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# LIMNOLOGICAL CONDITIONS IN ICE-COVERED LAKES, ESPECIALLY AS RELATED TO WINTER-KILL OF FISH

by

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## ERRATA

In Graph 3, the lower figure is not a graph of Clear Lake, Sta. 1, as labelled; but is of Green Lake, Sta. 1.

Page 52, line 2. Instead of "ice cover" it should read "snow cover."

Page 57, line 22. Instead of "East Lake" it should read "East Fish Lake."

Page 80, line 7. Instead of "Black (1940)" it should read "Black (1929)."

John Greenbank
9/24/1943

## CONTENTS

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"Here shall he see no enemy but winter and rough weather."
— As You Like It.

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## INTRODUCTION

### Purpose and Scope of the Study

In most fresh-water lakes of the higher latitudes of the temperate regions, winter brings about a set of conditions which differ sharply from those which prevail during the rest of the year. The ice cover, existing continuously for several weeks, and often blanketed by snow, rather effectively separates the body of water from the world above it, and makes it more certainly than ever a microcosm. Several otherwise normal processes are affected or suspended by this ceiling of ice and snow. Aeration of the water by the agitation of wind and wave is precluded; and even the exchange of gases with the atmosphere by bubbling and diffusion is greatly reduced. Heat exchange between air and water is interfered with, and transmission of light into the water becomes lowered, sometimes almost to the zero point.

The biotic consequences of these changed conditions are many and varied. The extreme stagnation that at times develops in the water may bring harm or death to countless organisms. Such a mortality, particularly when it is of fish, is known as winter suffocation, or winter-kill.

Since winter-killing may occur infrequently, it is perhaps not the most common cause of death of fish, nor that responsible in the long run for the greatest loss; but it undoubtedly is one of the most spectacular and dramatic, as well as one of the most intensive. The appearance of piles and windrows of dead fish along the shores of a lake, at the breakup of the ice, is evidence of the harshness and suddenness with which the forces of nature can act. And when a considerable proportion of the kill is made up of game and food fish, as it often is, the mortality assumes a serious aspect from the standpoint of fisheries management.

The significance and importance of the winter-kill problem was forcefully brought to the attention of those interested in Michigan fisheries by the extensive and heavy mortality which took place in the winter of 1935-36. During that winter a considerable number of lakes in southern Michigan were affected, and hundreds of thousands of fish died. Scenes such as those shown in Figures 1 and 2 were common. Table 1 includes a list of those lakes which, according to reliable information, were most seriously affected. There is no doubt that many other lakes suffered considerable loss, which either were not observed or were not reported.

During that winter, the Michigan Institute for Fisheries Research carried out a certain amount of preliminary investigative and attempted rescue work. Under the direction of R. W. Eschmeyer, G. P. Cooper, and O. H. Clark, experiments were performed in aeration of the water by pumping a stream of water into the air, and allowing it to run back into the lake through holes chopped in the ice. In other experiments, long holes were cut through the ice, in the hope that atmospheric oxygen would enter the water through surface agitation. These operations are shown in Figures 3 and 4. Several measurements of dissolved oxygen were made, as a check on conditions in the lakes on which the work was done; and following the breakup of the ice, determinations of the extent of kill were made. All of these investigations are summarized in two (unpublished) Institute for Fisheries Research reports (Eschmeyer, 1936; Cooper, 1936).

These emergency aeration experiments met with little apparent success. However, the work of that winter emphasized the desirability of an extended study of the winter-kill problem. Accordingly, the Institute arranged for such

Figure 1. Winter-killed fish, drifted along the shore of Green Lake after the break-up of the ice, 1936.
Photo by Ouradnik.

Figure 2. Close-up of large bluegills and other fish, winter-killed in Park Lake, 1935-36.
Photo by Laycock.

Figure 3. Experimental aeration of water.
Sugarloaf Lake, winter of 1935-36.
Photo by Eschmeyer.

Figure 4. Cutting holes in the ice.
Bateese Lake, winter of 1935-36.
Photo by Eschmeyer.

an investigation. The studies were carried out during the winters of 1937–38, 1939–40, and 1940–41, by the author, under the support of an Institute fellowship, and as a graduate research problem in the University of Michigan.

This paper is a report on those studies not only as they pertain directly to winter-kill, but also as they contribute to the knowledge of general limnological conditions in ice-covered waters. In addition it contains references to various studies of winter conditions in lakes made by other investigators.

Rather understandably, but none the less unfortunately, winter work in limnology and fisheries biology has been comparatively scanty in the past. The press of other duties, the difficulties of adapting apparatus and technique to work at freezing temperatures, and the physical hardships of winter weather have combined to keep many research workers indoors at a season when much useful and interesting information is to be found in the field. Hubbs and Trautman (1935) have called attention to the need for more winter studies; and Morgan (1939) stated that "the field of animal biology in winter is largely an open one." Hazzard (1942) has recently discussed some of the effects of ice and snow on fish life in streams and lakes.

## Acknowledgements

The investigation here reported could not have been performed without the generous assistance of many persons and agencies. Sincere and grateful acknowledgement is here extended to all of these.

Especially is gratitude due to the late P. S. Lovejoy, who was instrumental in instigating the study; to the Fish Division of the Michigan Department of Conservation, Fred A. Westerman, Chief, not only for financial support, but also for interest and encouragement; to A. S. Hazzard, director of the Institute for Fisheries Research, for able direction of the work; to the staff and employees of the Institute, for assistance outside the regular bounds of their duties;

and to the personnel of the Division of Field Administration, particularly for reports concerning lakes affected by winter-kill.

Acknowledgement is also given to Professor Carl L. Hubbs, of the University of Michigan Zoology Department, for help and guidance throughout the investigation and in the preparation of this report. Helpful advice was received from Professors Paul S. Welch, E. A. Woodward, A. F. Scherzer, and others, of the University of Michigan, Professor Chancey Juday and W. M. Manning, of the University of Wisconsin, Samuel Bousky, of the Physicists Research Company, Gilbert Stewart, of the Michigan Conservation Department, and others.

Grant J. Lindenschmitt, formerly craftsman of the University Museums, assisted in the design and construction of field equipment. Professor H. H. Higbie, of the University of Michigan, and W. F. Carbine, of the Institute staff, helped in the calibration of the submerged photometer.

The Associated Fishing Tackle Manufacturers, through a trust fund maintained at the University of Michigan, provided financial support that permitted the employment of several part-time assistants.

Professor H. W. Emerson, of the University Medical School, furnished the use of necessary laboratory facilities. W. J. Pasinski extended many courtesies in connection with the work done on his private pond. A. T. Stewart, superintendent, and the staff of the Drayton Plains fish hatchery, helped in the work done at the experimental ponds of that hatchery.

Clark Hubbs, Boyd W. Walker, and Raymond E. Johnson gave much voluntary assistance in the field and laboratory.

The drafting was done by C. M. Flaten and L. A. Krumholz, of the Institute. Photographs used were taken by W. C. Beckman, R. W. Eschmeyer, and F. W. Ouradnik.

## Historical

There is little doubt that winter-kill of fish has been observed at various times for perhaps many centuries; since its occurrence is of a very striking nature. It is only within comparatively recent years, however, that very many references to winter fish deaths have entered the general biological literature. A few of these reported observations are here cited.

Lühder (1871) described an instance of winter-kill in Germany in 1870–71. In 1871–72 a heavy mortality of fish took place in the Racine River, Wisconsin, where very large numbers of fish, including a large proportion of bass and pickerel, perished (Hoy, 1872). Knauthe (1899) reported the winter-kill of many fish in certain artificially enriched carp ponds in Germany. In the Illinois River fish mortality in winter has occurred, probably many times; for it was recorded for the winter of 1894–95 by Kofoid (1903), and for the winter of 1924–25 by Thompson (1925), who stated that it is of common occurrence. Evermann and Clark (1920) recorded a winter death of fish in Lake Maxinkuckee, Indiana, some time during the period of their investigations there, 1899 to 1908. In Lake Yskjärvi, Finland, a "wholesale mortality" during the winters of 1915, 1922, and 1924 was reported by Jääskeläinen (1930).

In more recent years, winter-kill, sometimes of considerable intensity, has been reported from these various places: Massachusetts (Sweetman and Warfel, 1936), Iowa (Aitken, 1938; Sheppard, 1938), Wisconsin (Milwaukee Sentinel, 1939), Minnesota (Milwaukee Journal, 1939; Olson, 1932; Smith, 1941), New York (Annin, unpublished, 1936), Montana (King, unpublished, 1937), and Utah (Higgins, 1933).

The most serious instances of winter-kill in Michigan which have been satisfactorily reported are summarized in Table 1. The material from which this table was constructed includes letters from various interested persons, answers by Conservation Officers to a questionnaire regarding fish mortalities, and notes on field observations by members of the staff of the Institute for

Fisheries Research. Figure 5 is a map showing the locations of these instances of winter-kill. No accurate, dated records of kills prior to 1930 are available; although many oral communications from local residents indicate that heavy mortalities occurred in various lakes in winters of many years past.

Many of the phenomena connected directly or indirectly with winter suffocation have been recognized and understood, though sometimes rather imperfectly, by various previous workers. The literature contains a fairly large number of references to conditions in stagnant water under the ice, including some mention of the causes and effects of winter-kill. Although some of these writings are based upon actual observation, many others consist in large measure of hypothesis and conjecture, partially or wholly unsubstantiated. That many of these hypotheses later have been proved to be true is, surely, a favorable commentary upon the soundness of the original supposition. That others have been found to be unsound or even absurd points to the lack of information upon which they were based. Not the least of the objects of the present study has been to obtain data which might contribute either to the proof or to the disproof of some of the theories and notions which have ardently been proposed concerning the subject. A brief summary of some of these ideas, especially those which form a historical background for this study, follows.

The function of an ice cover in preventing aeration of the water by wind action is rather obvious. It was recognized by as early an author as Hoy (1872), and has been mentioned by numerous writers since. That ice, if it is thick or cloudy, and especially if it is covered with snow, has another serious effect, in diminishing the transmission of light needed for photosynthesis, was understood quite clearly by Knauthe (1899). This effect has been reaffirmed by many authors; by Birge and Juday (1911), Olson (1932), Welch (1935), Titus (1936), Aitken (1938), and Hubbs and Eschmeyer (1938) — to mention only a few. The last-named paper also proposed the possibility that darkness may

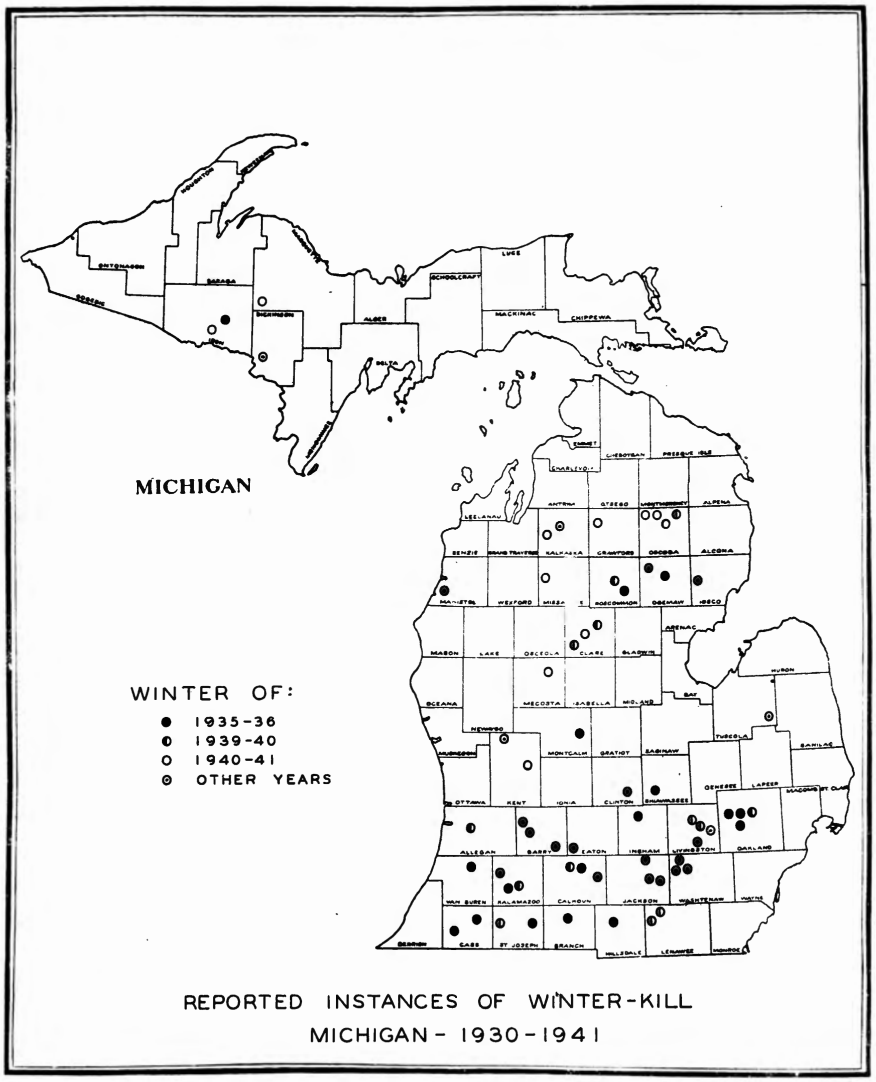

**Figure 5.** Instances of winter-kill reported in Michigan, 1930–1941.

favor bacterial action, and hence contribute in another way to harmful conditions.

The connection between winter stagnation and the abundance of organic materials in a lake has been pointed out by Drown (1892), Knauthe (1899), Welch (1935), and others; and various authors (Thompson, 1925; and others) have called attention to the fact that critical conditions are more apt to obtain in shallow lakes than in deeper ones.

Most of the authors have assigned the primary blame for the winter death of fish to diminished dissolved oxygen content of the water; but several papers have mentioned other factors as being chief or contributing causes. Hoy (1872) stated that the death of many of the fish in the Racine River was "caused, probably, by the poison communicated to the water by the multitude of decaying minnows." Wickliff (n.d.) added to lowered oxygen tension the presumed toxic effect of carbon dioxide, nitrogen, ammonia, and hydrogen sulfide. A popular point of view, expressed in the Milwaukee Sentinel (1939), referred to the "poisonous gases which mean death to the fish." In regard to the winter mortality of fish in acid bog waters, Jewell and Brown (1929) assumed the cause of death possibly to be either depletion of oxygen or the "production of toxic substances due to putrefaction."

## WATERS INVESTIGATED

The major part of the field work of the present study was done on four lakes, Clear Lake, Mud Lake, Green Lake, Bog Lake, and on a private farm pond, Pasinski's Pond, all in southeastern Michigan. All of these waters are included in Table 2, and also are described in some detail below. Bog Lake was studied only in the winters of 1939–40 and 1940–41; the other waters named were studied in those winters and also in that of 1937–38. During part of the winter of 1939–40, Richmond Lake was under observation; and also in that winter certain experiments, to be described later, were conducted in some small experimental ponds at the Drayton Plains state fish hatchery. Various other lakes in the southern peninsula of Michigan were used for occasional or single sets of observations.

Clear Lake, Mud Lake, Bog Lake, and Green Lake lie within that part of Washtenaw and Jackson Counties which has been designated the Waterloo Area, a region of generally poor farm land which was developed for several years by the United States Park Service as a recreational area. This area is a part of the Kalamazoo–Mississinawa morainic system, described by Leverett (1917), and is in the physiographic division of the Lower Peninsula known as the Thumb Upland (Veatch, Trull, and Porter, 1926). It is characterized by a rather rugged topography, abrupt transitions in soils types, and many and varied bodies of water. Within the Waterloo Area are many shallow, soft–bottomed lakes of the type which is apt to be subject to winter–kill.

Pasinski's Pond and Richmond Lake also are in the Thumb Upland. They are in a region of very numerous lakes, an area which occupies a large part of Oakland and Livingston Counties.

Table 2 gives some of the principal physical characteristics of the lakes studied. All of these lakes, with the exception of the dystrophic Bog Lake, are in the eutrophic class, according to the Thieneman–Naumann system. Since eutrophic lakes vary greatly in physiographic age and hence in organic richness, without sharp dividing lines, the lakes under study can be subdivided only in general, relative terms. Clear Lake may be designated as early-stage eutrophic, Mud and Green Lakes as mid-stage eutrophic, and Richmond Lake and Pasinski's Pond as late-stage eutrophic. Thus a graded series is established, on the basis, principally, of the general organic richness of the lakes and their apparent state of progress toward senescence. Obviously, their susceptibility to the development of stagnation follows much the same order. Brief individual descriptions of these lakes follow.

## Clear Lake
(Jackson County)

This lake, in the eastern part of Waterloo Township, is surrounded by steep wooded hills. It has only a vague stream connection with any other body of water, and receives most of its water supply from surface and subsurface run-in. Its morphometry is shown by the map, Figure 6, which also gives the locations of the sampling stations. The name of the lake is fully justified by the clearness of its water. Although there is considerable rooted vegetation in the shallower bays, the deeper parts of the lake have none. The bottom is largely marl in the shoal areas, and marl and peat in the deeper places. Compared to most of the more shallow lakes of the region, Clear Lake is relatively little advanced in eutrophy — in fact, in point of view of several of its characteristics, it is not far beyond the border-line between oligotrophic and eutrophic. Therefore it is classed, in Table 2, as early-stage eutrophic.

