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REPORT NO. 853a

FURTHER WINTER-KILL STUDIES

by

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FURTHER WINTER-KILL STUDIES

Introduction

The various conditions that exist in the small inland lakes of southern Michigan in the winter, in particular those having to do with the winter-kill of fish, were the subject of a rather intensive investigation, conducted in the winters of 1937-38, 1939-40, and 1940-41, and reported to the Institute for Fisheries Research*/. The present paper deals with some supplementary work performed in the winter of 1942-43, in the course of which follow-up study particular emphasis was placed upon possible means of alleviation or prevention of winter-kill conditions.

The work was sponsored and financed by the Institute for Fisheries Research, A. S. Hazzard, director. Grateful acknowledgement is extended to Professor Carl L. Hubbs, of the University of Michigan Museums, for supervision of the work, to Earl L. Hubbs and George Washburn for assistance in the field, and to members of the Institute staff for help in various ways.

Methods

The equipment and methods were mainly those used in previous winters and described in Report No. 853. A hand sled, fitted with a box (Figure 1), was used to carry equipment on the ice. The box used to hold reagent bottles is shown in Figure 2, and the operation of "fixing" dissolved oxygen samples is pictured in Figure 3. The latter figure also shows the felt-lined box used for carrying samples and for protecting them from the cold. The portable shanty, used particularly in the work of the earlier winters, for protection against the weather, is shown in Figure 4.

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*/Limnological Conditions in the Waters of Ice-covered Lakes, with Especial Regard to the Winter-kill of Fish. John Greenbank. I.F.R. Report No. 853.

Figure 1. Hand sled for transporting samples on the lake.

Figure 2. Box with reagent bottles (for dissolved oxygen tests).

Figure 3. "Fixing" dissolved oxygen samples.

Figure 4. Shanty.

As in the previous work, dissolved oxygen was determined by the "rapid" Winkler method. The samples were fixed in the field, and were titrated in the laboratory, the same day. Methyl orange alkalinity (for the "profile" described below) was determined in the standard manner, the titrations being made in the laboratory. In the work of 1942–43, water temperature, pH, and dissolved CO_2 were not measured.

The work of 1942–43 was confined to Green Lake, Washtenaw County. A description and map of this lake appear in Report No. 853. Stations 1, 2, and 5, referred to below, were located, as nearly as possible, in the same positions as before.

Weather, Snow, and Ice

Green Lake was frozen completely over by approximately December 1, 1942 (the exact day is not known, but ice 3 inches thick was recorded on December 5). This date is considerably earlier than average, for usually a complete cover of ice is not present on Green Lake, or similar lakes in the same region, until late December or, in some winters, until after January 1. As is the normal case, the ice was affected by several thaws, during the course of the winter. None of these, however, opened more than small local holes, and the seal of the ice was virtually complete throughout the winter. As shown in Table 1, the average thickness of the ice during most of its existence was from 8 to 12 inches. It is probable that it would have become considerably thicker, after the prolonged cold spells of early winter, had it not been insulated much of the time by a blanket of snow. The ice did not break up, to the extent of opening any large areas, until after March 20 (here, also, the exact date is not known). Thus an uninterrupted ice cover existed for at least 110 days, which is a period considerably longer than average.

Table 1. Thickness of ice and snow, Green Lake, 1942–43.

Date	Ice, inches	Ice, description	Snow, inches	Snow, description	Remarks
Dec. 5	3	Mod. cloudy	None	...	
16	6	Cloudy	1/2	...	
23	9	Cloudy on top	1	Crusty	Melting for first time in many days.
29	6	Soft, cloudy	None	...	Water on ice, after 3 days rain.
Jan. 4	8	Solid	2	Dry	
8	8	Fairly clear	3	Old drifts, plus new	Slush under snow in places.
12	8	...	3	Dry, firm	Slush under snow in places.
16	9	...	6	Drifts, plus new	2 1/2" new snow last night. Slush under snow in places.
22	12	...	10	Dry, over slush	Slush to within 3 or 4 inches of snow surface.
24	12	...	Tr.	Little dry snow	Melted and refrozen slush.
29	12	Cloudy on top	Tr.	Few skiffs	
Feb. 2	12	Cloudy on top	1	New, crusted	New within 2 or 3 days.
5	...	...	Tr.	Nearly gone	Rainy
8	12	...	1	Crusted	New on Feb. 7.
13	12	...	1/2	New	Old snow gone. New snow today.
22	12	...	None	...	
27	10	Firm	None	...	

Table 1 also gives the amount of snow on the ice at the time of each observation. This measurement, obviously, is subject to considerable variation, since the snow usually occurred in drifts. The recorded figure is that which most nearly represents the depth of snow over the largest part of the lake, ignoring local drifts or bare places. In Graph 1 is shown a curve representing the amount of snow on the ice. This curve is, of necessity, idealized to some extent, since actual observations were too infrequent to give the exact day-to-day changes. Its accuracy is helped somewhat, however, by the correlative use of snowfall data obtained from the University of Michigan weather station at Ann Arbor, since these data fix the dates of the major snowstorms of the general region.

During the last few days of December, rains and thaws melted the snow which was then on the ice. Then, starting in the first few days in January, there followed a period of about 20 days in which one snowfall after another occurred, until on January 22 the depth of snow on the ice was about 10 inches.

