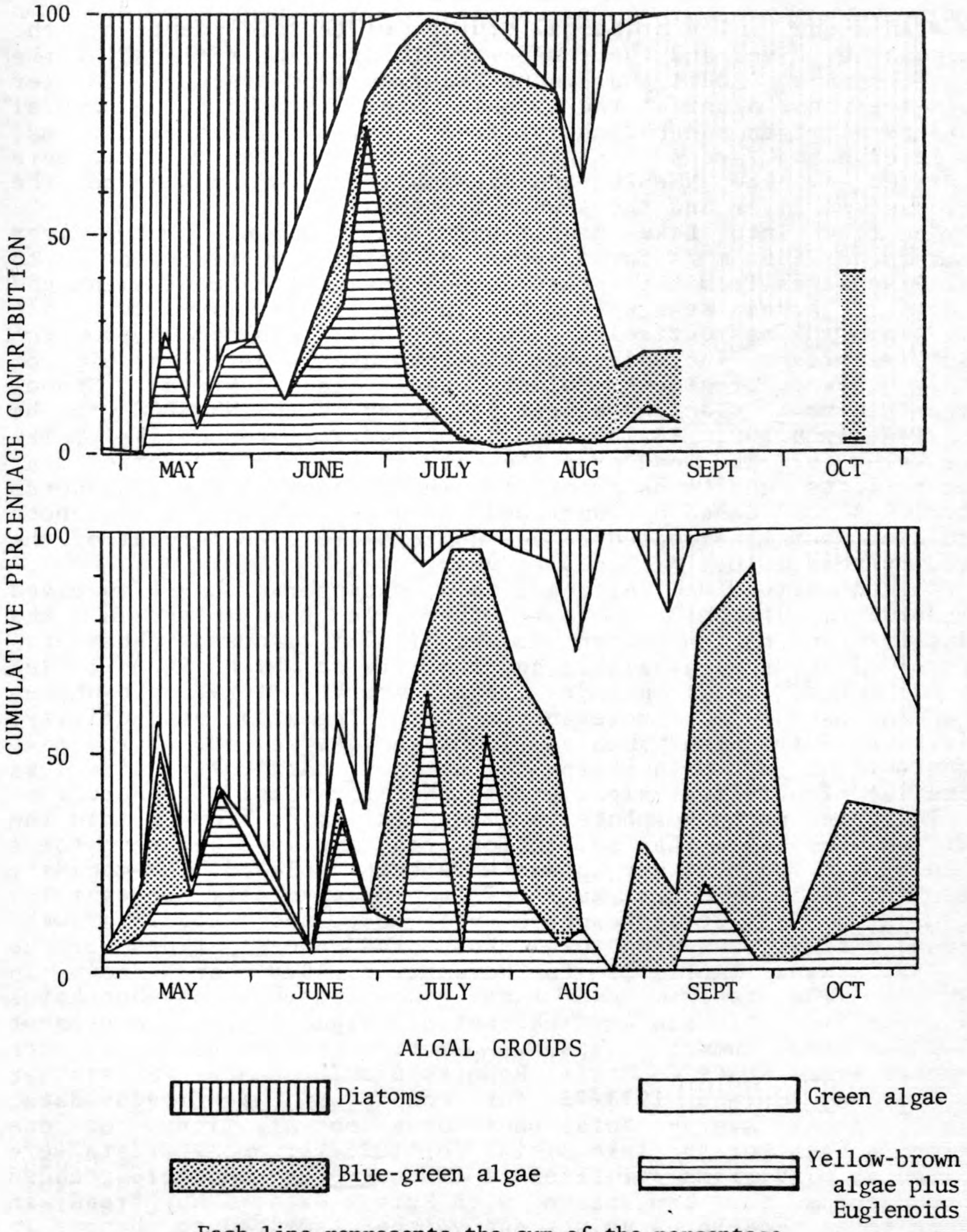


Figure 9.--Composition of phytoplankton samples, by algal groups, for Lake Winnisquam near Horse Point (top) and near Mohawk Island (bottom), 1976

Lake Winnisquam. The principal sources of these elements are the Winnipesaukee River and the sewage-treatment-plant effluent at the city of Laconia. Additional input occurred from a second, smaller sewage-treatment plant at the Laconia State School. The natural inputs of nitrogen and phosphorus from small tributary streams, and intervening areas draining directly to the lake, were calculated by the NHWSPCC and are small in comparison to the Winnipesaukee River and the sewage-treatment plants.