Clear Lake is considered to furnish fairly good fishing for largemouth bass, bluegills, and yellow perch. No winter-kill has been recorded for this lake. Hence it was included in this investigation as a more or less typical example of those lakes of the general region which do not develop winter-kill

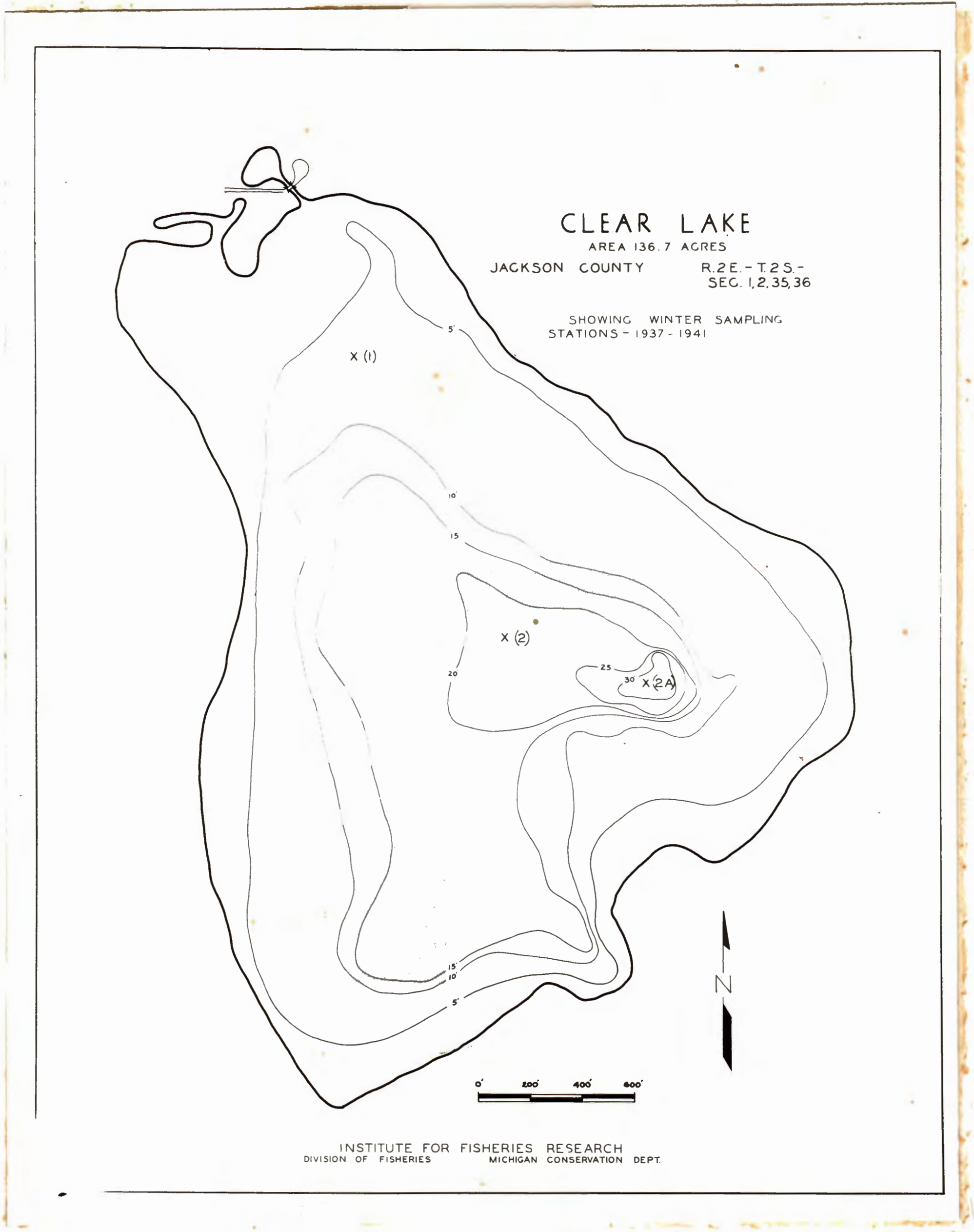

Figure 6. Sampling stations, Clear Lake.

conditions. It was thought that comparative data might thus be secured which would demonstrate some of the differences between lakes which are and those which are not subject to winter-kill, and hence might bring to light some of the governing factors in winter suffocation.

### Mud Lake
### (Lyndon Township, Washtenaw County)

This lake, as shown by Figure 7, is rather uniformily shallow, having no water over about 5 feet deep. It is surrounded by low wooded hills and grassy marsh. The inlet stream brings in a steady flow of water from Sugarloaf Lake, and there also is a steadily flowing outlet. Thus there is always some current through the lake, modifying many of its conditions to a certain extent. Otherwise its characteristics are rather typically those of many southern Michigan lakes. Its water is only moderately clear, and sometimes carries suspended material which causes an increased turbidity. Much of the bottom is composed of soft, organically rich material; but some areas have a large amount of marl. Rooted vegetation is moderately abundant over a large part of the lake. The water is hard, having a total alkalinity, to methyl orange indicator, of from 200 to 260 parts per million, expressed as $CaCO_3$.

Considering its size and depth, Mud Lake produces a reasonably large amount of fishing. Bluegills, largemouth bass, and northern pike are the chief game species. Undoubtedly there is considerable intermingling of the fish populations of Sugarloaf and Mud Lakes; and it is probable that, following the rather heavy winter-kill in Mud Lake in 1935-36, the lake soon was restocked from Sugarloaf Lake.

### Green (or Stoffer's) Lake
### (Northwest of Chelsea, Washtenaw County)

The size, shape, and depth of this lake, as well as the location of the sampling stations, are shown by Figure 8. Its surroundings are similar to

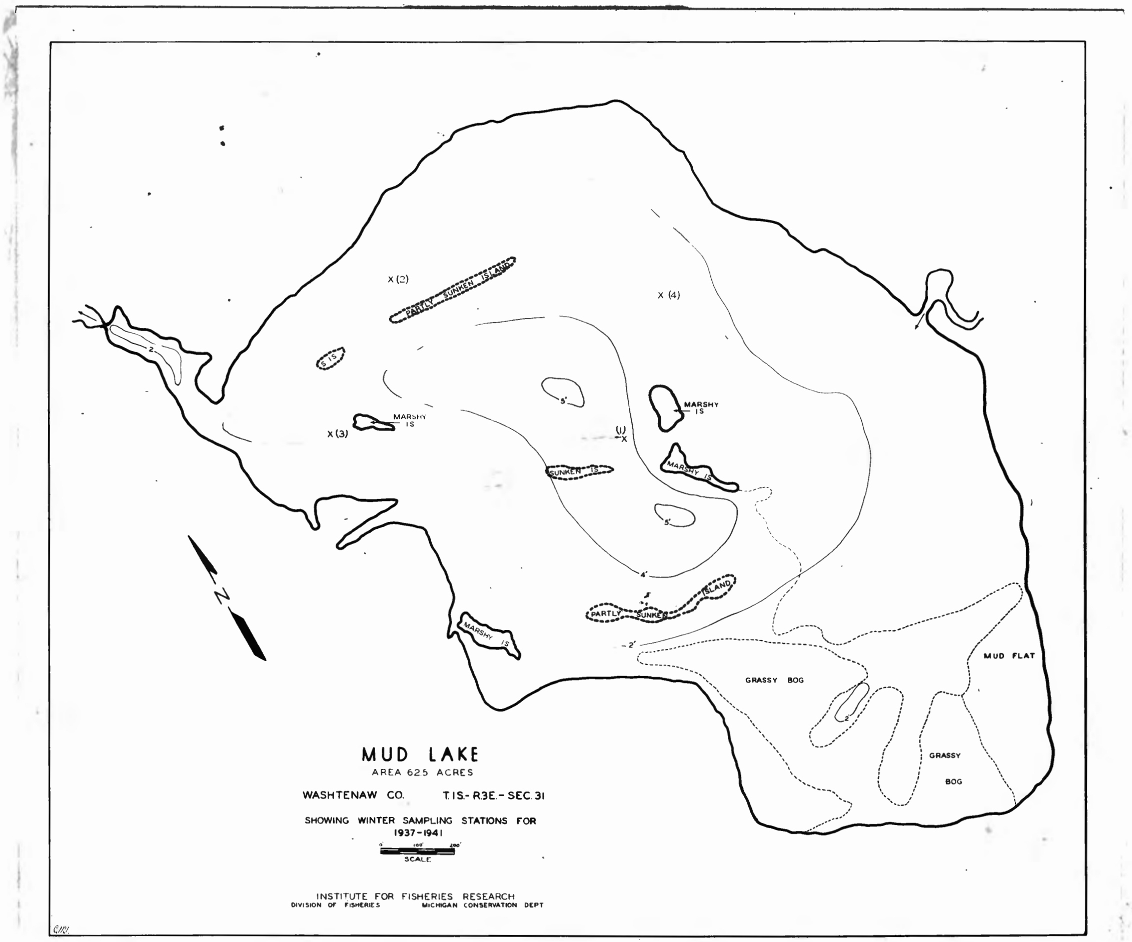

Figure 7. Sampling stations, Mud Lake.

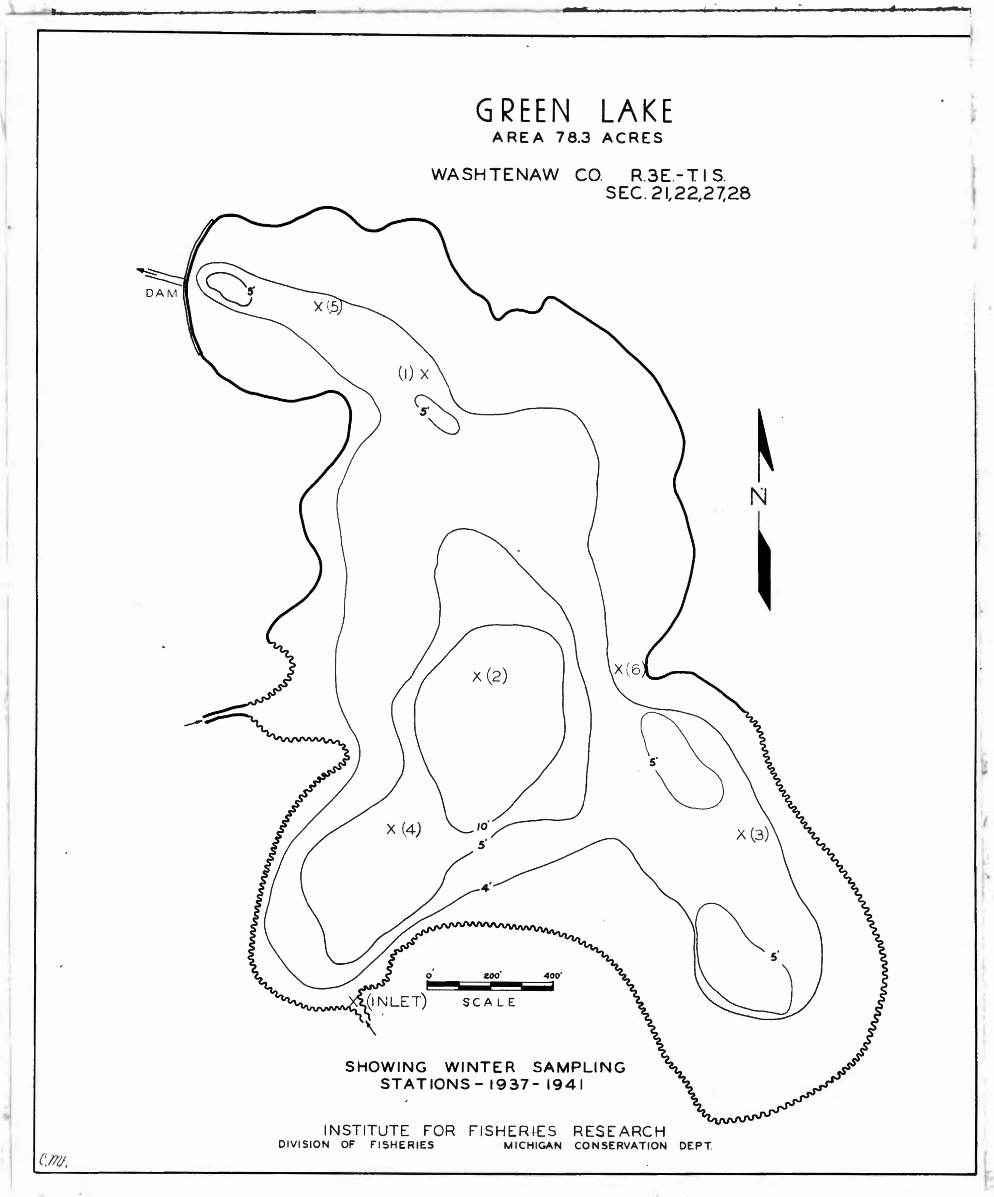

**Figure 8. Sampling stations, Green Lake.**

those of Mud Lake. It has a small but fairly steady inlet, which carries seepage water from a large marsh. Its outlet also is small. Over most of its area the lake is less than 5 feet deep, and the greatest depth only slightly exceeds 10 feet. Rooted vegetation is very dense over all of the shallower parts of the lake.

Green Lake is semi-artificial, in that it was enlarged a few years ago by the construction of an earth-fill dam. Even the newly flooded bottom, however, is of partly organic material; and the lake as a whole is rich enough in organic matter to be considered definitely eutrophic. It has suffered more or less severe winter-kill of fish in several different years. However, it has retained, or has been artificially restocked with, a sufficiently large population of bluegills, perch, and black crappies to provide fairly good fishing.

## Bog Lake (not officially named)

(Section 21, Lyndon Township, Washtenaw County)

This small pot-hole is a typical brown-water, acid bog lake, conforming well to the definition given by Welch (1935) for a bog lake. No map is available, but the lake is approximately 1/4 acre in size, and is almost a true oval in shape. At its present level, it is isolated from any other body of water; but at the slightly higher level which probably existed at some time in the past, it had an outlet. Its greatest depth, 6 feet, prevails over most of its area, since its shore is an abrupt drop-off. The one sampling station used in this work was in the center of the lake.

Bog Lake has a surrounding, encroaching *Sphagnum-Chamaedaphne* mat, which in turn is bordered by spruce and tamarack trees. It is further surrounded by low hills, not unlike those which border the many harder water lakes of the vicinity. Indeed, it is somewhat striking that Bog Lake is within a few hundred yards of another small lake, which lies in a somewhat similar basin, but which is alkaline, and bordered by a cattail-sedge mat. Other instances of the fairly close proximity of an acid bog lake to an alkaline clear water lake may be found in the same general region in southeastern Michigan.

Bog Lake fits quite well the general conception of a lake of the dystrophic type. Its water is stained a dark brown, very soft, and moderately acid. The bottom material is somewhat gelatinous, and very flocculent. Although some of this material is more or less in suspension in the bottom part of the water, there apparently is no definite false bottom such as that which occurrs in many bog lakes. The only species of fish known to live in Bog Lake is the mud minnow, Umbra limi. Nothing has been recorded concerning any possible winter-kill of fish in this lake in past years.

### Pasinski's Pond
(Livingston County)

This private pond was artificially constructed, about 1932, by damming a natural swale, It is surrounded by rolling farm land. It has no inlet, but receives run-in from the grassy hillsides, and also is fed by underground seepage. A small motor-driven pump, on the east shore of the north end of the pond, capable of delivering approximately 60 gallons per minute from a shallow well, is used, at times, to help maintain the water level in the pond. There is a small outlet which usually flows except during periods of drouth.

As shown by the map, Figure 9, the pond has an area of slightly less than 4 acres, and a maximum depth of about 5 feet. Its soft bottom has a rather high organic content. The water is choked with rooted water plants, almost the entire bulk of which consists of the waterweed Anacharis, with a few small local beds of coontail, Ceratophyllum. There is also a considerable amount of filamentous algae, most of which apparently is Spirogyra, with some Cladophora. The amount of algae present in a growing condition varies from one time to another, but is nearly always considerably greater in the end of the pond nearest the outlet (the south end) than in the other end. Pasinski's Pond is quite rich

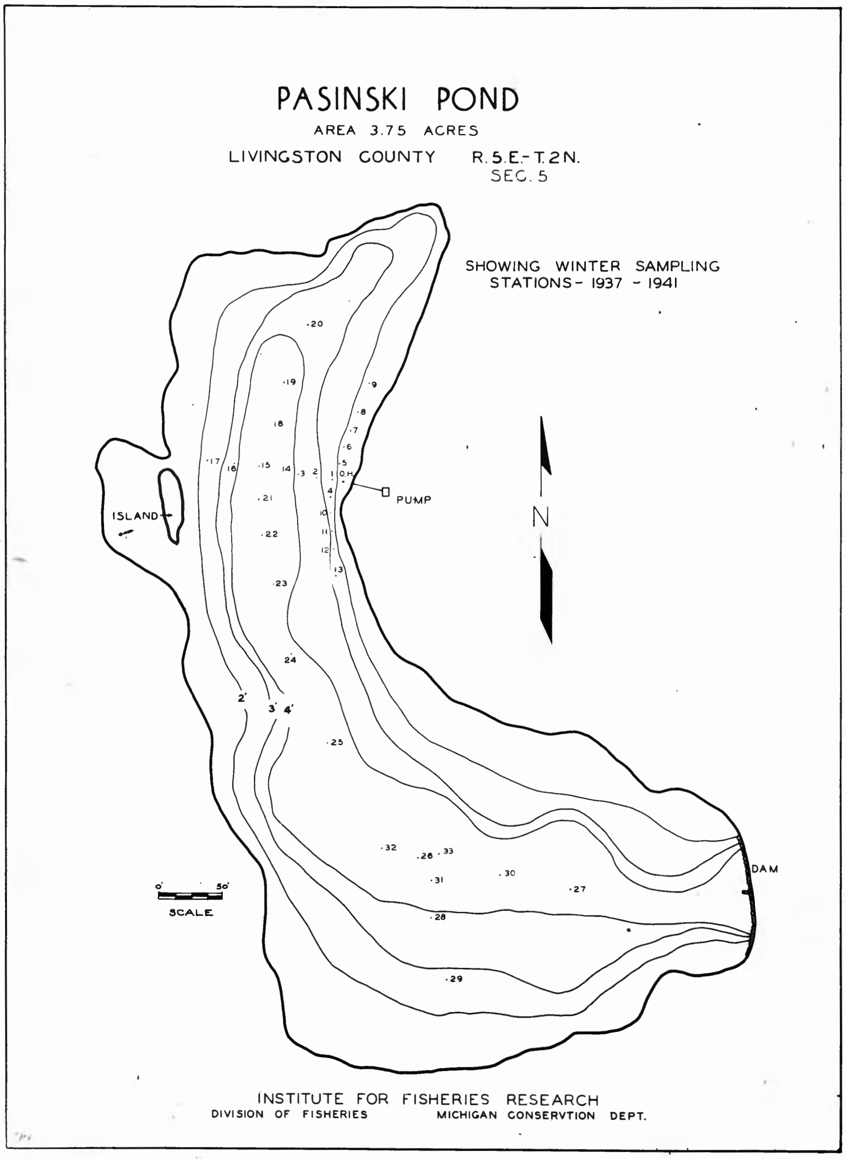

**Figure 9. Sampling stations, Pasinski's Pond.**

in total organic materials; in the classification used in Table 2, it is considered to be in the advanced eutrophic stage.

This pond has been the site of various activities of the Institute for Fisheries Research. It was poisoned in the fall of 1937 and again in the spring of 1938, in an attempt to destroy the abundant population of bullheads, Ameiurus nebulosus, which was then the only species of fish present. Large numbers of bullheads were killed, but an unknown number survived. The pond was stocked, in 1938, with several pairs of adult bluegills, which reproduced in that summer and again in 1939. In the summer of 1939 this stock of bluegills was used by W. C. Beckman, of the Institute staff, for certain fish marking studies.