There was, however, an accompanying process of much significance. The ice, never very thick, was not strong enough to completely support this load of snow. Starting about January 8 or 10, the ice gradually sank somewhat, forcing water up through cracks. Thus a slush became built up, under the upper layers of snow in most places, and completely breaking through the snow in some small patches. On the average, on January 22, the slush came to within 3 or 4 inches of the upper surface of the snow.*/

This water, naturally, put a still greater load upon the ice. On the other hand, opposing the sinking of the ice, was its inherent buoyancy, which produced a tendency for the ice to rise up through the superimposed water. It is possible that under certain circumstances this uprising might take place slowly, with the water gradually seeping down through the cracks in the ice.

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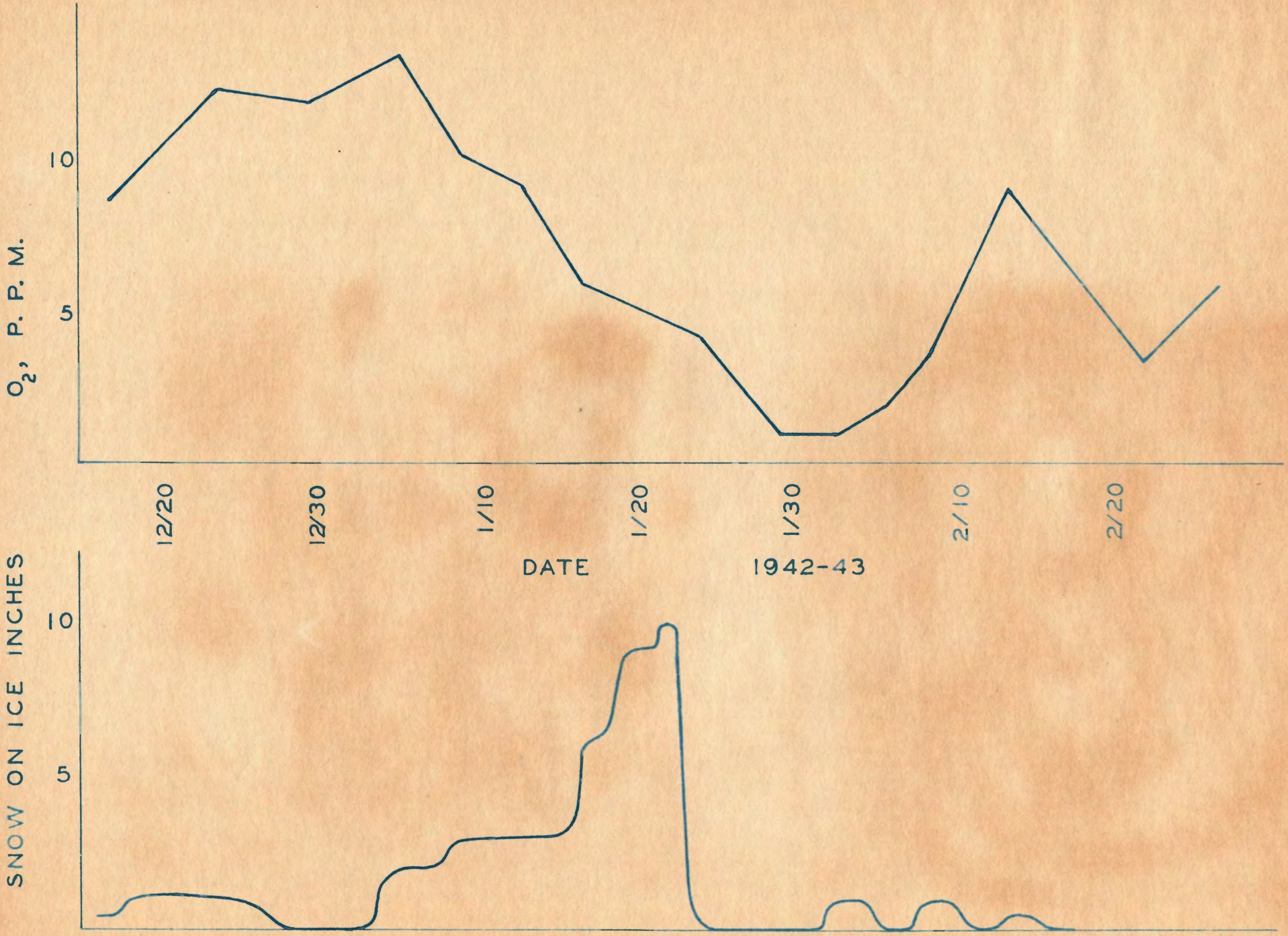
*/In Table 1 and Graph 1 the slush is treated as snow, since there was no accurate way of measuring separately the slush and the dry snow.



GRAPH I. DISSOLVED OXYGEN, GREEN LAKE, STA. I, SURFACE SAMPLE, 1942-43.
LOWER CURVE SHOWS DEPTH OF SNOW ON THE ICE OF THE LAKE.

However, on this particular occasion, the ice lifted rather suddenly, probably within the space of one night (that of January 22), much of the water on the ice no doubt flowing around the edges of the ice sheet. On January 24, following this lift, the ice literally was "high and dry." Dry snow was virtually absent, and that part of the slush which still remained on top of the ice had frozen into a rough, cloudy layer.

The ice was bare of snow for the remainder of January, and was snow-covered only for brief, irregular periods in February.

Dissolved Oxygen

Routine dissolved oxygen measurements were made at Stations 1, 2, and 5 (see Report No. 853 for station locations and descriptions), in the inlet stream at its mouth, and at the dam at the outlet. The values obtained are given in Table 2. The "surface" sample, at each station, was taken at about 4 inches under the surface of the water as it stood in the hole in the ice, and the deepest sample was taken approximately one foot off the bottom.

