PHYSICAL AND CHEMICAL LIMNOLOGY OF IDES COVE NEAR ROCHESTER, NEW YORK, 1970-1982

By Robert C. Bubeck, Ward W. Staubitz, Alan D. Weidemann, and Lisa P. Spittal

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CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS (continued)

TABLE

CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
centimeter (cm)	0.3937	inch
meter (m)	3.281	foot
square meter (m2)	10.76	square foot
kilometer (km)	.6214	mile
square kilometer (km2)	.3861	square mile
kilogram (kg)	2.2	pound

Temperature in this report is given in degrees Celsius, which can be converted to degrees Fahrenheit by the formula:

°F = 1.8 x °C + 32.

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "sea-level datum of 1929.")

The following water-quality terms and abbreviations are used in this report:

Milligram per liter (mg/L)
Microgram per liter (µg/L)
Nephelometric turbidity units (NTU)
Microsiemens per centimeter at 25°C (µS/cm)

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ABSTRACT

Ides Cove is a small embayment on the western shore of Irondequoit Bay near Rochester, N.Y. In 1982, alum was applied to the cove to seal the bottom sediments and thereby decrease nutrient fluxes in an effort to assess the applicability of this technique to Irondequoit Bay. Published data were used to develop a baseline analysis of the chemical and physical limnology of Ides Cove prior to the alum treatment and to provide a basis for comparison and evaluation of post-treatment data. The baseline analysis also enables evaluation of trends in the nutrient status and mixing patterns in Ides Cove since the decrease of sewage inflows and use of road salt in the Irondequoit Bay and Ides Cove drainage basins during 1970-82.

Data from 1970-72 and 1979-82 were used to construct partial and full-year depth profiles of several physical properties and chemical constituents of water in the cove; comparison of these profiles indicates a significant improvement in water quality between 1970 and 1982. The diversion of sewage out of the Irondequoit Creek drainage basin in the late 1970's resulted in an 80-percent decrease in total phosphate concentration and a 50- to 60-percent decrease in nitrogen (nitrate and ammonia) concentration in the cove. Indications of decreased primary productivity are associated with these lowered nutrient concentrations. Summer Secchi-disk transparency increased from 0.6 m (meters) in 1970-72 to 1.2 m in 1980-82; peak epilimnetic dissolved oxygen levels decreased from a range of 22 to 28 mg/L (milligrams per liter) to a range of 16 to 20 mg/L; and peak epilimnetic pH decreased from greater than 9.4 to between 8.8 and 9.0.

The decrease in the use of road salt in the Irondequoit basin beginning in 1974 resulted in a decrease in chloride concentration and gradient (difference between the surface and bottom concentration). The maximum annual chloride concentration in the epilimnion decreased from the 210-to-225-mg/L range in the spring of 1971-72 to the 140-to-150-mg/L range in the spring of 1980-82, and the gradient between the hypolimnion and epilimnion during the spring decreased from the 80- to 160-mg/L range in 1971-72 to the 0- to 90-mg/L range in 1980-82. Specific conductance values decreased similarly and indicate a comparable decrease in the density gradient from 1970-72 to 1980-82. The decrease in the density gradient resulted in an increase in the depth and duration of mixing in both the spring and fall of 1980-82, as illustrated by the profiles of physical properties, including temperature and specific conductance, and of chemical properties and constituents, including pH, alkalinity, dissolved oxygen, chloride, silica, and several species of nitrogen, phosphorus, and sulfur. These data indicate that Ides Cove, which was described as marginally meromictic in the early 1970's, had evolved by the early 1980's into a spring meromictic water body that underwent complete mixing in the fall and was approaching a consistent dimictic condition with spring and fall mixing. Thus, water quality and mixing patterns of the cove improved with the removal of sewage and the decrease in the use of road salt.

1 INTRODUCTION

PHYSICAL AND CHEMICAL LIMNOLOGY OF IDES COVE WAS ANALYZED TO EVALUATE CONDITIONS PRIOR TO THE 1982 ALUM TREATMENT

Bottom sediments of Ides Cove, a small cove on Irondequoit Bay, were treated with alum in 1982 to test its effectiveness in decreasing the flux of nutrients from the sediments to the water column. Monthly profiles of the depth distribution of selected chemical constituents measured prior to the alum treatment were plotted and analyzed to enable a comparison with conditions after the alum treatment.

Ides Cove is a small embayment with a surface area of 11,800 m2 on the western shore of Irondequoit Bay near Rochester, N.Y. (fig. 1). It is the deepest cove of the bay (8.8 m) and is separated from the bay by a submerged bedrock sill 50 m wide and 1.5 m deep that allows a free exchange of surface water between the bay and the cove (Bubeck, 1972). The bay and the cove are both highly eutrophic and have similar bottom sediments. The cove is protected from prevailing winds by steep slopes on the north and west, and, unlike Irondequoit Bay, was marginally meromictic in 1970-71—that is, it remained stratified throughout the year because natural protection from prevailing winds and the high density of the bottom waters relative to near-surface waters inhibited mixing (Bubeck, 1972).

Concern over the eutrophic condition of Irondequoit Bay led to several public policy changes during the 1970's. Principal among these were (1) a phosphate detergent ban in 1973, (2) the decrease in road-salt use by Monroe County in 1974, and (3) the diversion of treated sewage away from the Irondequoit Creek Basin in 1978-79. In a further effort to reverse the eutrophication of Irondequoit Bay, the Monroe County Environmental Health Laboratory (MCEHL) and the University of Rochester, as part of the U.S. Environmental Protection Agency's Clean Lakes Program, evaluated methods to decrease the diffusion of nutrients from the bottom sediments to the water column. The method selected entails the application of a layer of alum (aluminum sulfate) over the bottom sediments to form a barrier to the upward flux of nutrients to the water column. The alum was applied to Ides Cove in October of 1982 to test the feasibility of the method, which, if successful, could be applied to much larger areas in Irondequoit Bay. Ides Cove was selected as the test site because it is close to the bay and has similar water quality and bottom sediments.

In 1985, the U.S. Geological Survey (USGS), in cooperation with the MCEHL, began a 2-yr study to compile pretreatment data on the chemical quality and physical characteristics of Ides Cove to provide a basis for assessing the effectiveness of the alum treatment. Water-quality data from three sources—Bubeck (1972), Pesacreta (1981), and Burton and Holdren (1980, 1981, 1982a, 1982b, 1984)—were compiled and plotted as depth profiles to depict changes in mixing patterns and concentrations of nutrients and chloride over time. Because few data from 1973-78 were available, the profiles shown herein represent two periods—1970-72 and 1979 through October 1982. This survey of the pretreatment water-quality data also provides a baseline for documentation of changes in the water quality of Ides Cove since the cessation of treated sewage discharge in 1978-79 and the decrease in road-salt usage in 1974.

Purpose and Scope

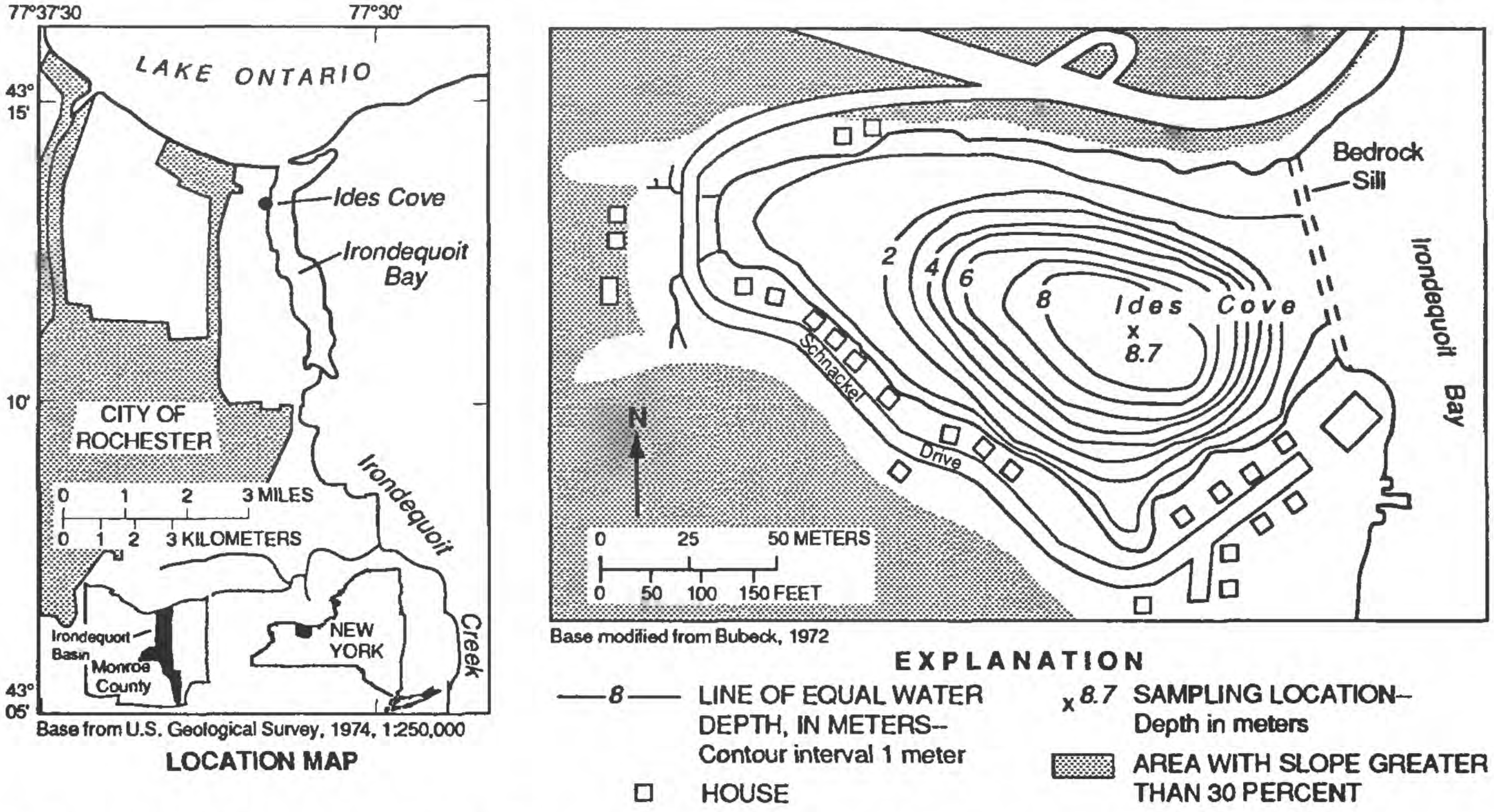
This report (1) describes the climatic and hydrologic factors that affect mixing and stratification of the water column in Ides Cove; (2) discusses potential sources of error in the data; and (3) describes changes in water clarity, specific conductance, and concentrations of selected chemical constituents and nutrients through comparison of depth profiles from the early 1970's with those from the early 1980's. The 18 profiles depict the depth of given values and concentrations from month to month through the two periods of record.

Previous Studies of Ides Cove

The first detailed study of Ides Cove (Bubeck, 1972) concluded that the cove was marginally meromictic—that is, a thin (1- to 1.5-m) layer of bottom water remained stratified and anoxic during the mixing periods from October 1970 through December 1972. The cove failed to mix below a depth of 7.5 m in the fall of 1970 and 1971 and did not mix below a depth of 6.5 m in the spring of 1971 or of 1972. Although complete (or nearly complete) mixing under the ice was observed in January 1973, water during the early 1970's was anoxic below a depth of 7.5 m and had a large oxygen deficit in the summer. The meromictic condition was characterized by specific conductance measurements as high as 2,200 µS/cm and chloride concentrations as high as 370 mg/L near the bottom, and large density gradients between the hypolimnion and epilimnion. Bubeck pointed out that the causes of the meromictic condition are complex and could be related to increased density of bottom waters as the result of (1) biochemical decomposition of organic materials and dissolution of inorganic compounds; (2) septic-tank leakage and discharge; and (3) washoff of road-deicing salts. Physical characteristics that inhibit mixing, such as protection from winds, long duration of ice cover, and a large depth-to-area ratio could also contribute to the meromictic conditions found in Ides Cove. Bubeck also observed excessive amounts of deicing salt on roads surrounding the cove and postulated that deicing salt could be the major cause of the marginally meromictic state. Bubeck's work (1972) also provides extensive nutrient data that describe the eutrophic condition of the cove in 1970 and 1971.

Pesacreta (1981) studied the stratification of Ides Cove in 1979-80 and noted that the resistance to mixing had decreased. Pesacreta and Makarewicz (1982) suggested that a discharge of natural saline ground water to the cove might have affected its stratification pattern, but they did not study the trends in other chemical constituents in the cove.

In 1979, Monroe County, in cooperation with the New York State Department of Environmental Conservation, began a long-term study of the water quality of the Irondequoit Bay watershed as a part of the National Urban Runoff Program (NURP). Concurrent with the NURP study, the MCEHL began a comprehensive water-quality monitoring program of the bay that included Ides Cove starting in September 1979.



Base from U.S. Geological Survey, 1974, 1:250,000

Base modified from Bubeck, 1972

Figure 1.--Location and depth of Ides Cove on Irondequoit Bay, Monroe County, N.Y. (Modified from Pesacreta and Makarewicz, 1982, p. 468, and Bubeck, 1972, p. 256.)

SNOWFALL AND ICE COVER AFFECT VERTICAL MIXING PATTERNS

The degree of mixing in Ides Cove is affected most greatly by the duration of ice cover and the quantity of snowfall and associated road-salt use. Mixing in Ides Cove is minimally affected by wind because the cove is protected on the north and west from the prevailing winds.

Wind

Wind is generally the major force driving the spring and fall circulation of shallow lakes. During those periods, density differences due to thermal stratification are so slight that turbulence from wind can provide mechanical mixing to the bottom. Because Ides Cove is bordered on the north, west, and south by relatively high hills, it is protected from the prevailing north and west winds. The driving force of wind for circulation is therefore much smaller in Ides Cove than in Irondequoit Bay, which has a 6-km unprotected north-south fetch. Only the relatively rare, strong eastern winds have much effect on mixing in Ides Cove.

Snowfall and Road-Deicing Salt

Heavy or frequent snowfall leads to increased application of deicing salt, which then enters the cove in washoff from adjacent roads (Bubeck, 1972). Increased salt concentrations tend to retard vertical mixing in the water column and thus increase its stability (Bubeck and others, 1971; Diment and others, 1974: and Burton, 1976). Variable amounts of snowfall were recorded at the Rochester International Airport during the study period—363 cm in 1970-71, 267 cm in 1971-72, 184 cm in 1979-80, 240 cm in 1980-81, and 326 cm in 1981-82—and resulted in variable use of road salt. Additionally, Bubeck and Burton (1989) demonstrated that deicing-salt use in the Irondequoit basin has been declining from a normalized rate of more than 225,000 kg per centimeter of snowfall in 1969-71 to 115,000 kg/cm by 1979-82. Although the amount of salt used in the immediate vicinity of Ides Cove is unknown, Pesacreta and Makarewicz (1982) suggest that it has also declined since the early 1970's.

Ice Cover

Early ice cover in the fall and prolonged ice cover in the spring can decrease wind-driven mixing. Ice usually covers Ides Cove from mid- to late December through the first 2 weeks of April. (Periods of ice cover are indicated in all chemical profiles herein). In 1980, ice did not completely cover the cove until early January, and in 1981, icemelt was early (mid-March).

Rainfall and Runoff

Greater-than-normal amounts of rainfall and runoff during nonwinter periods can increase turbidity and nutrient loads, and dilute relatively nonreactive constituents, such as chloride. Precipitation was greater than normal in June 1972, June 1980, and from July through September 1981 (fig. 2).

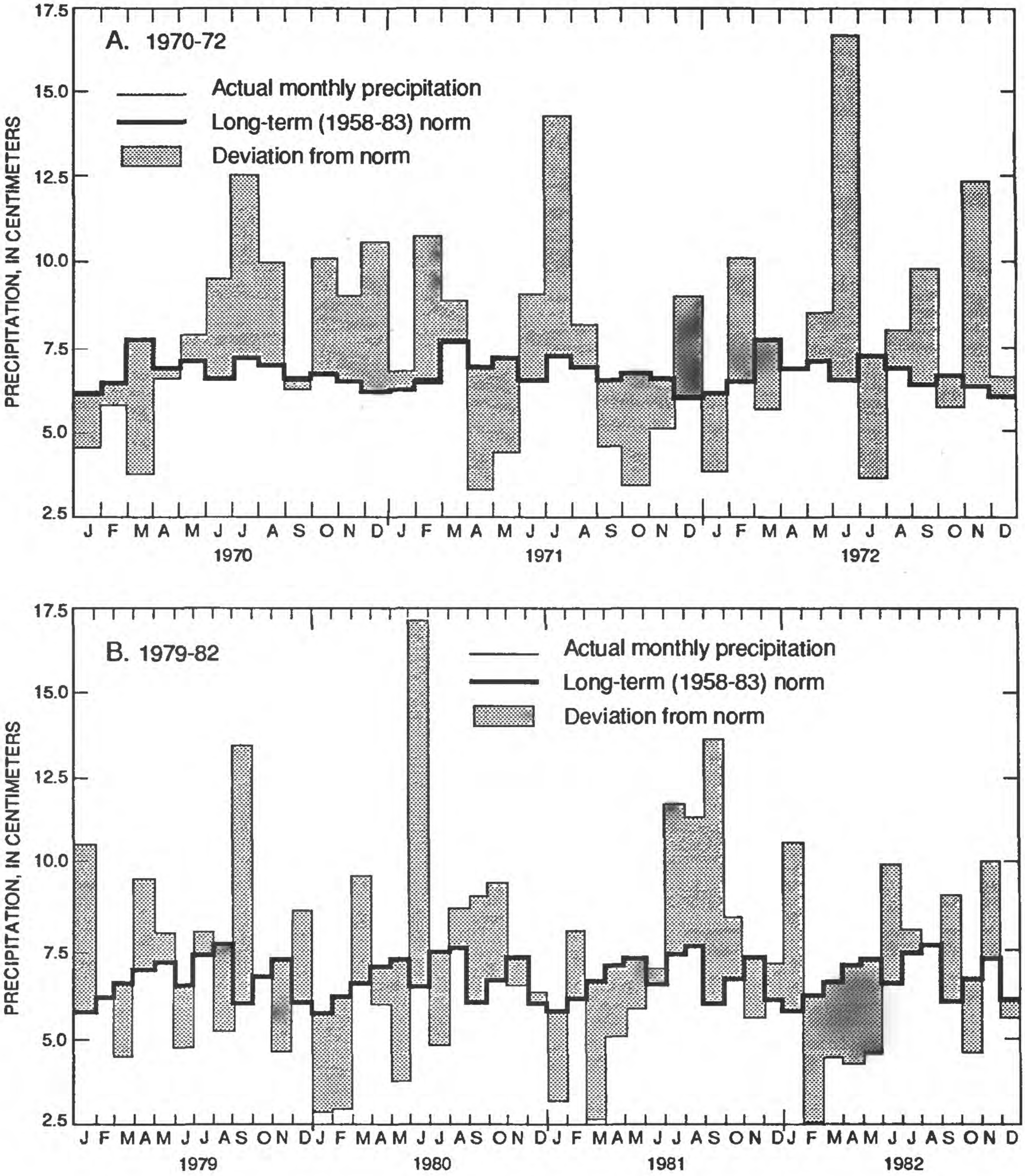


Figure 2.--Monthly precipitation and deviation from normal measured at the Rochester International Airport: A. During 1970-72. B. During 1979-82.

3 ERROR ANALYSIS

THE DEGREE TO WHICH DEPTH PROFILES REPRESENT ACTUAL WATER-QUALITY CONDITIONS DEPENDS ON THE PRECISION OF SAMPLING AND ANALYTICAL TECHNIQUES

The position of profile lines and the degree to which they represent actual conditions depend on spatial and temporal sampling intervals, lake-water levels, and the precision of analytical methods. Profiles for dissolved oxygen and pH are also affected by diurnal changes in primary production.

Depth profiles of chemical constituents and physical characteristics through time are used to indicate spatial and temporal changes in the physical and chemical limnology of Ides Cove. The profile lines, shown in figures 4A-4K, represent the depth of specified values of physical characteristics or concentrations of chemical constituents at a given site over time. The profile lines are either interpolated by a computer or drawn by hand (as was done in this study) along points of measured values of the physical characteristic or chemical constituent. How closely lines represent actual conditions depends on the spatial and temporal intervals at which the point values were measured and the timing of processes such as changes in water level and mixing, and diurnal changes in primary productivity, all of which affect the distribution or concentration of the physical characteristics or chemical constituents. The accuracy of the profiles also is affected by the analytical precision of laboratory and field measurements.