In the winter of 1939–40 a heavy winter-kill took place in Pasinski's Pond, apparently totally destroying the bluegill population, and killing many bullheads. Winter-kill in previous years has been reported; and in the summer of 1937 a number of largemouth bass were reported to have died because of summer stagnation.

## Richmond Lake
(Waterford Township, Oakland County)

This lake, for which no map is available, is about 15 acres in area. In most places it is less than 6 feet deep, and its maximum depth is not over 10 feet. It has no distinct inlet or outlet. The bottom is covered with a thick deposit of mucky peat, which at times becomes putrescent. The lake apparently is filling rather rapidly, and already may be considered to be well advanced in senescence. The present margin of peat foretells the eventual fate of the lake basin.

Richmond Lake was studied only in the winter of 1939–40, and starting at a time after rather serious conditions already had developed. One sampling station, in the deeper water, and an open hole in the ice were used for samples.

The lake had a rather heavy loss of fish that winter. Nothing is known concerning previous kills. The lake is not fished heavily; although it contains a moderate population of pan-fish.

## Hatchery Ponds

For some experiments described below, three small experimental ponds at the Drayton Plains hatchery were used. These ponds are entirely artificial, and are very nearly alike. Each is 50 by 100 feet, with a fairly uniform depth of about 3 feet. The bottom is soft mud, and there is a limited amount of rooted vegetation near the shores. The ponds may be filled with water from the Clinton River, and they have overflow outlets.

## Sampling Stations

During the course of the investigation, a large number of sampling stations were established. Some of these were used continuously throughout each of the three winters, some for only one or two winters or only part of one winter, and some only once or a few times. Table 3 lists, and gives some of the characteristics of, every station except those which were used only a very few times, or those in lakes which were visited only once or twice. The maps of Figures 6, 7, 8, and 9 show the locations of the stations on Clear, Mud, and Green Lakes, and Pasinski's Pond. A brief description of some of the major sampling stations follows:

In Clear Lake, a shallow station (Station 1) and a deep one (Station 2) were established in 1937-38. Station 2 was replaced, in 1940-41, by the still deeper Station 2a.

The original Station 1 of Mud Lake was used in all three winters. To it, in 1939-40, were added Stations 2, 3, and 4, principally because of their variety in type of bottom and amount of vegetation present. In 1939-40 and 1940-41, regular samples were taken also in the inlet and outlet streams.

In Green Lake, only Station 1 was used during the first two winters; but in 1940–41, several more stations were established, including Stations 2 and 4 in somewhat deeper water, and Station 3 over a marly bottom. The "open hole" listed in the table was a hole in the ice, a few feet across, artificially kept open for a long period of time in the winter of 1939–40.

At Bog Lake only one station, in the center of the lake, was used.

Richmond Lake also had an open hole for a considerable time in the winter of 1939–40. Besides this hole, one station, in the deeper part of the lake, was used.

In Pasinski's Pond, only Station 15 was used in 1937–38. In connection with experimental work on the pond in 1939–40, over 30 additional stations were established. Of these, Stations 20, 24, 26, and 27 were selected for sampling in 1940–41. The open hole of 1939–40 was at the point of discharge of the pump.

The depths of sampling, given in Table 3, were not entirely constant throughout the survey. They were affected to some extent by variations in lake water level, and by slight changes in station location. Although the stations usually were marked by stakes set into the ice, occasionally their exact locations became lost, and their positions no doubt changed somewhat from one winter to the next.

The primary sampling depth at each station was that designated as "surface" or "top". This sample was taken at from 4 to 6 inches below the surface of the water as it stood in the hole chopped through the ice. Thus, although this level at times may actually have been above the under surface of the ice, it is assumed that it held water which previously had been just under the ice, and which had flowed into the cut hole. This sampling depth is designated in Table 3 by the symbol S.

The sample of next importance at any given station came from about 1/2 to

1 foot above the bottom, this level being the deepest at which the sampler could be operated without stirring up the bottom materials. This sample, in various tables and graphs, and in the text, is called "bottom", abbreviated "bott." Samples commonly were taken also from the various intermediate depths listed in the table.

Stations in the various inlets and outlets were somewhat under the influence of current, as was also Station 1, and to some extent Station 3, of Mud Lake. All other stations were in relatively motionless water.

## PROCEDURE, METHODS, AND EQUIPMENT

The lakes were sampled periodically, each winter, throughout the entire period when the ice was safe to walk on. Whenever the ice was thick enough to permit doing so, an automobile was driven onto the lakes. At other times either a portable shanty or a specially fitted hand sled was used. This sled with its box is shown in Figure 10. Both the shanty and the sled were equipped with gasoline lanterns to prevent samples from freezing.

The hole for sampling was made beside the station marker, or at a short distance, where average conditions of ice and snow existed. The hole, from 8 to 10 inches in diameter, was cut with a steel ice-spud, using care so as to minimize the agitation of the water by upwelling.

Samples of water for chemical examination were taken, in 1937–38, by means of a Kemmerer-type water collecting bottle. In 1939–40 and 1940–41, however, a sampler modified somewhat from that figured in Standard Methods (American Public Health Association, 1936, p. 140) was used. This sampling can, with attached cord for hauling it, is shown in Figures 11 and 12. It consists essentially of a metal can, in which the sample bottle sits, with tubes for delivery of water and escape of air, so arranged that the volume of water in the bottle is displaced at least three times, without the entrainment of air bubbles. In this work, this sampler was found to be superior in many respects to the Kemmerer bottle. It is much less subject to trouble from freezing. It is more sturdy, and can better withstand the hardships of work under the ice. Since it is more compact it can take a sample from a thinner stratum of water, and from nearer the bottom.

When samples were taken at more than one depth at a station, an almost unvarying procedure was employed. The sample, or samples, from the "surface" depth was taken first, followed by that or those from the next lower depth,

Figure 10. Hand sled and box, used for carrying sample bottles. Also shows sampling operation.
Photo by Beckman.

Figure 11. Water sampler, used in obtaining samples for chemical analysis.

Figure 12. Sampler, inside view.

Photos by Beckman.

then from the next depth, and so forth. Thus no layer of water was subjected to agitation, by air bubbling from below it or by the sampler passing through it, before a sample from that layer had been secured (in regard to possible errors produced by certain modifications of the sampling technique, see Appendix).

Water samples were collected in 250-ml., ground-glass stoppered, bottles. Every possible effort was made to prevent their freezing, and yet to keep them at a low temperature until their analysis had been completed.

The methods used for chemical analysis were largely those of the Standard Methods of Water Analysis, 8th edition, of the American Public Health Association (1936).

## Dissolved Oxygen

Dissolved oxygen was determined in 1937-38 by the Rideal-Stewart modification of the Winkler method. This modification is extremely tedious at near freezing temperatures; so in 1939-40 and 1940-41 the rapid modification of the Winkler method, for waters containing organic matter (Standard Methods, 1936, p. 145), was used. In this method, 2 ml. of manganous sulfate solution, and 1 to 2 ml. of alkaline iodide solution, are used; and the sample is acidified immediately after a 30-second shaking, without allowing the precipitate to settle.

The procedure up to and including acidification was carried out in the field, sometimes at the station, but more often after the sample had been taken to the shore. At cold temperatures, it is likely that no significant change in the dissolved oxygen content of water in a tightly stoppered bottle takes place in an hour or two (Birge and Juday, 1911, p. 17). The "fixed" samples were titrated, after transportation to the laboratory, within a few hours and without having been allowed to warm up.

Results of the dissolved oxygen determinations are expressed in parts per million. It is probable that this expression has a more significant meaning than does per cent saturation. At any rate, since the temperature of the water under the ice stays within rather narrow limits, the two sets of figures for that water are closely proportional.

In 1937–38, the determinations of free carbon dioxide and of pH were made in the field. In the winters of 1939–40 and 1940–41, these analyses were made after the sample had been brought into the laboratory. These samples were taken in 250-ml. bottles, tightly stoppered; and were brought to the laboratory with as little warming as possible. The samples for alkalinity determinations and for "aerated pH" also were taken from these bottles after arrival at the laboratory.

## pH, Carbon Dioxide, Alkalinity

The pH was measured colorimetrically. In 1937–38 a Hellige disc-type comparator was used, and in 1939–40 and 1940–41 a Rascher-Betzold spot-plate, pipette type pH set. The former instrument was read to 0.2 pH units; the latter was graduated to 0.2 units, and was read to 0.1 unit. The series of indicators of each set is so arranged that, at least in certain parts of the pH scale, there is considerable overlap from one indicator range to the next; and thus some degree of check on readings is available. Even so, in the use of such a method an occasional error of 0.1 or 0.2 units, or even more, must not be entirely unexpected; for with some samples of water the colors are very difficult to match.

On a fairly large series of samples, in 1939–40 and 1940–41, a determination was made of pH after strong aeration, and again after equilibration with alveolar air. These tests were made in the laboratory, while the samples were still cold. Aeration was by means of the laboratory's compressed air supply. Equilibration with alveolar air was accomplished by bubbling the last portions of several normal breaths through a small sample of the water. The operator in every instance was the same, so that the determinations would be comparable.

Free carbon dioxide was determined, in 1937–38 and in 1940–41, by titration with standard alkali in the presence of phenolphthalein indicator, using as an end-point the appearance of a pink color which remained visible for 30 seconds. Results are expressed in parts per million, reckoned as $CO_2$, and are recorded only to the nearest part per million. Because of personal errors and inherent errors of the method the use of decimal fractions is felt to be unjustified.

In 1939–40 no carbon dioxide titrations were made. A rough estimate of the amount of free carbon dioxide may usually be obtained by a comparison of the initial pH of the sample with its pH after equilibration with air or with alveolar air (for formulae, see Powers, 1927, 1930; Peters, Williams, and Mitchell, 1940), or by a comparison of the pH with the total alkalinity (Water Works and Sewage, 1936). Too much credence, however, must not be placed in any exact figure so derived, since an error in the pH reading, such as is mentioned above, produces a corresponding error in the calculated carbon dioxide value.

Phenolphthalein alkalinity was determined by titration with standard acid, using as an end-point the disappearance of the last visible trace of pink of phenolphthalein indicator. Results are expressed in parts per million, calculated as $CaCO_3$.

Total alkalinity (methyl orange alkalinity) was measured by titration with standard acid, using methyl orange as an indicator. Results are given in parts per million, expressed as $CaCO_3$. Since one operator performed all of the titrations, and since the notoriously difficult determination of the end-point of methyl orange becomes much easier with practice, the results probably are consistent one with another, to within 2 to 4 parts per million.

## Biochemical Oxygen Demand

Biochemical oxygen demand was determined by constant temperature incubation in 250-ml. ground-glass stoppered bottles. The method used was that of the Public

Health Service (Theriault, 1927; American Public Health Association, 1936), with considerable modification and simplification. Undiluted samples were used whenever possible; when dilution was necessary, the preference in calculating weighted mean values was given to the sample least diluted. A dilution of 1:2 often sufficed, and the greatest dilution necessary, even with those samples having a high oxygen demand, was 1:5. All dilutions were made with aerated distilled water, and no bacterial seeding was used. Since the dilutions were not great, it is rather probable that sufficient inorganic nutrients and bacteria were supplied by the water sample, and that the principal limiting factor in the diminution of oxygen actually was the amount of available organic food material present. All of the results are expressed in parts per million.

B.O.D. measurements were made at two incubation temperatures: at the standard temperature of 20° C., giving results that may be compared with those of other investigators; and at 0° C. (0°-4° C.), which temperature more closely simulates natural conditions under the ice. Incubation at 20° was performed in an electric incubator, and at 0° in a standard household electric refrigerator. Most of the incubations were for the standard 5-day period; but one series of samples was incubated at 0° for 60 days.

## Light Penetration

Measurements of the penetration of light through water, ice, and snow were made with a specially designed submerged photometer, employing photoelectric cells. In recent years this type of photometer has come into rather common use, particularly in oceanography. Many different designs have been employed (Ellis, 1934; Pearsall and Ullyott, 1933; Burr and Burr, 1934; Utterback and Wilson, 1940; etc.). All, however, embody photoelectric cells of the selenium rectifier, or similar, type. They differ mainly in external design.

The photometer used here (see Figures 13 and 14) was built with special adaptations for use under ice. It consists essentially of a suitably housed

Figure 13. Submerged photometer, with cable and microammeter.

Figure 14. Target of photometer, showing method of suspension by electric cable.

Photos by Beckman.

receiver, embodying two Weston "Photronic" cells, and connected by a waterproof cable to a very sensitive multiple-range galvanometer. The brass housing case of the receiver can be fitted with a detachable pipe handle, enabling it to be thrust under the ice to a distance of approximately 2 feet from the edge of the hole which must be cut in the ice (see Figure 15). With this handle removed, the receiver can be lowered and raised by means of the electric cable. In general principle, the apparatus is similar to that described by Zinn and Ifft (1941); but differs in mechanical design, and in using an extra Weston cell for added sensitivity. In optical and electrical detail, it meets the chief specifications of the International Council for the Exploration of the Sea (Atkins, et al, 1938).

Between the cells and the water there is, first, a plate glass window, and above that a removable diffusing window made of single opal-flashed glass. The space between the two glasses may contain water or an interchangeable glass color filter. Also in this space may be inserted a light-reducing filter, for cutting down the intensity of light on bright days, so that the readings are not off the scale of the meter. The filter so used in this investigation was made of exposed and developed photographic film (a glass filter would be more durable).

Color filters of three wave-length ranges were used, approximating very closely the specified ranges of green, red, and blue, as given in Atkins, et al (1938). These colored glasses were obtained from the Corning Glass Works, and their exact specifications are;

Green, Corning No. 400-1; standard thickness. Maximum sensitivity at about 550 mμ, effective range from about 470 mμ to 640 mμ.

Red, Corning No. 245; standard thickness. Transmits freely above a sharp cut-off at about 600 mμ.

Blue (violet), Corning No. 511; standard thickness. Maximum transmission

Figure 15. Photometer in use, showing pipe handle for inserting target under the ice.
Photo by Beckman.

at about 410 mμ, effective range from about 360 mμ to about 470 mμ.

The procedure of making measurements of light penetration through ice and snow was as follows. An initial reading was made with the receiver in the air, resting horizontally on the surface of the ice. Then, with as little loss of time as possible, the receiver was thrust under the ice, and a reading was taken. Then another reading was taken in the air, and so forth, sufficient alternating readings being made to make sure that the intensity of daylight had remained reasonably constant throughout the process. If measurements at various depths were made, the same alternating reading procedure was followed. It was found that on either completely cloudless days or heavily overcast days the light remained sufficiently constant to provide acceptable results, over periods long enough to make the necessary number of readings. Utterback (1933), however, found that at certain times "the intensity of the visible light may vary within a few minutes by several per cent, even though there be a cloudless sky and a clear atmosphere." Hence, although considerable precaution was used, it is not impossible that an occasional small error may have entered into the results obtained. Measurements always were made at about the same time of day — usually close to noon — to avoid large changes in the angle of light.

Measurements of penetration of light through the snow cover were, of necessity, made indirectly. The penetration through the ice and the snow was measured; then the snow was removed, and a measurement made of penetration through the ice alone. From these two readings the amount of light penetrating the snow alone was computed.

The instrument was carefully calibrated, in terms of light intensity in foot-candles incident upon the face of the target, against a daylight type photoflood bulb, previously standardized against a bulb which had been calibrated by the U. S. Bureau of Standards. The temperature correction was ascertained by calibration at several temperatures. It was found, in agreement with the statement of Utterback and Wilson (1940), that the temperature correction is greater at higher illumination levels.

The results are expressed in terms of percentage penetration; i.e., the per cent of the light that is incident upon the upper surface of the layer of ice, snow, or water, that penetrates through that layer. Also given is the amount of light ("total" light) that impinges upon the photometer target. It must be remembered that this is not true total light, but rather is diffuse sunlight or daylight, as measured by a Weston Photronic cell, which has a maximum sensitivity in the yellow-green portion of the spectrum.

Possible error caused by the loss of low-angle light was not taken into account. Such loss is minimized by the opal glass diffusing window. Furthermore, the various readings are comparable, since the angle of light always was approximately the same.

## Other Factors

Only a limited number of measurements were made of water temperatures. For part of these a standard reversing thermometer, graduated to 0.2° C., was used; the remainder were made with a pocket thermometer, graduated to 1° F. The pocket thermometer was placed in water that had been rapidly hauled, in the sampling can, from the desired depth.

Other field observations, made either regularly or only occasionally, concerned such conditions as weather, thickness of ice and snow, appearance and odor of the water, condition and amount of macroscopic vegetation, and so forth. For none of these observations was any special equipment or technique needed.

## FINDINGS AND DISCUSSION

### Weather, Ice, and Snow

The winter climate of southeastern Michigan is moderately cold, with fairly even precipitation. Snows are apt to be frequent, but rather light. Many days are cloudy or partly cloudy, and there is fair to moderate humidity. There are many winter breezes and light winds, but rarely is there a storm of blizzard-like intensity. Midwinter thaws are frequent, and it is rather seldom that snow remains on the ground continuously throughout the winter.

The time of freezing-over of the lakes in the region not only varies with the size, depth, and exposure of the lake, but also varies greatly from year to year. Likewise there is considerable variation in the date of the spring breakup of the ice. In the winter of 1937-38 there was an ice-cover, at least on some of the lakes under observation, from before December 10 to about March 15. In 1939-40 the ice-cover did not form until almost January 1, but it lasted until about April 5. In 1940-41 the lakes froze over early, some of them being completely covered by December 5. A warm spell in late December partially or completely opened up the lakes for a few days, from about December 25 to about January 5. Bog Lake, alone of the lakes that were under observation, retained an unbroken cover of ice during this period. After the ice formed again in early January, it remained intact until almost April 1; however, it was soft and thin on some lakes after March 15. Table 4 gives the thickness of the ice on the various lakes of the survey, on the dates on which these lakes were visited. These figures represent, usually, the approximate average thickness; for the thickness of the ice often varied considerably from one part of the lake to another.

Also given in Table 4 is the depth of snow upon the ice from time to time. Obviously, only an approximately average figure can be given, because drifting often causes the snow to be much deeper in some places than in others. Tables

5 and 6 list the day by day figures for the amount of snow on the ground, at 7 A.M. each day, at the University weather station in Ann Arbor. Table 6 gives, in addition, the amount of snow on the lakes studied, for those dates on which it was measured. When more than one lake was visited on any one day, the figure used represents a weighted mean of the various lakes. This information is not available for 1935–36, and hence is not given in Table 5.

With a few discrepancies, the two figures, the one for the Ann Arbor weather station and the other for the lakes themselves, are in reasonably good agreement. Therefore a graph using compromise values from these two sets of figures is believed to represent fairly accurately the depth of snow from time to time in the general region. Such curve, for each of the winters of 1935–36, 1937–38, 1939–40, and 1940–41, is shown in Graph 1. It is probable that the value given by that graph for any particular day would not be far from the actual mean depth of snow on the ice of any one of the lakes studied, on that date.

