Effects of Ice Cover on Dissolved Oxygen in Silver Lake, Ontario

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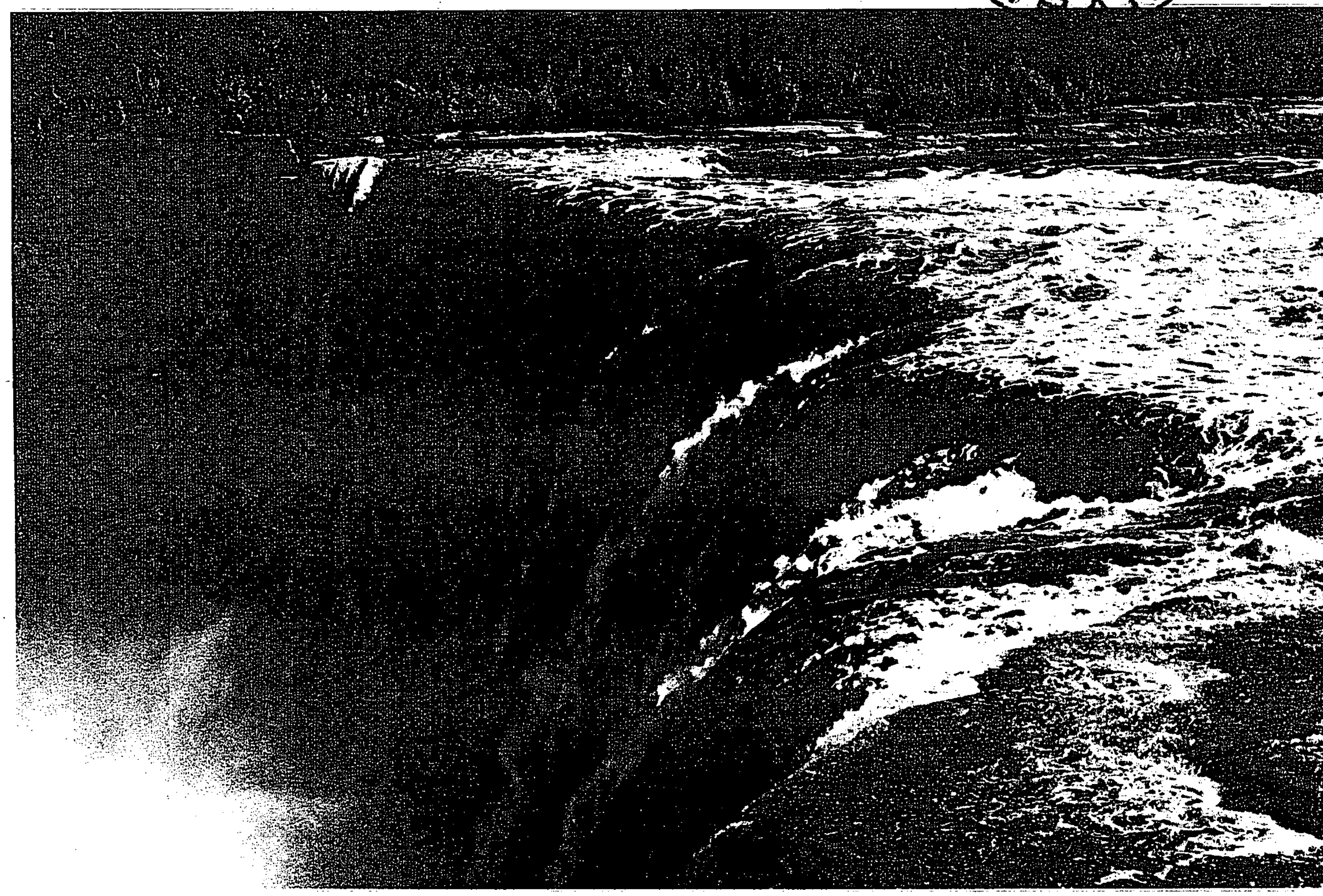

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Weekly sampling was performed at the deepest point (23 m) of Silver Lake for a few chemical parameters during the late fall and winter of 1973-74. The amount of dissolved oxygen in most of the water column decreased by about 2 ppm during the winter. At the bottom, the decrease in dissolved oxygen amounted to 4-5 ppm, and the level of hydrogen sulfide increased significantly. This decrease in the amount of dissolved oxygen is probably due to the prevention of atmospheric mixing by the ice and snow cover. In general, the amounts of orthophosphate, nitrate, chloride and total organic carbon remained constant during the winter, as did the values of specific conductance and pH.