The oxygen at the surface at Station 1 showed reasonably good correlation with the amount of snow on the ice (Graph 1). Starting shortly after the first snowfall in January, the oxygen continuously declined as the snow became deeper and, with a lag of only a few days, started to rise again after the ice became bare. The oxygen at Stations 2 and 5 (not graphed) did not show as clear-cut correlation, but did follow the same general trend.

The dissolved oxygen in the inlet stream was moderately high throughout the winter, most of the time being definitely above that at the outlet. This condition was in sharp contrast to that in 1940-41, during which winter the oxygen in the inlet was comparatively low for an extended period. There is no readily apparent explanation for the difference, but it is possible that it came about because of a different proportion of surface run-off to ground water.

Table 2. Dissolved oxygen, Green Lake, 1942-43.
Values are in p.p.m.

Station	Sampling depth	Dec.16	Dec.23	Dec.29	Jan. 4	Jan. 8	Jan.12	Jan.16	Jan.22
Sta. 1	Surf.	8.8	12.4	12.0	13.5	10.3	9.3	6.1	4.8
	4 ½'	7.6	4.5	2.7	4.0	0.4	1.2	0.4	4.0
Sta. 2	Surf.	7.9	11.2	10.7	13.4	10.4	7.8	7.8	6.7
	2'	7.6	7.8	9.4	8.1	5.6	4.1	4.1	3.0
	5'	5.4	6.1	3.5	3.1	2.2	1.8	0.4	0.2
	9'	4.6	3.1	1.6	2.0	0.7	0.5	0.0	0.0
Sta. 5	Surf.	...	11.6	11.6	10.4	10.6	8.0	4.1	3.7
	4'	...	2.5	1.7	2.9	1.6	1.1	0.2	0.4
Inlet	6"	2.9	5.2	11.4	5.9	6.6	6.0	7.9	5.1
Outlet	6"	6.2	7.1	9.3	10.5	4.5	4.9	3.3	3.2

		Jan.24	Jan.29	Feb. 2	Feb. 5	Feb. 8	Feb.13	Feb.22	Feb.27
Sta. 1	Surf.	4.3	1.2	1.2	2.1	3.8	9.1	3.6	6.1
	4 ½'	0.0	0.0	0.0	0.0	0.3	0.1	0.5	0.8
Sta. 2	Surf.	7.5	5.3	4.0	4.5	2.2	1.2	3.4	9.6
	2'	3.6	2.3	2.3	1.4	1.1	0.9	2.6	10.0
	5'	0.5	0.2	0.1	0.0	0.0	0.0	1.0	2.4
	9'	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sta. 5	Surf.	5.7	3.7	1.4	1.8	9.8	5.2	7.9	5.4
	4'	1.4	0.7	0.0	0.0	0.1	0.1	1.2	0.0
Inlet	6"	5.6	6.0	8.3	8.4	9.7	6.9	9.5	8.9
Outlet	6"	1.7	1.4	1.0	0.4	0.2	1.2	7.8	4.0

Dissolved Oxygen and Alkalinity Profiles

In the same manner which was used in 1940-41, described in Report No. 853, profile sections of Green Lake, showing isograms of dissolved oxygen, were drawn up for three different dates in 1942-43. Briefly, these profiles were derived as follows. Stations were made at regular intervals (about 150 feet) along a line from the mouth of the inlet stream of the lake to the outlet dam. This line made a very broad curve, following the channel of the lake (see map, Report No. 853). At each station, samples were taken at vertical intervals of one foot, starting one foot below the upper surface of the ice, which was itself approximately one foot thick. The dissolved oxygen in these samples is given in Table 3.

For each of the three dates on which this work was done, February 5, 8, and 22, 1943, a profile diagram was constructed (Graphs 2 and 3). On these diagrams, isograms connect points of equal dissolved oxygen concentration, as labelled. The upper foot of the lake's volume is shown as being filled with ice. The contour of the lake bottom along the line of transect is indicated by the heavy line at the bottom of each figure. The vertical scale is, of necessity, exaggerated with reference to the horizontal scale, being one hundred times as great.

These oxygen profiles show, for one thing, that there may be considerable lack of uniformity in oxygen relations between different parts of a lake. There is, moreover, a definitely noticeable tendency for the dissolved oxygen isograms to follow the contour of the lake bottom, as pointed out in the previous report. This tendency is displayed to some extent even by the uppermost of the isograms.

On February 5, the lake as a whole had reached perhaps its lowest dissolved oxygen content of the winter. As shown in Graph 2, only a very small part of the area of the transect had a value of 2.0 p.p.m. or more, and by far the largest part had less than 0.5 p.p.m. The inflowing water, however, was carrying

Table 3. Dissolved oxygen and methyl orange alkalinity profiles, Green Lake, 1943. Horizontal distances are in feet from mouth of inlet stream. See text.