It is readily apparent from this graph that in the year of the heavy winter-kill, 1935–36, not only was the snow fairly deep, but what also is very important, it remained on the ice for a long uninterrupted period. Likewise in 1939–40, a winter with some kill, although the snow was not so deep, it covered the ice for a rather long unbroken span of time. In contrast, in the winter of 1937–38, and even more so in 1940–41, the snow on the ice frequently was dissipated by thaw or rain; and hence, although there were many snowstorms, there were no extended periods of snow coverage. These two winters were virtually free from winter-kill in the region of southeastern Michigan under investigation. The interrelationships of snow-cover, light, and conditions in the water will be discussed more fully below.

## Water Temperature

Water temperature measurements were made fairly regularly in the winter of 1937–38, but only occasionally in 1939–40 and 1940–41. In Table 7 are given the temperatures for the lakes studied in 1937–38, both as read in degrees Centigrade, and as converted to degrees Fahrenheit (to the nearest 1/2°). Table 11 repeats these figures, for Station 2 of Clear Lake, but rearranged according to depth. There may be some reason to doubt the exactness of these figures, since the thermometer used that winter had not been calibrated for some time. However, the general trends may be noticed. One evident tendency is toward the development of a very abrupt drop–off in temperature in the upper few feet of water, with a much more gradual decline from there to the bottom. Another is a distinct warming up of the general mass of water as the season progressed. It is difficult to estimate what part of this increase in temperature was due to the oxidation of organic matter, and what part to heat produced by the radiant energy of sunlight. The occasional entrance into the lake of a considerable amount of comparatively warmer rain water may have contributed a small part of the heat.

## Dissolved Oxygen

By far the best single indicator of conditions for fish life in the water under the ice is the amount of dissolved oxygen. The determination of dissolved oxygen is a relatively simple and reliable procedure, and one which is capable of adaptation to winter field work. Therefore the data of this study contain a large proportion of dissolved oxygen values.

### Data and Graphs

The oxygen data are recorded in the following tables and graphs:

Tables 7, 8, and 9 contain the dissolved oxygen figures for the winters 1937–38, 1939–40, and 1940–41, respectively, for the principal bodies of water studied, arranged according to consecutive sampling dates for each depth at each station. Table 10 is similarly arranged, but is composed of data, for the three winters given above, for the miscellaneous lakes which were visited only once or twice.

The vertical distribution of dissolved oxygen is given, for certain stations in Clear, Green, and Bog Lakes, and Pasinski's Pond, in Tables 12 to 17. In these tables the arrangement is by depth for each sampling date.

In Graphs 2–8 are shown the trends in dissolved oxygen values throughout the winter, for certain lakes and stations. The horizontal and vertical scales are proportionately uniform throughout this series of graphs, so that the curves may more easily be compared one with another. On each graph also is shown the snow depth curve for the appropriate year (copied from Graph 1), to the same horizontal scale, in order that visual comparison may be made between the amount of snow upon the ice on any one date and the trend in oxygen value at the same time.

Graphs 9 and 10 show, for each of four selected stations (surface samples), the curves for the three winters 1937–38, 1939–40, and 1940–41. Again the horizontal and vertical scales are in the same proportions.

The vertical distribution of dissolved oxygen for various lakes and for certain selected sampling dates is shown in Graphs 11 and 12. In each of these graphs the horizontal scale (oxygen) is the same throughout the graph; the vertical scale (depth) varies, in Graph 11, with the lake. The method of diagramming dissolved oxygen in these graphs is similar to that sometimes used to show the vertical distribution of plankton. Included in Graph 11, for purposes of comparison, are diagrams for Lake Mendota, for certain dates in the winter of 1906–07, the data for which were taken from Birge and Juday (1911).

The highest oxygen values, for the several bodies of water, recorded during the survey were: Clear Lake, 16.2 p.p.m., Station 1 on January 20, 1940; Green Lake, 15.7 p.p.m., Station 1 on January 10, 1940; Mud Lake, 19.4 p.p.m. (approximately 135% saturation), at Station 4 on March 11, 1940; Bog Lake, 21.0 p.p.m.

(about 145% saturation), on February 11, 1941; and Pasinski's Pond, 28.0 p.p.m. (about 190% saturation), at Station 26 on January 31, 1941. During the winter of 1940–41 a considerable number of samples from Pasinski's Pond contained over 20 p.p.m. dissolved oxygen. The most rapid increase in oxygen noted was in Mud Lake, at Station 4, where the oxygen changed from 13.1 p.p.m. on March 8, 1940, to 19.4 p.p.m. on March 11, an increase of 6.3 p.p.m. in 3 days, or at the rate of 2.1 p.p.m. per day. The most abrupt decline recorded was in Pasinski's Pond, at Station 27. Here the oxygen fell from 12.3 p.p.m. on February 12, 1940, to 2.4 p.p.m. on February 14, a decrease of 9.9 p.p.m. in two days, or at the rate of 5 p.p.m. per day.

## Discussion

The oxygen in Clear Lake showed considerably less variation (Graphs 2 and 3) than that in the richer, more shallow lakes. At Station 1, in Clear Lake, the top and bottom samples were remarkably similar in oxygen content at nearly all times. At the deeper Station 2 (Station 2a in 1940–41) a much more evident stratification was found. The water layers at the surface, 10-foot, and 20-foot levels had an almost uniform content of dissolved oxygen at the start of the winter of 1939–40, but gradually developed the spread in oxygen values typical of stratification (Graph 2). Strangely enough, in the winter of 1940–41, the oxygen in the deeper water was rather low even at the onset of the ice cover; the oxygen curves for this station in Graph 3 are almost level throughout the winter. Apparently for some reason stratification already had developed before the first samples of that winter were taken (even though sampling was started two weeks earlier than in the preceeding winter). It is possible, although not definitely known to be the case, that following the fall overturn some sort of an oxygen demand (more or less pronounced and rather immediate) developed in the lower water, as from the settling of a suddenly killed crop of plankton, and that this demand was sufficient to bring about such early stratification.

The greater eutrophy of Mud Lake is reflected in its oxygen curves for 1939-40 (Graph 4). As may be seen by juxtaposing these curves with the curve which represents depth of snow, there was a definite response of the oxygen value-- especially at some stations -- to changes in light intensity. Stations 2, 3, and 4 showed low oxygen during the period of snow cover throughout most of February, and very sharp rises in oxygen in early and mid-March, when the snow was light or absent. These three stations, which initially were chosen on the basis of differences in vegetation and bottom materials (see under Sampling Stations, and also Table 3), failed to show many significant differences in dissolved oxygen values, the most evident one being that the oxygen at Station 2 (which had a soft marl bottom) for some reason dropped to a low value much sooner than did that at the other stations.

Station 1 was more or less directly in the path of flow of water crossing the lake, and hence its oxygen curves show less response to changing light conditions, because of the steadying influence of the inflowing water. However, it is of interest to note that, in spite of the current, a definite stratification existed, the bottom water always containing less oxygen than the surface water. The inflowing water itself scarcely could have had much stratification, since the stream was shallow; therefore even a transitory stay in the deep part of the lake was enough to bring about a distinct difference between surface and lower water.

In 1939-40 the outlet water of Mud Lake almost continuously had less dissolved oxygen than did the inflowing water (Graph 5). In 1940-41 exactly the reverse condition existed. In other words, during the one winter the water lost oxygen during its stay in the lake, in the other year it gained oxygen. Furthermore, it is evident that this difference in the relationship of the two curves came about not nearly so much by any shift in the curve for the inlet water from one year to the next, as by a vast change in the curve for the outlet. The correlation with the respective conditions of snow cover and light for the two winters is quite evident.

Curves are given for only one station in Green Lake (Graph 6), since this station fairly well typifies the lake. Here again the relationship between surface and bottom water (at a shallow station) is plainly evident. The curve for the bottom follows closely that for the top, but almost constantly remains below it. This relationship, repeated over and over for various lakes and stations, can lead logically to only one line of reasoning. The two levels of water are subject to the same influences, light on the one hand and oxygen demand on the other, but to different degrees. The bottom water either receives less light and hence produces less oxygen, or is subject to greater oxygen demand and hence loses more oxygen[1], or both; therefore the oxygen curve for the bottom water falls below that for the surface water. With such a difference, however, the two curves should become progressively more divergent throughout the winter (as in the case of the deeper station in Clear Lake, in 1939–40), instead of following each other so closely. For some stations, it seems as if almost as much divergence between the curves exists at the start of the winter as later, and that the curves tend to be roughly parallel. In other words, this is more evidence that stratification may take place, and quite rapidly, even before the ice forms, as is postulated above for the deep station in Clear Lake in 1940–41.

In respect to the amount by which the bottom water at a shallow station may remain lower in oxygen throughout the winter than the surface water, an interesting series is presented in the curves for the several lakes, starting with Clear Lake (Graphs 2 and 3), and progressing through Mud Lake, Green Lake, and Pasinski's Pond (Graphs 4, 6, and 8), to Bog Lake (Graph 7). In

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[1] It may be well to take into account the difference in temperature (usually almost 4° C.) between top and bottom, with perhaps a consequent difference in bacterial activity.

Clear Lake the oxygen was practically the same at the two depths (at Station 1); for Bog Lake the values were widely separated. Yet the tendency, discussed above, for the lower curve to parallel the upper one existed to some extent even in Bog Lake.

Green Lake (Graph 6) offers another example of the readily apparent connection between depth of snow on the ice and dissolved oxygen response, in a shallow eutrophic lake. The steady decline in oxygen during the long period of snow cover in 1939–40 contrasts strongly with the almost level (and relatively high) curve for the winter of 1937–38, a winter of comparatively little snowfall.

The typically dystrophic water of Bog Lake shows, in comparison with that of the other lakes studied, a set of extremes. Its power of oxygen stratification is almost unbelievably great (see Graph 7 and many of the diagrams of Graph 12). For example, on January 23, 1941, the oxygen at the surface was 20.2 p.p.m., while at a depth of 5 feet it was 0.0 p.p.m. Most of this difference of 20.2 p.p.m., or 16.2 p.p.m. to be exact, occurred between the 1-foot and the 2-foot levels (18.3 p.p.m. at 1 foot, 2.1 p.p.m. at 2 feet). No doubt such sharp stratification is associated with the brown suspended material of this bog water, and could very seldom, if ever, be found in a clear-water lake. Also exaggeratedly marked is the response of the surface water of Bog Lake (and to a certain extent the water at 1 and 2 feet) to changes in light conditions. This is quite evident in the fluctuations of the oxygen curves for 1939–40 (Graph 7) in respect to the corresponding changes in the snow-depth curve.

As discussed below, it is probable that the data from no one station in Pasinski's Pond can give a very complete picture of conditions in the pond as a whole; since the pond varies so greatly from one part to another. Especially does this qualification pertain to the winter 1939–40. In 1940–41 conditions were somewhat more nearly uniform throughout the pond, and hence may be studied with a fair degree of reliability by the use of one set of curves. Graph 8 gives the oxygen curves for Station 26, the deepest station in the pond, for 1940–41. Here it may be noted that, as in the case of other lakes, there is a considerable correspondence in the dissolved oxygen values for the various depths at the same dates. In this instance, however, there are certain deviations from that coordination. The values for the bottom water fluctuated to some extent without respect to that of the surface water, particularly on January 31, when the oxygen values at the bottom fell off, while the upper water was gaining oxygen. The extremely high oxygen values at this station throughout most of the winter of 1940–41 are indicative of abundant photosynthetic production of oxygen, during a winter of little snow.

The variation in the dissolved oxygen content from one winter to another is shown in Graphs 9 and 10. The oxygen in the water in Clear Lake (at the surface) was almost the same in each of the three winters, not deviating far from the saturation point most of the time. The evident conclusion is that this water, being only mildly eutrophic, contained not only very little dead organic matter to consume its oxygen, but also very little living phytoplankton to produce oxygen. Hence it simply retained its initial supply of oxygen throughout the winter, with little addition or deduction. It became neither excessively low in oxygen during a hard winter (1939–40) nor excessively high in oxygen during a very mild winter (1940–41). Such water probably would be safe from complete oxygen depletion in the longest, most severe winter of the past or future few centuries.

The curves for Mud Lake and Green Lake (especially the latter), however, very plainly show the comparative effects of the three winters on the dissolved oxygen content of the water. The winter of 1939–40 had the most adverse effect, that of 1940–41 the least. The greatest difference is furnished by the curves for Pasinski's Pond, which form an almost perfect spread in the anticipated order.

Changes in vertical distribution of oxygen take place as the winter season progresses (Graphs 11 and 12). For instance, as mentioned above and as shown on Graph 11, the water of Clear Lake was almost uniform at all depths at the start of ice cover in 1939-40. Oxygen at the lower depths gradually decreased, until on March 16 it was very much less than at the surface (correspondingly, the diagram for that date is semi-triangular). A somewhat similar sequence is shown by the diagrams for Lake Mendota, on the same graph, except that the oxygen in Lake Mendota tended to decrease mainly at the bottom, maintaining a somewhat uniform distribution in the upper half of the water (Lake Mendota of course is much deeper than Clear Lake).

However, in Clear Lake in 1940-41, as well as in Green Lake in the same winter, stratification was fairly well developed very early in the winter; and the general shape of the oxygen distribution diagram remained somewhat the same throughout the winter. Some rather bizarre figures appear on Graph 11, most of which are occasioned by somewhat sharp changes in the oxygen in the surface water — such as in Clear Lake on March 13, 1941, when run-in water had appreciably lowered the oxygen at the surface.

In Bog Lake, in each of these two winters, the oxygen at the bottom was very low even at the start of the winter. Here, however, rapid and extreme changes occurred in the amount of oxygen in the upper water; so that the diagrams of Graph 12 vary exceedingly, from the almost perfect triangle for January 30, 1940, to the thin wedge for March 3 of the same winter, to the wine-glass shaped figure for December 21, 1940.

The peak values of dissolved oxygen mentioned above (i.e., 21.0 p.p.m. for Bog Lake and 28.0 p.p.m. for Pasinski's Pond, in 1940-41) are somewhat unusual for ice-covered water, although the literature has recorded a few similar instances.

Griffiths (1936) reported an oxygen content of 22.0 p.p.m. for Long Pool, England, under the ice in February, 1930. A lake in Minnesota (Olson, 1932) had 16.8 p.p.m. of oxygen in January, 1930. In Lake Mendota (Birge and Juday, 1911), on March 29, 1906, the upper water contained 12.5 cc. per liter (equal to about 17.9 p.p.m.) of oxygen. Knauthe (1899) and others also have reported oxygen values in excess of saturation for water under the ice.

## Special Observations — Green Lake

### Forty-eight-hour Oxygen Run

In order to determine the effects of alternating light and dark periods upon the dissolved oxygen content in the water under the ice, and the possible existence of a diurnal oxygen cycle, a two-day run of sampling was conducted on Green Lake, from January 17 to 19, 1941. Samples were taken at two-hour intervals, starting at 5 P.M. on January 17 (Friday), and ending at 3 P.M. on January 19 (Sunday). The stations used, and the sampling depths, were: Station 2 at 1/2 foot, 2 feet, 5 feet, and 9 feet; and Station 6 at 1/2 foot and 3 feet. Determinations were made of pH as well as of dissolved oxygen. The data obtained are given in Tables 18 and 19; and Graph 13 shows the dissolved oxygen curves.

Although certain sampling errors may be involved (see Appendix), it is believed that the figures are accurate enough to warrant the following conclusions: The oxygen in the surface water remained practically constant throughout the forty-eight hours; the slight fluctuations apparently show no correlation with periods of light and dark. Much greater changes appear in the values for the deeper samples. This situation is exactly the reverse of that which would be expected if changes in light were the cause of fluctuation, since the upper water is more subject to these changes. The fluctuations of the curves for the lower depths are apparently quite at random, and probably are largely explainable by imperfections in the sampling technique, or by shifts in the stratified layers of water.

It is evident, therefore, that no well-defined, if indeed any, diurnal variation in oxygen was present. The processes of photosynthesis and of decomposition are considerably slowed down by low temperatures; furthermore, at such temperatures there probably is somewhat of a lag in the reaction of the photosynthetic process to changes in light (i.e., oxygen evolution continues for some time after the light disappears). This example of course does not prove that diurnal variations in dissolved oxygen under the ice never exist. It may be that at certain times, particularly during periods of unusually high oxygen production (as in Pasinski's Pond in 1940-41), a slight diurnal cycle is present. However, for the average ice-bound lake, diurnal variations in oxygen apparently are insignificant.

## Temperature and Oxygen Profiles

On February 2, 1941, oxygen determinations were made at a series of points along a course from the inlet of Green Lake, across the lake, to the outlet. This course followed a somewhat zigzag line, and included Stations 4, 2, 1, and 5 (see map, Figure 8). At each sampling point on the course, oxygen and temperature measurements were made at depth intervals of one foot. The data are given in Table 20 (temperatures were measured in degrees Fahrenheit, to the nearest 1/2 degree, and converted to degrees Centigrade).

Graph 14 is drawn up in an idealized profile plan, showing isothermal lines, and lines of equal oxygen tension. As shown by this graph, the oxygen stratification tends to be sharpest near the bottom, and tends to follow the bottom contour. Temperature on the other hand changes most rapidly immediately under the ice, and the isotherms tend to follow the surface contour. These facts are substantiated by various other observations. The situation just described is apparently the one which commonly prevails in the ice-covered waters of shallow lakes.

## pH, Carbon Dioxide, Alkalinity

A fairly complete set of observations was made, for the lakes studied, of the pH, methyl orange and (if present) phenolphthalein alkalinity, and (except in 1939–40) free $CO_2$. These data are given in Tables 7 to 10, and 12 to 17, along with the corresponding dissolved oxygen figures. With the exception of one graph (Graph 15, explained below), these data are not presented pictorially, because (1) accurate correlations are somewhat hard to establish, and because (2) the story is told more forcefully and understandably by the dissolved oxygen graphs. However, a few general observations may be in order.

As might be expected, free $CO_2$ and pH are fairly closely correlated with dissolved oxygen. The same processes of decay which use oxygen produce carbon dioxide, and hence lower the pH. Conversely, the photosynthetic production of oxygen uses up carbon dioxide and raises the pH. To a certain degree, therefore, $CO_2$ or pH could furnish a fairly reliable index to conditions under the ice, especially if the usual or normal values are known. However, certain complications, some of which may be unforeseen, may arise. The pH may be influenced (in bog lakes it most probably is) by acids other than carbon dioxide. Inflowing water, or melted snow and ice, may greatly alter the buffering power of the water, and hence affect pH.