Depth and Frequency of Sampling

Although data sets from three different researchers were used to develop the profiles for this report, the frequency and depth of sampling were similar in each data set, and sampling was always done at about the same location (the deepest part of the cove, shown in fig. 1). Generally, water-column samples were collected at least once per month and usually twice per month, although some samples were missed during periods of ice formation or breakup in the early and late winter. Water temperature, pH, and specific conductance were generally measured at 0.5-m depth intervals, and samples for laboratory analysis of chemical constituents were collected at 1- to 2-m intervals. The profiles developed from these data generally can be considered representative of actual conditions to within 1 m of depth and within 1 week in time.

Water Levels

Seasonal variations in the water level of Ides Cove introduce seasonal variations in the relative depth of a given profile line. The water level in Ides Cove is controlled by the water level of Lake Ontario. Each year, lake-level fluctuation ranged from 0.5 to 0.75 m (based on Lake Ontario mean depth) except in 1972, when heavy summer rains caused lake levels to rise more than 1 m (fig. 3). Lake levels generally increase from a minimum in December and January to a maximum in May and June. The profiles in this report were drawn according to the recorded sampling depth (depth below water surface). Important to the interpretation of the profiles is the decline in lake levels throughout most of the summer, which are reflected as slowly rising slopes in the profile lines from the late spring to fall.

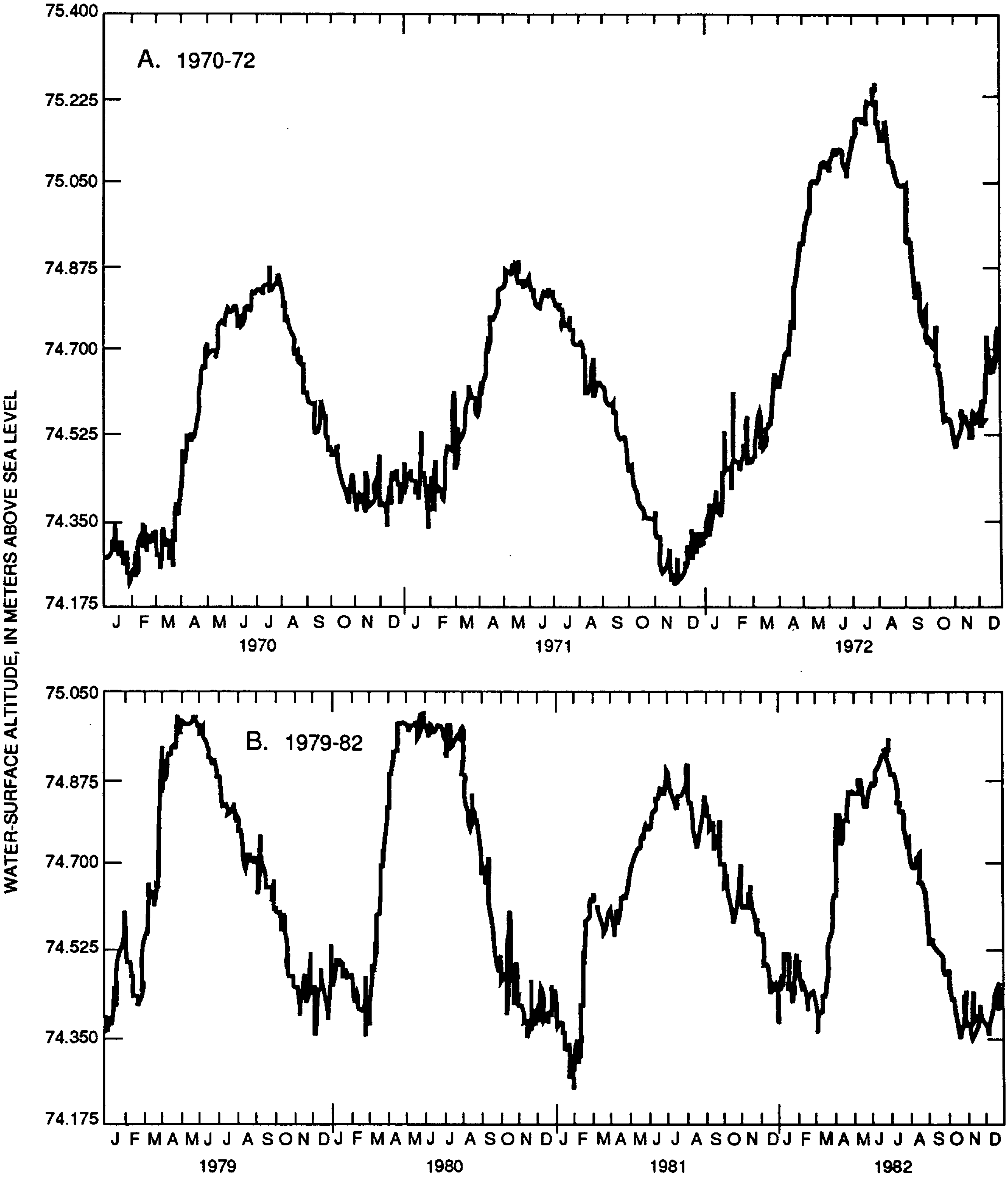


Figure 3.--Water-surface elevation of Lake Ontario measured at Oswego, N.Y. A. During 1970-72. B. During 1979-82. (Data from Hood and others, 1982, 1983, 1984, and U.S. Geological Survey, 1971, 1972, 1973.)

Sampling Methods and Analytical Procedures

This report summarizes data from three sources: Bubeck (1972), Pesacreta (1981), and MCEHL (Burton and Holdren, 1980-84). Differences among the analytical sampling methods and procedures used by these investigators could have yielded some systematic errors in the data and, in turn, in the comparison of the 1970-72 results with those from 1979-82. Pesacreta and MCEHL measured alkalinity, temperature, specific conductance, and dissolved oxygen independently in 1979 and 1980 but seldom sampled on the same day of the week or at the same time of day. The MCEHL sampled Mondays through Fridays around noon, and Pesacreta sampled on Saturday mornings. Not all constituents can be expected to show stable, uniform values because the water mass is in constant movement, and many constituents or properties undergo reactions and thereby change in concentration. Temperature, dissolved oxygen, and pH are especially subject to diurnal variations. Near-surface temperatures measured by Pesacreta in the fall were lower than those measured by the MCEHL. Differences were also observed in dissolved oxygen concentrations and pH that are attributed to photosynthetic processes, whereby oxygen concentration increased by as much as 4 mg/L (about 40 percent) from Pesacreta's morning measurement to MCEHL's mid-day measurement. Because the data presented here could eventually be compared with the post-treatment data collected by MCEHL, the profiles were drawn from the mid-day sampling data.

4. PHYSICAL AND CHEMICAL LIMNOLOGY

4 PHYSICAL AND CHEMICAL LIMNOLOGY

A. Specific conductance

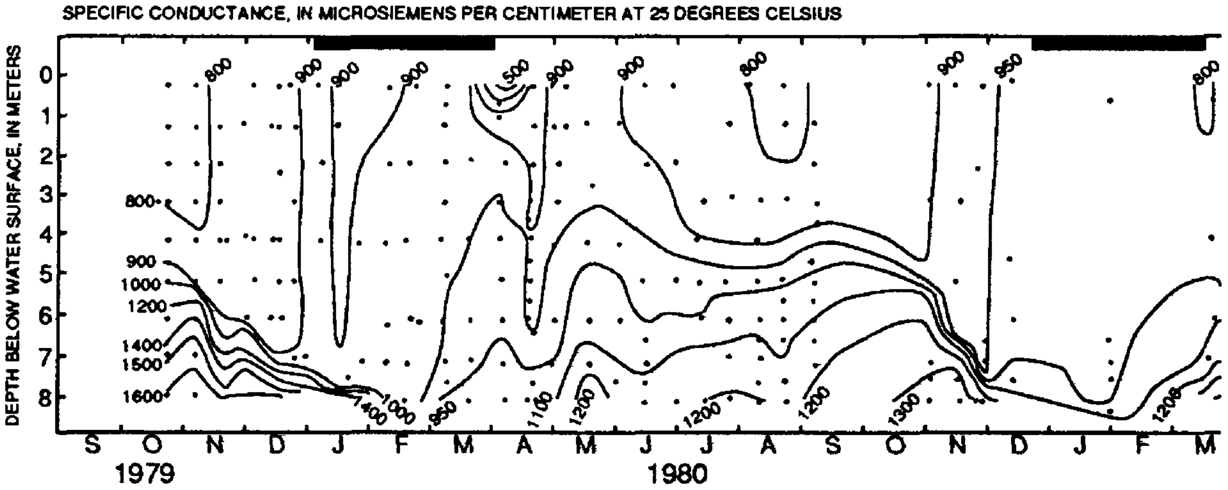
DECREASING SPECIFIC CONDUCTANCE INDICATES A WEAKENING OF THE CHEMICAL GRADIENT

Specific conductance is an indicator of dissolved-solids concentration. Both the specific conductance values and the gradient through the water column were generally smaller in the early 1980's than in the early 1970's. This resulted in decreased water-column stability and increased mixing in the early 1980's.

Specific conductance is a measure of the ability of a solution to conduct an electric current. The presence of charged ions in solution makes the solution electrically conductive. As ion concentrations increase, conductance of the solution increases; therefore, specific conductance is a measure of dissolved solids concentration (Hem, 1985, p. 66). Specific conductance is expressed in units of microsiemens per centimeter (μS/cm) at 25°C. The gradient of specific conductance represents the chemical concentration gradient of the water column and is an indirect measure of its resistance to mixing. If circulation (or mixing) to the bottom in spring or fall is incomplete, ions accumulate to a greater extent in the hypolimnion than in the epilimnion and create a specific-conductance gradient between the surface and bottom waters. The larger the gradient from surface to bottom, the greater the resistance to mixing and, therefore, the greater the stability of the water column. Seasonal circulation causes gradients to diminish. The profiles of specific conductance (fig. 4A) show distinct periods with strong chemical gradients and periods with weak ones; the former reflect periods of stability, and the latter reflect periods of seasonal mixing.

Specific conductance generally increased in the bottom waters under winter ice cover as a result of the inflow of dissolved solids from groundwater seepage (Pesacreta and Makarewicz, 1982) and deicing-salt washoff. In early spring, specific conductance of the near-surface water decreased as freshwater accumulated under the melting ice cover, as seen in the profiles for March 1971 and 1980. The gradient that forms just before ice-melt could inhibit spring mixing. The profiles also show that the spring conductivity gradient in April 1982 was only about 50 μS/cm. Those in previous years had been 1,000 μS/cm in May 1971, 400 μS/cm in April 1972, and 500 μS/cm in April 1981. In the spring of 1980, when mixing was nearly complete, the gradient in April was only 100 μS/cm.

The specific-conductance profiles show that autumnal circulation started about a month earlier (Sep-



tember) in 1979-82 than in 1970-72 (October) because the dissolved-solids concentration and specific-conductance gradient of the early 1980's had decreased. Mixing continued until ice cover formed in mid- to late December. Mixing was incomplete in the early 1970's but was complete or nearly so in the early 1980's. Fall mixing was evident to a depth of 7.5 m in 1970, 6 m in 1971, and 4.5 m in 1972, then to 7.5m in 1979 and 1980 and to 7.0 m in 1981. In 1980 and 1981, mixing under the ice was evident in January and February. Mixing under the ice appears to be common at Ides Cove, and the lack of mixing under the ice in 1982 can perhaps be attributed to the large amount of snowfall (326 cm) in the 1981-82 season and the associated intrusion of salt-laden runoff from early snowmelt.

Overall, specific conductance values were generally lower in 1979-82 than in 1970-72. For instance, specific conductance in the bottom 2 m in 1979-82 ranged from 950 to 1,600 µS/cm, compared to 1,300 to 2,200 µS/cm in 1970-72. Similarly, specific conductance during fall mixing was 300 to 600 µS/cm lower in 1979-82 than in 1970-72. The most important difference, however, is that the specific-conductance gradients between the surface and the bottom during the summers decreased about 40 percent between 1971-72 and 1980-82. The gradient on about September 1 ranged from 660 to 700 µS/cm in 1971-72 and from 300 to 485 µS/cm in 1980-82.

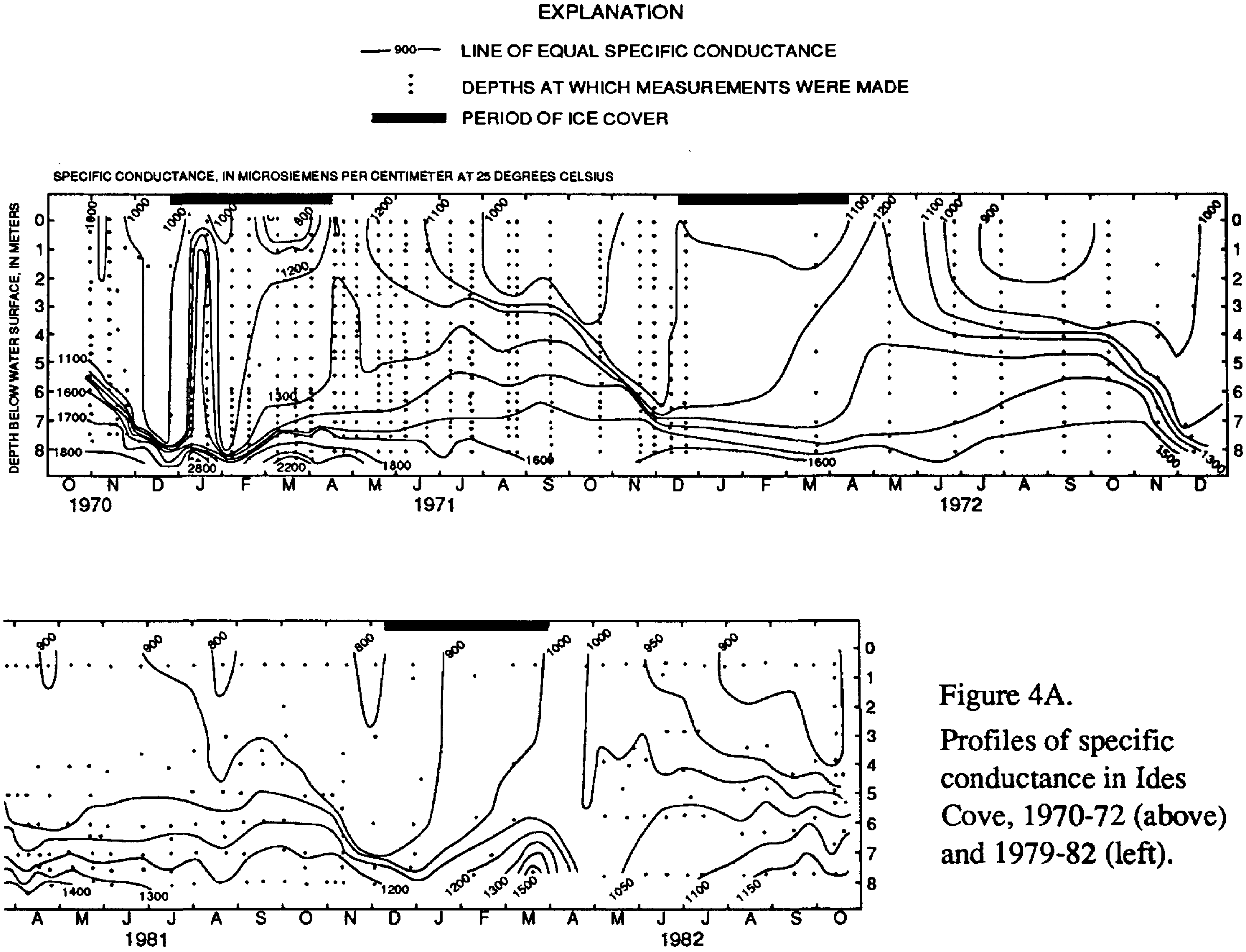


Figure 4A.
Profiles of specific conductance in Ides Cove, 1970-72 (above) and 1979-82 (left).

4 PHYSICAL AND CHEMICAL LIMNOLOGY

B. Water Temperature

WATER COLUMN WAS LESS STABLE IN THE EARLY 1980'S THAN IN THE EARLY 1970'S

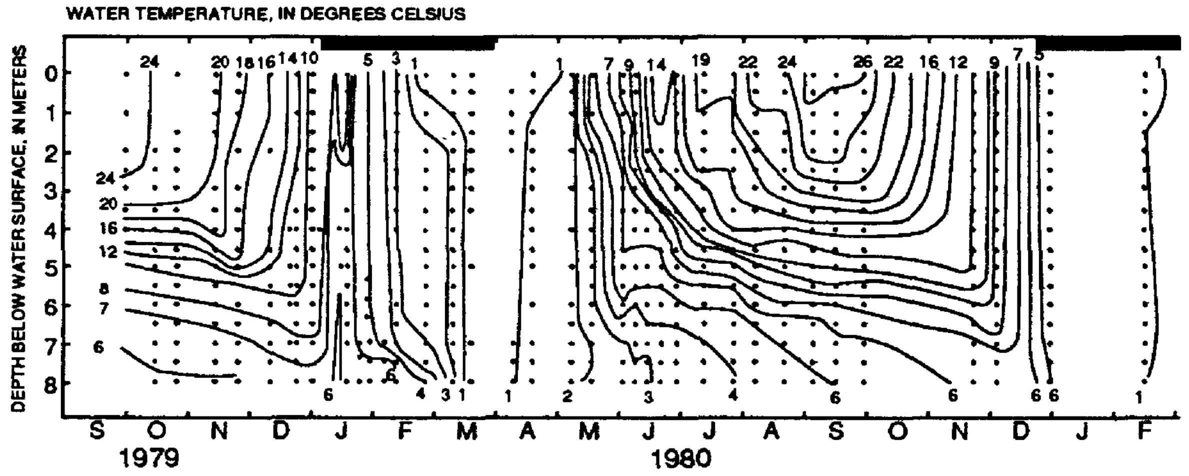
Temperature profiles from Ides Cove show a pattern of rapid warming in the spring, stable stratification in the summer, mixing in late fall, and inverse stratification under ice cover. Deepening of the summer thermocline and earlier isothermal conditions in the fall of 1979-81 indicate less stability in the water column in the early 1980's than in the early 1970's.

Temperatures throughout the water column vary with climatic conditions, and water temperature in the epilimnion is additionally affected by the exchange of water with Irondequoit Bay. Water in the epilimnion warms rapidly after ice-out in the spring. The rate of spring warming can be seen in the spacing of the profile lines in figure 4B. Closely spaced profile lines, such as in April 1972, April 1981, and April 1982, indicate rapid warming; wider spacing, such as in the spring of 1971 and 1980, indicates slower warming. Although the rate of spring warming varies from year to year, the water temperature of the epilimnion generally reaches 16°C by mid-May.

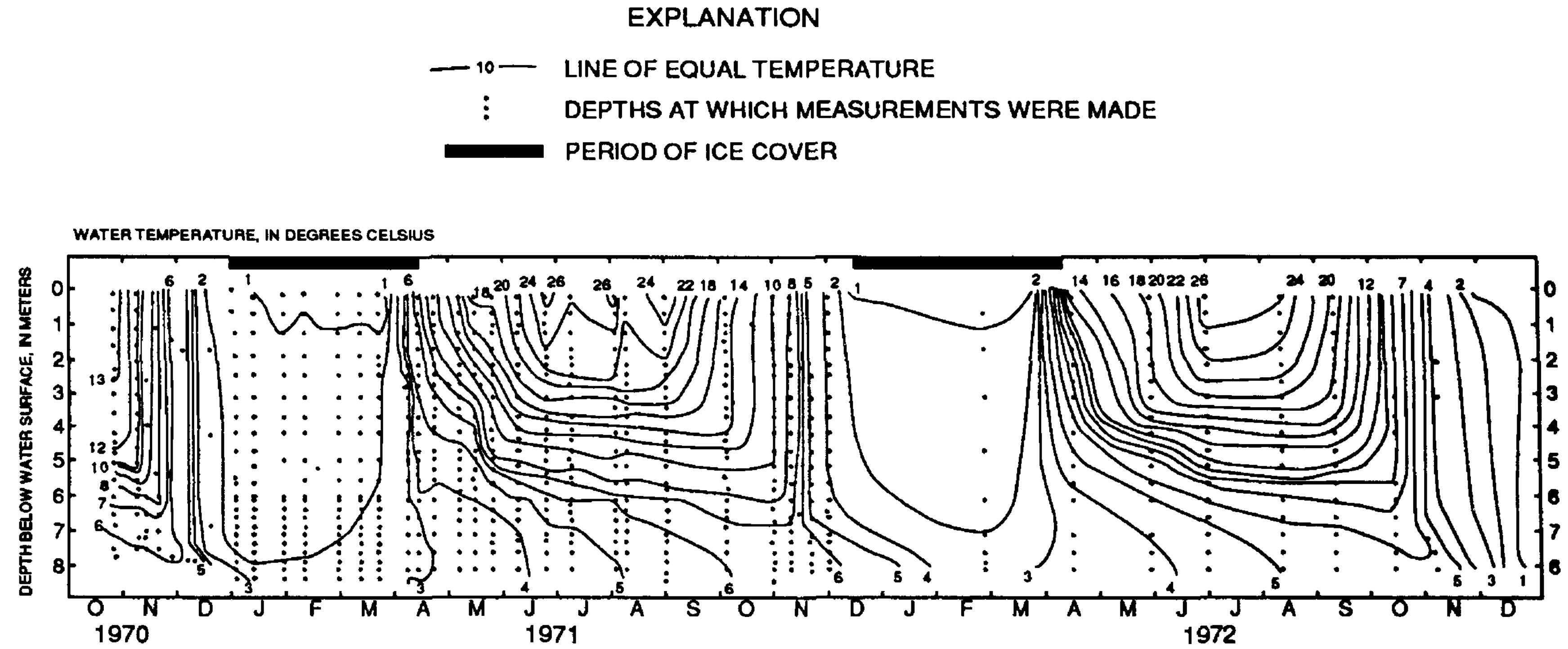
Once the water temperature of the epilimnion exceeds 12°C, density decreases rapidly, and thermal stratification begins. The thermocline in Ides Cove steepens rapidly, enhanced by chemical gradients that increase stability. Thermal stratification is strongest in July and August, when the temperature of the near-surface water is 24 to 26°C and bottom water is 5 to 6°C, and the temperature gradient through the thermocline is about 6°C/m. The thermocline appears to have deepened between 1970 and 1982, suggesting a decrease in the stability of the water column.