Distance from inlet, feet	Total depth, feet	Sampling depth, feet	Dissolved oxygen, p.p.m.			M.O. Alk., p.p.m. 2/22/43
			2/5/43	2/8/43	2/22/43	
— 90	1 ½	1	8.4	9.7	9.5	132
50	2 ½	1	8.4	9.9	8.8	140
		2	8.1	7.8	3.5	165
150	4 ½	1	...	6.9	9.4	130
		2	...	5.8	2.2	183
		3	...	3.6	2.5	184
		4	...	...	0.8	195
250	8 ½	1	3.4	6.6	8.5	126
		2	0.8	5.6	3.4	170
		3	0.2	3.0	2.5	184
		4	0.0	1.3	1.0	188
		5	0.3	...	2.1	196
		6	0.0	...	...	...
		7	0.1	...	...	...
		8	0.0	...	...	...
400	10 ½	1	1.4	4.3	9.2	120
		2	1.3	3.9	4.4	170
		3	1.2	2.1	1.3	188
		4	0.3	0.0	1.0	190
		5	0.2	...	...	...
		6	0.2	...	...	...
		7	0.0	...	...	...
		8	0.0	...	...	...
		9	0.0	...	...	...
		10	0.0	...	...	...
550	9 ½	1	0.9	1.6	8.5	134
		2	0.5	1.3	4.7	172
		3	0.5	0.4	3.6	186
		4	0.3	...	...	...
		5	0.2	...	...	...
		6	0.1	...	...	...
		7	0.4	...	...	...
		8	0.0	...	...	...
		9	0.0	...	...	...
700	7	1	1.2	1.2	7.5	144
		2	0.4	0.3	5.2	176
		3	0.2	0.7	3.7	188
		4	0.1	...	...	...
		5	0.0	...	...	...
		6	0.0	...	...	...
		6 ½	0.0	...	...	...

(Continued)

Table 3. Dissolved oxygen and methyl orange alkalinity profiles, Green Lake, 1943. Horizontal distances are in feet from mouth of inlet stream. See text.
(Continued)

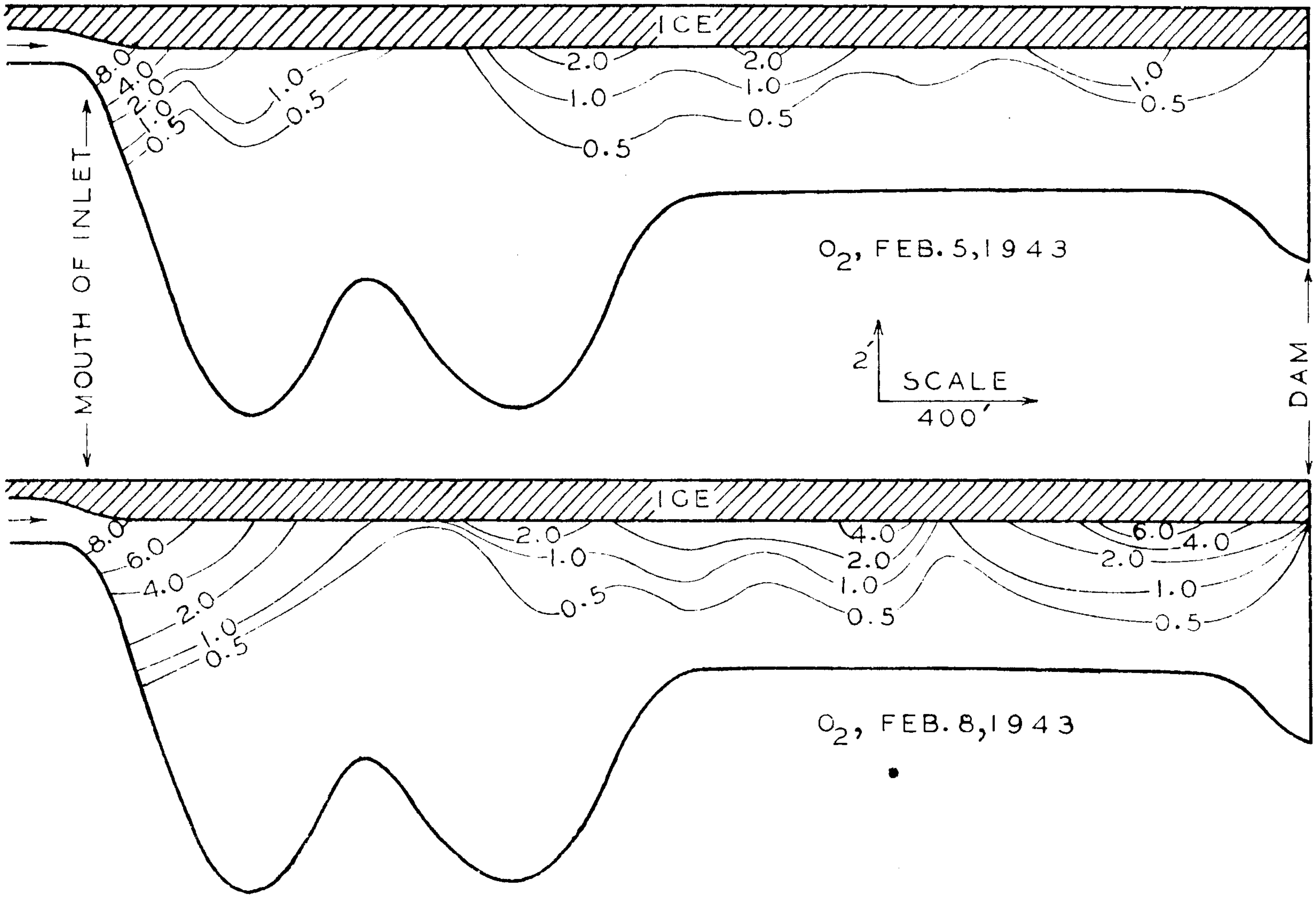
Distance from inlet, feet	Total depth, feet	Sampling depth, feet	Dissolved oxygen, p.p.m.			M.O. Alk., p.p.m.
			2/5/43	2/8/43	2/22/43	2/22/43
850	8 ½	1	0.3	0.6	7.0	154
		2	0.2	0.2	4.4	180
		3	0.1	0.1	3.3	190
		4	0.2	...	...	...
		5	0.0	...	...	...
		6	0.0	...	...	...
		7	0.0	...	...	...
		8	0.0	...	...	...
1000	10	1	1.0	2.2	6.2	158
		2	0.3	0.2	3.9	184
		3	0.1	0.1	3.3	190
		4	0.2	...	...	...
		5	0.0	...	...	...
		6	0.0	...	...	...
		7	0.0	...	...	...
		8	0.0	...	...	...
		9	0.0	...	...	...
1150	10	1	4.5	2.2	3.4	144
		2	1.4	1.1	2.6	176
		3	0.8	0.5	2.4	188
		4	0.2	0.8	1.8	196
		5	0.0	0.0	1.0	150
		6	0.0	...	...	...
		7	0.0	...	...	...
		9	0.0	0.0	0.0	224
1300	8	1	2.2	1.9	2.3	170
		2	1.0	0.8	2.4	182
		3	0.2	0.2	1.8	188
		4	0.7	0.0	1.1	190
		5	0.1	...	...	...
		7	0.0	...	...	...
1500	4 ½	1	1.2	4.0	1.8	174
		2	0.5	1.4	1.6	184
		3	0.5	0.7	0.5	186
		4	0.2	...	...	...
1700	5	1	2.1	3.8	3.6	142
		2	0.5	0.8	1.7	174
		3	1.1	0.3	1.4	182
		4 ½	0.0	0.3	0.5	186