Résumé

Au cours de l'automne et de l'hiver 1973-1974, on a fait toutes les semaines un échantillonnage à l'endroit le plus profond (23 m) du lac Silver pour mesurer quelques paramètres chimiques. La quantité d'oxygène dissous dans la majeure partie de la colonne d'eau a diminué d'environ 2 ppm durant l'hiver. Au fond du lac, la diminution était de 4 à 5 ppm, et le niveau d'hydrogène sulfuré augmentait considérablement. Cette diminution de la quantité d'oxygène dissous est probablement attribuable à la prévention d'un mélange atmosphérique par les glaces et la couche de neige. En règle générale, les quantités d'orthophosphate, de nitrate, de chlorure et de carbone organique total ont été stables durant l'hiver, de même que les valeurs de la conductance et du pH.

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INTRODUCTION

Lakes and rivers in Canada are covered with ice and snow for a significant part of the year. This insulating layer prevents aeration of the water by wind, influences heat exchange and reduces the amount of light that can penetrate into the water. Depending upon the conditions in the lake, the amount of dissolved oxygen may become low enough, so that fish are killed (Greenbank, 1945; Magnuson and Karlen, 1970). Some qualitative effects of ice cover on lakes and rivers have been known for some time (Drown, 1892; Cooper and Washburn, 1946; Halsey, 1968), but very little quantitative work has been done. For example, Croxton, Thurman and Shiffer (1937) found that the fraction of total radiant sunlight penetrating a snow cover decreases rapidly as the thickness of the snow increases and is apparently zero at a thickness greater than 200 mm. Dirt, soot, granular snow conditions, and wetness are all factors that tend to diminish the penetration of light through snow. They found that 33% of total incident sunlight is transmitted through 350 mm of clean ice and concluded that in a case in which there is ice but no snow cover of lakes, sufficient light penetrates the ice to permit photosynthetic activities of most water plants. Where the ice is covered by a layer of snow, it is doubtful that the illumination would be adequate. Greenbank (1945) confirmed these findings and emphasized that the condition of the ice is important in consideration of transmission effects. He found that in one lake there was 84% transmission of total incident sunlight through 190 mm of clear ice, but only 14-22% transmission through ice of the same thickness that was "cloudy" or "milky."

The effects of ice and snow cover on lakes and rivers in Canada are in many ways important and problems such as seasonal effects on the concentrations of dissolved substances, and on the mechanisms of photosynthesis and nitrogen fixation, merit more detailed consideration. This preliminary study was undertaken in an effort to examine the effects of ice and snow cover on some chemical constituents of the water of a nearby lake.

Silver Lake (44° 50′ lat., 76° 35′ long.), of glacial origin, is part of the Mississippi watershed in southeastern Ontario. Some of the physical characteristics are height above sea level, 206 m; area, 246 ha; maximum depth, 23 m; mean depth, 10.7 m; volume, 8.3×10^6 m^3; length, 5.0 km; width, 0.8 km; Secchi disc visibility, 3.7 m (October 1973); one permanent inlet, three additional seasonal inlets and one permanent outlet.

PROCEDURES

Sampling was done weekly as a function of depth at the deepest point in the Lake (23 m). Depth profiles of temperature, conductivity and dissolved oxygen were obtained with YSI meters. Samples were collected with a Van Doren bottle and stored in polyethylene bottles for transport to the laboratory. In addition, samples in glass BOD bottles were fixed according to the azide method for the determination of dissolved oxygen by Winkler titration (American Public Health Association, 1965). The following determinations were made in the laboratory at 25°: pH, nitrate, chloride and sulfide ions by Orion pH meter and ion-selective electrodes (nitrate ion was also determined spectrophotometrically according to *Standard Methods for the Examination of Water and Wastewater,* 1965); orthophosphate ion by the spectrophotometric stannous chloride method (*Standard Methods for the Examination of Water and Wastewater,* 1965); and dissolved oxygen by the Winkler method mentioned. Ultraviolet spectra were recorded of samples that had been filtered through 8 μm Millipore filters. These spectra were used to calculate approximate values for total organic carbon (TOC) according to the correlation method of Dobbs, Wise and Dean (1972). In addition, a more detailed analysis of one particular set of samples was performed by the Analytical Service Section of the Canada Centre for Inland Waters in Burlington, Ontario.