Beginning in mid-August, heat loss at night exceeds heat input during the day and results in surface cooling and a deepening of the thermocline in October and November. Isothermal conditions were observed in late fall of 1979-81, in contrast to the fall of 1971 and 1972, when a temperature gradient was observed. This change indicates a decrease in the stability of the water column by the early 1980's and an increase in fall mixing.

Ice generally forms on Ides Cove by late December. The difference in density between water of 0°C immediately below the ice and warmer



water beneath it results in an inverse stratification that is maintained throughout the winter by intrusion of cold water near the surface, slight warming of deep water through low-level heat flux from bottom sediments and ground-water inflow, and the accumulation of dissolved salts (Bubeck, 1972; Bubeck and Burton, 1989). Inverse stratification beneath the ice was strong in the winters of 1970-72 but was weak or absent in 1979-82 (fig. 4B), which again suggests a decrease in the stability of the water column in the early 1980's relative to that in the early 1970's.



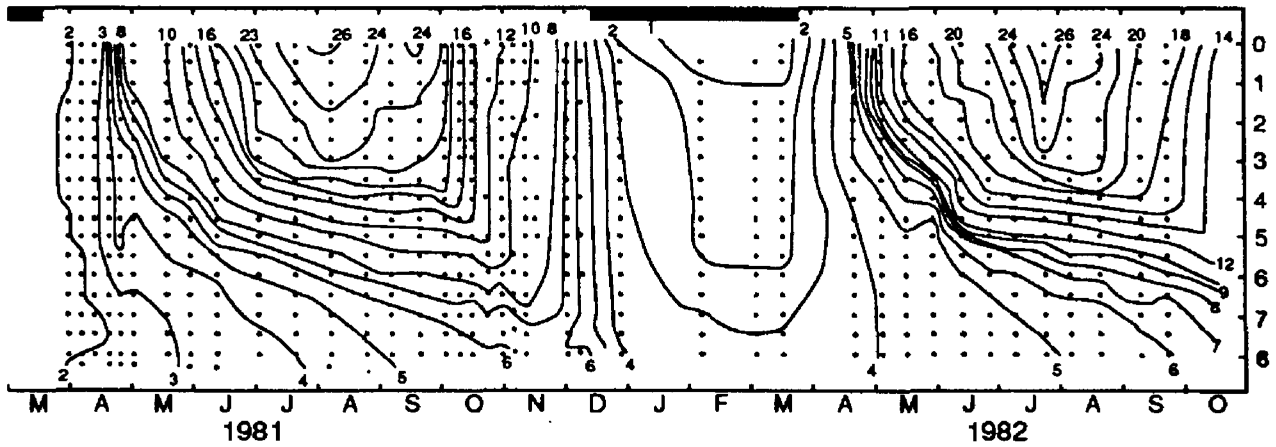


Figure 4B.
Profiles of water temperature in Ides Cove, 1970-72 (above) and 1979-82 (left).

C. Water clarity

MIDSUMMER WATER CLARITY WAS GREATEST DURING 1982

Before 1982, water clarity in midsummer, measured as Secchi-disk transparency, was 0.6 to 0.7 m, but in midsummer of 1982 it was about 1.2 m. The increase in water clarity can be ascribed to a decrease in both phytoplankton biomass and the abundance of gas-vacuolate blue-green algae.

Water clarity is a measurement of the transparency of water to light. It can be measured in the water column by the Secchi disk, a black-and-white disk, 20 cm in diameter. The mean depth at which the disk is no longer visible to the observer's eye and the depth at which it reappears upon being raised is termed the Secchi-disk transparency (Wetzel, 1983). Although this method relies on visual judgment, it is a valid basis for comparison of water clarity. Turbidity, another indicator of the water clarity, is measured in the laboratory as a quantitative expression of the optical property that causes light to be scattered and absorbed rather than transmitted in a straight line (American Public Health Association, 1985). Measured Secchi-disk transparency in 1970-72 and 1980-82 is plotted in figure 4C. Monthly values of water clarity (as Secchi-disk transparency and turbidity) are listed in the table on page 15.

Seasonal variations in clarity follow the cycles of phytoplankton blooms and suspended particulates. A strong link between the presence of the gas-vacuolate blue-green algae bloom and turbidity has been shown by Weidemann (1985) and

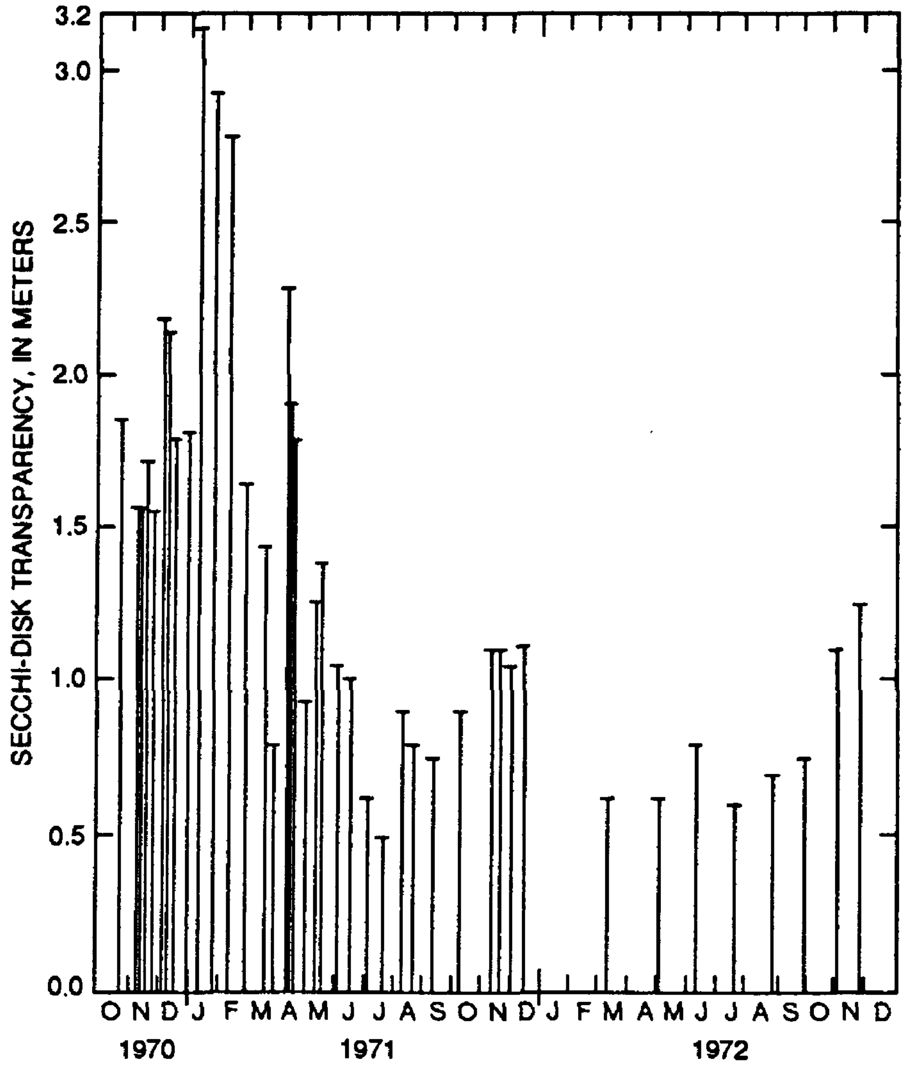


Figure 4C.--Depth profiles of Secchi-disk transparency in Ides Cove, 1970-72.

Weidemann and Bannister (1986). Clarity was greatest (1.2 to 3.1 m) in January or February under the ice when algal production and suspended material were both at an annual minimum and was least (0.6 to 1.4 m) from July through September, the peak of gas-vacuolate blue-green algae blooms (fig. 4C and table 1). Midsummer water clarity measured as Secchi-disk transparency ranged from 0.6 to 0.7 m during 1970-81 and had increased to 1.2 m by 1982, concurrent with a decline in the population of gas-vacuolate blue-green algae (Weidemann, 1985).

Table 1.--Monthly summary of water clarity, 1970-72 and 1980-82. [Secchi-disk transparency in meters; turbidity (in parentheses) in nephelometric turbidity units (NTU). Dashes indicate no data]

Month	1970	1971	1972	1980		1981		1982	
January	--	3.1	--	--	--	1.0	--	1.2	(2.0)
February	--	2.8	--	2.0	(2.0)	--	--	2.1	(1.7)
March	--	1.3	0.5	--	(6.0)	1.2	(3.9)	1.5	(1.7)
April	--	1.7	0.6	0.7	(3.3)	1.2	(4.3)	1.2	(3.4)
May	--	1.3	--	1.0	(3.0)	1.2	(2.6)	1.4	(2.3)
June	--	1.0	0.8	0.8	(6.9)	1.3	(5.3)	1.4	(2.6)
July	--	0.6	0.6	0.7	(8.6)	--	--	1.2	(2.6)
August	--	--	0.7	0.6	(14.7)	0.6	(12.5)	1.1	(2.5)
September	--	0.7	0.8	--	--	0.9	(8.6)	1.4	(3.8)
October 1.8	0.6	1.1	0.9	(3.2)	0.9	(3.9)	1.5	(2.0)	
November	1.6	1.1	1.2	1.6	(1.6)	1.4	(2.2)	1.4	(1.0)
December	2.0	1.1	--	--	--	2.6	(2.0)	2.0	(1.7)

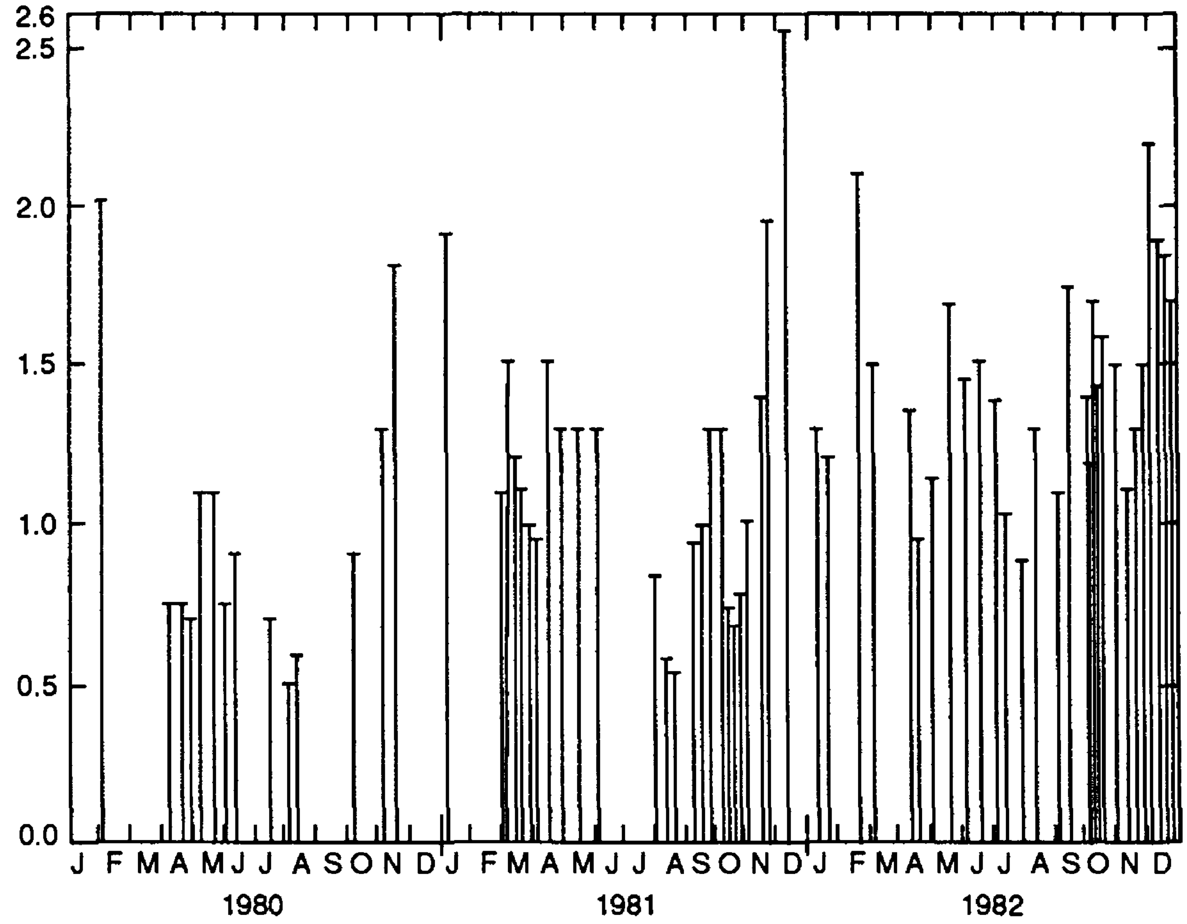


Figure 4C.--Depth profiles of Secchi-disk transparency in Ides Cove, 1980-82.

4 PHYSICAL AND CHEMICAL LIMNOLOGY

D. pH

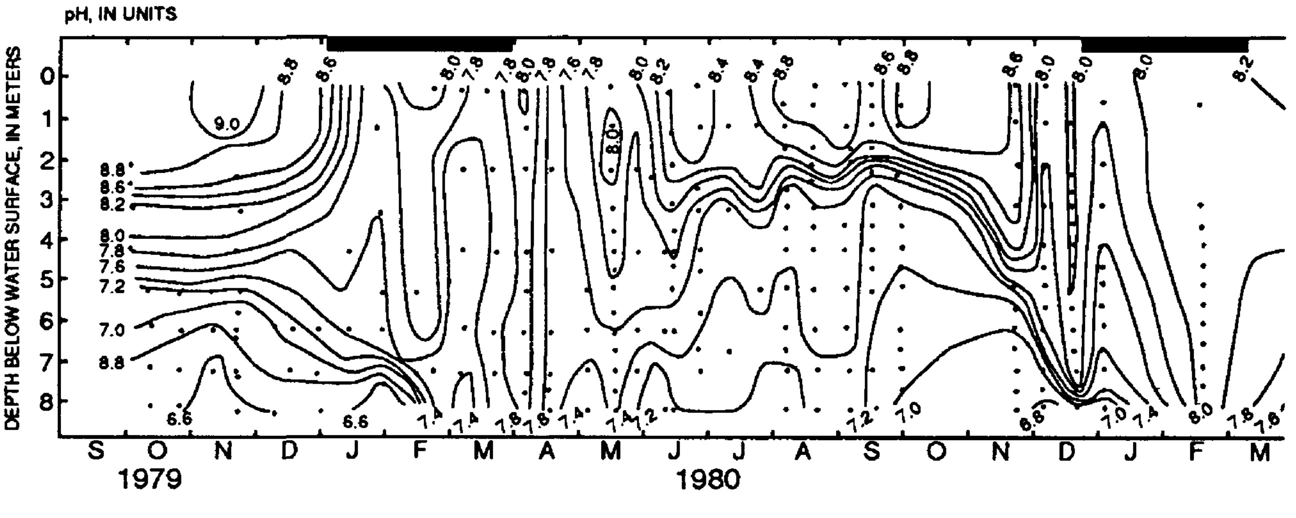
DECREASE IN pH OF EPILIMNION INDICATES A DECLINE IN OVERALL ALGAL PRODUCTIVITY

The pH of the epilimnion generally increases in summer through the removal of CO_2 during photosynthetic activity by algae. The decrease in the magnitude and duration of high pH in the epilimnion between 1970-72 and 1979-82 indicate decreased algal productivity.

The seasonal fluctuations of pH in Ides Cove are typical of hard-water lakes with high algal productivity in the epilimnion and strongly reducing conditions in the hypolimnion. During the spring, when most of the water column was mixed, pH was fairly uniform from surface to bottom and neutral to slightly alkaline—pH 7.0 to 7.8 (fig. 4D). Epilimnetic pH generally increases in summer as CO_2 is removed during photosynthetic activity, whereas bottom-water pH decreases as CO_2 is produced as a byproduct of decomposing organic matter.

Summer epilimnetic pH values in 1971 were as high as 9.4, and values in excess of 8.8 were regularly recorded from early June through mid-October. By the summers of 1980-82, pH had decreased considerably, however, and episodes of pH greater than 8.6 were brief— an indication that productivity had declined by 1980-82.

In the hypolimnion, the duration of periods when pH was less than 7.0 decreased from nearly 18 months in 1971-72 to 1 to 3 months in 1980-82. The shortening of periods with low pH could indicate a weakening of reducing conditions in the bottom waters through increased circulation (vertical mixing) during the spring and fall in 1980-82.

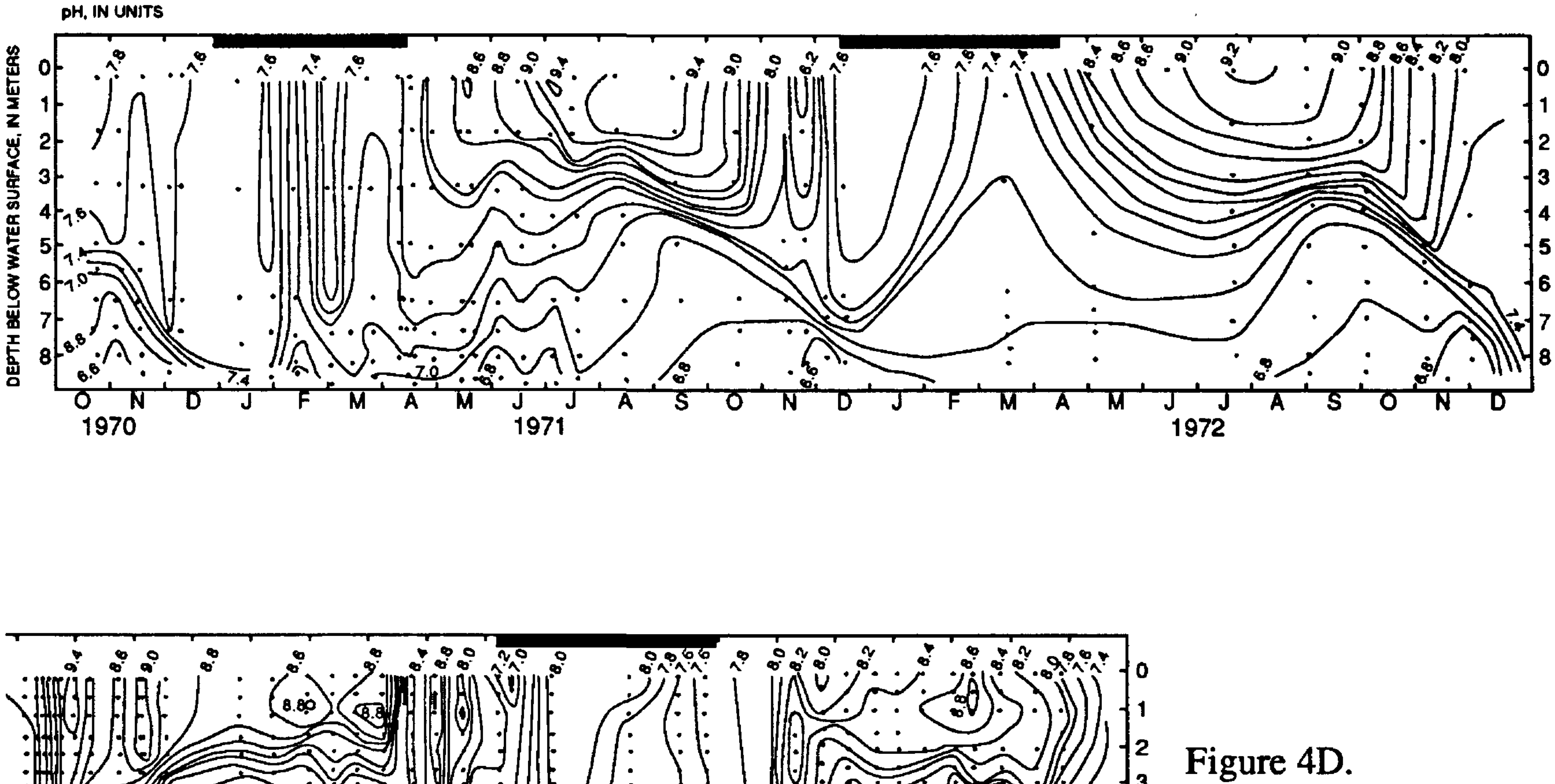


EXPLANATION

—7.4— LINE OF EQUAL pH

⋮ DEPTHS AT WHICH MEASUREMENTS WERE MADE

▬ PERIOD OF ICE COVER



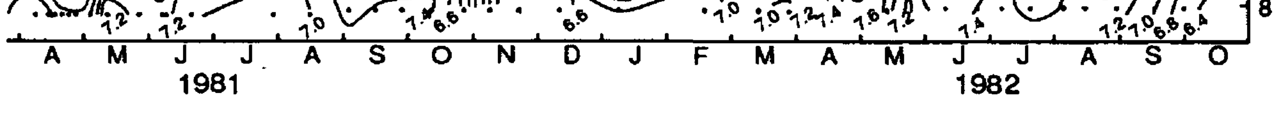


Figure 4D. Depth profiles of pH in Ides Cove, 1970-72 (above) and 1979-82 (left).