The physiological significance of free carbon dioxide is briefly discussed, below, in the section on winter suffocation.

Titratable alkalinity to phenolphthalein usually indicates reasonably good condition of the water, since this alkalinity is dissipated by the $CO_2$ produced by decomposition; and when present in appreciable quantities under the ice, as in Pasinski's Pond in 1940–41, it means that photosynthesis has been intense enough to utilize a certain amount of half-bound $CO_2$, thus liberating calcium carbonate.

Under the influence of developing stagnation, the so-called total alkalinity, or titratable alkalinity to methyl orange, gradually increases, by a relatively small amount. Under conditions of stratification, the water near the bottom usually has a higher methyl orange alkalinity than that near the surface. Graph 15 (for Clear Lake, 1939-40) shows this difference, as well as the tendency for the curves representing the alkalinity at various depths to spread apart somewhat as the winter progresses, after starting at almost the same value. This behavior is comparable to that of the dissolved oxygen at the same station in that winter (discussed above). The sharp fluctuations and extremely low values shown by the curve of the surface water were caused by dilution with run-in water from rain or melted snow and ice.

## Biochemical Oxygen Demand

The biochemical oxygen demand (abbreviated B.O.D.) is the oxygen consumed, by bacterial action[1], in a certain period of time, from a sample incubated in the dark at a fixed temperature. Conventionally, if the limiting conditions are not indicated, it is understood that the time period is five days (120 hours) and the incubation temperature 20° C. In the present series of B.O.D. determinations a considerable number of samples were incubated at 0° C.; one set of these had an extended incubation — up to 60 days. These procedures are indicated in the tables.

B.O.D. gives a rather accurate picture of the relative organic richness of a water sample, and the likelihood of the depletion of its dissolved oxygen supply in a given time. When measured at 0° C., the B.O.D. of a sample of water from an ice-covered lake provides a rough indication of the probable behavior of that water with respect to oxygen depletion.

The B.O.D. data obtained are summarized in Tables 21, 22, and 23. As mentioned above, in the section on Methods, the values given in these tables usually are the weighted means of two or more samples, which often were set up at different

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[1] Theoretically only bacterial action is involved. Actually part of the demand (usually a small part) may come from purely chemical — not biochemical — oxidation.

dilutions. The greatest stress in the weighting was placed upon the samples least diluted, and little weight was given to samples whose final oxygen content was close to zero. Table 21 gives the B.O.D. values for five-day incubation at 20°, and Table 22 those for five-day incubation at 0°. Table 23 contains the data from the 60-day B.O.D. run at 0°.

Certain facts are apparent. The B.O.D. of the water in Clear Lake was very much less than that of the more eutrophic waters. Extremely high B.O.D. was found for many samples from Bog Lake and from Pasinski's Pond. The B.O.D. at 0°, for nearly all of the waters studied, showed correlation with that at 20°. The values for 0° averaged on the order of four-tenths of those for 20°.

Quite worthy of note is the regularity with which the B.O.D. at any particular station was higher in the upper water than near the bottom. Sometimes the differences were very large, such as that between 24.2 p.p.m. and 3.6 p.p.m. (Pasinski's Pond, Station 27, February 12, 1941, and many other examples). This sharp decline in B.O.D. with increasing depth fits in very well with the hypothesis that suspended organic matter (such as dead plankton) is a prime agent of oxygen consumption in the water; and that this material, produced in the surface water, is oxidized as it slowly settles through the water, and hence its power of utilizing oxygen diminishes as it sinks. Opposed to this reasoning stands the fact that the upper water usually maintains, throughout the winter, much more oxygen than does the bottom water. This latter difference, however, can at least in part be accounted for by the much greater production of oxygen in the upper water.

The high B.O.D. values obtained for certain samples (Tables 21 and 22) indicate water exceedingly rich in organic material. Many samples from Pasinski's Pond had a 5-day demand, at 20°, of over 25 p.p.m., with a high of 42.0 p.p.m. (for Station 15, on January 16, 1941). These values are even higher than those of many badly polluted waters. In the waters of Green Bay (Williamson, et al, 1939), for instance, which were subject to sulfite pulp mill pollution, most of the samples taken had a 5-day B.O.D. of 10 p.p.m. or less; and even in the extremely putrid waters of East River values higher than 25 p.p.m. were very seldom encountered.

Graph 16 shows the B.O.D. at 0°, over an extended period of time, of three samples from Station 26, Pasinski's Pond, and one sample from Clear Lake (the samples were taken on March 11, 1941). The curves as drawn are somewhat idealized, because too few data are at hand to make sure the exact shape of the curves. However, they are of the same shape as B.O.D. curves in general, and hence probably are reasonably accurate.

The curves for the three depths in Pasinski's Pond exhibit a remarkable spread; and also quite a contrast to the almost flat curve for Clear Lake. The water at the surface in Pasinski's Pond had approximately nine times as much B.O.D. in five days (22.5 p.p.m.) as did that in Clear Lake in sixty days (2.6 p.p.m.). Such comparative figures go far toward explaining why Pasinski's Pond can lose nearly all of its dissolved oxygen within a few days, while Clear Lake almost invariably retains oxygen nearly to the saturation point throughout the entire winter.

## Light Penetration

### Data, sources

During the winter of 1940-41, a considerable number of measurements were made of the transmission of light through water, ice, and snow, in the various situations which obtained at the lakes which were being investigated. The photometer used, and the methods employed are described above. That winter was a somewhat mild one in southern Michigan, particularly in regard to snowfall; hence comparatively few measurements involving a snow cover could be made at the regular lakes of the survey. However, visits were made to South Londo Lake, Iosco County, and East Fish, Middle Fish, and West Fish Lakes, Montmorency County, each of which had an ~~ice~~ snow cover of from 6 to 10 inches. Several measurements were made in each lake. The light transmission data are summarized in Tables 24 to 27, and are discussed below.

Considerable information was obtained from the literature. Numerous papers have been written concerning light penetration into water, both sea water and that of lakes. Among the many investigators who have done work on this subject, there may be mentioned Clarke, Shelford, Poole and Atkins, Utterback, Birge and Juday, and Pearsall and Ullyott, most of whom are cited below. Although much less work has been done on snow and ice, a few informative papers have appeared. As specifically cited below, certain data from these papers are here presented for purposes of comparison with those of this investigation.

## Transmission through Water

The characteristics of various waters with respect to the transmission of light have been reviewed by Welch (1935, pp. 72–79), Birge and Juday (1929), and more recently by Clarke (1939) and by Utterback (1941), and therefore are only briefly mentioned here. The observations of this study agree, in general, with the conclusions of these various writers.

It is well known that even the clearest waters impede the passage of light to a certain extent. Light (in the yellow-green region of the spectrum) is reduced by passing through 100 meters of distilled water, to between one and two per cent of its incident value (Clarke, 1939). Natural waters vary from those almost as clear as distilled water, to the highly colored waters of bog lakes or the extremely turbid waters of silt-laden streams, in which the light may be reduced to a fraction of one per cent at a depth of one meter.

It has been demonstrated that, as a rule, the diminution of the intensity of light in its passage through water follows a definite mathematical formula, the relationship between the depth of water and the amount of light penetrating to that depth being such that it may be plotted on semi-logarithmic paper as a straight line[1] (Clarke, 1939, p. 27). The slope of that line, then, is an index of the relative transparency of the water. Many examples of this relationship have been presented by Clarke, by Birge and Juday (1929), Utterback (1941), and others.

The penetration of light through the ice-covered waters of some of the lakes of this study is plotted in this manner in Graph 17 (this graph is explained more fully below). Quite evident are the comparative rapidity with which the colored water of Bog Lake reduced the quantity of light, the moderately good transmission through the rather clear waters of Clear and East Fish Lakes, and the extremely low loss of light in the water of Crater Lake (data from Utterback, et al, 1942).

As indicated in the papers quoted above there are very large differences in the relative transmission, through water, of light of various spectral qualities. These differences depend, in kind and amount, upon the type of water. In distilled water, or other very clear water, such as that of the Sargossa Sea, penetration is best effected (within the range of visible light) by blue light, and progressively less well by green, yellow, and red light.

In slightly less clear water, such as that of the clearest inland lakes of this region, light in the green or yellow-green portion of the spectrum is transmitted in the greatest amount, red light in the least, and blue light to an intermediate extent. In moderately clear lakes, penetration is greatest in the yellow-green, and considerably less in both the red and the blue, the latter two being about equal. As shown in Graph 18, the water of East Fish Lake was found to have these characteristics.

In the less transparent waters there is a shift toward greater relative penetration in the longdr wave lengths (yellow, orange, and red light); and in

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[1] In many lakes, however, certain conditions, such as differences in the amount of suspended material at various depths, may cause more or less irregular variations in the transparency of the different layers of water (see Whitney, 1938; Chandler, 1942; and others).

waters of very low transparency, such as highly colored bog waters, the transmission of red light is many times as great as that of green light, and blue light is almost entirely excluded. This differential penetration in colored water is illustrated by Graph 19, which shows the relative spectral transmission through the water of Bog Lake. It is probable that the relatively lesser ability of light of the shorter wave lengths to penetrate bog water depends in some way on the presence of suspended particles, which scatter certain kinds of light, since water which is turbid because of suspended silt exhibits the same property (Higgins, 1932, p. 523).

In addition to the loss of light in the water itself, there is, in open water, a surface loss, sometimes amounting to a considerable portion of the total light. According to Clarke (1939), only a small part of this loss actually is due to reflection; the remainder is caused by a proportionately high rate of extinction in the upper layer of water.

Since all of the observations of the present study pertained to water which was covered with ice, it is difficult to assign any value for "surface loss," if indeed such loss existed. In making a measurement of the light penetration through the ice, the target of the photometer was held as tightly as possible against the under surface of the ice. However, since there was a small space between the top of the target and the Weston cells, and since ice normally rests in, rather than above, the water, it is apparent that the actual water-ice interface was above the cells. Therefore any loss which this interface, per se, may have caused would have been calculated as part of the loss in transmission through the ice. It seems probable that such loss was small.

Furthermore, the existence and amount of any extra loss in the uppermost layer of water, under the ice, is difficult to judge from the data at hand. The difficulty of accurately gaging the depth of the target (within the first one or two feet below the ice), combined with the possibility of error caused by stray light from the side, prevented the precision of measurement necessary to determine the exact behavior of the water immediately under the ice. Another possibility, about which only speculative statements can be made, is that of reflection of light, back into the upper water, from the under surface of the ice (or of the snow).

In general, on the basis of the data as they appear in Table 24 and in Graphs 17 and 18, it is apparent that there was no very great difference in the percentage absorption of light in the uppermost foot of water as compared with the water of the deeper layers. There was perhaps a slight tendency toward such a difference in Bog Lake; but that difference possibly can be accounted for by the greater amount of suspended material in the upper water.

## Transmission through Ice

Of much greater, and therefore more striking, effect in absorbing light is the cover of ice and snow. The measurements made of light transmission through snow and ice are given in Tables 24 to 27. Table 25 is a summary of the percentage transmission through ice of various thicknesses and conditions, arranged in descending order of percentage. The values ranged from 84 per cent, for 7 1/2 inches of very clear ice, to 7.2 per cent for 10 3/4 inches of very cloudy ice.

The figures in this table compare fairly well with the few data which are to be found in the literature. Sauberer (1938) found the transmission through 25 mm. (1 inch) of clear ice to be about 84 to 87 per cent, and through 4 cm. (1 1/2 inches) of "schneeis" to be about 45 per cent. The figures given by Croxton, Thurman, and Shiffer (1937) are: 4 inches, 86 per cent; 6 inches, 66 per cent; and 14 inches, 33 per cent. Zinn and Ifft (1941) gave the results of only one measurement; through 4 1/2 inches of ice, with a "slush cover," approximately 65 per cent of the incident light penetrated. Chandler (1942) found 58 per cent transmission through 40 cm. (16 inches) of ice — a percentage transmission equivalent to that through the same depth of Lake Erie water with a turbidity of about 20 p.p.m. The data of these various writers were obtained by the use of instruments and techniques which varied somewhat, one from another; but in general they probably are properly comparable.

It is readily apparent (from Table 25) that the penetration of light through ice varies greatly with the condition of the ice. For example, 7 1/2 inches of clear ice transmitted 84 per cent, as against 22 per cent for 7 1/2 inches of "partly cloudy" ice. Only 7.2 per cent of the incident light passed through 10 3/4 inches of ice described as "very cloudy." This ice was extremely full of minute air bubbles, which gave it somewhat the appearance of opal glass, and rendered it probably as opaque as any ice likely to be encountered on natural waters, except that which might have inclusions of dirt or other foreign matter. Similarly, the "clear" ice just mentioned probably was almost as crystal-clear as any which ever freezes on inland lakes. Between these two extremes, the ice of most lakes may vary greatly in character, and in ability to transmit light, depending on the manner in which it was frozen, on the various thaws and freezes, and on many other factors. However, the approximate range of the percentage transmission is delimited by the figures of Table 25, since the thicknesses of ice given in the table are about those usually present on these lakes in an average winter.

As with water, it is probable that a part of the total loss of light in passing through ice consists of "surface loss." For ice this loss is largely undefined and unmeasured. If the usually rather dark appearance of the ice on a lake (especially if the ice is clear) may be used as a criterion, surface reflection apparently is of relatively small amount; and it is probable that most of the total loss actually occurs within the ice. At any rate, and of necessity, the data given here in regard to light absorption by the ice include whatever absorption may take place both at the upper surface of the ice and at the water-ice intersurface.

It is assumed that the transmission of light through ice, if the ice is uniform in character throughout, probably takes place according to a mathematical relationship such as that described above for water. Following this assumption, the points on Graphs 17, 18, and 19, representing the percentage amount of light entering the ice and that emerging from it, respectively, are connected with a straight line. As above, the slope of that line indicates the relative light-absorbing power of the ice. Comparative lines of this sort have been drawn, on Graph 17, for several of the lakes studied.

The transmission of light through ice apparently varies somewhat with the region of the spectrum. As stated by Dorsey (1940, p. 398), ice in large masses has a blue appearance, probably caused by light scattering. Sauberer (1938) found very little difference between the various spectral bands, in transmission both through clear ice and through "schneeis." In the data of Table 25, the clearer ice showed no significant differences in relative transmission of light of different colors. However, the more turbid ice showed a pronouncedly lower relative penetration of blue light. Apparently, therefore, a proportionately large loss of blue light is associated not so much with pure ice as with included particles, such as air bubbles, or possibly (in the case of the ice of Bog Lake) particles of coloring matter which may have become frozen into the ice. In Graphs 18 and 19, the slightly different slopes of the lines for the transmission of various colors through the ice of East Fish Lake and Bog Lake are evident.

## Transmission through Snow

The penetration of light through snow is considerably harder to measure accurately than that through ice or water, not only because of the difficulties in making observations under natural conditions (i.e., without disturbing the snow), but also because of the many variations in the character of the snow. However, the information obtained is of value in establishing a general range for the ability of snow to transmit light, and thus in showing the relative absorption by snow, ice, and water.

With the exception of one series of experimental determinations, the measurements of light transmission through snow made during the course of this study were performed on the ice of various lakes, without disturbing the natural snow cover. Thus they were of necessity indirect measurements; that is, the value was calculated from the transmission through snow and ice, compared to that through ice alone, after the snow had been removed. There is no apparent reason to suppose, however, that such calculation is invalid; probably the only significant error is that caused by surface loss from the ice (see above), in the latter measurement; and this loss likely is relatively small.

Kalitin (1931) made an extensive series of measurements by placing the target of a photometer on an open field, and allowing the natural snowfall to cover it. The chief difficulties in interpreting the data so obtained lie in the variations in amount and quality of light from time to time, and the changes in the character of the snow between readings. Most of the remainder of the few observations which have entered the literature have involved some sort of an artificial set-up, with consequent disturbance of the snow. However, as in the case of transmission through ice, it is likely that, in spite of variations in procedure and apparatus, the measurements of various writers may satisfactorily be used to form a general idea of the light-transmitting qualities of snow.

The reflection of light from the surface of snow is very much greater than that from water or ice. The albedo, expressing the ratio of reflected light to total incident light, varies, according to the tabulation by Dorsey (1940, pp. 486-487), from 40 or 50 per cent to over 90 per cent. Thams (1938) gave for new snow 82 per cent, for old snow 60 per cent, and for melting snow 50 per cent. Sauberer (1938) found new snow to have an albedo of about 84 per cent, and old snow about 72 to 76 per cent. The figures of Kalitin (1930; 1931) range from 52 per cent for old, grainy snow, to 87 per cent for fresh, dazzling white snow. Considerable and rapid changes were noted. After experimental wetting of the snow surface, the albedo was 52 per cent. Hand and Lundquist (1942) gave values up to 89 per cent for clean white snow.

In the measurements of this investigation (Tables 24, 26, and 27), separate account was not taken of the loss from the snow surface; the figure given is that for the amount of light which emerged from the bottom of the snow layer, expressed as a percentage of that incident upon the upper surface. Stated in terms of true transmission through the snow, i.e., as the percentage of light actually entering the snow, the ratio would be larger by an undetermined amount. However, since the concern of this study is with the amount of light ultimately passing through the sequent snow, ice, and water, the amount of loss by reflection at the surface of the snow is of interest chiefly in helping to explain the tremendous power of snow to reduce light intensity.

In Table 26 are summarized the snow transmission measurements on the various lakes. Percentage transmission varied from 28 per cent for 1 inch of slushy snow, to 0.7 per cent for 10 inches of dry snow. Apparently crusted snow allowed somewhat less penetration than light, dry snow.

Table 27 shows the percentage transmission through snow artificially placed upon the photometer target. A thickness of 1 inch permitted only about 4 or 5 per cent of the light to pass through it; at 4 inches only a slight trace of light remained. These figures are subject to the possible error caused by the use of light (incandescent bulb) of relatively low intensity; the transmission percentages thus may be proportionately somewhat low (see reference, below, to Croxton, et al).

Figures from the literature are somewhat scattered. Thams (1938) recorded 13 per cent transmission for 10 cm. (4 inches) of snow, and 0.6 per cent for 50 cm. (20 inches); these figures seem somewhat high as compared to those of other workers. The transmission found by Croxton, Thurman, and Shiffer (1937), using snow artificially placed above the photometer, varied from 11.7 per cent for 1 inch, to 0.03 per cent for 7 inches. These latter writers found a lower percentage transmission for light of low intensity, and considerable differences caused by differences in the quality of the snow. Clean and fresh snow allowed the greatest penetration, clean but wet snow the next greatest, and granular snow the least. This order agrees with the findings of Hand and Lundquist (1942), that within a certain range the higher the water content of the snow the less light transmitted. The figures given by Hand and Lundquist, for "fine granular compact" snow, range from 22.3 per cent for 1/2 inch, to 1.2 per cent for 5 3/4 inches. Kalitin (1931), in a table of summary, gave percentage transmissions ranging from 21.7 per cent for 2.5 cm. (1 inch), to 0.09 to 0.03 per cent for 62 cm. (about 24 inches). Again wet snow was found to transmit light less freely than did dry snow.