RESULTS AND DISCUSSION

Temperature measurements indicated that the fall turnover occurred about November 22, 1973; after that point the temperature of the deeper waters increased relative to that of the surface waters. At the end of February, the temperature varied from 0° at the ice-water interface to 4.5° at the bottom. Figure 1 shows the ice and snow thickness on Silver Lake as a function of time during the winter. A thaw of about ten days duration in late January melted all of the snow; after that time there was never more than 80 mm of snow on the ice, and the top 80 mm of the ice became cloudy. Work was interrupted by a rapid thaw at the end of February. The concentrations of some chemical constituents of the water of Silver Lake in winter are shown in Table 1. These values are generally constant with depth except within 0-2 m from the bottom, in which case there may be a rapid change, the value approaching that shown in parentheses. Figure 2 shows the difference in the amount of dissolved oxygen as a function of depth between the ice-free season and the point of maximum ice cover. The amount of dissolved oxygen in the water of Silver Lake appears to show only a gentle decrease with depth; the "under-ice profile" is essentially shifted 1-2 ppm lower than the "fall profile," except at greater depths where the difference is greater, presumably because of the oxygen demand of the sediment. During the same period the concentration of sulfide ion at the bottom increased from 1-22 ppm.

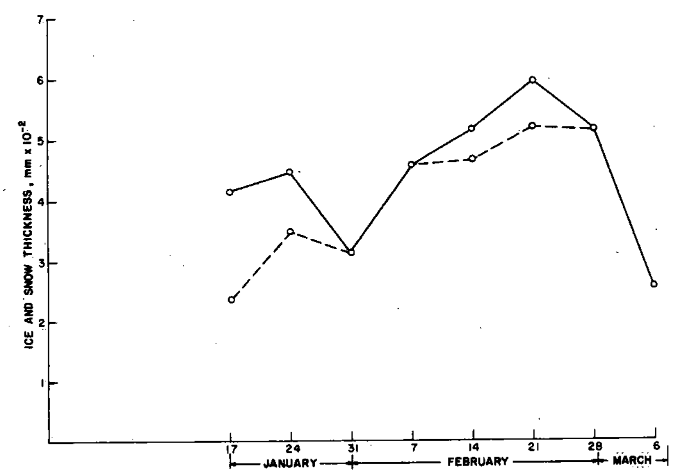

Figure 1. A plot of ice and snow thickness on Silver Lake during the winter of 1973-74. Dashed line, ice thickness; solid line, ice and snow thickness.

The values of pH remained relatively constant with depth at 7.0 during the fall; under ice, the values were again constant with depth, but at pH 7.5. In each case there was a drop of about 1 pH unit at the bottom.

The concentration of nitrate ion remained relatively constant with depth throughout the fall and winter at 1.5 ppm. There was satisfactory agreement between values of nitrate ion concentrations obtained by the spectrophotometric method and values obtained using ion-selective electrodes. The concentration of chloride ion at the fall turnover was constant with depth at 3.5 ppm; the values then increased, so that on February 21, 1974 the value immediately beneath the ice was 10 ppm, decreasing gradually to 6.5 ppm at the bottom. The concentration of orthophosphate ion was constant with depth throughout the fall and winter at 0.05 ppm, except at the bottom where the value rose to 0.5 ppm. In late February, the amount of total phosphate at the bottom was 13 ppm.