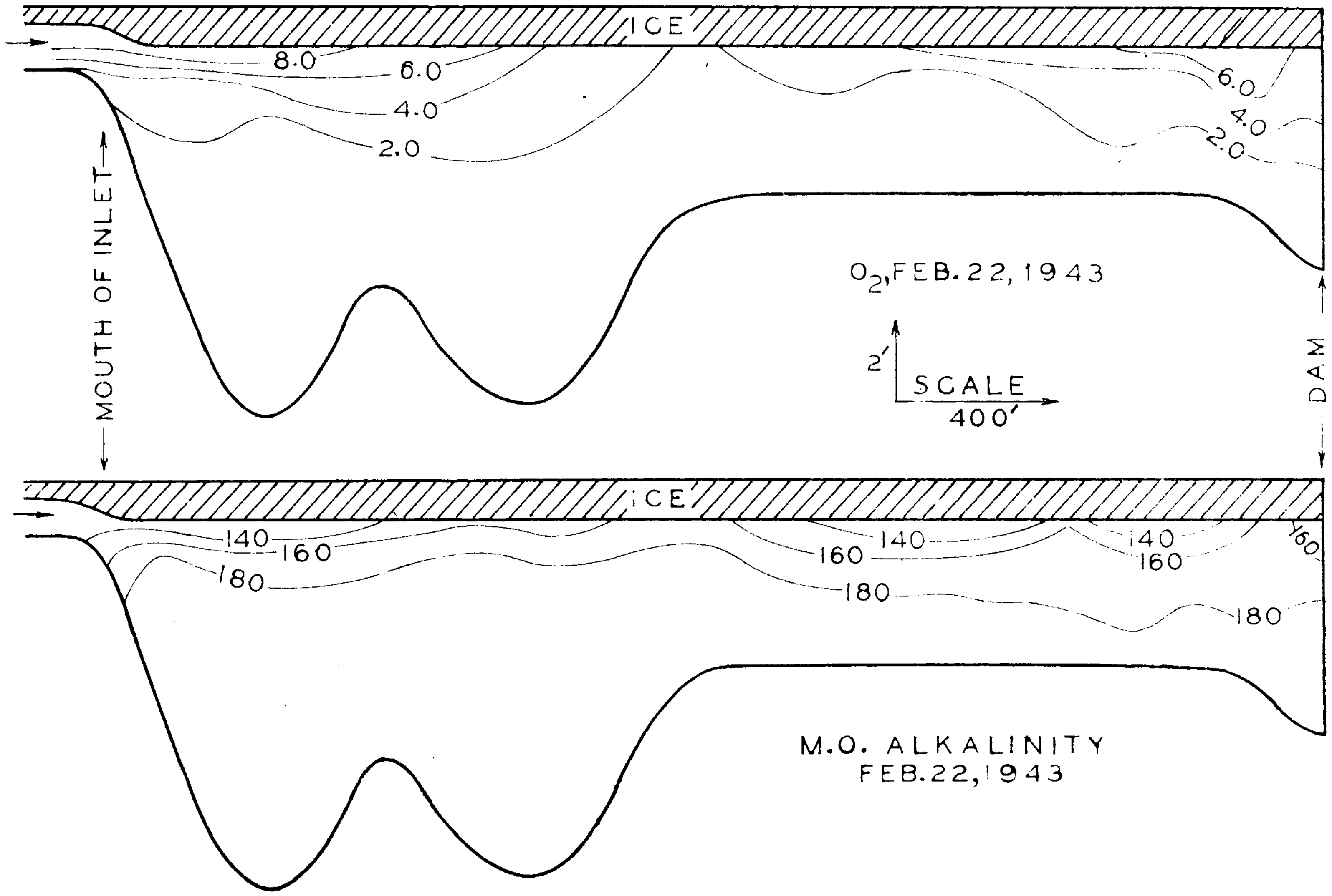
(Continued)

Table 3. Dissolved oxygen and methyl orange alkalinity profiles, Green Lake, 1943. Horizontal distances are in feet from mouth of inlet stream. See text. (Continued)