The flow into Lake Winnisquam from the Winnipesaukee River has averaged 14.98 m^3/s for 42 years of streamflow record prior to 1976. Discharges from the State School sewage-treatment plant and the city of Laconia sewage-treatment plant are estimated to be 946 and 9,463 m^3/d, respectively. Loads of total phosphorus from the tributary streams (including the Winnipesaukee River), the city of Laconia sewage-treatment plant and the State School sewage-treatment plant have been estimated by the NHWSPCC to be approximately 9,500, 18,100, and 1,400 kg/year, respectively. The above value for the load from the city of Laconia sewagetreatment plant reflects conditions prior to implementation of phosphorus removal. A load based on upgraded treatment has not yet been calculated, but is expected to be approximately 20 percent of the 18,100 kg/year value, or 3,620 kg/year.

Concentrations of nitrogen and phosphorus have received considerable attention as to the role they play in the productivity of phytoplankton. Wetzel (1975) discusses phosphorus in terms of the mass available and the rate at which it is cycled and exchanged, and concludes that perhaps total phosphorus concentrations are most relevant to increasing algal productivity. Activities of organisms such as "luxury uptake" of phosphorus make concentrations of orthophosphate at any particular time less indicative of potential algal growth than the total phosphorus.

Increased orthophosphate may be available from within the water column of the epilimnion via cycling before stores accumulated through luxury uptake have been depleted. The rapidity with which cycling occurs may result in apparently constant low concentration of orthophosphate yet sustained algal growth. Maximum, minimum, and mean total phosphorus concentrations for the sampling season (April 27 to November 3, 1976) are shown in table 10. The table shows that concentrations of phosphorus sufficient to maintain a substantial algal crop are present throughout the summer season. Total phosphorus data were extracted from NHWSPCC Staff Reports 62, 70, and 72 for similar time periods during 1973-75 for comparison with 1976 data. Table 11 shows average total phosphorus concentrations for one station in each of the lake basins for 1973-76. NHWSPCC data were reported as milligrams per liter to thousandths and were rounded to hundredths for comparison with Survey data. No trend in average total phosphorus values can yet be ascribed to changes in sewage-treatment practices. Concentrations at the Mohawk Island station indicate the more enriched condition of the lower basin when compared to the upper basin.

Table 10.--Concentrations of total phosphorus observed at four stations on Lake Winnisquam, two stations on the Winnipesaukee River (inflow and outflow), and the final effluent from two sewage-treatment plants discharging to the lake

(Data are for the period April 27 to November 3, 1976.)

Lake station	Epilimnion			Mid-Thermocline			Mid-Hypolimnion			Near Bottom		
Near	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
Three Islands	0.10	0.01	0.03	0.03	0.01	0.02	0.05	0.01	0.03	0.11	0.01	0.05
Pot Island	.04	.01	.02	.06	.01	.03	.05	.01	.03	.07	.02	.04
Horse Point*	.08	.01	.02	.04	.01	.02	.03	.01	.02	.05	.01	.02
Mohawk Island	.05	.02	.03	.21	.01	.05	.41	.02	.15	.59	.02	.20

*Chemical analyses discontinued for Horse Point station on September 8, 1976.