It is not certain in all cases, but apparently all of the figures given above were based upon total amount of incident light (rather than upon that remaining after surface reflection loss), as are the figures in Table 24. That means, then, that wet snow transmits less of the total incident light than dry snow, in spite of the fact that dry snow has a higher loss by reflection.

Graph 20 shows the relative light-transmitting properties of snows as measured by various observers (see discussion above). The assumption again is made that a logarithmic relationship holds between depth of snow and percentage penetration; hence that the graph on semi-logarithmic paper is a straight line. This assumption has been made by Sauberer (1938), who gave an actual absorption coefficient. If the assumption is true, then the relative slopes of the lines on Graph 20 give some indication as to the relative powers of these various snows to absorb light.

Each of these lines, produced to the axis of the graph, would intercept that axis below the 100 per cent mark. The difference, presumably, represents that part of the light which was lost in surface reflection.

Graph 17 is a composite diagram of the combined effects of snow, ice, and water in diminishing light intensity. Starting at 100 per cent of incident illumination, each line shows, first, the drop in intensity caused by the snow (if snow was present), next the further drop in passing through the ice, and finally the diminution caused by the water. The plotted value for percentage intensity at any point on the line represents, theoretically, the amount of light penetrating to that particular depth of snow, ice, or water (this does not hold strictly true for the snow, since the surface loss is not shown). The line for Crater Lake (data from Utterback, Phifer, and Robinson, 1942; Brode, 1938, also gave some data on light penetration in this lake) does not include ice, since the water was open at the time of observation.

The tremendous differences in the amount of light reaching various depths under different conditions of snow and ice are readily apparent from the graph. For example, for the dates given for the respective lakes, Clear Lake received more light (1.1 per cent transmission) at the 32-foot depth than did Bog Lake at 1 foot under the ice, and 22 times as much as did South Londo Lake just under the ice (0.05 per cent)! The light penetrating to the bottom of East Fish Lake (under the given set of conditions) was only 0.03 of that which reached the top of the snow cover. That percentage transmission was only approximately one-fourth as much as the amount which reached a depth of 120 meters (about 400 feet) in Crater Lake (data from Utterback, et al, 1942).

In terms of foot-candles of light falling upon the target of the photometer (see under Methods), a few sample readings, taken from Table 24, are: Of 7600 foot-candles falling upon the snow on South Londo Lake, March 5, 1941, only 4 f.c. penetrated the snow plus ice. At Clear Lake, on February 23, 1941, an incident illumination of 8000 f.c. resulted in the penetration through the ice of 6700 f.c., or 84 per cent, and to the bottom of the lake (30 feet) of 112 f.c., or 1.4 per cent. Seventeen hundred times as much light penetrated

7 1/2 inches of clear ice with no snow as was transmitted through 24 inches of partly cloudy ice covered with 10 inches of snow (the respective percentages of transmission were 85 and 0.05).

The transmission of light through snow apparently varies somewhat with the region of the spectrum. Sauberer (1938) found the relative penetration to be the greatest in the green-yellow portion of the spectrum, and to fall off in the blue and slightly in the red. Kalitin (1931) stated that absorption of light by wet snow is greatest in the longer waves (i.e., in the red). The somewhat scanty data of the present study (Tables 26 and 27) apparently show a somewhat reduced penetration in the red and blue spectra. Especially was the transmission of blue light proportionately lower through crusted snow (Middle Fish Lake), while the dry snow of East Fish Lake had slightly lower penetration by the red light (Graph 18).

## Relation to Photosynthesis

In spite of considerable work by various investigators, comparatively little exact information is available regarding the quantitative light requirements of aquatic plants under various conditions. It is extremely difficult, in measuring those requirements, to control all of the necessary factors. It is evident, however, that for any given set of conditions there must exist an intensity of light which will promote photosynthesis, and below which photosynthesis will be overbalanced by respiration. Such an amount of light has been termed the compensation intensity.

Clarke (1939) cited references which place the compensation intensity (plant species and other factors not stated) at about 350 to 500 lux (approximately 30 to 45 foot-candles). Wilson (1935) found the lower limit of certain types of aquatic vegetation, in a lake in Wisconsin, to be at a depth at which the light amounted to from 4.4 to 6.8 per cent of the "total sunlight at zenith" — that is, at roughly 400 to 600 foot-candles. It seems likely, however, that factors other than light intensity also operated to limit the maximum depth of growth of these plants. Pearsall and Ullyott (1934) found rooted vegetation to be adversely affected when the light intensity was cut down from about 4 or 5 per cent to about 1 1/2 or 2 1/2 per cent.

Little is known about the light requirements of the phytoplankters of inland lake waters. Probably there are considerable differences among the various species; and such factors as temperature must have a certain effect. However, some of the figures given in Table 24 for the amount of light penetration through snow plus ice cover are such small fractions of the amounts proposed as general aquatic plant compensation intensities, that it seems almost certain that such small amounts of light could not maintain a favorable balance of photosynthesis over respiration and decay. On the other hand, there appears to be reason to suppose that the amount of light which penetrates even 1 1/2 to 2 feet of moderately clear ice (with no snow cover) is enough to satisfy the requirements for photosynthesis.

Photosynthesis is controlled to a large degree by the quality, as well as the quantity, of light. In general, red light is more effective than that of shorter wave lengths. Some aquatic plants, however, such as certain diatoms, have been found to be able to utilize almost any part of the visible spectrum (Jenkin, 1937). As discussed above, there are certain differences in the transmission through ice and snow of light of various wave lengths. However, in general these differences are relatively small; and it is probable that the more important effect of the ice and snow is that of reducing the quantity, rather than of changing the quality, of light.

## Relation to Dissolved Oxygen

The measurements of light penetration made during this study were too limited in number to justify an attempt to show a correlation between light intensity and oxygen production which would be expressable as a mathematical function. However, as is discussed above, a definite connection is demonstrable between the dissolved oxygen in the water and the amount of snow on the ice; and in this manner the effect on the oxygen tension of the water of changes in the light intensity is clearly shown. It appears conclusively evident that a heavy snow cover upon the ice so greatly reduces the amount of light entering the water that photosynthesis by the phytoplankton virtually ceases, with a consequent and almost certain reduction in oxygen production.

## EXPERIMENTAL STUDIES

### Pumping Experiments, Previous Workers

Experimental aeration of water under the ice has been attempted by various workers. In Iowa, in 1935 and 1936, air blowers were used (Aitken, 1938). These blowers delivered a large volume of air, under fairly low pressure, into the water. They were not very successful, however; presumably a relatively small part of the air actually went into solution in the water. In 1936–37, pumping water into the air was tried, the object being for this water to absorb or entrap air and carry it back into the lake. The method was held to be impractical for aerating large lakes.

Various pumping procedures have been tried in Minnesota. Some small success attended the experiments in which a stream of water and one of compressed air were mixed at the point of entrance to the water. However, here again it was found that the method probably was not suitable for aerating large bodies of water.

In Michigan, during the severe conditions of the winter of 1935–36, the Institute for Fisheries Research attempted experimental aeration by means of a stream of water pumped from the lake, sprayed into the air, and allowed to return through holes cut in the ice. This experiment has been referred to by Hubbs and Eschmeyer (1938), and is more fully described in an unpublished report by Eschmeyer (1936). The operation is shown in Figure 3. Although the water at the point of entrance through the ice was found to have a very much increased oxygen content, this increase was transitory, and had disappeared after 28 hours. Furthermore, the effect was very local, indicating the method to be of small value for application to any considerable area.

## Pumping Experiment, Pasinski's Pond

Pasinski's Pond was used, in February and March, 1940, for an experiment in aeration by means of a pumped stream of well water. This pond is described above; Figure 9 is a map showing its outline, submerged contours, and the location of sampling stations. Somewhat elongate in shape, the pond is morphometrically one simple basin. However, for purposes of interpreting certain data, it has been found convenient to divide the pond, arbitrarily, into two parts, the north and south ends. This division is based upon the kind and amount of vegetation. The south end contains large beds of filamentous algae (principally *Spirogyra*), as well as an almost solid mat of *Anacharis*. Algae are practically absent from the north end, which has, in addition to considerable *Anacharis*, a fair amount of pond-weed (*Potamogeton*). As shown on the map, the well and the pump are located on the eastern shore of the north end.

At the start of the winter of 1939-40, only one sampling station (Station 15) was used. This station was approximately in the center of the north end of the pond, and directly opposite the pump (about 75 feet from the point of discharge of the pump). The dissolved oxygen at this station (the surface sample) dropped rather rapidly and steadily, from 19.1 p.p.m. on January 7, to 0.5 p.p.m. on February 10 (see Graph 21).

On February 10 the pump was set in operation. Driven by an electric motor, it pumped approximately 60 gallons per minute. The well water, as it came from the pump, carried only about 1.5 to 2.0 p.p.m. dissolved oxygen; but by running through wire mesh and over an inclined trough it increased its oxygen content to about 4 to 6 p.p.m. (Table 28). Its temperature was approximately 50° F. (10° C.). The pump discharge and the aerating device are shown in Figure 16.

The pump was operated continuously for seven days, until February 17. During that time the discharge from the pump melted a hole through the ice at

Figure 16. Pumping experiment, Pasinski's Pond. Pump discharge and aerating device.

Figure 17. Open hole produced by pumped water.

the edge of the pond, roughly 8 or 10 feet in diameter (Figure 17). This hole remained open during the time that the pump was running, and for two or three days after it was shut off; and it constituted the "open hole" to which reference is made in Table 28 and elsewhere in this paper. The position of the open hole, relative to the pump discharge, is shown by Figure 17.

On February 10 about twenty-five stations were established, in a sort of geometric pattern, in the north end of the pond, and three stations in the south end. On various subsequent dates about seven or eight other stations were added. The method of marking these stations with stakes is shown in Figure 18.

Samples were taken at these stations, at intervals of from two to four days, from February 10 until April 1. Uniformly, the samples were taken at the "surface" (actually about one-half foot below the surface), except that enough check samples were taken at other depths to show that the highest oxygen values always were to be found in the upper water (see discussion on dissolved oxygen consumption in lakes). The oxygen values of these samples are given in Table 28.

After having run for seven days, the pump was turned off on February 17. It was started again on February 28, and ran continuously until March 6.

The original idea was to use the south end of the pond as a control, in order to determine the amount of aeration accomplished in the north end by the pump. This plan was found to be faulty, however; since initial conditions in the two ends of the pond were quite different. Presumably because of the activities of the algae in the south end, the water there had very much more dissolved oxygen at the start of the experiment than did that at the north end.

Unfortunately, the dissolved oxygen data of Table 28 appear not to be amenable to most methods of statistical treatment. Average values are scarcely valid, since there is so much fluctuation between stations, and also since too few stations in the south end are represented. An attempt was made to draw up maps, for various successive dates, showing lines of equal oxygen value; but for

Figure 18. Pumping experiment, Pasinski's Pond. Method of marking sampling stations by stakes.

the reasons just given these maps entirely failed to give a clear-cut picture of the conditions.

However, Graph 21 is of some help in interpreting the possible effect of the pumping. On this graph are shown the dissolved oxygen values for Station 15 (north end) and Station 27 (south end). In accordance with the above explanation, these two stations do not necessarily represent mean or average values; rather they are merely somewhat typical of conditions in the two ends of the pond.

At the time the pump was first put into operation, on February 10, the oxygen was much higher at Station 27 than at Station 15, but was declining rapidly at the former station. Perhaps under the influence of the pumping, or perhaps for some other reason, the oxygen gradually increased at Station 15 until February 19, when it was 2.4 p.p.m.; meanwhile that at Station 27 had gone down to a low of 0.7 p.p.m. on February 17. From February 22 until March 1 the oxygen at nearly all stations remained quite low — in fact, even decreased at some stations — in spite of the fact that the pump was again put into operation on February 28.

From March 1 to March 4 there was considerable rise in the oxygen at Station 27, as well as at other stations in the south end; while the oxygen at Station 15, and at most other stations in the north end, still remained low, in spite of the pumping. Then, from March 4 to March 8, there was a rather sharp increase in oxygen in both ends of the pond. As shown by the curves of Graph 21, this increase was larger, and began earlier, in the south end. Probably the increase was due to renewed photosynthetic activity, since nearly all of the snow had left the ice (as indicated by the snow depth curve for 1939-40, in Graph 1). The south end of the pond, containing more algae, responded much sooner and to a greater extent to the changes in light than did the north end.

After March 8, the oxygen in the south end continued to be higher than in the north end. The peak values on March 29 presumably were occasioned, in part, by run-in water from rain and melting snow.

Further evidence that the pumping had very little, if any, beneficial effect is to be found in Table 28. On the sampling dates during the first period of operation of the pump, February 10 to 17, only seven samples of all those taken in the north end (Stations 1–23) had 2.0 p.p.m. or more of dissolved oxygen, and nono had over 2.8 p.p.m. Most of the samples ranged from 0.2 to 1.5 p.p.m. Of the samples from the stations nearest the pump (Stations 1–7, 10, 11, 14), only two had 2.0 p.p.m. or more; and oxygen values as low as 0.3 p.p.m. were found within 20 feet of the discharge point of the pump after four days of operation (Station 1 on February 14).

Pumping 60 gallons per minute, or about 11,000 cubic feet per day, the pump would displace approximately 1/40 of the volume of the pond per day (assuming that the pumped water did not set up a current which would shunt it to the outlet). If the pumped water, containing about 5.0 p.p.m. of dissolved oxygen, became completely mixed with the pond water, it could (theoretically) raise the oxygen content of the entire volume of water approximately one-fortieth of 5.0 p.p.m., or about 0.125 p.p.m., per day[1], or about 0.9 p.p.m. in 7 days. Or if it is arbitrarily assumed that only (say) the northern one-third of the volume of the pond were affected, then the oxygen content at that end could be raised about 2.7 p.p.m. in 7 days.

It is quite evident that no such increase took place during the period February 10 to February 17. Probably the explanation lies in the high oxygen demand which had been built up in the water. Very little oxygen, if any, was being produced by photosynthesis in the north end of the pond; and an oxygen deficit

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[1] Obviously the pumped water, carrying only 5.0 p.p.m. of oxygen, could increase the oxygen in the pond water only if the latter had less than 5.0 p.p.m. to begin with; and the full amount of the increase given in the computations above could come about only if the pond water had zero oxygen at the start. If pumping were started when the oxygen content of the pond water was still above 5.0 p.p.m., it might actually lower the oxygen in the pond – this effect, however, likely would more than be offset by the displacement of water having high oxygen-consuming power by water with presumably less oxygen demand.

existed, which could not be overcome by the efforts of the pump.

If the pump were operated for long periods of time (a somewhat expensive and troublesome procedure) it probably would be of considerable help in forestalling the development of serious conditions. But once those conditions have developed in the pond, pumping well water apparently is almost useless.

On February 14, four days after the pump first was started, there were several bluegills in the open hole, still alive but not very active. On February 19, two days after the pump was turned off, the open hole contained hundreds of dead bluegills. Mortality struck rather suddenly; for on February 17 there were few, if any, dead fish. Apparently all or most of the bluegill population died within a few days; for no dying or newly dead bluegills were observed during March.

The bullheads began to die somewhat later than did the bluegills. Very few dead bullheads were seen in early February, but on February 28 many were dead or dying. The mortality of the bluegills apparently was complete; intensive seining the following summer failed to take any of them. Only a part of the bullheads died. Altogether some 13,000 bluegills and over 1000 bullheads were killed.

## Snow Removal, Hatchery Ponds

Three of the small experimental ponds at the Drayton Plains state fish hatchery (described in the section on Waters Investigated) were used. Early in December, 1939, these ponds were filled with water from the river, to a depth of about 2 1/2 feet. In order to maintain the water level, a small flow was permitted to run into and out of each pond. Unfortunately, this flow remained somewhat larger than was intended, and (as discussed below) affected the results of the experiment to a certain extent. However, the flows through the three ponds were very nearly the same; and, since the ponds were practically identical in dimensions and other aspects, the results of the experiment are probably quite valid.

The three ponds were allowed to remain undisturbed, except for the taking of samples, until February 12. On that date the snow (about 3 inches in depth) was shovelled cleanly off the ice of Pond 10. From that time on, the snow was removed from this pond soon after each new snowfall. On February 17 the ice on Pond 8 was completely covered with a layer of opaque building paper, which was held in place with snow. The paper stayed in place very well until the break-up of the ice. Pond 9 was left unmodified throughout the experiment, as a control.

From January 7 until the break-up of the ice, dissolved oxygen samples were taken periodically in all three ponds. Two sampling stations were used for each pond, one in the center of the pond, and one at the outlet weir box. The sampling depth was 1 foot. Data for these samples are given in Table 29. In Graph 22 are shown the dissolved oxygen curves for the center stations.

In view of the fact that the three curves stayed so closely together until the beginning of experimental conditions, their divergence after that time seems to be definitely significant. Evidently the amount of light entering the water did have an appreciable effect upon the dissolved oxygen. It is only reasonable to suppose, furthermore, that this effect would have been much greater had there not been a continuous partial displacement of the water.

The water in the paper-covered Pond 8 at times equalled, in dissolved oxygen, the water in the river. This seems to indicate that the differences between the curves for the three ponds were due not so much to diminution of oxygen in Pond 8 (probably the inflowing water carried enough oxygen to satisfy the relatively small oxygen demand present), as to its greater production in Ponds 9 and 10. The amount of light entering Pond 9, through the snow-covered ice, apparently was enough for some photosynthesis (it must be remembered that for a time in early March the ice of Pond 9 was bare or nearly so); and the water in Pond 10, with the snow removed, received more light and did still better in oxygen production.

# THE OXYGEN BALANCE OF AN ICE-COVERED LAKE

The relative abundance or lack of dissolved oxygen is so definitely a controlling factor in the life processes in an ice-bound lake that careful consideration should be given to the various agents which act to lower or raise the dissolved oxygen content. The following discussion attempts to collate some of the information to be found in the literature, as well as certain observations of the present study.

Two diametrically opposed sets of processes exist and usually are concurrently active — those which consume oxygen, and those which replenish it. The precarious balance between the two is fine indeed; and when this balance is upset the consequences may be sudden and intense. The action of these processes is greatly influenced by the low temperature of the water in winter. Also it is limited considerably by the ice cover, and by the almost complete immobility which arises from thermal stratification and lack of wind agitation. Except for these modifications, the processes of oxygen utilization and oxygen renewal are in general the same processes which exist in the summer.