4 PHYSICAL AND CHEMICAL LIMNOLOGY

E. Dissolved Oxygen

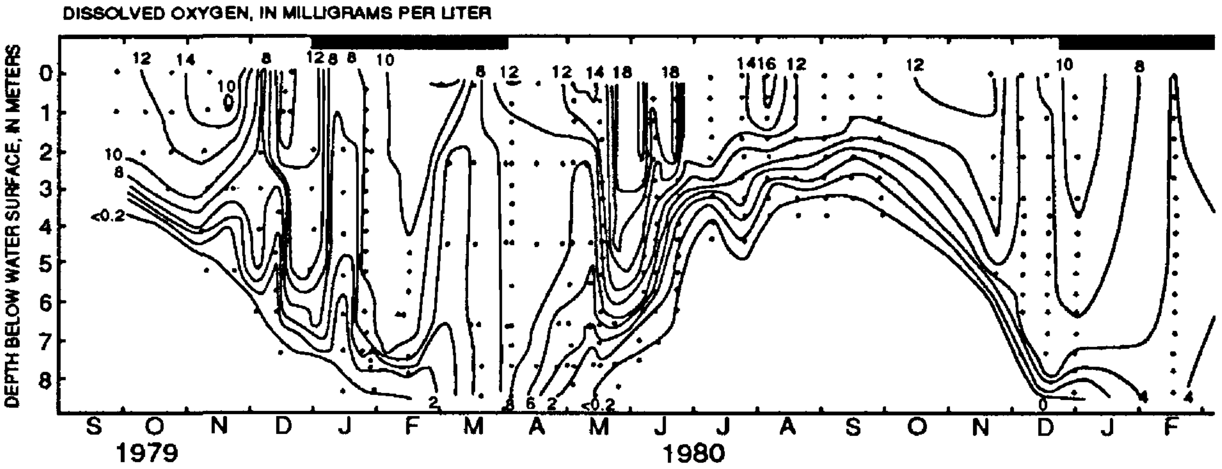
HYPOLIMNION OF IDES COVE WAS ANOXIC FOR LONG PERIODS IN ALL YEARS OF STUDY

Epilimnetic concentrations of dissolved oxygen varied seasonally from below saturation to 2 times greater than saturation, whereas the hypolimnion was often anoxic. Although oxygen was present in bottom waters in spring and fall of 1980-82, oxygen depletion was rapid, and periods with oxic conditions were of short duration.

The dissolved oxygen profiles of Ides Cove (fig. 4E) show great variability, both seasonally and with depth. Epilimnetic concentrations of oxygen varied seasonally from below saturation to 2 times greater than saturation, whereas the hypolimnion was often anoxic. The variability in the oxygen concentration is largely due to the high algal productivity in the epilimnion (producing oxygen), the decomposition of organic matter in the hypolimnion (consuming oxygen), and the mixing of these two layers.

After spring mixing, dissolved oxygen concentrations in the epilimnion increased through algal production and generally exceed saturation levels from spring through fall. During this period in 1971 and 1972, oxygen concentrations generally exceeded 16 mg/L and were as high as 28 mg/L in April 1972. By 1980-82, oxygen concentrations were generally less than 16 mg/L and did not exceed 20 mg/L at any time of measurement. The decrease in epilimnetic oxygen concentrations is another indication that algal productivity decreased after 1970-72.

Decomposition of organic matter in the bottom sediment of Ides Cove produced a highly reducing environment that sustained an anoxic hypolimnion for long periods in all years of study. In 1971 and 1972, the bottom water was anoxic throughout both years. By 1980-82, when mixing was more complete, oxygen was detected in the bottom water in each spring and fall, but oxygen depletion in the hypolimnion was rapid, and periods with oxic conditions were short.

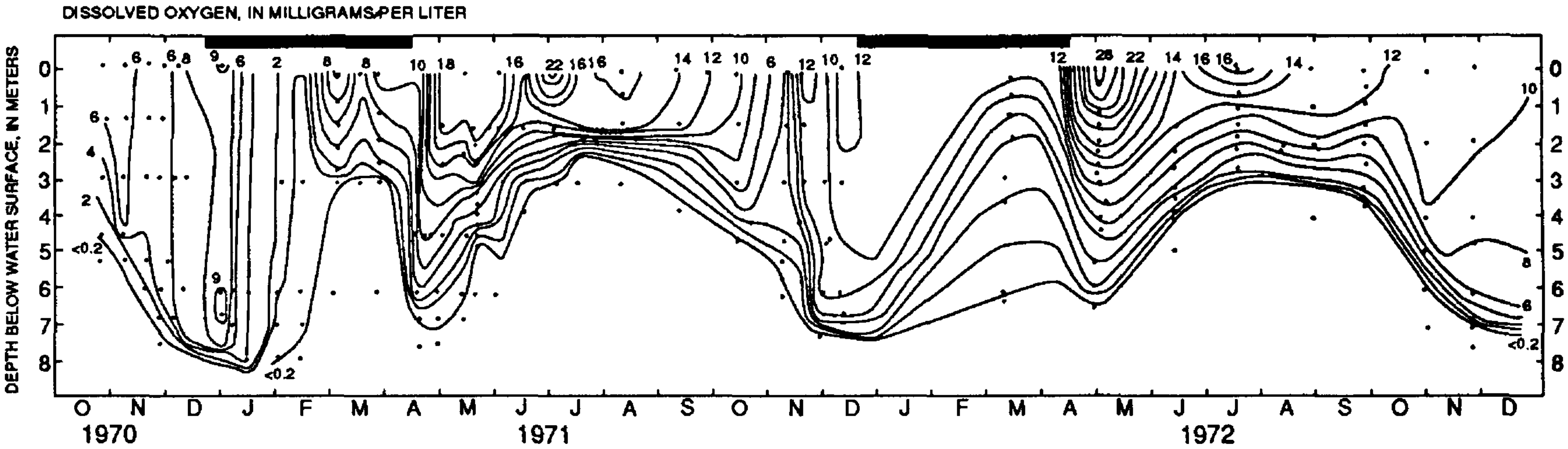


EXPLANATION

—10— LINE OF EQUAL CONCENTRATION

⋮ DEPTHS AT WHICH MEASUREMENTS WERE MADE

▬ PERIOD OF ICE COVER



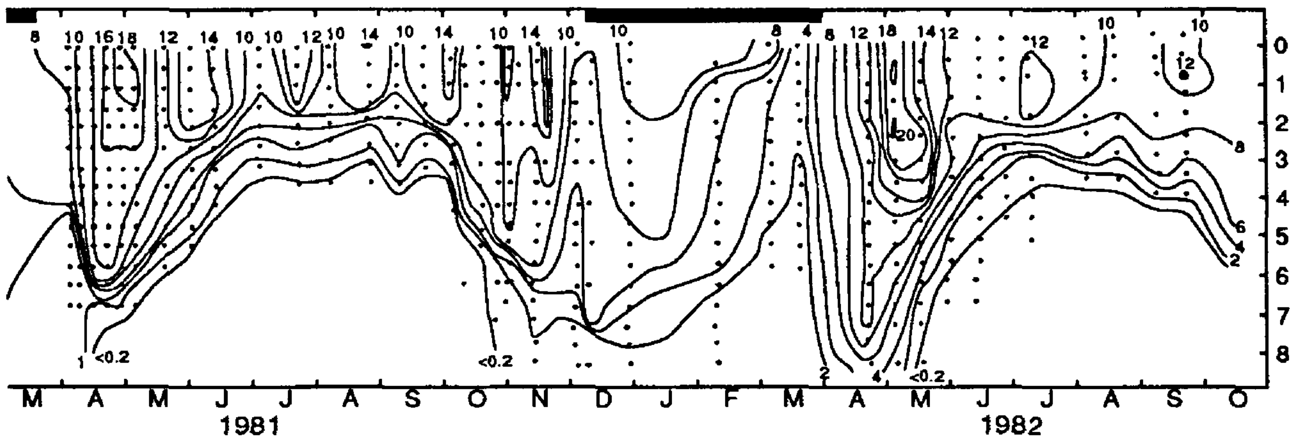


Figure 4E.

Depth profiles of dissolved oxygen in Ides Cove, 1971-72 (above) and 1979-82 (left).

F. Alkalinity

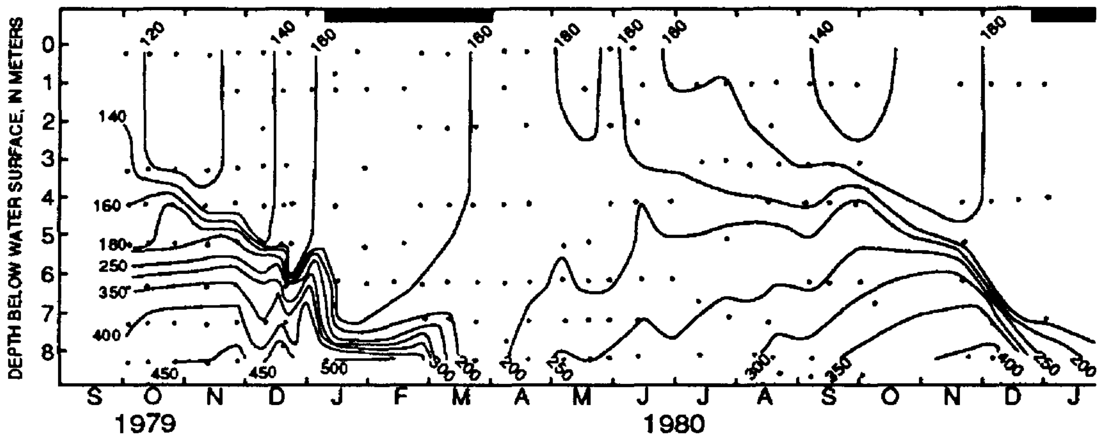
IDES COVE IS TYPICAL OF A WELL-BUFFERED, HIGHLY PRODUCTIVE, HARD-WATER LAKE

The concentration and seasonal pattern of alkalinity show little change through the study period, other than evidence of deeper mixing in later years.

Alkalinity can be defined as the capacity of a solution to neutralize acid (Hem, 1985) and is reported as an equivalent concentration of calcium carbonate ($CaCO_3$) in mg/L. The alkalinity of Ides Cove is typical of a well-buffered, highly productive hard-water lake. The alkalinity is produced largely by dissolved carbonate and bicarbonate ions that result from (1) dissolution of atmospheric carbon dioxide in water; (2) dissolution of carbonate in rocks and sediments; and (3) decomposition of organic matter in the anoxic hypolimnion. Additional alkalinity in the hypolimnion may result from the presence of hydrogen sulfide (HS^-) under anoxic conditions.

The vertical distribution of alkalinity in Ides Cove is controlled largely by stratification and mixing, and the seasonal patterns were generally consistent from the 1970's to the 1980's. The alkalinity of the epilimnion was generally highest in the spring after mixing with bottom waters, then decreased through the summer, when the water column stratified. In 1971 and 1979-82, alkalinity decreased from the 180- to 200-mg/L range in the spring to the 120- to 140-mg/L range in late summer and early fall, and then increased to the 160- to 180-mg/L range after fall mixing. In 1971, meltwater under the ice in February and March diluted the alkalinity concentrations to as low as 120 mg/L (fig. 4F).

The seasonal variation of alkalinity in the hypolimnion was inverse to that in the epilimnion. Alkalinity concentration in the hypolimnion was lowest (200 to 300 mg/L) in the spring after mixing and slowly increased through the summer to concentrations of 380 to 450 mg/L by fall. During fall mixing, alkalinity concentrations of 160 to 180 mg/L through most of the water column were similar from year to year. The deepest waters usually remained stratified, however, and had alkalinity concentrations of 200 to 500 mg/L. Complete mixing probably occurred in fall of



1980, just after the ice cover when the alkalinity concentration was 180 mg/L throughout the water column, and in the spring of 1982, when the alkalinity concentration was 200 to 220 mg/L throughout the water column. Overall, the concentration of alkalinity changed little from 1970-71 to 1979-82, but seasonal mixing patterns indicate deeper and more complete mixing in later years.

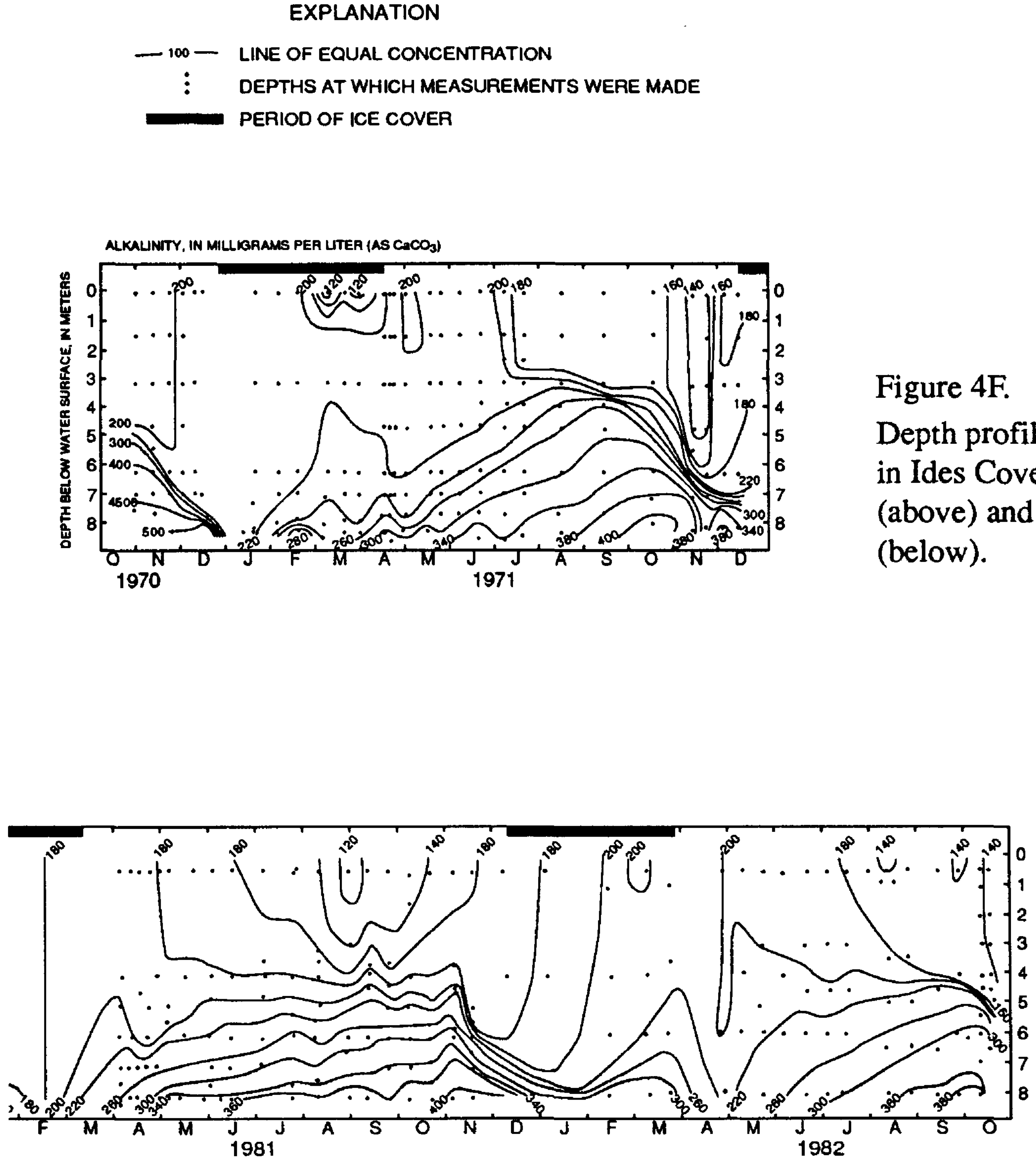


Figure 4F.
Depth profiles of alkalinity in Ides Cove, 1970-71 (above) and 1979-82 (below).

4 PHYSICAL AND CHEMICAL LIMNOLOGY

G. Sulfur

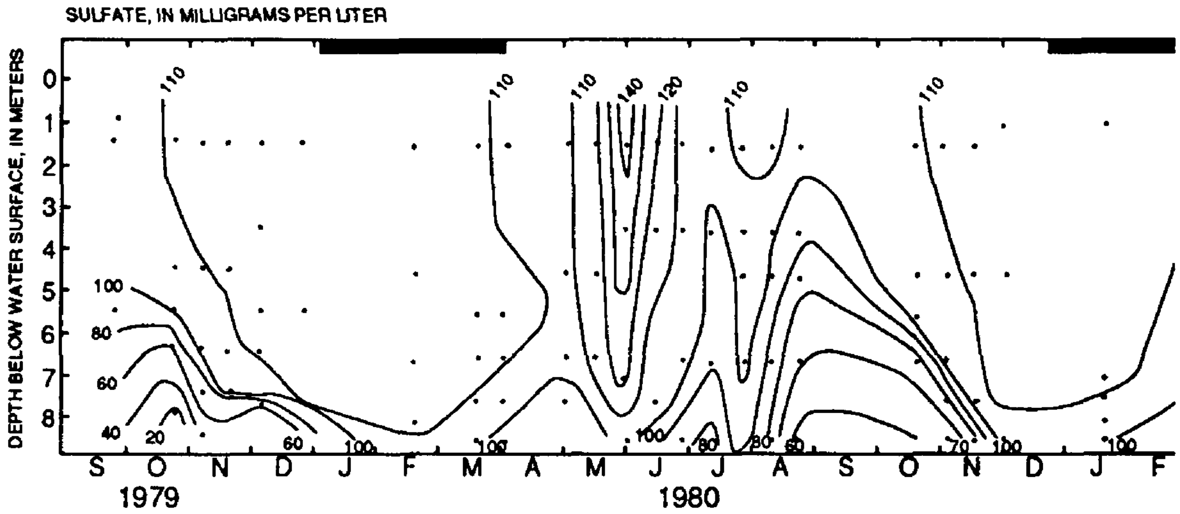
1. Sulfate

SULFATE CONCENTRATIONS ARE RELATED TO THE AEROBIC CONDITIONS OF THE WATER

Concentrations of sulfate in the epilimnion were relatively stable throughout each year, whereas those in the hypolimnion decreased from spring to fall as the water became anoxic.

Under the aerobic conditions of the epilimnion, the concentration of sulfate remains relatively stable throughout the year, from 100 to 120 mg/L, with only occasional deviations. The concentrations decreased to 40 mg/L in March 1971, however, as a result of dilution by meltwater beneath the ice (fig. 4G-1), and increased to 140 mg/L in May 1980.