Distance from inlet, feet	Total depth, feet	Sampling depth, feet	Dissolved oxygen, p.p.m.			M.O. Alk., p.p.m. 2/22/43
			2/5/43	2/8/43	2/22/43	
1850	4 ½	1	1.4	3.5	3.2	136
		2	0.5	1.4	2.4	162
		3	0.1	0.7	1.8	168
		4	0.3	...	...	...
2000	5	1	0.8	5.6	4.2	130
		2	0.3	2.4	1.0	172
		3	0.3	0.7	0.8	182
		4	0.2	...	...	...
2150	4 ½	1	0.8	1.0	4.4	128
		2	0.5	0.4	0.8	172
		3	0.4	0.4	0.6	184
2300	4 ½	1	0.7	2.3	5.5	130
		2	0.2	1.5	1.5	174
		3	0.2	0.3	0.9	170
2450	5	1	1.3	2.6	5.0	152
		2	0.2	0.6	2.9	176
		3	0.4	0.9	2.4	176
		4	0.1	...	...	...
2600	4 ½	1	1.8	9.8	7.9	122
		2	1.0	1.7	3.5	166
		3	0.3	0.9	2.9	174
		4	0.0	0.1	1.2	176
2750	5	1	0.8	6.5	7.5	130
		2	0.6	1.3	2.8	168
		3	0.2	0.8	2.0	180
		4	0.0	...	...	...
2900	5	1	0.8	4.6	7.5	156
		2	0.5	1.0	5.9	176
		3	0.4	0.7	6.3	168
3050	6 ½	1	0.3	2.5	5.4	174
		2	0.2	0.8	4.5	174
		3	0.2	0.5	3.7	180
		4	0.0	...	...	...
		5	0.0	...	...	...
		6	0.0	...	...	...
3090	4 ½	Surf.	0.4	...	...	...
		1	0.1	0.2	7.8	134
		2	0.0	0.3	6.3	166
		3	0.0	0.3	5.5	176
		4	0.0	...	...	...

GRAPH 2. DISSOLVED OXYGEN PROFILES, GREEN LAKE, 1943.
VALUES IN P.P.M.





GRAPH 3. DISSOLVED OXYGEN AND METHYL ORANGE ALKALINITY PROFILES, GREEN LAKE, FEB. 22, 1943. VALUES IN P.P.M.

over 8 p.p.m. at this time. The amount of oxygen enrichment which thus far had been brought about by this means is evident from the diagram. It must be remembered, of course, that the diagram represents a section along the channel; the effect of the inlet upon the lake as a whole is not nearly so great as might be supposed from the diagram.

The oxygen along the profile had increased noticeably by February 8, mainly as a result of rains and thaws. That this increase came from the surface is well indicated in the diagram, which shows a vertical shift in the isograms. However, in spite of this shift, the same general pattern was carried over from the one date to the other. During the three-day interval a large amount of water, relatively high in oxygen, was brought in by the inlet; its effect is displayed in the changed pattern of the isograms at that end of the section.

By February 22, a considerable amount of oxygen had been added to the upper water, by run-in and stream flow (possibly also to some extent by photosynthesis), almost completely obliterating the former pattern of the profile (Graph 3). A few vestiges of that pattern remained, however, particularly the "low" point at about 1500 feet from the mouth of the inlet. The local effect of water from the inlet stream had largely been absorbed by, even as it contributed to, the general increase in oxygen in the upper layers of water.

Evidence that much of the increase in oxygen was caused by run-in water is given by the diagram for methyl orange alkalinity, for the same date (February 22). The alkalinity isograms tended somewhat to follow those for oxygen. The normal situation toward the end of winter stagnation is for the alkalinity to be greatest at the bottom, and least just under the ice; but without the influence of run-in, the alkalinity at the surface in Green Lake usually does not fall below 175 p.p.m. (see Report No. 853). The values, shown on the diagram, of 140 p.p.m. or less, definitely are attributable to run-in water.

As pointed out in the previous report, this very soft run-in water at times may reduce the methyl orange alkalinity, locally just under the ice, to a few p.p.m.; however, mixing by diffusion or by current soon lessens this effect.

An index, by means of which the relative average amounts of oxygen represented on the three dissolved oxygen profile diagrams may be compared, has been derived as follows. For each diagram, the area between each two consecutive isograms was measured, and computed in terms of per cent of the total area of the diagram. This figure then was multiplied by the mean oxygen value of the two isograms (Table 4), this mean being assumed to be the average value for the interval between those two particular lines. These products were totalled, and their sum divided by the total area (i.e., by 100 per cent). This quotient was assumed to represent the average value for the entire diagram, and thus for that transverse section of the lake at that time.

How reliably this index may be applied to the lake as a whole is not known; for of course only one section is represented, and that a rather special one (i.e., along the channel). However, it surely is a much better index than one obtained from only a single station; and it at least gives a rough idea of the condition of the entire lake.

These calculated mean values were:

Feb. 5 .... 0.6 p.p.m.
Feb. 8 .... 1.0 p.p.m.
Feb. 22 .... 2.1 p.p.m.

These figures show something of the increase (mentioned above) of oxygen from one of these dates to another. They also point out that which is not instantly apparent in the diagrams, that is, that as concerns the section as a whole the increase in oxygen was not numerically great, even though the water near the surface was greatly enriched in oxygen. A lake may show apparently great recovery from low oxygen conditions, when judged by one or a few surface samples, and yet continue to be relatively low in average oxygen content. In

Table 4. Derivation of mean oxygen values for profile diagrams, Green Lake, 1943, by use of average values for intervals between successive isograms. See text.