## Oxygen Consumption

### Respiration of Fish

It is a rather common concept that the respiration of the fish is a chief factor in the diminution of the dissolved oxygen. And indeed, in occasional instances, this may be true. Some bodies of water, such as pot-holes, rearing ponds, etc., may have an extremely high concentration of fish. Kochs (1891) estimated the fish in certain wintering ponds to amount to 1 to 1 1/2 kilograms per cubic meter of water, which is roughly equivalent to 2700 to 4000 pounds per acre-foot. Certainly such an amount of fish would consume an appreciable quantity of oxygen, even at winter temperatures. However, such quantities are rather exceptional. The concentrations of fish in lakes such as those of the present study, and of other lakes in the northern United States, are on the order of a few hundredths of the extreme figure given above. Even in organically rich, shallow ponds of this region, probably a standing crop of 75 to 100 pounds per acre-foot is very rarely exceeded.

There is scant information available concerning the oxygen requirements of fish at near-freezing temperatures. Some of the data of the literature are summarized in Table 30. Probably the average value for the warm-water fishes commonly found in southern Michigan waters (such as black bass, sunfish, suckers, yellow perch, pike, etc.), for the temperature range 0-4° C., is somewhere between the highest and lowest of these figures. Probably most or all of these fishes have, at low temperatures, a lower metabolic rate than trout, and many or most of them have higher rates than goldfish or tench.

For purposes of comparison, it is perhaps of interest to make a rough theoretical computation of the amount of oxygen used by the fish in a given body of water. During the winter of 1939-40 Pasinski's Pond had an average volume, excluding ice cover, of approximately 350,000 cubic feet (9,900 cubic meters), or about 8.0 acre-feet. This amount of water weighs 22,000,000 pounds. If it were saturated with dissolved oxygen, at 0° to 4° C. (i.e., with about 14 p.p.m.), the water in the pond would contain about 300 pounds of dissolved oxygen. Suppose there were in the pond 500 pounds of fish (62.5 pounds per acre-foot). This is an extremely hypothetical figure, and very probably is considerably too high. Using the also very hypothetical figure of, say, 25 cc/kg/hr. (= 0.000036 lb/lb/hr.) for the average oxygen consumption of the bluegills and bullheads in the pond, the figure obtained for the oxygen used by the fish, is 0.018 pounds of oxygen per hour, or 0.43 pounds per day. At that rate, 300 pounds of dissolved oxygen would meet the respiratory needs of the fish for 700 days (actually, of course, the fish would be unable to utilize the last of the oxygen, because of their inability to extract it at low tensions).

In comparison, Kochs (cited above), using the value given by Regnard of

14.8 cc. of $O_2$ per kg. of goldfish per hour, and the (slightly too low) figure of 10.58 p.p.m. for dissolved oxygen at saturation, obtained the theoretical result that the water in the carp wintering ponds which he was studying held only a 20-day supply of oxygen for the fish.

It seems rather certain that in the average Michigan lake which is subject to winter kill, the fish play a very minor part in the depletion of the dissolved oxygen under the ice. The respiration of other aquatic vertebrate animals also has little influence upon the oxygen supply, since most of them, with the exception of tadpoles and immature salamanders, are air-breathing.

## Respiration of Invertebrates

It is extremely difficult to evaluate properly the part played, in the oxygen depletion of a lake, by the respiration of invertebrate animals, since the two chief governing factors — i.e., the number of organisms present, and the oxygen requirements of each — are to a large extent unknown. Especially is this true in the winter.

Comparatively few quantitative studies of winter zooplankton have been made. No doubt there is considerable variation from lake to lake and from one winter to another. In general, however, the total zooplankton is usually at a minimum in winter. Very few of the larger zooplankters (copepods, daphnids) have been found to display winter pulses, and these pulses probably are transitory or local. Naber (1933) concluded that the plankton animals perform a very small part in the removal of oxygen from a lake. Considering the small size of these animals, and the reduction in their oxygen requirements brought about by low temperatures, it seems likely that their respiration accounts for a rather insignificant portion of the oxygen consumed during the period of ice cover.

The bottom-dwelling invertebrates usually are more abundant in winter than in summer, since many insects pass the winter as aquatic larvae or nymphs. These immature insects may be present locally in almost prodigious numbers, an example being the concentrations, in places in many Michigan lakes, of burrowing mayfly nymphs, which constitute an important source of bait for winter fishing. Midge-fly larvae often are present in many hundreds or even thousands per square foot of bottom. Since winter is a time of growth and activity for the aquatic insects, they require a certain amount of oxygen, even at low temperatures.[1]

With the exception of an occasional concentration, most other benthic invertebrates are present in much smaller numbers. Relatively large forms, such as crayfish, mussels, or the like, probably are rather lethargic in the winter.

No matter what the total oxygen-consuming power of the bottom animals, it is obvious that they can have a direct oxygen-depleting effect upon only the thin layer of water in direct contact with the bottom (the indirect transmission of this effect, as set forth in the microstratification theory, is discussed below). Of the sporadic migrations of bottom dwellers into the upper water, little mention need be made. When occasioned by adverse conditions near the bottom, as they often are, these migrations may be said to represent mainly an effect, rather than a cause, of oxygen diminution.

On the whole it seems probable that, compared to the amount of oxygen used by the decay of dead or inert material, that consumed by invertebrates is a proportionately small amount.

## Respiration of Plants

Living plants, both macrophytes and plankton algae, use oxygen for respiration. Under the proper conditions, these plants produce much more oxygen than they use (the possible diurnal variations under the ice are discussed in the section on "Dissolved oxygen"). When adverse conditions arise, however, oxygen

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[1] It must be remembered that the temperature on or near the bottom usually is 3°-4° C. higher than that just under the ice — probably a significant amount as related to metabolism. For that matter, inhabitants of the profundal regions of deeper lakes live, the year around, at temperatures only slightly above 4° C.

production falls off, and eventually is over-balanced by oxygen consumption. It is difficult to say at what point a plant can no longer be considered to be in a living state, and beyond which its oxygen-consuming process is one of decay rather than of respiration. However, for purposes of convenience, it is perhaps justifiable to represent most of the oxygen demand of the plants under the ice as being occasioned by their decomposition, whether or not they are in a strict sense dead.

Not usually thought of in the flora of a lake are the minute spore-forming plants of the genus Micromonospora, which have been shown by Umbreit and McCoy (1941) to be rather numerous in several Wisconsin lakes, and which are believed by these authors to play a definite part, although probably a small one, in the dissolved oxygen cycle. Their importance probably lies in the quality, rather than the quantity, of organic material which they oxidize; since they have the ability to attack such usually resistant materials as chitin, lignin, cellulose, etc.

Fungi also often are present in lake water, but it is doubtful if they ever reach sufficient concentrations to be very important as an agent in oxygen depletion. The activities of the water and bottom-mud bacteria are discussed in the sections below.

## Decay of Bottom Materials

The role of decomposition of bottom materials in the utilization of oxygen is a very important one, and has been the subject of much discussion. The relative importance of the organic matter in the lake bottom and that suspended or dissolved in the water is somewhat speculative, and various more or less divergent views have been expressed.

It has long been known that in winter, as well as in summer, the water near the bottom of a lake is more apt to be lacking in oxygen than that nearer the surface; and many writers have associated this lack with decomposition of the bottom mud.

In this connection it is of interest to note that, as discussed under Special Studies, the lines of equal oxygen concentration tend to follow the bottom of the lake in their configuration. Drown (1892) found, in the oxygen content of the water in several ponds in the winter, variations which appeared to have a connection with differences in the composition of the bottom materials, and concluded (p. 341) that "it is the character of the bottom of the pond, rather than the organic matter in solution and suspension in the water, which determines the amount of oxygen remaining in solution." Birge and Juday (1911) observed that the greatest decrease in oxygen, in winter, was near the bottom, and indicated that bottom decay is an important factor. Miyadi (1934) said (p. 236): "it is a recent common opinion to esteem the bottom deposit higher than the decaying plankton organisms sinking down from the epilimnion in diminishing the oxygen of the deep water." And Henrici (1939) made the well-nigh dogmatic statement: "It is the tremendous oxygen-consuming power of the large numbers of bacteria in the lake bottom which . . . . causes oxygen to disappear below the thermocline in stratified eutrophic lakes, which causes fish to suffocate in shallow lakes in the winter."

In his microstratification theory Alsterberg (1927) gave the decay of bottom materials as the chief cause of oxygen depletion in the deeper water of a lake, particularly in the thin layer of water lying directly on the bottom. The oxygen lack of this microstratum is gradually transmitted, he believed, into a deficiency in subsequently shallower layers through water movements brought about by wind or otherwise. As Welch (1935, p. 121) has pointed out, this transmission might be produced in an ice-covered lake by convection currents, or by the rising of gas bubbles from the bottom.

In regard to the vast potentialities of many lake bottoms for the consumption of oxygen, there can be no question. In the deeper portions of most eutrophic lakes, and indeed throughout the entire area of many shallow lakes, the bottom is heavily blanketed with a soft, semi-organic material variously termed "muck", "peat", "humus", "Schlamm", etc. Consisting to a large extent of the dead remains of plants and animals, this material is rich in carbonaceous and nitrogenous substances in various stages of decomposition. The combustible organic matter may constitute as much as 50 per cent of the total weight (Birge and Juday, 1911; Black, 19~~40~~29; Juday, Birge, and Meloche, 1941).

In some lakes and ponds, the bottom may be further enriched by the deposition of various other organic substances. Griffiths (1936) considered the partially disintegrated remains of an unusually abundant stand of <u>Nuphar</u> to be a factor of considerable importance in the lowering of dissolved oxygen in a certain ice-covered pool. It is probable that in Pasinski's Pond, in the present study, the rich growth of <u>Anacharis</u> and of <u>Spirogyra</u> was at times sufficiently in a state of decay to use a rather large amount of oxygen.

At times water running into a lake, from fields or in inlet streams, may carry suspended material which settles to the bottom, adding to the organic load. If domestic sewage or other organic pollutional waste is allowed to enter a lake, it may form sludge deposits of great oxygen-consuming power. The danger of adding too much sewage or manure to winter carp ponds has been recognized by Knauthe (1899), Sniesko (1941), and others. The likelihood of the formation of extensive sludge deposits in most lakes, however, is small, except in instances of out-and-out pollution.

The mechanics of the decomposition of bottom materials, and the part played therein by bacteria, has been the subject of considerable study. It is well known that bacteria in the bottom sediment are very numerous and very diverse. Also, logically, these bacteria are adapted to the utilization of the bottom materials for their food. As is discussed below, many of these forms exist anaerobically, but there are sufficient others which can carry on aerobic decomposition when oxygen is available. Naturally, the activities of the bacteria are correlated with the temperature, but a large amount of decay goes on even at temperatures near freezing. Again probably some sort of an adaption may be assumed; since the bottom mud usually is relatively cold the year around.

The amount, and nature, of the bacterial decomposition depends also to a large extent upon the composition of the bottom deposit. Waksman (1941) divided the organic matter in lake bottoms into (1) readily decomposable constituents, such as carbohydrates and certain proteins, and (2) the more resistant "lake humus" components, such as lignins, etc. The organic matter on the bottom of dystrophic lakes has been shown (Henrici, 1939) to be much less easily decomposed than that of eutrophic lakes.

## Activities of Gases

An important part in the oxygen cycle is taken by the several gases which are generated during the processes of decay of organic matter. These gases, methane, carbon dioxide, hydrogen sulfide, ammonia, nitrogen, and possibly carbon monoxide and others, may be formed in the water, but are more apt to arise in large quantities from the decomposition of bottom muck. Their production comes about principally through the activities of anaerobic bacteria, which are present in the bottom materials in great numbers and many forms. Experiments have shown (Allgeier, Peterson, Juday, and Birge, 1932; Black, 1929) that gas production by these organisms is very much slowed down at low temperatures. The former authors found the decomposition to be only about one-fifth as much at 7° C. as at 23°; Black obtained only about a quarter as much gas from a sample kept at 4° C. as from one at room temperature. The gas produced at 4° was about half methane, the remainder being carbon dioxide, hydrogen, and nitrogen. It is obvious, furthermore, that the amount of anaerobic decomposition which takes place on the lake bottom is closely correlated with the kind and amount of organic material present, just as in the case of aerobic action (see above), and that it may be much higher in sediments of a distinctly sludge-like nature.

The occurrence of these gases of decay in winter-bound lakes has been reported by several writers. Kochs (1891) spoke of the presence in winter carp ponds of methane, ammonia, and hydrogen sulfide, the last of which he believed to be an important agent of oxygen consumption. Under the extremely stagnant conditions found by Knauthe (1899) in a small pond, methane was so abundant that "large bubbles of this harmful gas gathered in the middle of the pond under the ice and . . . . . . the young people of the village found pleasure in boring holes in the ice, and burning the gas at the holes."

During the course of the present study, gas evolution was noted many times. At the time of heavy fish mortality in Pasinski's Pond, in February, 1940, a very pronounced stench arose from holes chopped in the ice, the odor being at least in part that of hydrogen sulfide. In the same winter, the stagnant water of Richmond Lake also stank strongly for many days. At other times, and in other lakes, occasionally bubbles of gas were observed escaping from the water; but their composition is not known, since tests for the various gases were not made. Continuously throughout the entire period of ice cover (even during the comparatively mild winter of 1940–41), the water from the lower depths of Bog Lake reeked with hydrogen sulfide. The fact that the upper water usually was virtually $H_2S$-free indicates that the gas either was oxidized before it reached the surface, or was held in chemical or physical combination in the lower water.

The possible harm to the fish caused by directly toxic properties of various gases is discussed below. The often more serious effect of these gases is the removal of dissolved oxygen from the water. This oxygen depletion may occur in two ways — by chemical or biochemical oxidation, or by the sweeping action of the gas in bubbling through the water.

Kusnetzow (1935) gave a rather strong argument for the theory that, in some lakes at least, the bacterial oxidation of methane and hydrogen arising from the bottom sediments may be the principal factor in the removal of oxygen from the water in winter. In lakes in which the oxygen remained at a high level throughout the winter he found the amount of methane and hydrogen coming from the bottom to be much less than in the "fish suffocation" lakes, although both types of lakes abounded in water bacteria. He concluded, therefore, that it is not alone the simple respiration of the bacteria, but rather their increased activity in the presence of methane and hydrogen, that exerts heavy demands upon the dissolved oxygen (to purely chemical oxidation of these gases he attributed an insignificant part).

It is barely possible, of course, that Kusnetzow's explanation may be somewhat in reverse, and that the increased production of methane and other reducing gases may appear partly as a result, rather than entirely as a cause, of oxygen depletion, since lowered oxygen near the bottom would favor the activities of anaerobic (gas-producing) bottom bacteria. From the limited observations of gas production in Pasinski's Pond and Richmond Lake, mentioned above, it is impossible to state definitely whether the presence in the water of large amounts of methane and hydrogen sulfide preceded or followed a major decline in dissolved oxygen; and it is difficult, therefore, to tell to what extent the dissolved oxygen was affected by the bottom gases.

The purely mechanical action of gas bubbles in removing oxygen probably is of considerable significance at times (Welch, 1935, p. 91; Knauthe, 1899). The bubbles of gas may entrap oxygen and carry it to the surface, where it is lost to the atmosphere. The amount of oxygen so removed depends upon the number, size, and character of the gas bubbles, the temperature, etc.; and the last small fraction of the dissolved oxygen is harder to remove than that near or in excess of saturation.

## Decay of Suspended Material

Suspended particulate matter in lake water may arise from various sources, chief of which usually is the dead remains of plankton (for the purposes of this discussion living plankton is not termed "suspended"). It also may contain remains of dead bodies of higher plants and animals. In open water it is contributed to by wind-blown materials, but this source is precluded by ice cover. Naturally-formed detritus, and occasionally pollutional wastes, may be carried in by streams, but stream flows are usually at a minimum in winter.

The quantity of material in suspension varies from lake to lake and from time to time, from an amount detectable only upon concentration, to that sufficient to render the water distinctly turbid. In general it is apt to be much greater in very rich bodies of water than in those less eutrophic. It is somewhat cyclic, perhaps, following cycles of plankton abundance.

The material varies somewhat in composition, but it is very rich in organic matter. It is scarcely heavier than water, and sinks very slowly. This probably is particularly true in the winter, not only because the water is slightly denser, but also, as Welch (1935, p. 85) has mentioned, because it has a greater viscosity at low temperatures. As a consequence of slow settling, the suspended organic material is in contact with the water, and subject to bacterial action, for a fairly long time.

Since it contains a large proportion of organic substance, it is to be expected that the suspended material is capable of utilizing considerable oxygen. It seems that lake water usually contains large numbers of bacteria, although these numbers may decline somewhat in winter. Henrici (1939) found in Lake Mendota that "under the ice in winter the bacteria are uniformly few in number until the bottom meter is reached, where they show an amazing increase." He pointed out, also, that bacteria in the water are for the most part periphytic, i.e., attached to suspended materials or to living plankton. Blue-green algae especially are collectors of bacteria (Henrici and McCoy, 1938). By this means the bacteria are given ready access to the dead plankton material.

The amount of bacterial action depends to a certain extent upon various physical and chemical factors, and upon the kinds of organic matter present. On the whole, the statement of ZoBell (1940) that plankton remains are more readily oxidizable by bacteria than is the dissolved organic matter in the water, probably holds true. However, certain materials, such as chitin, lignin, and humus-like compounds, are less amenable to bacterial attack than the simple carbohydrates and proteins, and may reach the bottom unaltered. The semi-colloidal suspensoids of dystrophic lakes have been said to be relatively resistant to water bacteria.

Bacterial oxidation is, of course, slower at low temperatures than at higher ones. ZoBell obtained a $Q_{10}$ for water bacteria of about 2.1, in the region 8°–25° C. Short-time (5-day) biochemical oxygen demand tests at 0° give correspondingly lower results than those at 20° (see discussion under the section on B.O.D.). It is of interest to note, however, that the eventual (ultimate) B.O.D. may be fully as great at low temperature.

Many opinions have been expressed regarding the relative importance of suspended material as an oxygen-depleting agent. Birge and Juday (1911, p. xiii), in defining the zone of decomposition, stated that the dead materials settling into this zone are instrumental in oxygen utilization; much evidence has been produced by various workers to substanitate this view. Rawson (1939) summarized the theory by saying that "there would seem to be greater possibility that the original explanation was the correct one, i.e., that hypolimnial consumption of oxygen is largely due to decomposition of dead plankton falling through the hypolimnion."

Very divergent ideas, however, have been proposed by various writers (Brown, 1892; Alsterberg, 1927; Henrici, 1939; etc.). As discussed above, the theories of some of these workers, in assigning a larger share of the oxygen consumption to various other factors, have greatly minimized the part played by the decay of suspended matter.