Sulfate concentrations in the hypolimnion were variable and decreased whenever oxygen concentrations decreased. The highest concentrations of sulfate in the hypolimnion were measured in late winter and early spring, when the water column was well mixed and oxygenated. As the hypolimnion became anoxic and sulfate was slowly reduced to sulfide and(or) hydrogen sulfide, sulfate concentrations gradually decreased. In 1971, the concentration of sulfate below a depth of 7 m decreased from about 100 mg/L in April to less than 10 mg/L by October. Similar trends were observed in 1981 and 1982, when sulfate concentrations decreased to less than 20 mg/L before the fall mixing. Sulfate concentrations increased once again after the fall mixing, when oxygen concentrations increased in the hypolimnion.



EXPLANATION

—10— LINE OF EQUAL CONCENTRATION

⁝ DEPTHS AT WHICH MEASUREMENTS WERE MADE

▬ PERIOD OF ICE COVER

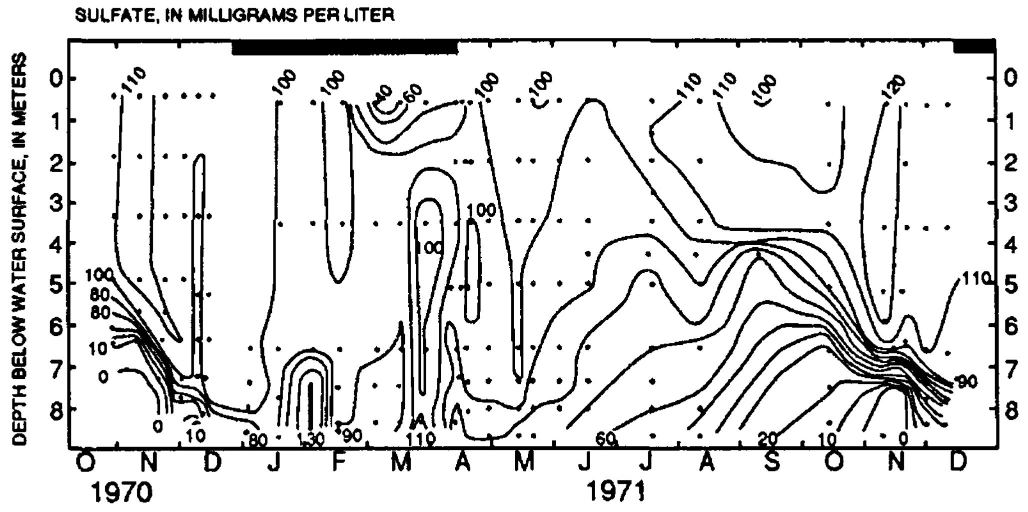
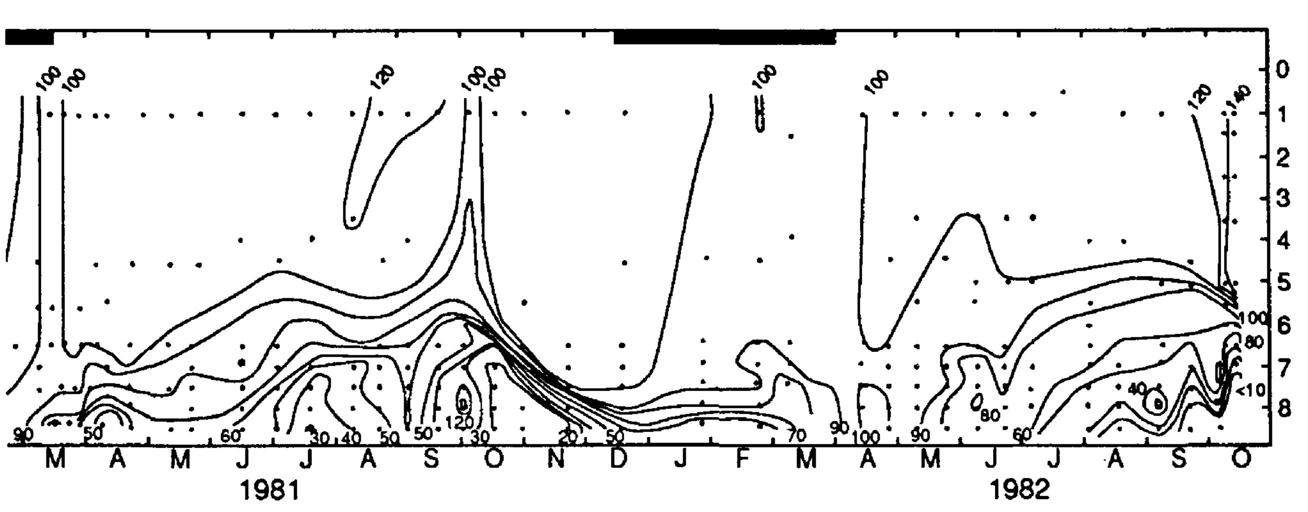


Figure 4G-1.
Depth profiles of sulfate in Ides Cove, 1970-71 (left) and 1979-82 (below).



4 PHYSICAL AND CHEMICAL LIMNOLOGY

G. Sulfur

2. Hydrogen Sulfide

HYDROGEN SULFIDE CONCENTRATIONS VARY INVERSELY
WITH OXYGEN AND SULFATE CONCENTRATIONS

Hydrogen sulfide was not detected in the well-oxygenated epilimnion but was consistently found under anoxic conditions in the hypolimnion. Decreased concentrations of hydrogen sulfide in the hypolimnion in 1981 and 1982 indicate more complete mixing and shorter periods of anoxia than in 1971.

Hydrogen sulfide (H_2S) was measured only when oxygen concentrations were less than 4 mg/L or when sulfide odors from water samples were noticeable. The profiles shown in figure 4G-2, which represent the only years in which hydrogen sulfide measurements were made, indicate that hydrogen sulfide concentrations varied inversely with oxygen and sulfate concentrations. Hydrogen sulfide was not detected where oxygen concentrations were greater than 2 mg/L and thus was not detected in the well-oxygenated epilimnion.

The lowest concentrations of hydrogen sulfide in the hypolimnion were detected after spring mixing (1982) or after winter mixing beneath the ice (1971). As the hypolimnion became anoxic in the late spring and summer, hydrogen sulfide slowly accumulated as sulfate was reduced. The concentrations of hydrogen sulfide decreased in the fall as the hypolimnion mixed with oxygenated water from the epilimnion.

Both the concentrations and volume of water containing hydrogen sulfide were smaller during 1981-82 than during 1971. The maximum concentration decreased from 43 mg/L in 1971 to 30 mg/L in 1981 to 20 mg/l in 1982. The minimum depth at which hydrogen sulfide was detected increased from about 2.5 m in 1971 to 3.5 m in 1981 and 4.5 m in 1982. Both of these trends probably result from more complete mixing and shorter periods of anoxia in 1981-82 than in 1972.

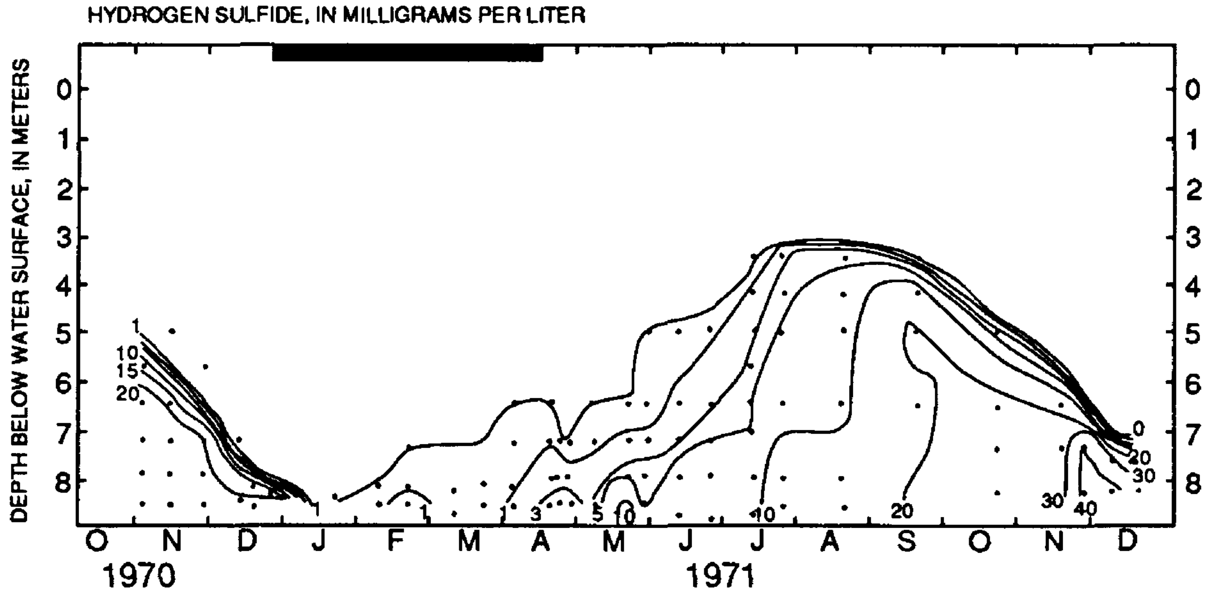


Figure 4G-2.—Depth profiles of hydrogen sulfide in Ides Cove, 1970-71.

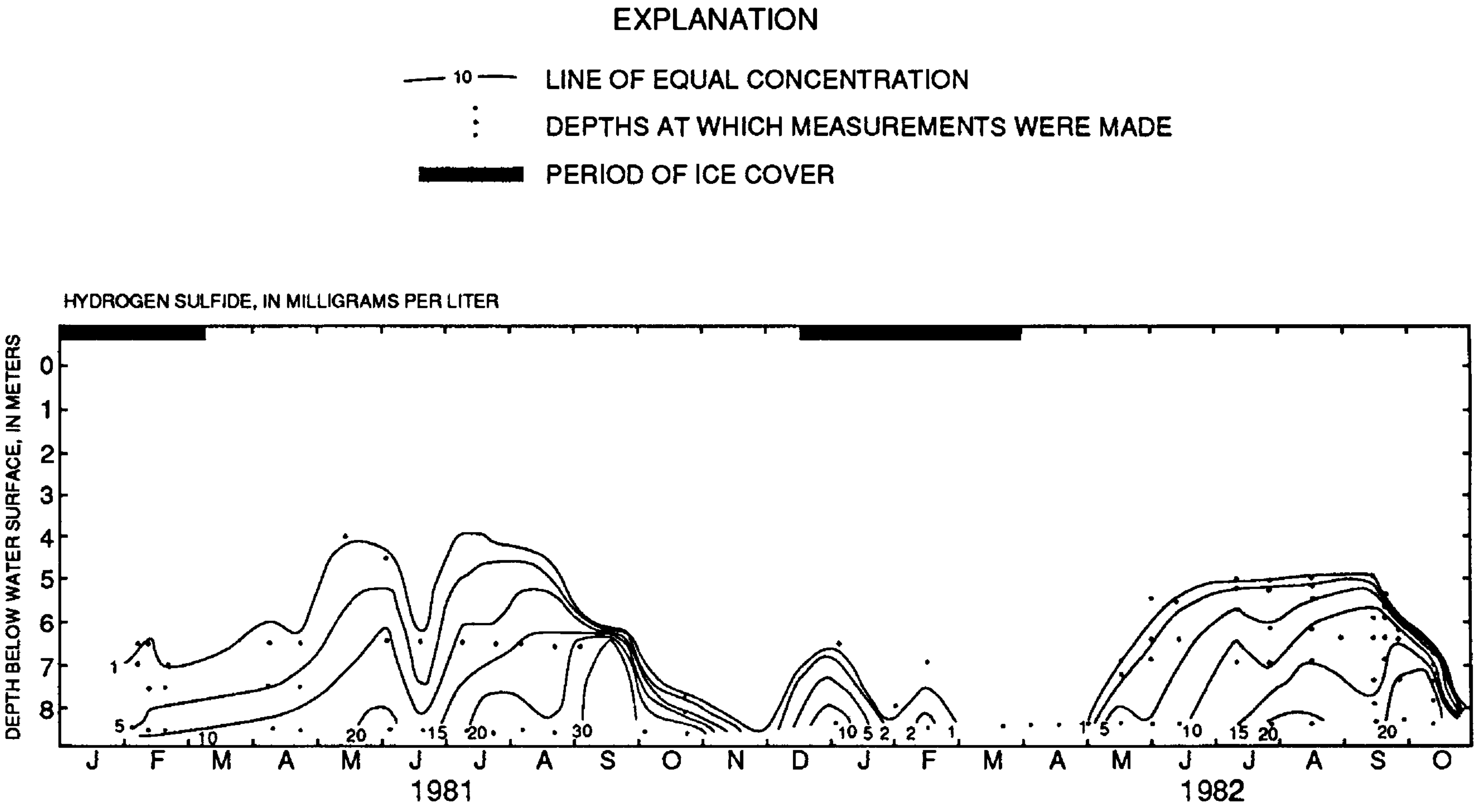


Figure 4G-2.—Depth profiles of hydrogen sulfide in Ides Cove, 1981-82.

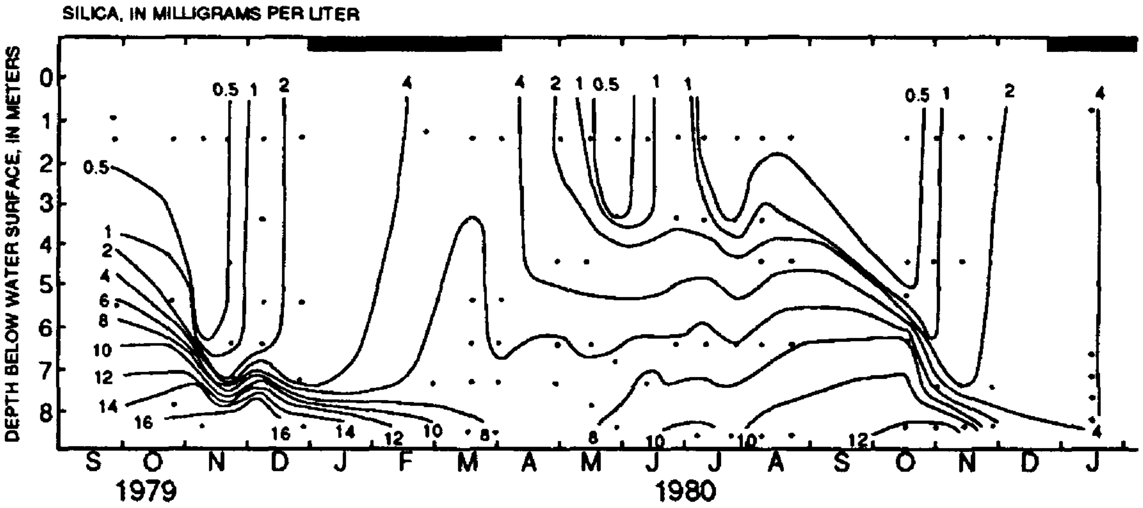
SILICA CONCENTRATIONS ARE CONTROLLED BY THE SEASONAL FLUCTUATION OF THE DIATOM POPULATION

Silica concentrations decrease to less than 0.5 mg/L in the summer as silica is incorporated into diatom frustules. The frustules eventually settle to the bottom, where the silica dissolves and is redistributed into the overlying water. During periods of stratification in the summer and winter, silica accumulates in the hypolimnion to concentrations of 12 to 26 mg/L.

Silica generally is found in the water as dissolved silicic acids. In the particulate form, it is most commonly associated with diatom frustules and less frequently with organic complexes and inorganic particles (Wetzel, 1983, p. 331). The data evaluated in this study represent total molybdate-reactive silica and, therefore, include most dissolved forms that are readily available to algae and also some organic or inorganic complexes that are not.

Silica concentrations in the epilimnion varied seasonally in an inverse relation to the diatom population (Weidemann, 1985). Silica concentrations ranged from a seasonal maximum of 6 to 8 mg/L during winter 1970-71 to 4 to 6 mg/l during winters of 1979-82, when the diatom population was at a seasonal low. Silica was at a seasonal minimum of less than 0.5 mg/L by May and early June and again in October and November during 1979-82. Although it was also at a seasonal minimum of less than 0.5 mg/l in May and early June of 1971. it increased to 4 to 6 mg.l in the fall of 1970 and 1971 (fig. 4H). The onset of the spring silica minimum coincided with the ice-out and warming of water. Diatoms are most abundant when the water temperature is about 12°C, which generally occurs around early May. The diatoms *Stephanodiscus* and *Cyclotella* have been repeatedly found in abundance in near-surface samples taken from Irondequoit Bay during October and November (Weidemann, 1985). The diatom abundance is coincident with the fall silica minima. The low midsummer values of silica in 1980 can be ascribed to unusually high numbers of centric diatoms, which included *Cyclotella* and *Coscinodiscus*.

Diatoms gradually sink in the water column and accumulate at the bottom. Dissolution of the frustules and diffusion of silica from the bottom



sediments increases the concentration of silica in the hypolimnion, where seasonal high concentrations were reached during the stratified periods of the summer and winter. Silica concentration in the hypolimnion decreased during the spring and fall mixing periods as silica was redistributed throughout the water column. The redistribution of silica from the hypolimnion during mixing periods is an important source of silica for diatom growth in the epilimnion.

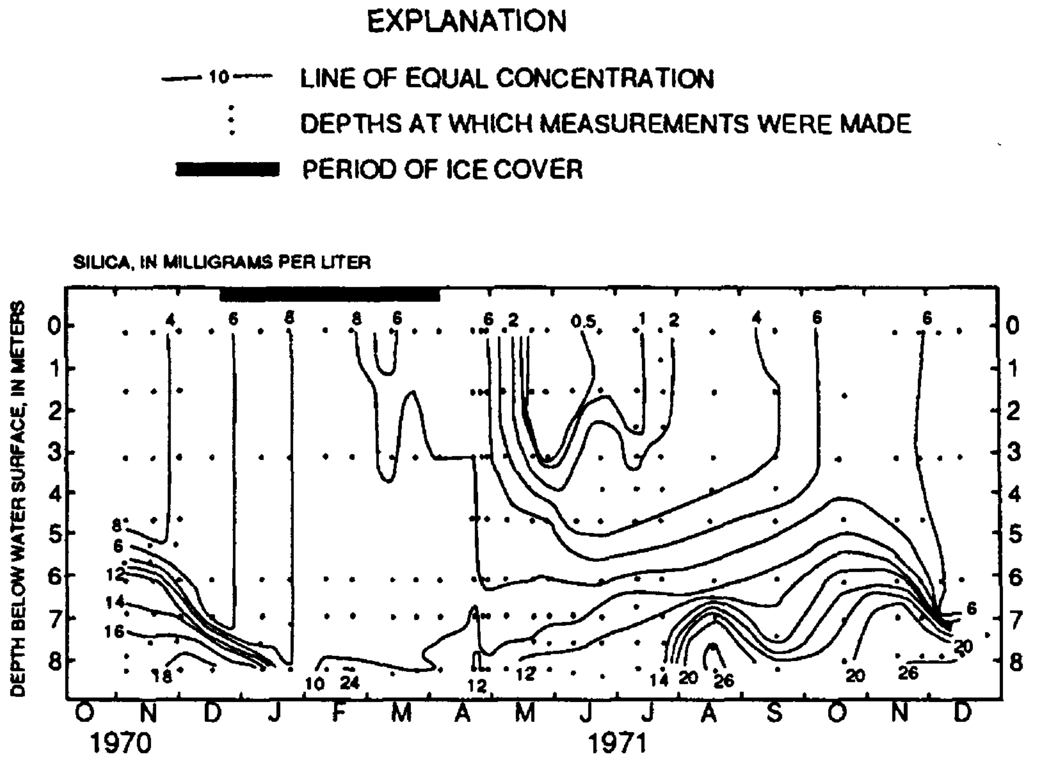
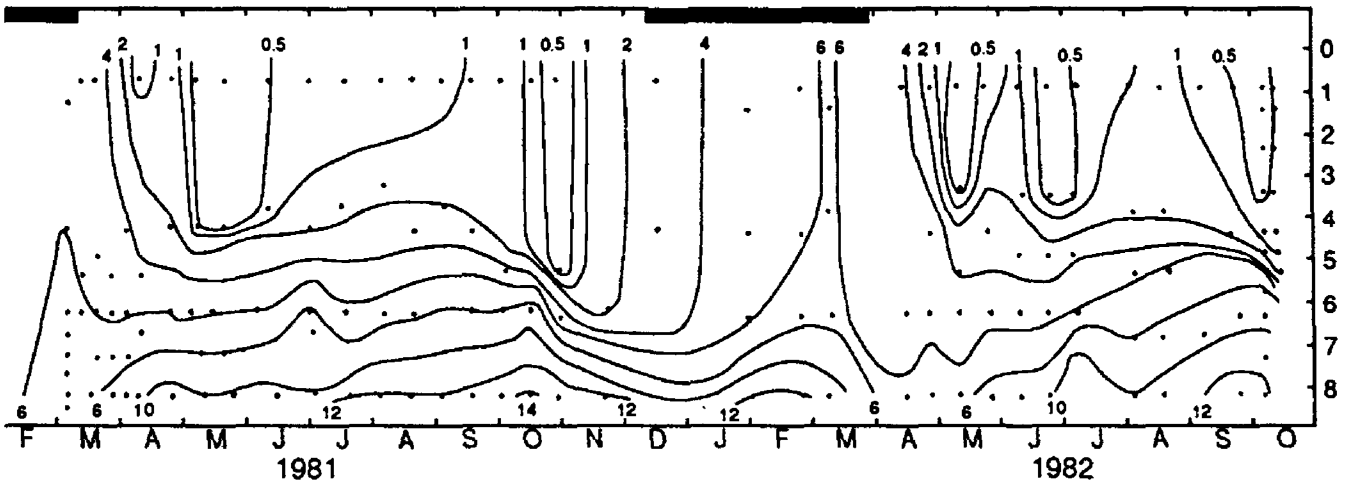


Figure 4H.
Depth profiles of silica in Ides Cove, 1970-71 (left) and 1979-82 (below).