Tributary station	Max	Min	Mean
Winnipesaukee River at Martel's Bait Shop (inflow)	0.10	0.01	0.03
Winnipesaukee River at Lochmere (outflow)	.09	.02	.03
City of Laconia sewage-treatment plant	2.8	.47	1.3
Laconia State School sewage-treatment plant	5.9	3.0	4.2

Table 11.--Comparison of average total phosphorus concentration for May-October periods from 1973 through 1976

Station and year	Epilimnion	Mid-Thermocline	Mid-Hypolimnion	Near Bottom
Near Pot Island				
1973	0.02	0.02	0.02	0.09
1974	.03	--	.03	.04
1975	.01	.01	.02	.04
1976	.02	.03	.03	.03
Near Mohawk Island				
1973	.02	.05	.10	.20
1974	.02	--	.17	.27
1975	.01	.02	.09	.16
1976	.01	.05	.16	.20

Nitrogen concentrations were generally many times greater than phosphorus concentrations. The average ratio of total nitrogen to total phosphorus ranged from 11:1 to 16:1 for the lake stations. The State School sewage-treatment plant had an average total nitrogen to total phosphorus ratio of 7:1; whereas, the city of Laconia sewage-treatment plant, an advanced treatment system with phosphorus removal, had a ratio of 20:1. The ratios represent only the relative concentrations in the various waters, the loads contained or contributed depend on the volumes involved.

Samples of bottom sediment from Lake Winnisquam were analyzed for total phosphorus, total nitrogen, total organic carbon and total copper (table 12). The concentrations observed are shown in table 11. The ratio of total nitrogen to total phosphorus (2.5 to 12:1) in bottom sediments is generally lower than that in the water column (11 to 16). The difference between the ratio in the sediment and the ratio in the water column indicates the tendency of the lake sediments to retain phosphorus. The mechanism through which the retention occurs may be related to the relative solubilities of nitrate and phosphate in an oxygenated system. As anaerobic (reducing) conditions develop near the lake bottom, the solubility of metallic phosphates increases or the degree to which phosphates are bound through sorption decreases and phosphate diffuses into the water (Stumm and Morgan, 1970). As mixing in the water column restores aerobic conditions, the solubility of the metallic phosphates decreases causing some of the phosphorus to be precipitated or re-sorbed onto sediments. In productive lakes, nitrogen tends to accumulate near the bottom as NH_3-N due to the decomposition of settled planktonic debris. Also, under anaerobic conditions, the release of NH_4 from sediments is increased as the redox potential is reduced. Denitrification ("...biochemical reduction of oxidized nitrogen anions, NO_3-N and NO_2-N in the oxidation of organic matter.", Wetzel, 1975), may occur rapidly under anaerobic conditions resulting in a potential loss of nitrogen as N_2 to the atmosphere, providing fixation of nitrogen does not occur to prevent the loss. Under aerobic conditions, NH_3-N accumulating in the hypolimnion may be converted to NO_2 and NO_3 through bacterial nitrification. "Nitrification may be broadly defined as the biological conversion of organic and inorganic nitrogeneous compounds from a reduced state to a more oxidized state." (Wetzel, 1975).