Isograms enclosing interval	Mean value for the interval, p.p.m.	% of total area within interval	Product, (% area) × (mean value)
	2/5/43		
0.0 — 0.5	0.25	75.2	18.8
0.5 — 1.0	0.75	12.4	9.3
1.0 — 2.0	1.5	9.0	13.5
2.0 — 4.0	3.0	2.4	7.2
4.0 — 8.0	6.0	0.5	3.0
8.0 —	(8.0)	0.5	4.0
		100.0	55.8
	Mean = 55.8 ÷ 100 = 0.6 p.p.m.		
	2/8/43		
0.0 — 0.5	0.25	64.5	16.1
0.5 — 1.0	0.75	10.0	7.5
1.0 — 2.0	1.5	12.9	19.4
2.0 — 4.0	3.0	7.9	23.7
4.0 — 6.0	5.0	2.9	14.5
6.0 — 8.0	7.0	1.4	9.8
8.0 —	(9.0)	0.5	4.5
		100.1	95.5
	Mean = 95.5 ÷ 100 = 1.0 p.p.m.		
	2/22/43		
0.0 — 2.0	1.0	65.2	65.2
2.0 — 4.0	3.0	21.4	64.2
4.0 — 6.0	5.0	8.1	40.5
6.0 — 8.0	7.0	3.8	26.6
8.0 —	(9.0)	1.4	12.6
		99.9	209.1
	Mean = 209.1 ÷ 100 = 2.1 p.p.m.		

fact, it seems to be the normal case, in the average eutrophic lake in this region, that the oxygen near the bottom diminishes quickly after the lake becomes ice-covered, and remains low throughout the winter; thus leaving the shifting back and forth between high and low values to the oxygen in the water near the surface. In effect, a "squeezing-out" is accomplished; that is, the fish presumably are confined, for a large part of the winter, to a more or less thin layer of water immediately under the ice.

Light Penetration

A very few measurements were made of light penetration through ice and through snow, in the winter of 1942-43. The apparatus and technique used were those described in Report No. 853. The data obtained (Table 5) merely extend somewhat, rather than actually supplement, those in the previous report.

As shown by Table 5, the light transmitted through approximately 15 inches of partly cloudy ice was from 2 to 12 per cent of the incident light. About one inch of crusted snow permitted the passage of from about 9 to 20 per cent of the light.

"Total light" (i.e., the light of the visible spectrum as measured by a Weston Photronic cell), red light, and green light all were transmitted in about the same degree through the cloudy ice; but the penetration of the blue light was significantly less. Since this difference is less evident in clear ice (Report No. 853), it seems probable that there must be some correlation between the minute air bubbles in the cloudy ice and the blocking of the blue rays — possibly a phenomenon analogous, or identical, to that exhibited by water containing materials in fine suspension.

Through one inch of crusted snow the percentage transmission was about the same in each of the three spectral bands mentioned.

Table 5. Percentage transmission of light through ice and snow, Green Lake, 1943. Transmission through snow alone derived by computation. For definition of "total" light, see text.

Snow		Ice		Transmission through:	Per cent transmission of:			
Thickness, inches	Description	Thickness, inches	Description		"Total" light	Red	Green	Blue
2 ½	Crusted	15	Cloudy on top	Snow + ice	0.35	0.32	0.40	0.13
1	Crusted	15	Cloudy on top	Snow + ice	0.34	0.40	0.48	0.17
				Ice alone	2.04	2.41	2.12	0.95
				Snow alone	16.7	16.6	22.6	17.9
1	Very crusted	15	6" cloudy, 9" clear	Snow + ice	1.15	...	...	...
				Ice alone	8.7	...	...	...
				Snow alone	13.2	...	...	...
1	Very crusted	15	Cloudy on top	Snow + ice	1.21	1.24	1.17	0.65
				Ice alone	11.6	12.4	12.6	7.2
				Snow alone	10.4	10.0	9.3	9.0

Snow Removal

On January 22, 1943, the snow on a roughly measured one-acre area of Green Lake was melted down by means of a stream of water pumped from beneath the ice. For this work a centrifugal pump, with a capacity of about 3000 gal/min, and directly driven by an air-cooled gasoline motor, was used (Figure 5). This pump was loaned by the Drayton Plains Hatchery. The intake pipe of the pump was thrust through a hole in the ice, and the outflow took place through a 2 $\frac{1}{2}$- inch rubber-lined canvas hose about 20 feet long. In order to cover the acre plot (which was rectangular, roughly 300 by 150 feet), the pump had to be moved from one position to another about eight or ten times. Laying off the plot, chopping holes for the pump, and performing the actual pumping took two men about 7 to 8 hours.

Part of the time the water was sprayed onto the surface of the snow in a very coarse spray (Figure 6), part of the time it simply was allowed to run from the open end of the hose out onto the ice, through and under the snow (Figure 7). The former method was only slightly more effective, and of course involved more effort, than the latter.

At the time of the pumping, the snow over most of the lake was from 8 to 10 inches deep, including the slush, which came in most places to within 3 or 4 inches of the surface of the snow. The snow on the experimental plot was somewhat less deep than this average.

No effort was made, in the pumping, to completely melt the snow to water. Rather, it was only wet down into a thin slush. The difference in appearance between the treated and untreated areas is shown in Figures 6, 7, and 8. The slush formed by the pumping subsequently froze into firm, although rough and somewhat cloudy, ice. As has been demonstrated previously (see Report No. 853), even cloudy ice has many times the light transmitting ability that snow has.