4 PHYSICAL AND CHEMICAL LIMNOLOGY

I. Chloride

CHLORIDE CONCENTRATION AND GRADIENT BETWEEN SURFACE AND BOTTOM WERE SMALLER IN 1981-82 THAN IN 1971-72

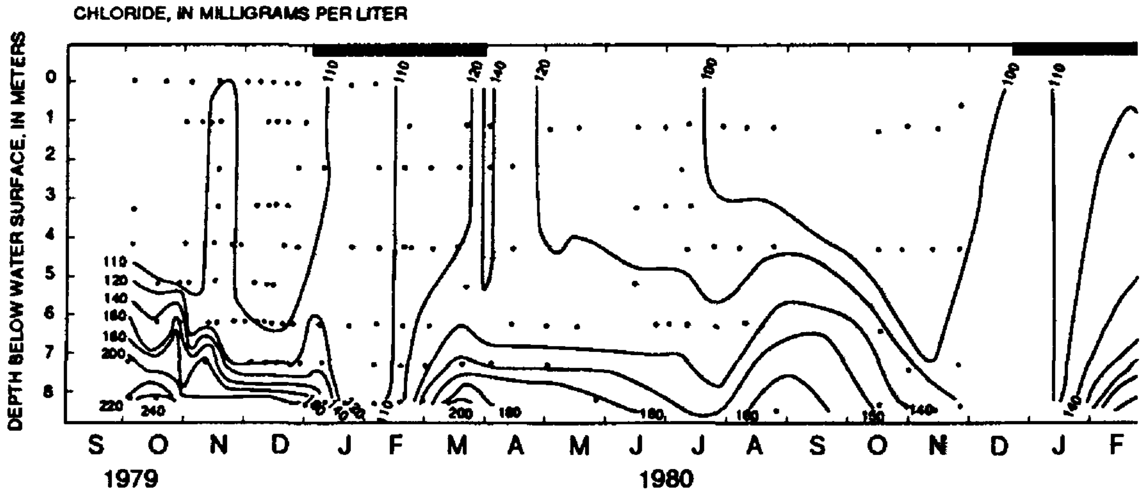
During 1970-72, the surface-to-bottom chloride gradient indicated meromictic conditions throughout the year. After decreased use of road salt in 1974, the chloride concentrations and gradient through the water column decreased appreciably in summer and fall, and the depth of mixing increased in spring and fall.

Chloride is a major component of the ionic composition of Ides Cove and strongly affects the electrical conductivity of the water. As such, the temporal and spatial distribution of chloride is similar to that of specific conductance (section 4A). Chloride enters the cove as deicing-salt runoff during the spring thaw as water washes over salt-laden roads around the cove (Bubeck, 1972) and through ground-water seepage (Pesacreta and Makarewicz, 1982) and by the exchange of water with Irondequoit Bay. Road-salt usage in the Irondequoit basin decreased after 1974 (Bubeck and Burton, 1989), but the amount of decrease in the Ides Cove area is unknown.

The chloride profiles (fig. 4I) show that the highest chloride concentrations in the epilimnion occurred in March and April after snowmelt and after mixing in the spring. The maximum annual chloride concentrations measured in the epilimnion were 210 mg/L in April 1971 and 225 mg/L in April-May 1972 but had decreased to 140 mg/L by March-April 1980, 130 mg/L in April 1981, and 150 mg/L in April 1982.

Chloride is a conservative constituent; thus, its concentration in a lake remains stable until diluted by precipitation or by water with a lower chloride concentration. The concentration of chloride in the epilimnion of Ides Cove decreased slowly throughout the summer and early fall. The effect of dilution was most apparent in 1972, when above-normal precipitation in June (fig. 2A) resulted in a 30-percent decrease in chloride concentration, from 180 mg/L to 120 mg/L over a 6-week period. In other years, the concentration declined only about 20 percent over the 3- to 4-month summer period. After summer stratification, chloride concentration in the epilimnion again increased in the fall through mixing with water from the more concentrated hypolimnion.

Chloride concentrations in the hypolimnion were also greatest in the early spring just after snowmelt, then gradually decreased through the early summer after complete or partial mixing in the spring, and substantially decreased in the late



fall and early winter as the hypolimnion mixed with water from the more dilute epilimnion. The profiles in figure 4I show that the cove mixed completely in the spring of 1982 but not in the spring or fall of 1971, 1972, 1980, or 1981, nor in the fall of 1970 or 1979. The depth of mixing in 1980 and 1981 was greater than in 1971 or 1972, however.

Chloride concentrations in 1980-82 were substantially lower in both the epilimnion and the hypolimnion than in 1971-72. The maximum annual chloride concentrations in the epilimnion decreased from 210 mg/L in 1971 and 225 mg/L in 1972 to 140 mg/L in 1980, to 130 mg/L in 1981, and to 150 mg/L in 1982, and those in the hypolimnion decreased from 390 mg/L in 1971 and 290 mg/L in 1972 to 200 mg/L in 1980, to 240 mg/L in 1981, and to 180 mg/L in 1982. During this period, both the chloride concentration in the water column and the top-to-bottom concentration gradient decreased. The gradient during the summer and fall decreased from a range of 110 to 130 mg/L in 1971-72 to a range of 20 to 60 mg/L in 1980-82. In addition, a gradient from the bottom to the surface (meromixis) was observed throughout the year in 1971 and 1972 but decreased in the fall of 1980 and 1981 and disappeared for periods in the winters of 1979-80, 1980-81, and the spring of 1982. The decrease in chloride concentrations, the lessening of the gradient, and the changing mixing patterns over the 10-yr period indicate that (1) a decreasing amount of chloride was entering the cove (probably from the decrease in road-salt usage), and (2) the stability of the water column was also decreasing. The resulting increase in the degree of spring and fall mixing is reflected in the 1980-82 chloride profiles as well as profiles of other chemical constituents in the same period.

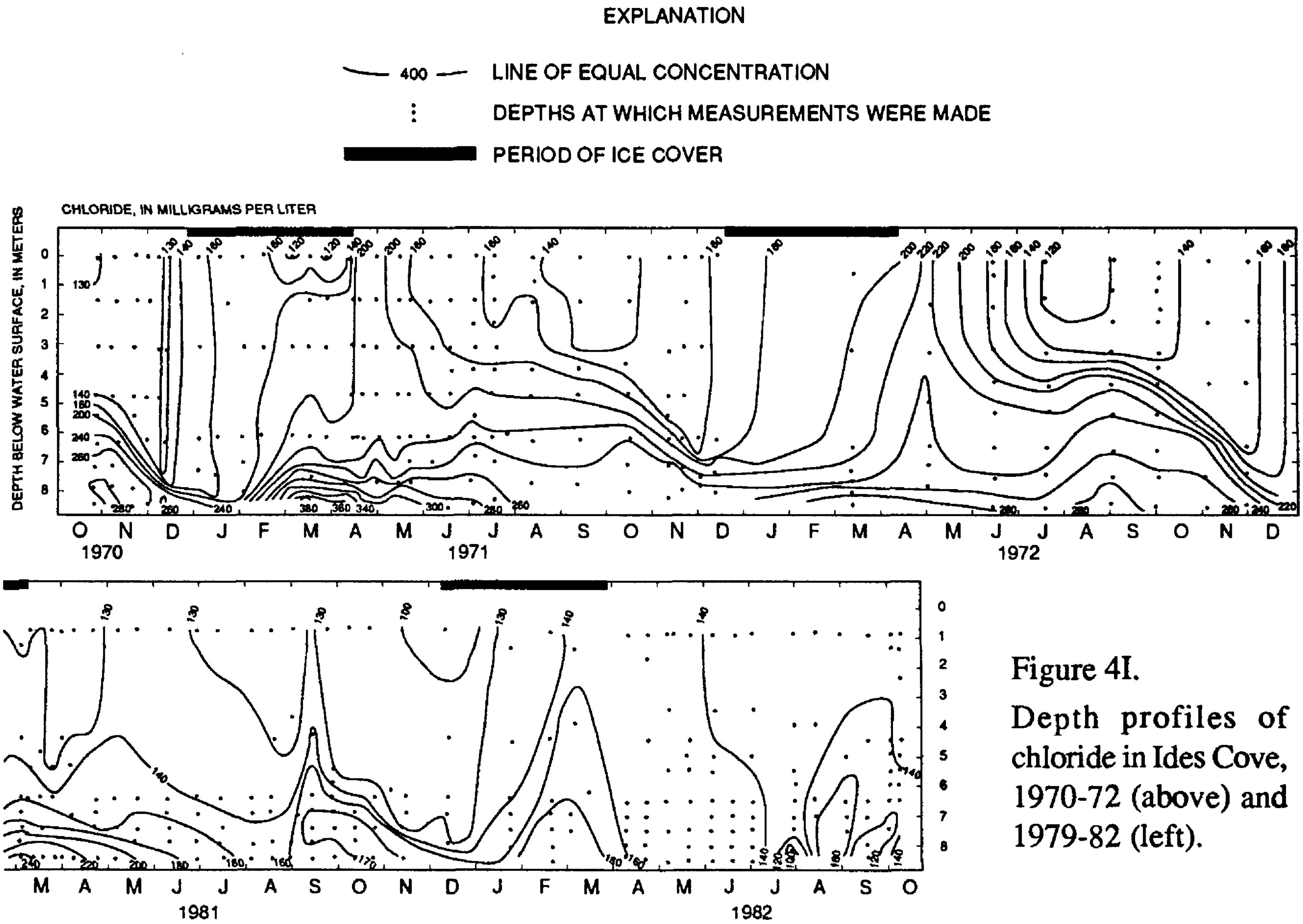


Figure 4I.
Depth profiles of chloride in Ides Cove, 1970-72 (above) and 1979-82 (left).

4 PHYSICAL AND CHEMICAL LIMNOLOGY

J. Phosphorus

1. Soluble Reactive Phosphate

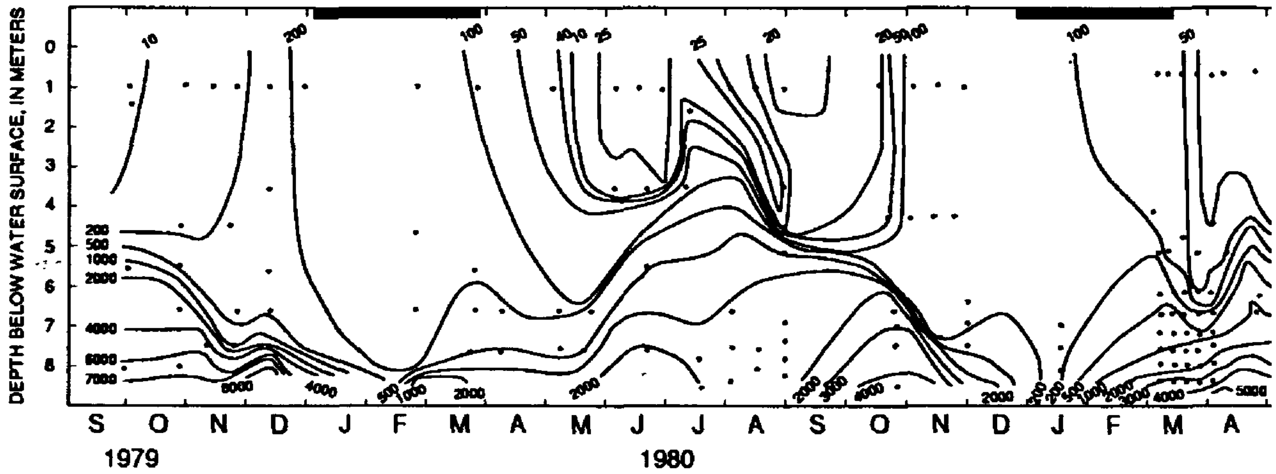
PHOSPHATE CONCENTRATIONS IN THE EPILIMNION WERE ABOUT 90 PERCENT LOWER IN 1980-82 THAN IN 1970-71

In 1970-71, concentrations of soluble reactive phosphate (SRP) ranged from about 350 μg/L at the surface to 10,000 μg/L at the peak of accumulation in the hypolimnion. By 1982, SRP concentrations at the surface were occasionally less than 5 μg/L and fluctuated with algal blooms, and SRP concentrations in the hypolimnion did not exceed 3,100 μg/L. This large decrease occurred after the ban on phosphate detergents in 1973 and sewage diversion in 1978.

Phosphate in the water column consists of soluble and particulate fractions. The soluble fraction contains (1) phosphate that is chemically reactive with molybdate (termed soluble reactive phosphate, SRP) and is assumed to be readily available to plants for growth, and (2) dissolved organic phosphate, which is usually negligible. The particulate fraction contains biological and inorganic detrital material. Particulate and soluble forms of phosphorus can eventually become available to plants and, thus, are important contributors to eutrophication.

Because phosphate is an essential nutrient for algal growth, epilimnetic SRP concentrations decrease during algal blooms. Epilimnetic concentrations in Ides Cove were generally lowest during summer stratification, when algal growth was greatest, but increased in the fall as algal populations declined and phosphate-rich hypolimnetic waters mixed with the epilimnetic waters. The concentration of SRP in the epilimnion ranged from 1,500 μg/L in November and December of 1971 to less than 5 μg/L in June and July of 1980. Phosphorus does not appear to have been a limiting nutrient in 1971 because SRP concentrations did not fall below 400 μg/L during the summer (fig. 4J-1).

Before the diversion of treated sewage and combined sewer overflows from the Irondequoit Bay drainage basin in 1978 and the New York State phosphate detergent ban in 1973, phosphate loadings to Ides Cove were very large, and phosphate accumulated in the bottom sediment. Although the phosphate loadings to the bay, and therefore to Ides Cove, had decreased by the early 1980's, and phosphate concentration in the epilimnion had



decreased by about 90 percent (from 400 µg/L in the summer of 1971 to less than 50 mg/L in the summer of 1980-82), a large reservoir of phosphates still remained in the bottom sediments.

During stratification, the hypolimnion is anoxic, and phosphate readily diffuses from the sediments to the overlying waters, where it accumulates from the lack of mixing with the epilimnion. In 1971, SRP in the bottom water reached concentrations of 6,000 µg/L by late summer, but in 1980-82 they ranged from only 3,000 to 4,000 µg/L during late summer. Phosphate also accumulated in the deep waters during winter stratification; SRP in the bottom water reached concentrations of 7,000 µg/L in February 1971 and 5,000 µg/L in March 1981.

Although the concentration of SRP in the hypolimnion was 30 to 40 percent less in 1980-82 than in 1971, it was still relatively high. The large reservoir of SRP in the hypolimnion that results from diffusion from the bottom sediments might have promoted algal growth and abundance in the early 1980's. With SRP concentrations of less than 20 µg/L in the epilimnion, phosphorus was probably the limiting nutrient, and the eddy diffusion of phosphate-rich water from the hypolimnion into the epilimnion could have been the primary source of phosphate that sustained algal growth in midsummer.

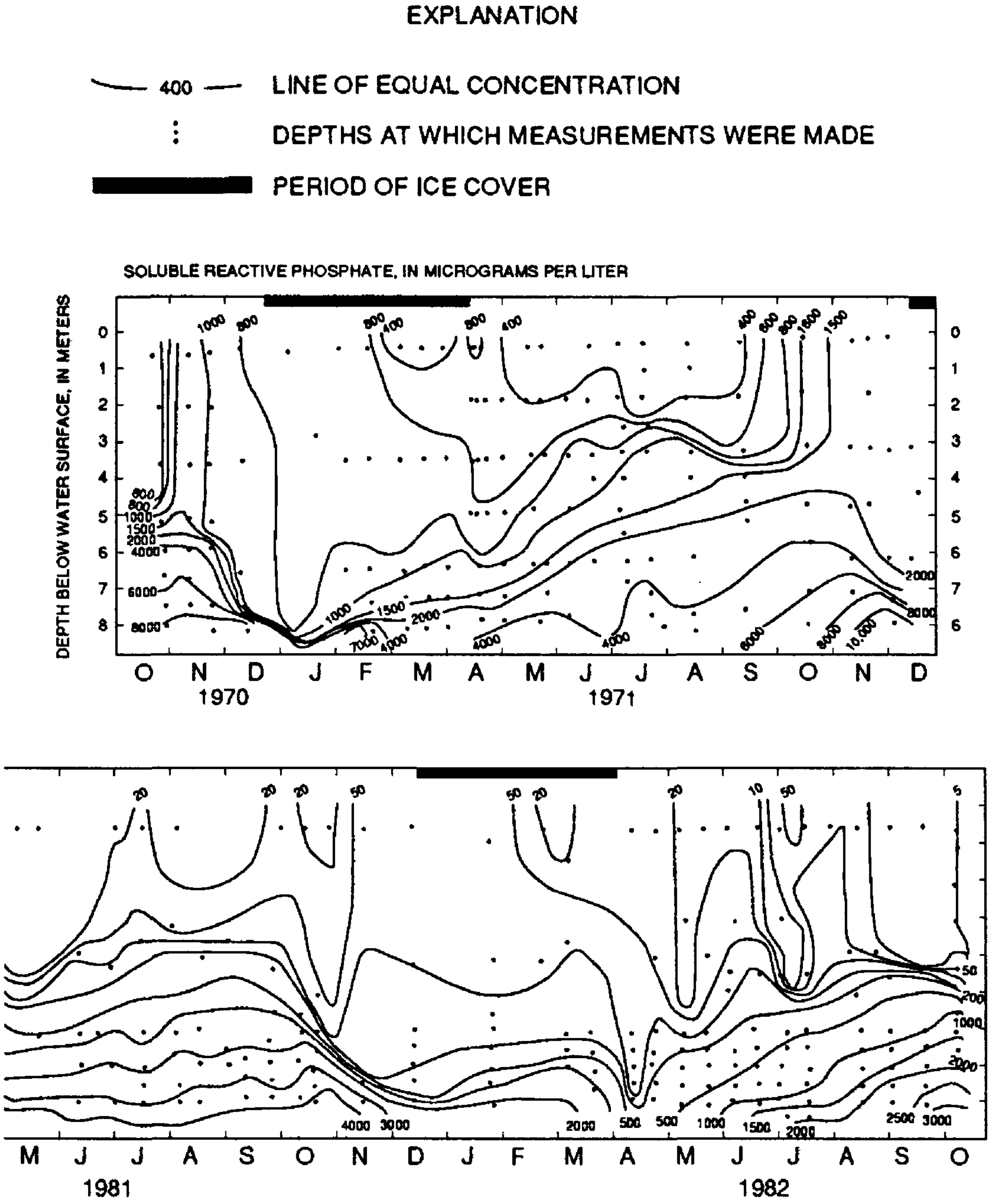


Figure 4J-1.
Profiles of soluble reactive phosphate in Ides Cove, 1970-71 (left) and 1979-82 (below).

4 PHYSICAL AND CHEMICAL LIMNOLOGY

J. Phosphorus

2. Total Phosphate and Total Iron

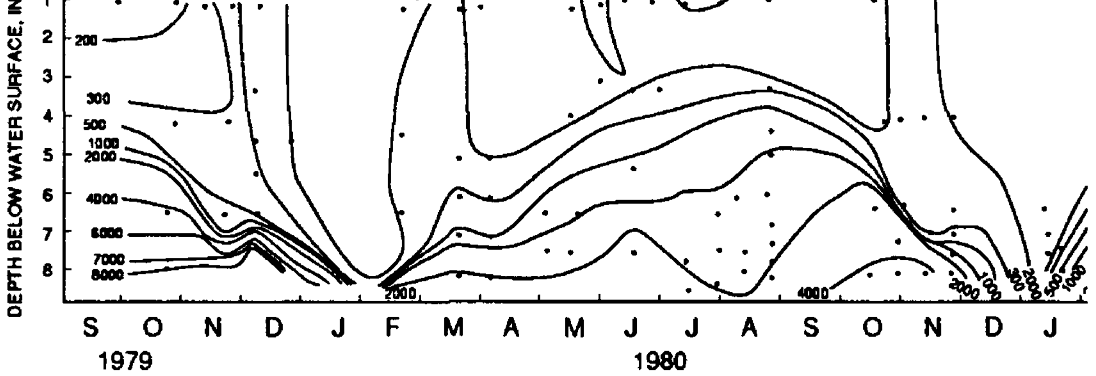
TOTAL PHOSPHATE CONCENTRATIONS APPEAR
TO HAVE DECREASED SINCE 1970

Total phosphate concentrations in the epilimnion decreased from at least 400 µg/L in the summer of 1971 to 100 µg/L or less in the summers of 1980-82.