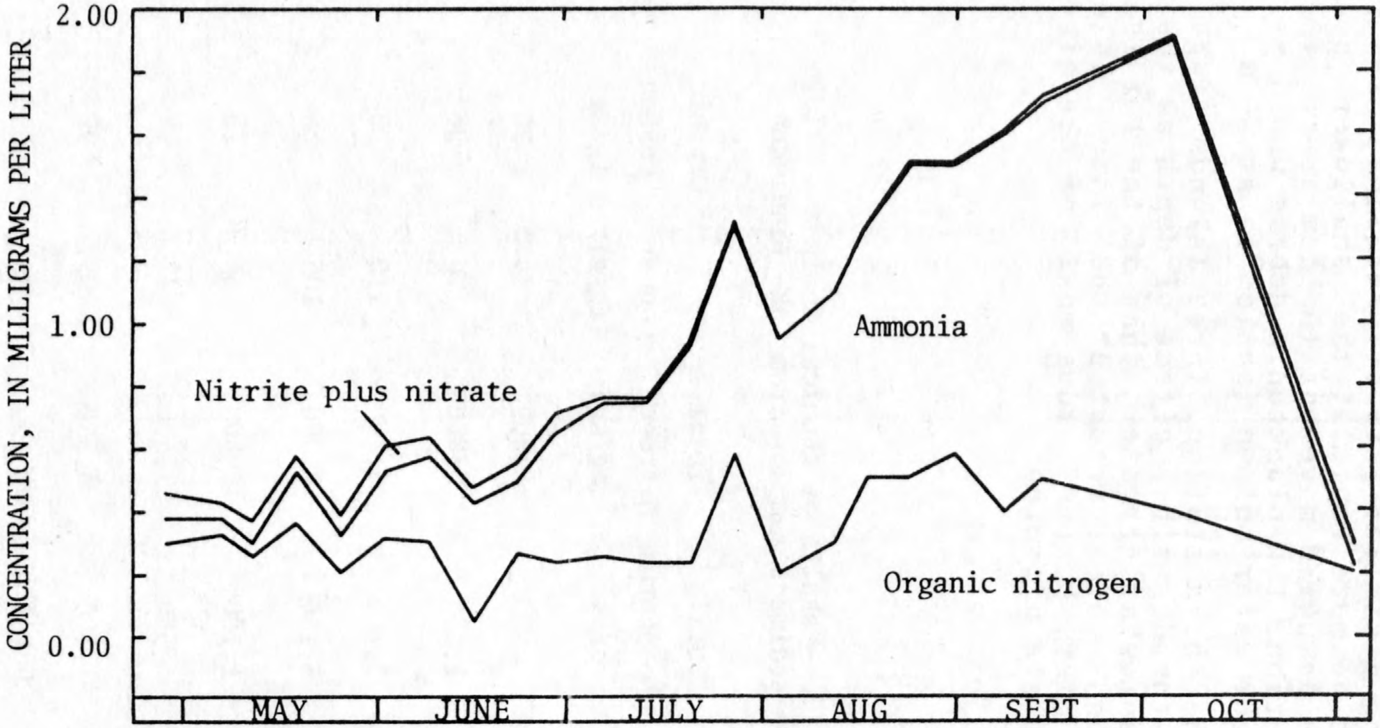
The net effect of the processes described above is to recycle (or lose) nitrogen more effectively than phosphorus resulting in an accumulation of phosphorus disproportionate to algal cell content of nitrogen and phosphorus. The rate of phosphorus accumulation is dependent on the productivity of the lake and the phosphorus loading.

Examples of NH_3-N accumulation in the hypolimnion at three stations (figs. 10, 11, and 12) on Lake Winnisquam illustrate the lack of nitrification (high NH_3-N, low NO_3-N) at the Mohawk Island (fig. 10) station due to the anaerobic conditions, and the result of apparent nitrification (high NO_3-N, low NH_3-N) at the Pot Island station (fig. 11) which remained aerobic throughout the sampling period. The marked difference between these two stations was also evident in the previously illustrated dissolved oxygen profiles. Other additional factors to take into account in comparing the two stations are depth and settling time of planktonic debris. Assuming a similar rate of settling, it follows that accumulation must be more rapid at the shallower station due to the limitation in downward movement (bottom is at 18 m) whereas, at the deeper station, the planktonic debris would be distributed throughout a larger water column (bottom is at 50 m).

Data from the third station, Three Islands (fig. 12), (bottom at 19 m) support the described effect of depth as the accumulation of nitrogen is somewhat greater than at the Pot Island station. Aerobic conditions were present at the Three Islands station throughout the summer, however, thus most of the nitrogen appears as organic or nitrate nitrogen.