It was intended, of course, that the untreated area would serve as a

Figure 5. Pump and motor.

Figure 6. Pump discharge by spray.

Figure 7. Discharge through open end of hose.

Figure 8. Contrast between flooded and nonflooded areas; Green Lake, January 22, 1943.

control, and thus that parallel oxygen determinations in the days following the experiment would show the effect, if any, that the melting of the snow might have on the dissolved oxygen. Unfortunately, in the two days from January 22 to 24 the lifting of the ice described above took place, leaving practically the entire area of the lake with very little dry snow. A few small local areas retained from 1/2 to 2 inches of snow for a few days, and some of these were utilized for oxygen determinations, but to all practical intent the desired control was nonexistent.

Dissolved oxygen figures (averages) for several stations within and outside of the treated area, on three sampling dates following the experiment, are given in Table 6. These data show an apparent slight trend for the oxygen to be higher in the treated area than outside it. Because of the circumstances just described, however, no very large amount of significance may be attached to this seeming difference. Furthermore, even within the area the oxygen declined somewhat in the ten days after the pumping. Thus if the light which penetrated the ice actually was sufficient to produce oxygen, it still was not capable of quickly overcoming the serious oxygen-depleting conditions which had arisen.

However, as mentioned above, by about February 5 the lake as a whole apparently had reached its low point (as regards dissolved oxygen), and recovery from that time on was general and fairly rapid. There was no appreciable amount of snow on the ice most of the remainder of the winter.

Any attempt to remove snow by an automobile-propelled scraper was precluded by the thinness of the ice during the period of heavy snow cover, as well as by the slush which formed under the snow and which would have prevented the traction needed for the exertion of power sufficient to move the scraper blade.

Table 6. Snow removal experiment, Green Lake, 1943.
Dissolved oxygen, p.p.m., average values for stations within and outside of treated area. Number of stations averaged and range of values, in parentheses.

Date	Surface sample				2–foot sample			
	Inside		Outside		Inside		Outside	
1/22[*]	(4)	5.2 (4.2–6.4)	(1)	6.1	(1)	2.5	(1)	2.5
1/24	(10)	6.4 (4.3–11.2)	(7)	4.6 (3.2–7.2)	(7)	3.1 (1.8–4.9)	(7)	1.7 (0.6–2.3)
1/29	(10)	3.8 (3.0–4.7)	(7)	2.9 (2.0–3.8)	(7)	2.5 (2.1–2.8)	(7)	1.9 (1.1–3.1)
2/2	(5)	3.2 (2.8–3.7)	(5)	2.3 (1.1–3.7)	(3)	2.1 (1.8–2.3)	(5)	2.0 (1.0–3.0)

[*] Before pumping, January 22.

Sundry Considerations

On March 24, 1943, Green Lake was practically free from ice, except at the south end; and an inspection was made of most of the shore-line. Altogether not over 25 dead fish were found. Since at least this number might be expected to result from normal mortality during such a period, it is probable that no actual winter-kill took place, in spite of the rather low oxygen values that existed in the lake for a considerable period (see above). This again calls to attention the almost amazingly low concentrations of dissolved oxygen which fish under the ice can tolerate (for a more elaborate discussion of this subject, see Report No. 853).

Under the influence of a rather heavy snow cover, the lake was well along in the processes of oxygen depletion, and no doubt would have gone much farther, had not the snow been dissipated, as described above. The sudden shifting of the ice, between January 22 and January 24, apparently depended upon two factors, the combination of which is more or less uncommon in this part of Michigan; i.e., not only was there more snow upon the ice than usual, but also the ice was snow-covered throughout all of the early winter, and being thus insulated it did not freeze as thick as usual. Hence the ice was not heavy enough to support the weight of snow, and gradually sank into the water, producing slush under the snow. This in turn led to the sudden rising of the ice, as described above.

In contrast to this, in the winter of 1935-36, during which winter a heavy kill took place in many southern Michigan lakes, apparently the ice became much thicker before it was covered with snow, and therefore was able to support a considerable mass of dry snow. Thus there appears definitely to be a rough correlation between the relative thicknesses of ice and snow and the ability of the ice to support the snow without sinking into the water. Considered in this light, a very heavy snow cover may not necessarily lead to the production of adverse water conditions, since for a given thickness of ice on a given lake, there probably is a maximum load of snow which it can maintain in a dry condition. This relationship may possibly be a contributing factor to the relative dearth of winter-kill in lakes of northern Michigan (although the factor of lack of eutrophy probably is the dominant one), since these lakes usually have much more snowfall than those in the southern part of the state.

Thus also is indicated the greater potentialities, for bringing about winter-kill, of a heavy snowfall late in the winter than of an earlier one; for if the bulk of the snow does not come until after the ice has become thick it can be supported by the ice. This appears to have been the case in 1935-36, when the snowfall, although heavy, was comparatively late in the season.

On the basis of the experiment conducted on Green Lake, there seems to be reason to believe that practical use can be made of water pumping in snow removal, at least upon relatively small lakes. It is possible that a somewhat larger pumping unit, if mounted upon a truck and provided with the proper accessories in the way of hose, means for making holes in the ice for the pump intake, etc., might be able to cover several acres (perhaps even 40 or 50 acres) per day.

On the other hand, there still seems to be doubt that much practical use can be made of snow-scraping equipment, for it probably is seldom that conditions ideal for its use will be found. Furthermore, the pumping procedure is basically the better in at least one important respect; that is, once the snow is wet down it can no longer be shifted back onto the cleared area by winds, as it can be when merely scraped to one side.

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