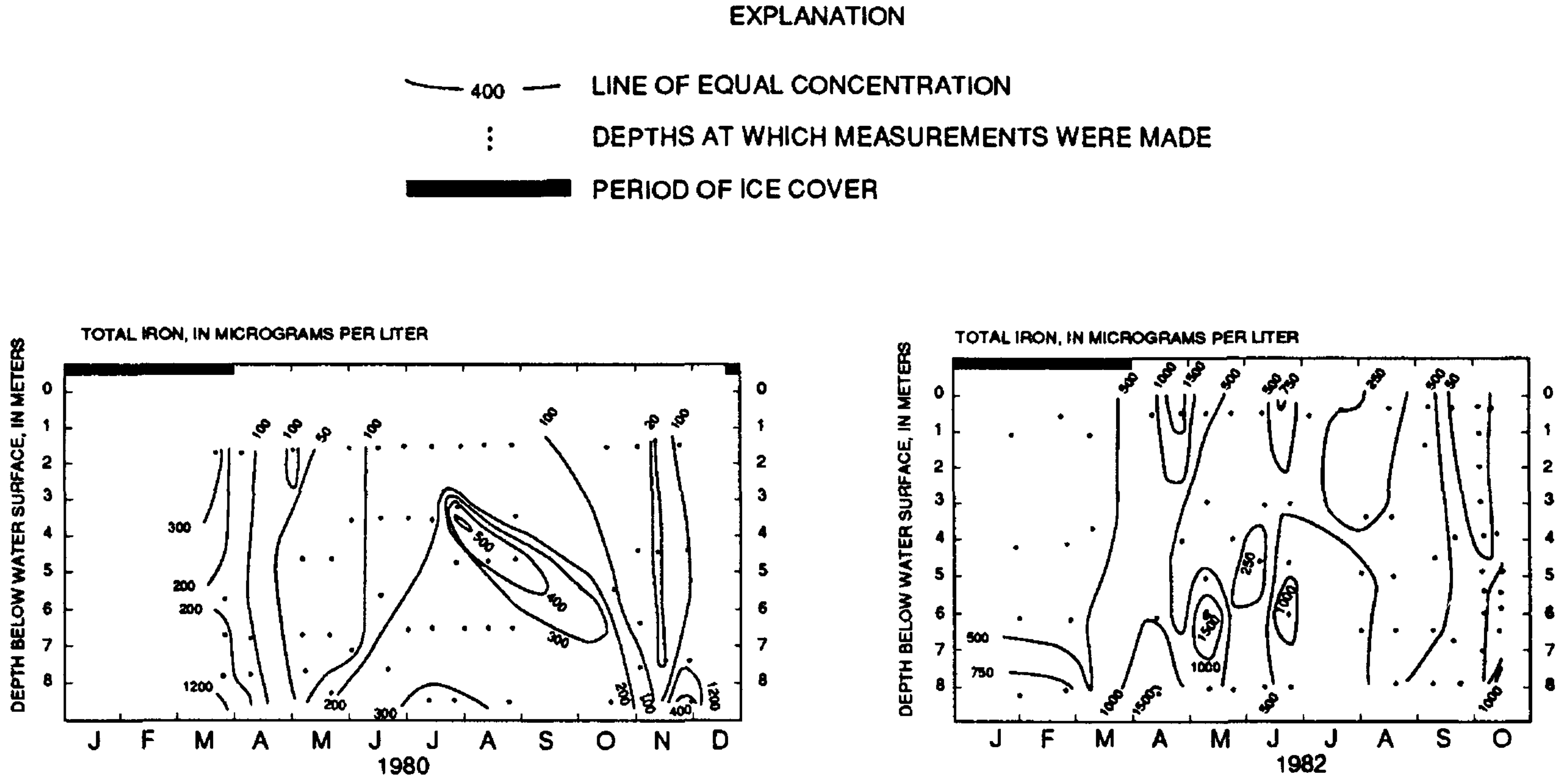
Total phosphate (TP) was not measured in 1970-72, but its concentration can be approximated if the phosphate is assumed to be mostly in the form of soluble reactive phosphate (SRP). This is a reasonable assumption for the hypolimnion because, as the profiles show, the concentrations and yearly patterns for TP (fig. 4J-2) were nearly identical to those of SRP (fig. 4J-1) in the hypolimnion during 1979-82. This assumption may not be valid for the epilimnion, however, because TP concentrations were as much as twice the SRP concentrations during 1979-82. SRP concentrations in the epilimnion in 1970-72 should represent at least the minimum TP concentrations.

As with SRP, TP concentrations decreased appreciably between 1970-72 and 1979-82. TP concentration in the epilimnion was at least 400 µg/L (the concentration of SRP) in the summer of 1971 and decreased to the 100- to 140-µg/L range in 1980, the 80- to 130-µg/L range in 1981, and the 50- to 80-µg/L range in 1982. TP concentrations during fall mixing also decreased from the 800- to 1,500-µg/L range in 1970-71 to about 200 µg/L in 1979-81, and maximum concentrations in the hypolimnion decreased from at least 10,000 µg/L in 1971 to the 8,000- to 3,000-µg/L range in 1979-82.

A rapid decrease in TP and SRP occurred



after the mixing in December 1979, November 1980, and April 1982, possibly as a result of the precipitation of phosphate-metal complexes, such as ferric phosphate, which could have formed when the phosphate and iron-rich hypolimnion mixed with the oxygenated epilimnion. The profiles for total iron (below) indicate that iron concentrations decreased at the same time as mixing (April-May 1980, November 1980, and April-May 1982).



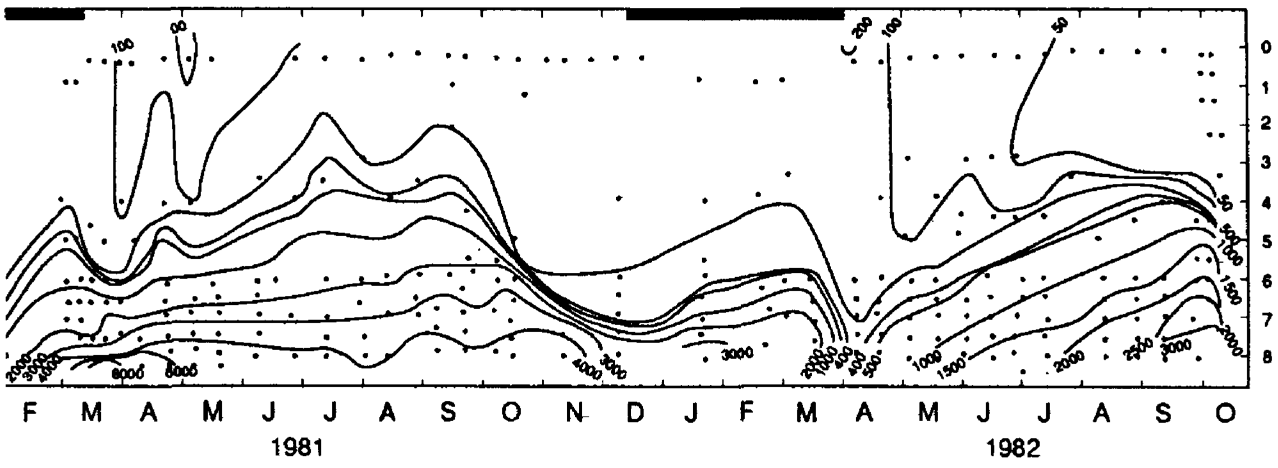


Figure 4J-2.

Depth profiles of total iron in Ides Cove, 1980 and 1982 (above), and total phosphate in Ides Cove, 1979-82 (left).

4 PHYSICAL AND CHEMICAL LIMNOLOGY

K. Nitrogen

1. Nitrite

NITRITE CONCENTRATIONS WERE LARGEST
DURING SPRING AND FALL MIXING

Nitrogen in water samples from Ides Cove has been measured as nitrite, nitrate, ammonia, total organic nitrogen, and total nitrogen. Nitrite is an intermediate form in the oxidation of ammonia to nitrate and is indicative of mixing of oxygenated with reduced layers of water.

Nitrogen is an essential nutrient for plant and animal growth and, like phosphate, can promote eutrophication of a water body. Nitrogen can occur in water in several forms—dissolved nitrogen gas; dissolved nitrate, nitrite, ammonia, and organic nitrogen (including urea), and particulate inorganic and organic nitrogen. Except for heterocyst-containing cyanobacteria, most algae prefer nitrate or ammonia as their nitrogen sources for growth. Nitrate and ammonia generally are the most abundant forms of inorganic nitrogen in lakes. When phosphate and other minerals necessary for growth are in sufficient supply, nitrogen can become depleted and limit the total algal biomass. Nitrogen could occasionally have been the limiting nutrient in Ides Cove in 1970-72, when phosphate was relatively abundant (Bannister and Bubeck, 1978).

Inorganic nitrogen occurs in the water column of a lake as ammonia, nitrite, or nitrate, depending on whether the water is under oxidizing or reducing conditions. Nitrite represents the transition from the reduced state (ammonia in anoxic water) to the oxidized state (nitrate in oxic water) and vice versa. Nitrite concentration in natural waters is usually low but increases during periods when anoxic (reduced) water from the hypolimnion mixes with the oxic (oxygenated) water in the epilimnion.

Nitrite was measured in Ides Cove only in 1970-71. The profiles in figure 4K-1 show that nitrite concentrations were highest in the fall, concurrent with November-December mixing, then declined in January and February as nitrite was converted to nitrate in the oxygenated water column. From March through April, nitrite concentrations increased at depths of 1 to 7 m and decreased below the 7-m depth, coincident with the decreasing oxygen concentrations through the water column (fig. 4E). Nitrite concentrations also peaked in June 1971 at depths of 2.5 to 4.5 m, indicating that this was the mixing and nitrogen-transition zone between the reducing and oxidizing waters. As the dissolved oxygen concentration decreased in the hypolimnion and phytoplankton consumed the available nitrate and ammonia in the epilimnion, nitrite concentrations decreased below detection limits throughout the water column from July through August.

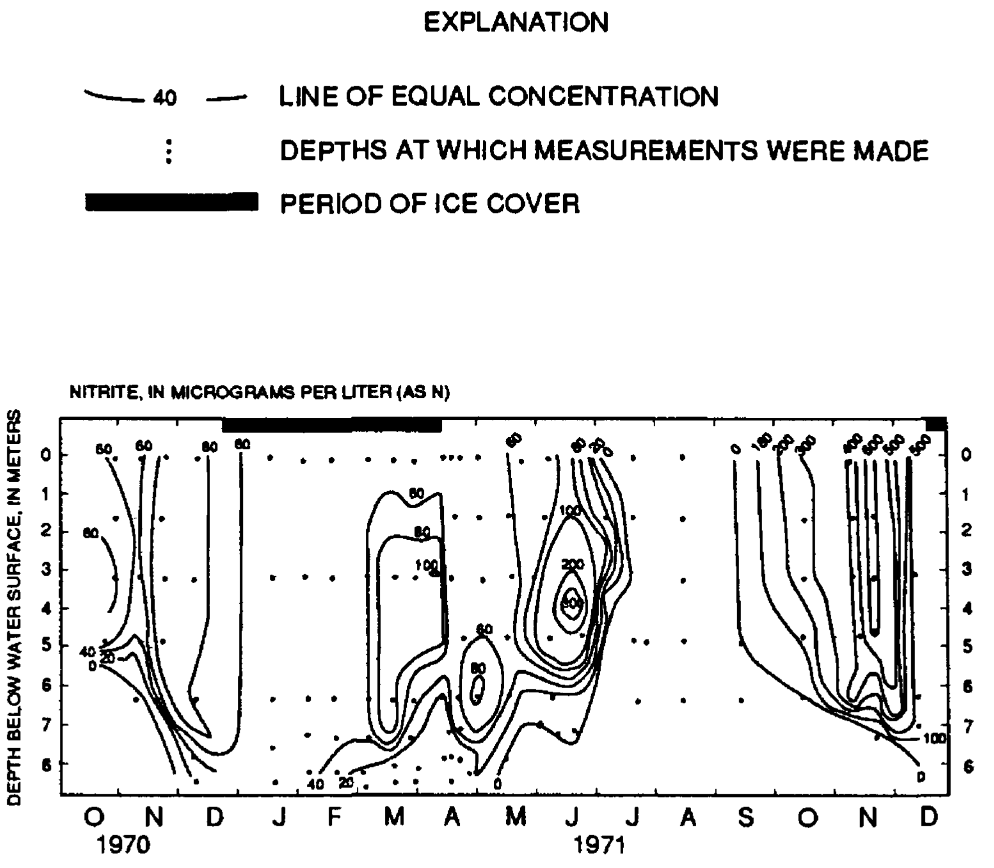


Figure 4K-1.—Depth profiles of nitrite in Ides Cove, 1970-71.

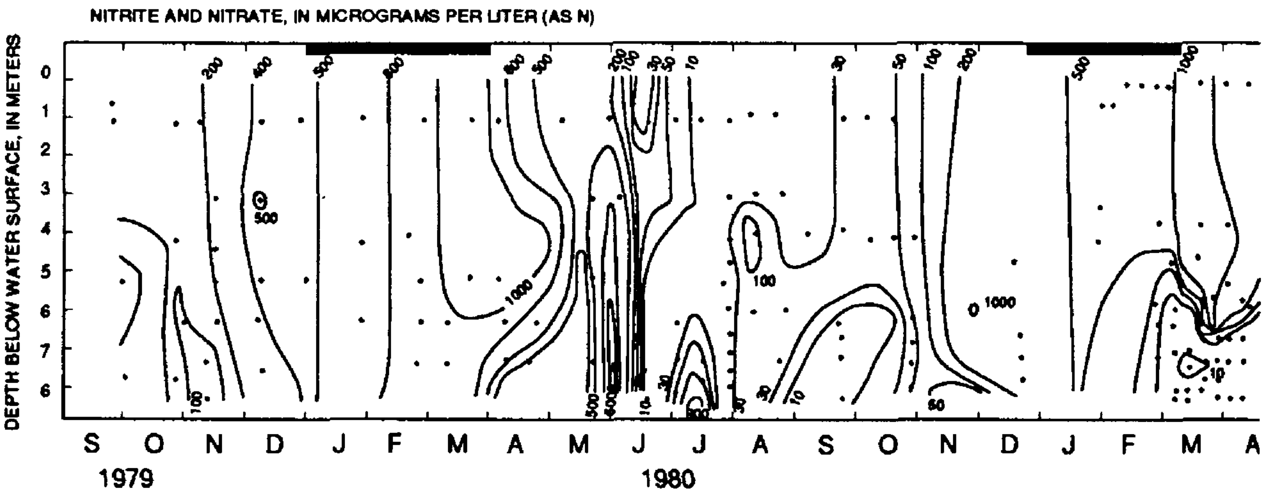
2. Nitrate

NITRATE CONCENTRATIONS VARIED SEASONALLY IN RESPONSE TO CHANGES IN ALGAL PRODUCTIVITY AND THE OXIDATION STATE OF WATER

Nitrate concentrations in the epilimnion ranged seasonally from less than 10 µg/L during the summer to more than 1,000 µg/L during the winter. Maximum annual nitrate concentrations in the epilimnion decreased from 2,800 µg/L in December 1971 to about 1,000 µg/L in March 1980-82. Nitrate concentrations in the hypolimnion followed the trend of the observed oxygen profiles.

Annual trends in the concentration of nitrate are affected by at least four processes: (1) consumption of nitrate by phytoplankton, followed by settling and decomposition of the phytoplankton, (2) release of reduced nitrogen from bottom sediments, (3) reduction of nitrate to ammonia in the hypolimnion, and (4) oxidation of ammonia to nitrite and then nitrate during mixing. Nitrate concentrations generally were high (500 to 1,000 µg/L in 1980-82; 1,800 to 2,000 µg/L in 1970-71) under the ice when the water column was well mixed and had a high oxygen concentration. After spring mixing, nitrate concentrations in the epilimnion gradually decreased to less than 30 µg/L in July and August through uptake by phytoplankton. In the fall, the concentrations increased again as consumption by phytoplankton decreased and ammonia from the hypolimnion was oxidized to nitrate and redistributed through the water column during fall mixing. Nitrate concentrations after fall mixing were as high as 2,800 µg/L in 1971, but in 1980-82 were only between 200 and 500 µg/L.

The nitrate profiles for the hypolimnion in 1971 differ markedly from those for 1980-82 (fig. 4K-2). During 1971, nitrate was absent from the hypolimnion from March through November and was near the detection limit (10 µg/L) throughout the water column from July to September 1971. During 1980-82, nitrate in the lower hypolimnion ranged from 10 to 30 µg/L only from August through October 1980, from March through May



1981, and from May through September 1982, and for short periods throughout the water column each summer. Nitrate concentrations closely followed the observed oxygen trend and provide further evidence of increased mixing in the early 1980's.

Pockets of nitrate were observed in 1981-82 during periods when the hypolimnion was anoxic, and concentrations also increased near the bottom in May and July 1980. Whether these were due to the decreased stability of the water column or the release of nitrate from the bottom sediment, or were an artifact of sampling or analyses, is unknown.

EXPLANATION

— 400 — LINE OF EQUAL CONCENTRATION

⋮ DEPTHS AT WHICH MEASUREMENTS WERE MADE

▬ PERIOD OF ICE COVER

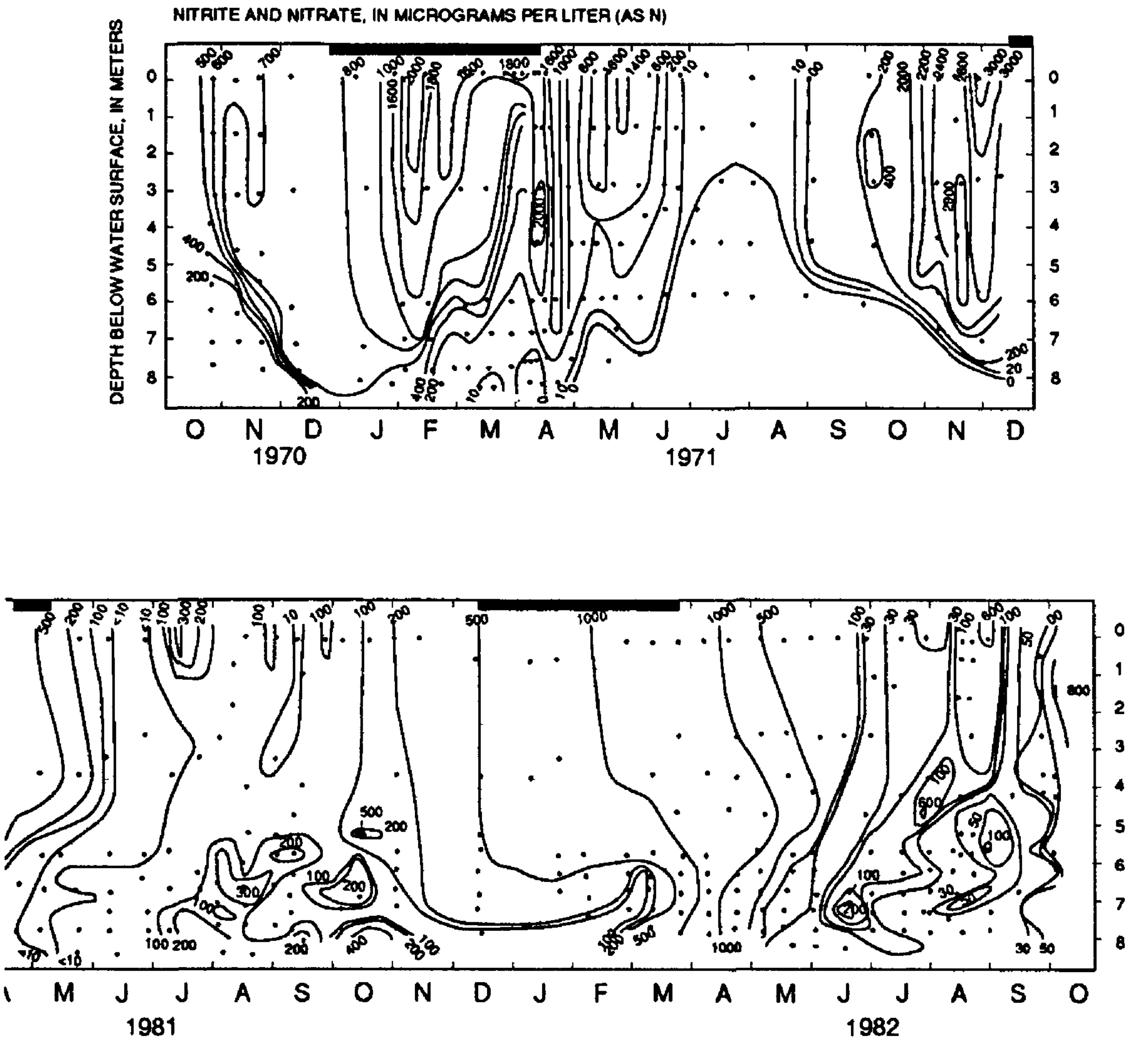


Figure 4K-2.
Depth profiles of nitrite plus nitrate in Ides Cove, 1970-71 (left) and 1979-82 (below).