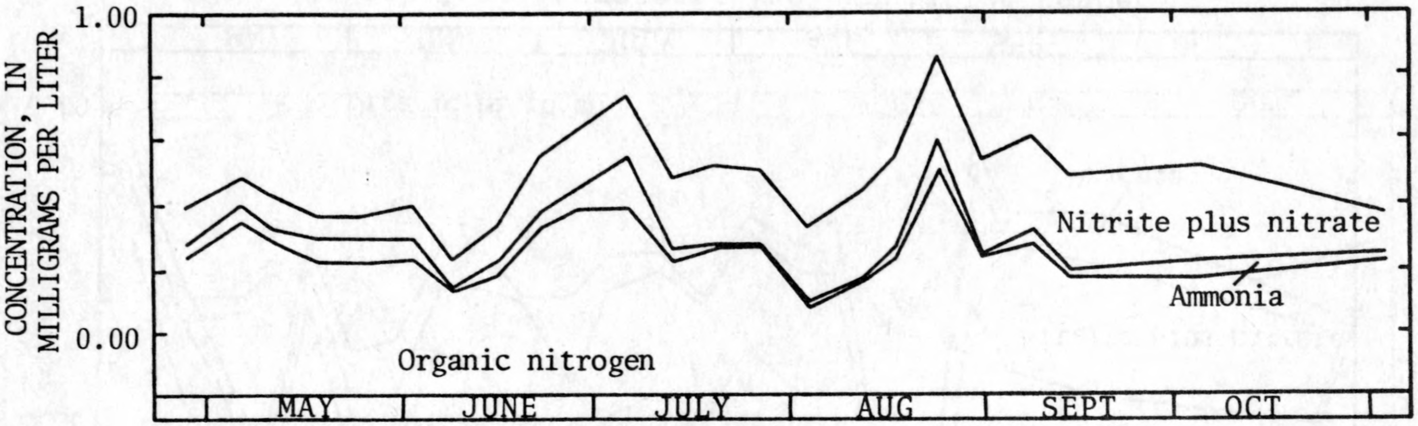
Table 12.--Results of chemical analyses of 1976 bottom-sediment samples from Lake Winnisquam

Station	Date	Total phosphorus (mg/kg)	Total nitrogen (mg/kg)	Copper (µg/g)	Organic carbon (g/kg)	Nitrogen to phosphorus ratio
Three Islands	6-22	950	5,500	30	73	5.6:1
	11-4	1,600	9,800	190	98	6.1:1
Pot Island	6-22	2,100	8,200	110	90	3.9:1
	11-4	3,100	7,900	100	86	2.5:1
Horse Point	6-22	1,100	6,800	51	78	6.2:1
	11-4	550	1,400	42	18	2.5:1
Mohawk Island	6-22	1,300	4,300	95	92	3.3:1
	11-4	760	9,100	200	69	12.0:1