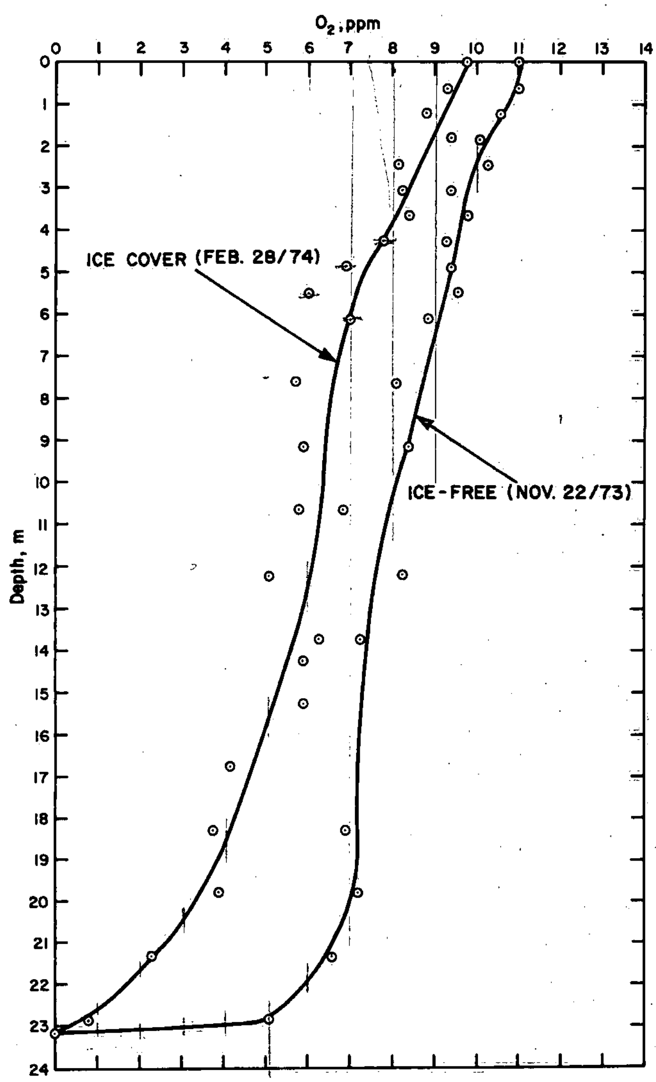

Figure 2. Plots of dissolved oxygen versus depth under ice cover and during ice-free conditions.

The values of specific conductance were generally constant with depth at 20 μmho mm^{-1} until mid-February, when an abrupt increase to 25 μmho mm^{-1} appeared at about 18 m and persisted to the bottom. This increase was noted for the duration of experiments on the ice, and was not correlated with any increase in concentration of the ions monitored on a long-term basis, i.e., phosphate, chloride, nitrate or sulfide ions.

Dobbs, Wise and Dean (1972) have developed an approximate correlation between the absorbance of a filtered sample of water at 254 nm and the total organic carbon (TOC) content of that water. Their relation covers different raw and treated waters and may be stated as TOC $(ppm)/A_{254nm}^{1cm} = 4.43 \times 10^1$. This method will not of course reveal the amount of dissolved organic substance that does not absorb light at 254 nm, nor does it take into account the amount of suspended material in natural waters, although they have provided for a turbidity correction. Nevertheless, we have used this correlation as a fast method for providing rough TOC estimates. We find that the TOC remains relatively constant with depth throughout the fall and winter at about 6 ppm, except at the bottom where the value increases to about 30 ppm.

Table 1. Chemical Characteristics of Silver Lake

Constituent	Concentration (ppm) or value
Total alkalinity ($CaCO_3$)	110
Bicarbonate (HCO_3^-)	150
Calcium	45
Chloride	10
Colour (Hazen units)	10(70)
Total hardness	150(170)
Extractable iron	0.01(20)
Extractable manganese	0.01(10)
Magnesium	9
Potassium	1.5
Silica	5(40)
Sodium	5
Sulfate	20
Turbidity	0.3 JTU
Specific conductance	300(400)

Note: Samples were collected on February 28, 1974. The values indicated are constant over 23 m from surface to bottom unless indicated otherwise by the bottom value in parentheses.

The most noticeable effect of the ice cover on Silver Lake in winter is to reduce the amount of dissolved oxygen by 1-2 ppm throughout the depth of the water. The decrease is presumably due both to the prevention of aeration of the water by wind and to the diminished rate of photosynthesis by micro-organisms. Since the amount of dissolved oxygen in the summer is high (9 ppm) even at depths (e.g., 20 m) at which one would not expect much photosynthetic evolution of oxygen, we are inclined to support the former mechanism, i.e., the decrease in the amount of dissolved oxygen in the waters of Silver Lake is due largely to the prevention of aeration of the water by wind. It is expected that winter conditions would have more pronounced effects on shallower, more eutrophic lakes or bays of rivers in which photosynthesis is relatively more important. In this context, a problem that deserves careful attention is the quality of light transmitted by ice and snow cover, and its photosynthetic effectiveness as a function of depth beneath the ice.

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