4 PHYSICAL AND CHEMICAL LIMNOLOGY

K. Nitrogen

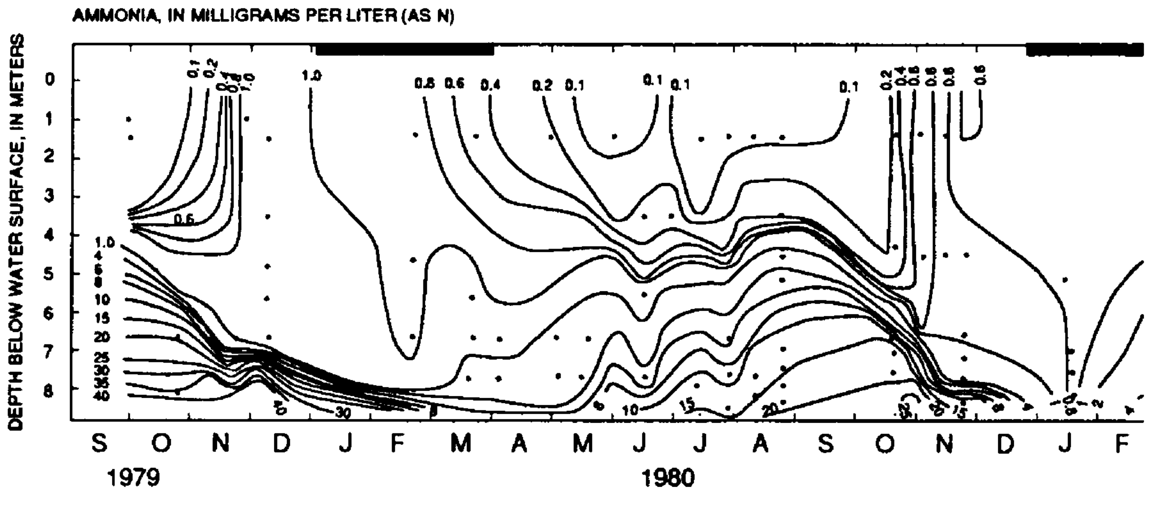
3. Ammonia

HIGHEST AMMONIA CONCENTRATIONS WERE IN THE HYPOLIMNION

During periods of stratification, the highest ammonia concentrations were in the hypolimnion, and the lowest were in the epilimnion. Although the seasonal patterns remained constant, ammonia concentrations were generally less during 1980-82 than in 1971.

Ammonia concentrations in the epilimnion were relatively low (less than 4 mg/L) throughout the year and reached their lowest values during the summer, when the oxygen concentrations and algal populations were the highest. Ammonia concentrations were higher in the anoxic hypolimnion (fig. 4K-3) and reached their maximum during periods of stratification, when ammonia released by the bottom sediments became trapped in the hypolimnion. The highest annual ammonia concentrations (60 mg/L in 1971, 40 mg/L in 1979, 25 mg/L in 1980, and 1981, 20 mg/L in 1982) were reached in October or November, during the fall mix. High ammonia concentrations were also measured in the hypolimnion in January and February 1982 (18 mg/L), when the water column was stratified under the ice, and the bottom waters were anoxic (fig. 4E). Ammonia concentrations in the hypolimnion rapidly decreased during spring and fall, when mixing with oxygenated water from the epilimnion occurred. During 1980 and 1981, ammonia concentrations decreased sharply, from 25 mg/L in November to 2 to 4 mg/L in December, which indicates that the cove did not completely mix before ice cover, but may have mixed after ice formed in December of both years.

In general, ammonia concentrations in Ides Cove decreased from 1970-71 to 1982. During mixed conditions, ammonia concentrations of the upper water column in the spring and fall decreased from 2 mg/L in 1971 to a range of 0.8 to 0.1 in 1980-82, and maximum concentrations in the hypolimnion decreased from 50 to 60 mg/L in the fall of 1971 to 20 to 25 mg/L in the fall of 1980-82.



The decrease in maximum ammonia concentrations between 1970-71 and 1980-82 is likely due to the diversion of treated sewage away from Irondequoit Bay and the decrease in the use of deicing salts in the bay's drainage basin. The former decreased the inflow of ammonia to the cove, and the latter enhanced mixing, which helped to dilute and flush the residual ammonia from the cove.

EXPLANATION

— 40 — LINE OF EQUAL CONCENTRATION

⋮ DEPTHS AT WHICH MEASUREMENTS WERE MADE

▬ PERIOD OF ICE COVER

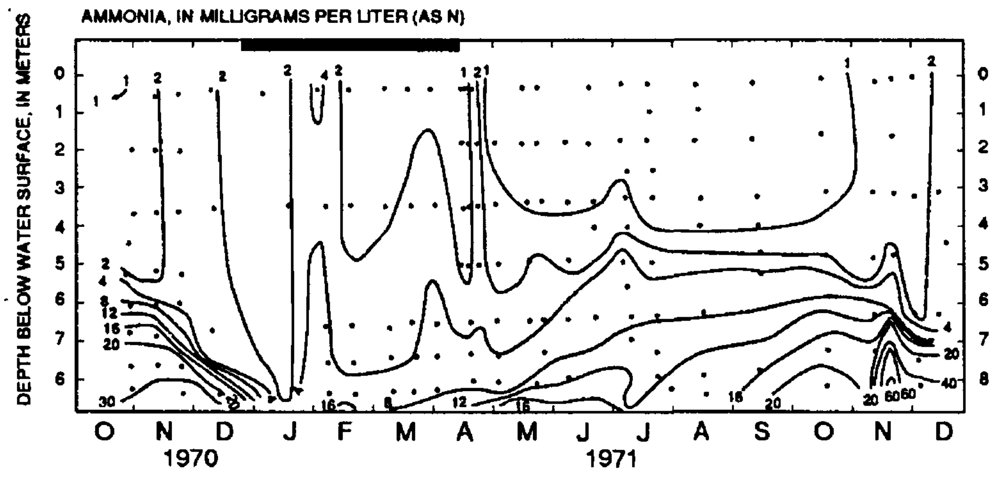
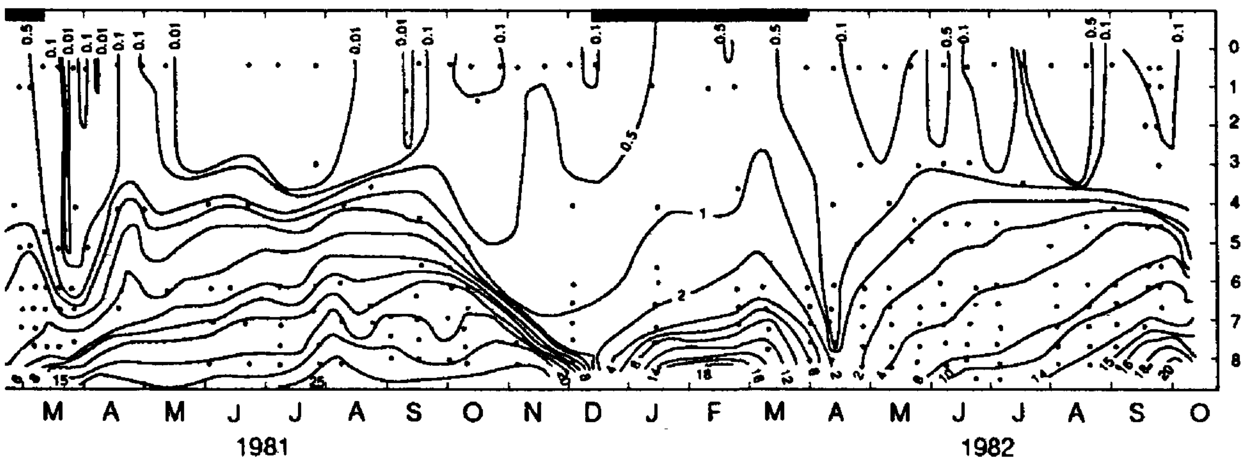


Figure 4K-3.
Depth profiles of ammonia in Ides Cove, 1970-71 (left) and 1979-82 (below).



4. Total Organic Nitrogen and Total Nitrogen

THE PREDOMINANT NITROGEN SPECIES IN IDES COVE ARE AMMONIA AND ORGANIC NITROGEN

The distribution of total nitrogen is similar to that of ammonia and organic nitrogen. Concentrations in the hypolimnion are higher than those in the epilimnion.

Total organic nitrogen and total nitrogen were measured only in 1981 and 1982. The distribution of organic nitrogen was similar to that of ammonia (fig. 4K-3). Organic nitrogen concentrations in the hypolimnion were 5 to 10 times higher than those in the epilimnion. The highest hypolimnetic concentrations were reached during stratified periods but underwent erratic increases and decreases (fig. 4K-4). The fluctuations in the organic nitrogen concentrations were probably caused by the settling and decomposition of organic matter as phytoplankton blooms came and went. Concentrations in the hypolimnion were much less in 1982 than in 1981 because the complete mixing in spring 1982 provided less carryover of residual nitrogen species from stratification beneath the ice.

Total nitrogen concentrations indicate that ammonia and organic nitrogen are the predominant nitrogen species; therefore, the distribution of total nitrogen is similar to that of ammonia and organic nitrogen, with high concentrations in the hypolimnion and low concentrations in the epilimnion. The total nitrogen profiles (fig. 4K-4) indicate complete mixing of the water column in April 1982.

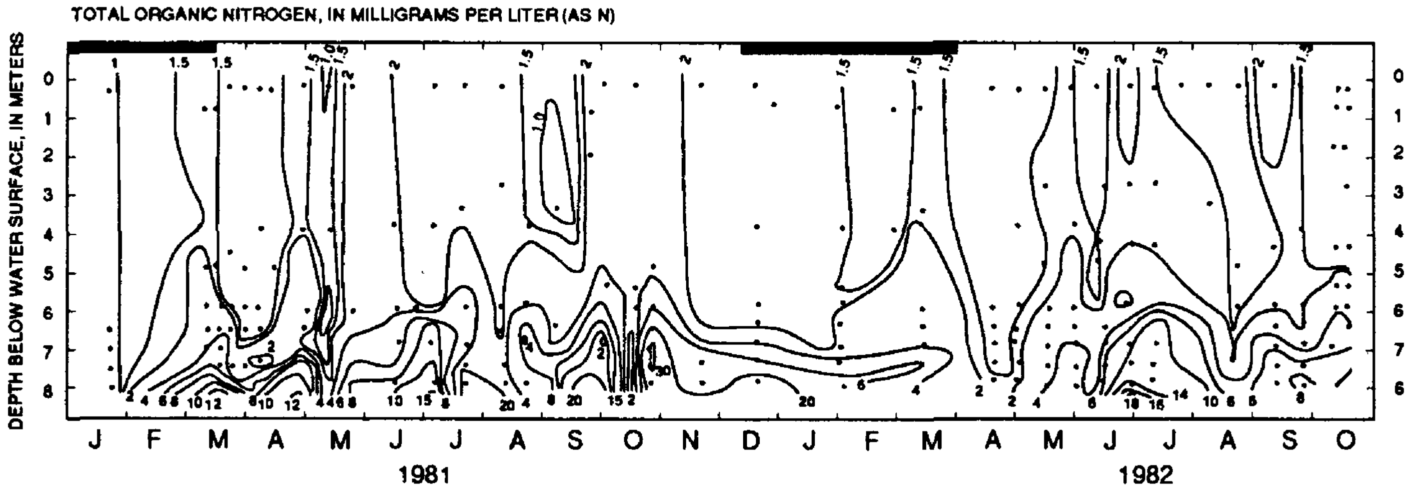


Figure 4K-4.—Depth profiles of total organic nitrogen in Ides Cove, 1981-82.

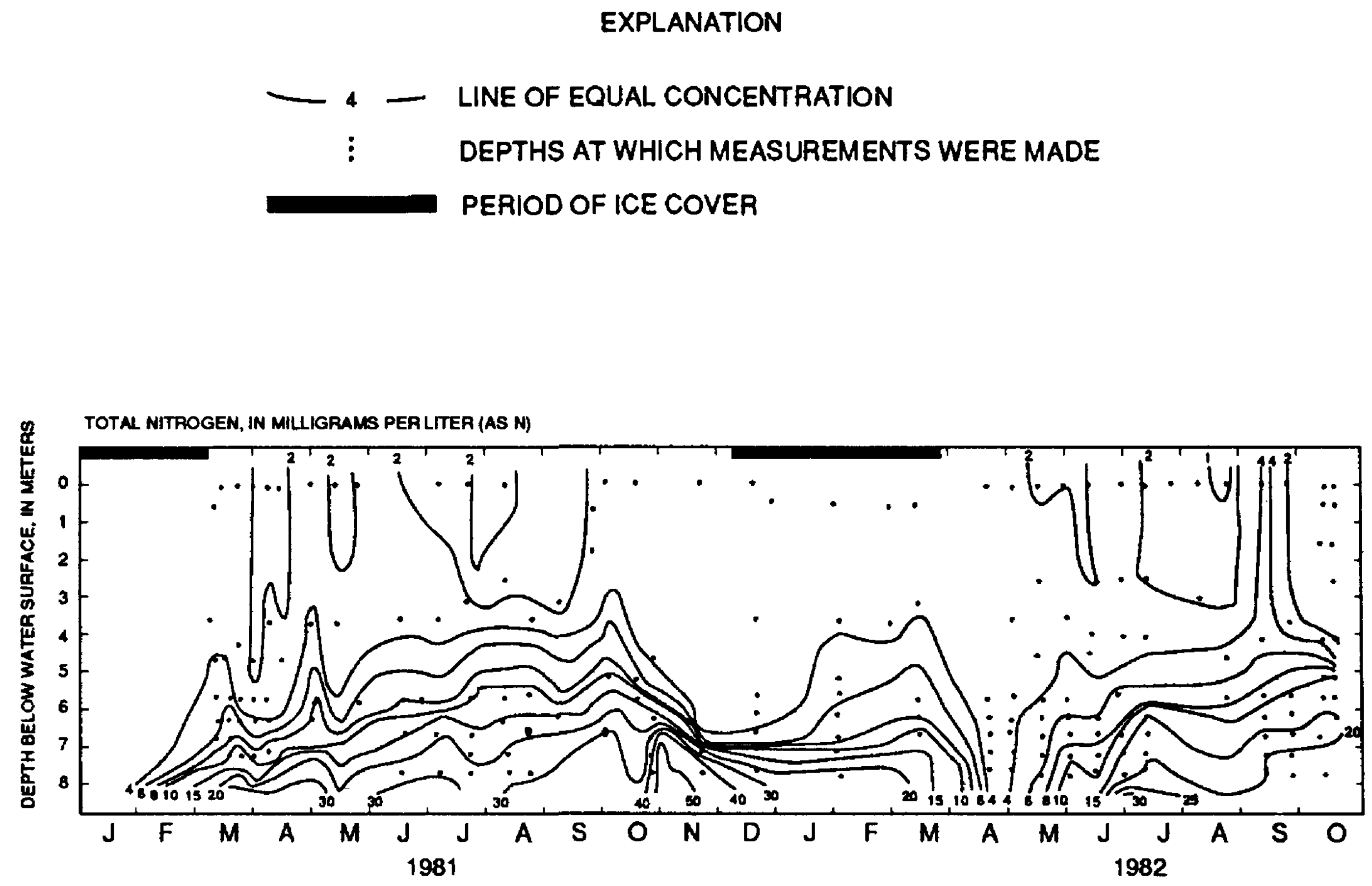


Figure 4K-4.—Depth profiles of total nitrogen in Ides Cove, 1981-82.

5 SUMMARY AND CONCLUSIONS

THE NUTRIENT STATUS AND MIXING PATTERNS OF IDES COVE IMPROVED FROM THE EARLY 1970'S TO THE EARLY 1980'S

Concentrations of nitrogen, phosphorus, and chloride decreased from 1970-72 to 1979-82, and the depth and duration of spring and fall mixing increased.

Ides Cove is a small embayment on the western shore of Irondequoit Bay near Rochester, N.Y. In October 1982, alum was applied to the bottom sediment in Ides Cove as a test to determine the applicability of this technique to decrease nutrient fluxes from the sediments of Irondequoit Bay. This report, a compilation of data from three previously published studies, provides an analysis of the temporal and depth distribution of chemical and physical properties in Ides Cove before the 1982 alum treatment and serves as a basis for comparison and evaluation of post-treatment data. The data also allow comparison of the nutrient status and mixing patterns of Ides Cove before and after the diversion of sewage in 1978 and the decrease in road salt usage since 1974 in the Irondequoit Bay and Ides Cove drainage basins.

The data from earlier studies were used to develop annual and partial-year depth profiles of 18 physical characteristics and chemical constituents for 1970-72 and 1979-82, where data were adequate. The accuracy of these profiles is dependent upon the spatial and temporal sampling intervals, lake level, diurnal changes in chemical constituents, and precision of analytical methods. The concentration and distribution of individual constituents and consequently the shape of the profiles are also affected by climatic and hydrologic events such as ice cover, precipitation, and runoff. Although these factors introduce a degree of uncertainty, the profiles present a great deal of information and allow ready identification of changes in the temporal and spatial distribution of chemical constituents and physical characteristics.

Comparison of the 1970-72 profiles with those for 1979-82 indicate that nutrient concentrations in Ides Cove decreased appreciably. After diversion of sewage out of the Irondequoit drainage basin in the late 1970's, total phosphate concentrations in Ides Cove decreased by 80 percent by the early 1980's, and nitrogen (nitrate and ammonia) concentrations decreased by 50 to 60 percent. Associated with these lowered nutrient concentrations are indications of lower primary productivity; the Secchi-disk transparency in summer increased from 0.6 m in 1970-72 to 1.2 m in 1980-82; peak epilimnetic dissolved-oxygen concentrations in summer decreased from the 22- to 28-mg/L range in 1970-72 to the 16- to 20-mg/L range in 1980-82; and peak epilimnetic pH decreased from more than 9.4 in 1970-72 to between 8.8 and 9.0 in 1980-82.

Although phosphorus concentrations in the water column had declined appreciably by the 1980's, SRP concentrations remained high (as much as 3,000 µg/L) in 1982 in the hypolimnion during winter and summer stratification. Much of this phosphorus probably originated in the bottom sediments and entered the epilimnion through mixing and diffusion, where it sustains algal growth.

Notable changes in chloride concentrations and mixing patterns since the early 1970's also are evident. After a decrease in the use of road salt since 1974, the maximum annual chloride concentration observed in the epilimnion decreased from the 210- to 225-mg/L range in the spring of 1971-72 to the 140- to 150-mg/L range in the spring of 1980-82, and the difference between the surface and bottom concentrations during the spring decreased from the 80- to 160-mg/L range in 1971-72 to the 0- to 90-mg/L range in 1980-82. Similar decreases in specific conductance and in the specific-conductance gradient between surface and bottom suggest a comparable lessening of the density gradient between 1970-72 and 1980-82. The decrease in the density gradient caused an increase in depth and duration of mixing in both the spring and fall of 1980-82, as illustrated by the profiles for temperature, specific conductance, pH, alkalinity, dissolved oxygen, chloride, and various forms of nitrogen, phosphorus, and sulfur.

These data show that Ides Cove, described by Bubeck (1972) as a marginally meromictic system (not mixing completely in the spring but mixing to within 1 m of the bottom in the fall), had changed by the early 1980's to a spring meromictic system (not mixing completely in the spring but mixing completely to the bottom by fall or during early ice cover). Complete mixing in April 1982 indicates that the cove could be approaching a dimictic condition (mixing completely to the bottom in the spring and fall).

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