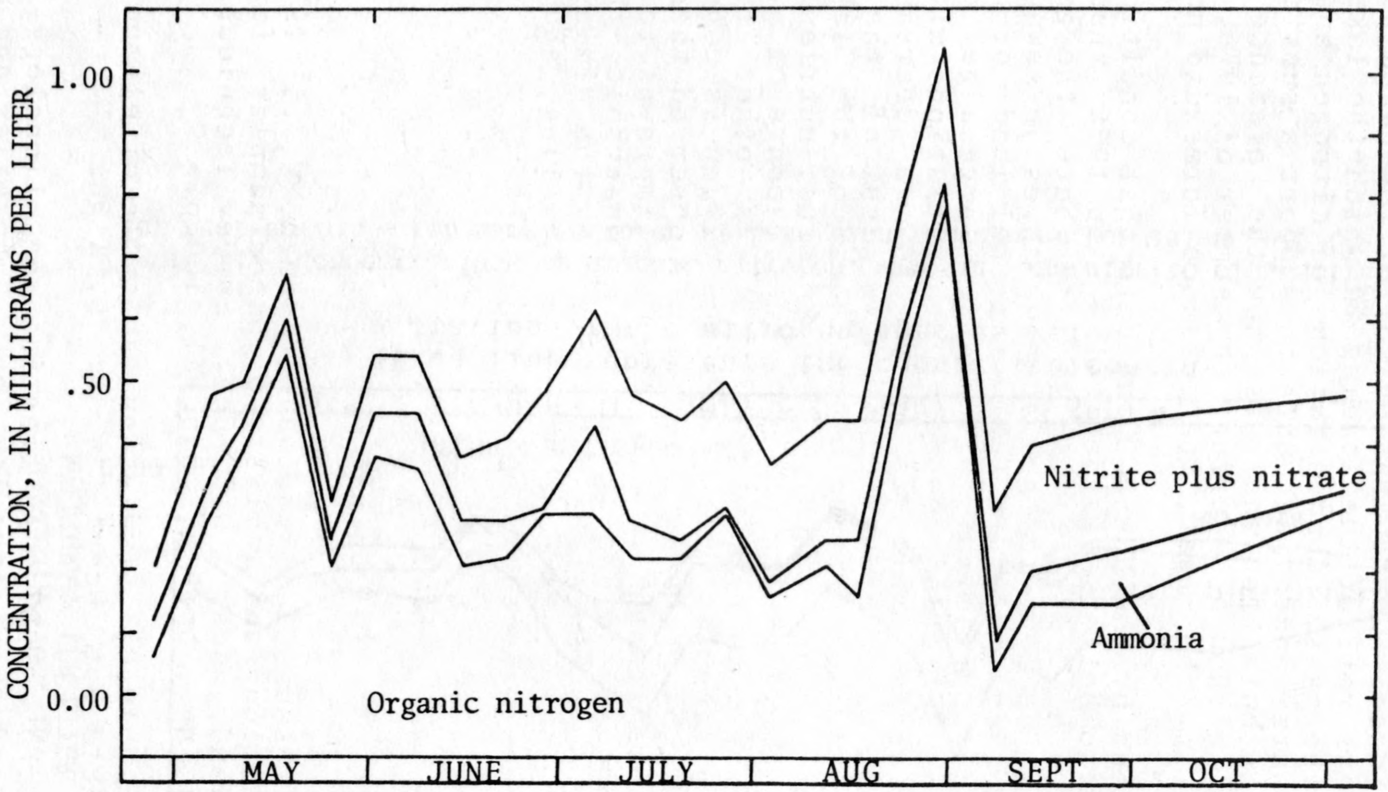
(Each line represents the cumulative concentration of the nitrogen species below it.)

Figure 10.--Concentrations of organic nitrogen, ammonia, and nitrite plus nitrate for near-bottom water samples taken at Lake Winnisquam near Mohawk Island, 1976



(Each line represents the cumulative concentration of the nitrogen species below it.)

Figure 11.--Concentrations of organic nitrogen, ammonia, and nitrite plus nitrate for near-bottom water samples taken at Lake Winnisquam near Pot Island, 1976



(Each line represents the cumulative concentration of the nitrogen species below it.)

Figure 12.--Concentrations of organic nitrogen, ammonia, and nitrite plus nitrate for near-bottom water samples taken at Lake Winnisquam near Three Islands, 1976

CONCLUSIONS

Lake Winnisquam has become enriched with nutrients through many years of sewage discharge from the city of Laconia and the Laconia State School. Concentrations of nitrogen and phosphorus in bottom sediments reflect the loading to which the lake has been subjected in the past. Concentrations of nitrogen and phosphorus in the lake water appear adequate to support a substantial algal population. Phytoplankton analyses show the presence of nuisance forms of algae although, during the summer of 1976, unlike many summer seasons in the past, the nuisance forms did not appear in great numbers.

Observations by the NHWSPCC indicate that conditions at Lake Winnisquam were better, esthetically, in 1976 than in recent years. It is not yet possible to attribute the general lack of algal blooms in 1976 to the recent changes in sewage-treatment practices, however, because the internal load of nutrients in the lake is still sufficient to support a large algal population.

Comparisons of total phosphorus concentrations with data of the 3 previous years (table 12) do not show a decreasing average concentration as might be anticipated in light of the absence of algal blooms. Because of the internal load of the lake and the continuing, but reduced input of phosphorus, nutrient concentrations in the lake water may not show the response of the lake to changes in sewage management as well as other factors. In particular, the rate at which dissolved oxygen is consumed in the hypolimnion may be a change more readily observed than decreasing phosphorus concentrations. If the lake improves to the point where the hypolimnion does not become anaerobic, then perhaps further improvement will be accelerated by the diminished availability of phosphorus via mineralization, cycling, and mixing from the enriched deep waters and bottom sediments.

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