Observations of the present survey indicate rather strongly that, in the lakes studied, the suspended material played a definite, and probably a large, part in the oxygen diminution under the ice. For example, in Pasinski's Pond at times in the winter of 1940–41 the coincident occurrence of a large amount of suspended matter and of a very high oxygen demand (as measured by B.O.D. tests) was too marked to be casual. The argument is strengthened by the correlation observed between B.O.D. and amount of suspended material at various depths. On numerous occasions in Pasinski's Pond (and likewise in Bog Lake) the water near the surface was much more turbid with suspended matter, and at the same time had a much higher B.O.D., than that nearer the bottom.

## Decay of Dissolved Organic Matter

It is difficult to distinguish, entirely, between dissolved and suspended materials; and therefore difficult to assign the proper relative oxygen-consuming power to each. In practical work, in the determination of quantities in lake water, distinction usually is made on the basis of passage through a high-speed centrifuge or a fine filter. The "dissolved" material so obtained may include a small proportion of substances which are not true solutes, but very fine suspensoids or colloids.

Birge and Juday (1926) published the results of an extensive study of the organic content of several Wisconsin lakes. They found the amount of dissolved organic matter to be considerably higher in these inland lakes than in the sea, and usually to be several times as great as the amount of organic matter contained in the standing crop of plankton. The dissolved organic matter varied, in the several lakes, from about 6 to about 30 mg. per liter.

This material, according to Birge and Juday, is derived chiefly from plankton, although a small part of it may come from the disintegration of higher plants or from other sources. Its composition is somewhat complex, but it is relatively rich in various carbohydrates (only a small part of which, however, is sugars or other simple carbohydrates), and nitrogen in the form of peptides, amino acids, etc. Obviously these substances are potentially capable of utilizing rather large quantities of dissolved oxygen (for example, the complete oxidation of only about 12 mg. of carbohydrate per liter would require all of the dissolved oxygen in water saturated at 4° C.). The extent of their oxidation, however, depends upon their suitability and availability as food for the water bacteria. On this question there has been considerable discussion. At least some of the dissolved substances, such as complex nitrogenous compounds, have been thought to be very resistant to bacterial action (Krogh, 1931; ZoBell, 1940). Others, however, such as simple amino acids and carbohydrates, probably are utilized to a certain extent by bacteria, the amount of such use depending upon the numbers and kinds of bacteria present, the temperature, etc. In the B. O. D. tests of the present study no attempt was made to determine the proportion of the oxygen demand of the water which was due to the dissolved material; but it seems likely that it was an appreciable part.

Although not classed as an organic substance, ferrous iron may be mentioned here as being a possible factor in dissolved oxygen reduction. Sometimes present in solution in certain lake waters, particularly of dystrophic lakes, it may, under the proper conditions, be converted into ferric iron, either chemically or biochemically, with the resultant consumption of oxygen. In certain brown-water lakes reported on by Brehm and Ruttner (1926), ferrous iron, of allochthonous origin, was said to exert a very high oxygen demand. In most clear-water lakes, however, probably this factor is a very minor one.

## Ground Water and Run-in Water

In certain lakes subterranean inflow may be of an appreciable amount, even in winter. This ground water often is very low or totally deficient in dissolved oxygen, and if its flow amounts to any considerable part of the volume of the lake, it may reduce the oxygen concentration of the whole. Shopinzev (1940) held the large proportion of ground water in the Volga, in the winter, responsible for the lowered oxygen content of the river. It is questionable, however, that ground-water is a significant source of oxygen reduction in most Michigan lakes in the winter; for its flow usually is not very large.

Likewise, water brought into a lake by streams may be lacking in dissolved oxygen, and by mixing with the lake water may lower the oxygen content of the latter. Wiebe reported (1938) an unusual zonation of dissolved oxygen in Norris Reservoir, which he believed to be caused by inflowing water low in oxygen. In some of the winter-kill lakes of southern Michigan, inlet streams may at times help to lower the oxygen, particularly in the immediate vicinity of the inlet. The inflowing stream in Green Lake, in 1940-41 (the only winter during which samples were taken from the inlet), was rather low in oxygen most of the time, since it derived its flow mostly from swamp water. However, the flow was so small that the effect upon the lake as a whole was negligible. Mud Lake, on the other hand, being scarcely more than a much broadened part of a stream, has considerable current through it all winter, and is therefore somewhat subject to the influence of inflowing water. But the inlet stream, being in turn the outlet of a larger and deeper lake (of which it receives the surface water), remained about as well supplied with oxygen, during the winters of 1939-40 and 1940-41, as did Mud Lake, and therefore cannot be said to have been an agent of oxygen depletion in the lake.

As has been mentioned above, in the section on Dissolved Oxygen, run-in water arising from rain or melting snow or ice on the surface of the lake, sometimes is lower in oxygen than the water immediately under the ice, and hence upon mixing it may actually lower the oxygen content of the upper layer of water. The total body of water, however, is not affected to any alarming extent, since the run-in water is comparatively small in volume, and usually carries at least some dissolved oxygen.

## Oxygen Replenishment

Once sealed in by a covering of ice, a lake cannot acquire oxygen, as in the summer, by wind agitation. Even the small blessing of surface diffusion is seriously restricted. Advantageously enough, a lake usually enters the winter period with its oxygen concentration at the normal annual maximum, i.e., saturation at 4° C., or about 13 p.p.m. In the deeper, more oligotrophic type of lake this initial oxygen supply may be adequate to carry the lake through the entire winter. But in shallow, organically rich lakes the processes of respiration and decay, discussed above, undoubtedly would consume the oxygen supply long before the end of winter, were that supply not somehow replenished.

Except for artificial aeration, and the ingress of oxygen-bearing water (discussed below), augmentation of the oxygen supply can be brought about by only one means — photosynthesis. In many lakes, therefore, the maintenance under the ice of a copious oxygen supply is absolutely dependent upon the presence and activity of green plant life. The interrelationships of ice and snow cover, light, and plants are discussed elsewhere in this paper; the present section is given to a discussion of the potentialities, per se, of the plants as a source of oxygen in the winter.

### Higher Plants

The importance of rooted plants as oxygen producers in the winter is not well known. The situation is complicated by great variations in the kinds and numbers of these plants which may be in an active state under the ice cover. Many observations have been made of various rooted aquatic plants which were quite green under the ice, particularly early in the winter, before much snow had fallen. Olson (1932) stated that "higher aquatic plants in many instances die off in the fall . . . . . . There are a few plants, however, that remain active through the winter, and these can produce oxygen in considerable quantities when light is available." He reported the observation of green aquatic vegetation through the ice in late January, 1930, at which time the water in the immediate vicinity of the plants was supersaturated with oxygen. It is not especially uncommon for winter fishermen in spearing shanties on southern Michigan lakes to notice considerable rooted vegetation in a green condition. Early in the winter such plants as Vallisneria and certain pond-weeds may still be quite actively vegetative.

However, for most of the higher plants (with particular reference to those inhabiting Michigan winter-kill lakes), winter is usually a time of little or no activity. With few exceptions, the lakes of this study contained very little vegetation in a green condition at most times throughout the three winters of the survey. Cattails, bulrushes, and water-lilies were brown at the onset of the ice; coontail, bladderwort, and most pond-weeds died down, to a large extent, soon after. The large beds of Anacharis (Elodea) which fill Pasinski's Pond were partially green at times, and may have contributed some oxygen to the water (see the section on Oxygen). Occasionally in Mud Lake and Green Lake a certain amount of green color was evident in some of the weeds, especially when the ice was bare (although the response to changing light intensity is nowhere nearly as rapid as it is in the single-celled plants). On the whole, however, the higher plants are believed to be a relatively insignificant source of oxygen in these lakes in the winter.

## Non-plankton Algae

Certain of the filamentous algae are occasionally found in abundance in the winter. It is fairly well established that many algae can thrive at low temperatures, given the proper conditions of light and so forth. Smith (1933, p. 23) defines a group of algae, which he designates "winter annuals", which vegetate in the winter and fruit in early spring. This group includes one or two species of Spirogyra, as well as several single-celled algae. Knauthe (1899) attributed a part of the winter oxygen production, in the ponds he studied, to filamentous algae.

In Pasinski's Pond, in the winters of 1939–40 and 1940–41, a very large mass of Spirogyra was present, especially in the south end of the pond. This material stayed green during a considerable part of each winter; its greenness varied with the amount of light which penetrated the ice and snow cover. The Spirogyra quite evidently had an appreciable effect upon the dissolved oxygen content of the water (see the section on dissolved oxygen in Pasinski's Pond). In none of the other bodies of water studied were non-plankton algae noted in any appreciable concentrations.

## Phytoplankton

It has long been known that the microscopic plants of the plankton play an extremely important part in the replenishment of dissolved oxygen in lakes, even under the ice. Knauthe (1899) was well cognizant of the interrelations of light, an abundant crop of phytoplankton, and the production of oxygen in ponds in winter. He found, at times, a very pronounced supersaturation of oxygen, coincident with intense activity of the plankton plants. Griffiths (1936) stated that the oxygen concentration in Long Pool, in February and early March, was "associated with a maximum abundance of phytoplankton, consisting mainly of Dinobryon, Uroglenopsis, and Eudorina."

Quantitative information concerning phytoplankton in ice-covered lakes is somewhat scarce. Trends of thoughtof various writers have indicated (1) that the phytoplankton as a whole may diminish in the colder months, (2) that diatoms may become relatively abundant in winter at the expense of green and blue-green algae, and (3) that there are apt to be large fluctuations from lake to lake and from winter to winter. Whereas some specific studies have been more or less in agreement with these general ideas, others stand more or less at variance. Kofoid (1903) found that the Illinois River, as well as an inland lake, contained in the winter a relatively high amount of plankton, of which a fair proportion may be presumed to have been phytoplankton. Griffiths (cited above) reported that, for Long Pool, phytoplankton was "even moderately abundant only during the colder months." In Lake Mendota, in 1916–17 (Birge and Juday, 1922), the total phytoplankton was somewhat less in quantity in the winter than in the summer; Microcystis showed relatively little decline; Aphanizomenon reached a peak in early January and fell off sharply in late February; Tabellaria began to increase in late winter. The predominant plant of the nannoplankton in winter was Aphanocapsa, which was little changed from its summer concentration; in late winter Chlorochromonas began to appear in fair abundance. In their survey of Green Bay, in 1938–39, Williamson et al (1939) found the net phytoplankton to be very small in amount throughout the entire period of ice cover (based on samples from only one depth, 6 feet), and to consist of a few diatoms and very little else. Nannoplankton was not determined. The bloom of Aphanizomenon which had appeared in a large part of the bay in late November, was well dissipated by the time the ice had become solid, in mid-January.

Unfortunately, in the present study no quantitative data regarding plankton were obtained. Nothing like a bloom — nor any other very noticeable concentration of phytoplankton was observed at any time during the three winters. It is assumed, however, that a considerable amount of plankton algae (possibly a large proportion of which was nannoplankton) was present and active, at least part of the time. The many sudden and great increases in dissolved oxygen which were recorded are believed not to be attributable to any other source; since usually they occurred in the virtual absence of green rooted plants or filamentous algae.

## Bacteria

Certain bacteria, such as the green and red sulphur bacteria, possess pigments somewhat related to chlorophyll, and are able to utilize light for photosynthesis. However, according to Van Niel (1935), who has made an extensive study of these photosynthetic bacteria, it is very doubtful that they produce any oxygen. The nature of their action is parallel to, rather than identical with, that of green plants. Carbon dioxide is reduced, but the necessary H is derived from organic substances (or from $H_2S$), rather than from water.

Thus these bacteria cannot properly be considered as direct contributors of oxygen to lake water. They may have an indirect effect, in that they stabilize substances such as $H_2S$ and $CO_2$, and thus reduce the potential oxygen demand of the water. Little is known regarding the activities of any of these bacteria at low temperatures (Van Niel states that the optimum temperature for most of them is about 35° C.); but it is possible that they may exist and operate in lakes in the winter, particularly in bog lakes, which usually contain an abundance of hydrogen sulfide.

## Run-in Water

As mentioned above, ground water and the waters of inflowing streams of certain types are often low in oxygen and therefore more detrimental than helpful to the oxygen supply of a lake. Marsh-fed inlets are often oxygen-poor. However, run-in water which arises from rain or melting snow or ice usually contains a few parts per million of dissolved oxygen, and may thus bolster a depleted oxygen content. As discussed above, this effect is often transitory, and usually confined to the upper layers. Nevertheless, such run-in water probably helps occasionally to tide a lake over a perilous period (see, in particular, oxygen data for 1937-38).

## WINTER SUFFOCATION OF FISH

If the oxygen-replenishing agencies fail to produce oxygen as rapidly as it is being consumed, a serious shortage of dissolved oxygen may ensue, and the fish may be endangered. Certain things should be known concerning the suffocation of fish under the ice. How prevalent and how serious is winter-kill? What is the physiological basis for the death of the fish? What are the general consequences of winter-kill; and what can be done to prevent it?

### Incidence of Winter-kill

As might be expected, the extent of the damage by winter suffocation may vary from the loss of only a few fish to the complete or almost complete annihilation of the fish population of a lake. The death of relatively small numbers of fish during any one winter probably indicates only an indirect connection (i.e., one of aggravation), if any, with winter-kill. A certain number of fish succumb, during the winter, to disease, parasites, or accident. Birds are excluded from the water by the ice, and other scavengers are less active in winter than in summer; decomposition of fish carcasses proceeds somewhat more slowly at low temperatures; and thus quite a few fish which have died during the winter come to the attention of the casual observer at the time of break-up of the ice.

There are records of the destruction by winter-kill of extremely large numbers of fish. In the mortality in the Racine River, Wisconsin, described by Hoy (1872) "thousands of barrels" of fish died. According to Olson (1932), 20,000 pounds of dead carp were removed in one day, in the winter of 1928-29, from a small lake (McCabes Lake) in Minnesota. In Crystal Lake, near Gulfport, Illinois, over 80,000 pounds of fish, mostly carp and buffalo, were found dead at the end of the winter of 1939-40 (Illinois Natural History Survey, personal communication). At Georgetown Lake, Montana, in the winter of 1936-37, more than 700,000 trout are said to have perished (King, 1937). In Michigan, especially in the winter of the "big freeze-out", 1935-36, many severe fish losses have occurred.

In Table 1 only the designations "light", "heavy", and "very heavy" are used in referring to the extent of damage to the fish of various lakes, since actual numerical data are too few to justify tabulation. However, in the reports of various observers, references to "many hundreds", "thousands", and "large numbers" appear quite frequently. Cooper (unpublished report, 1936) gave the following estimates of fish killed in certain lakes in southern Michigan, in 1935–36: Bateese Lake, over 200,000; Mud Lake, over 75,000; Green Lake, between 75,000 and 100,000; and Park Lake, over 150,000.

Complete destruction of a fish population apparently is very rare. It has been recorded by Knauthe (1899) for a carp pond, but this was a very artificial situation. After a kill in a shallow lake in Minnesota, in 1935–36, it was asserted (Milwaukee Journal, 1939) that "not one living fish could be found in the lake." In Pasinski's Pond, in 1939–40, the bluegills were all killed, but most of the bullheads survived. This pond is scarcely typical of southern Michigan lakes, being very small and exceedingly rich in organic matter. No other substantiated record of a complete winter-kill of fish in Michigan waters exists. On the other hand, many lakes which were thought, at the time, to be entirely killed out, have later been found to contain a surviving stock. It is difficult, of course, to be certain whether or not the fish have all been killed in any particular lake; since nearly all of these lakes have stream connections, at least during high water, through which fish might enter following the kill.

## Physiological Aspects

### Cause of Death

Mention has been made, in the introduction, of the theories and beliefs of various writers as to the modus operandi of winter-kill. Although certain of these writers have blamed such factors as "poisonous" gases (presumably hydrogen sulfide, ammonia, or methane), the weight of majority opinion has placed the responsibility for fish death upon lowered dissolved oxygen tension. This theory has been fairly well substantiated in the literature; observed oxygen values of a very small amount, or none, have been reported many times as existing at the time of, or just before or after, winter fish mortality.

The present survey presents still more of the same kind of evidence. Wholesale death in Pasinski's Pond in February, 1940, occurred at the only time during the three winters of the study when the dissolved oxygen in the pond fell to 1 p.p.m. or less for several consecutive days (Table 28, Graph 21). At the time when many fish were in distress, or dying, in Richmond Lake, the water had only a fraction of a part per million of oxygen. Likewise, the studies made by the Institute for Fisheries Research during the severe winter of 1935–36 (Cooper, 1936; Eschmeyer, 1936 — unpublished Institute reports) showed extremely low oxygen concentrations prevailing at the time of mortality.

However, it must be remembered that, almost invariably, low dissolved oxygen concentrations under the ice are accompanied by various other adverse conditions. The very processes of decay which consume the oxygen, produce, at the same time, considerable quantities of carbon dioxide, methane, hydrogen sulfide, and possibly ammonia. Hence, any conclusion, *a priori*, that lack of oxygen is indisputably the cause of death, is unjustified. The solution of the problem must rest on physiological experiments, because the several factors can not readily be disentangled in nature.

Here again, the reasoning tends to be somewhat speculative. It is axiomatic that fish die if the oxygen tension of their medium remains for any considerable time below a minimum value. But it also is well known that the various noxious gases named above, if present in sufficient quantity, can be fatal to fish. Carbon dioxide alone, in high concentration, can kill fish, even in the presence of abundant oxygen. Furthermore, it is established that there are complex interrelationships between the various factors. To take an extremely common example, the presence of considerable carbon dioxide greatly reduces the ability of fish to utilize oxygen at low tensions (Fry, 1939; and others). In other words, the toxicity of carbon dioxide increases with lowered tension of oxygen.

The literature on winter mortality of fish has insufficient quantitative information on which to base any definite conclusions regarding the relative importance of these various factors, if indeed the effects of low oxygen and high $CO_2$, for example, are ever separated in nature. Nor do the data of the present study give rise to any completely satisfactory deductions. Except for oxygen, carbon dioxide is the only dissolved gas which was measured. In general, the $CO_2$ concentrations, although appreciable, were not alarmingly high, and the increases were somewhat gradual (a point probably of some significance, as discussed below). It is probable that, compared to the dissolved oxygen at its lowest levels, the carbon dioxide was not the most dangerous factor. In other words, it seems likely that were the two conditions to exist one at a time, which they usually do not, the diminished oxygen would be much more apt to be fatal than the increased carbon dioxide. Also, although no concrete assuring evidence is at hand, it appears possible that the amounts of hydrogen sulfide and other poisonous gases which usually were present in the lakes under study were not in excess of the toleration limits of the fish.

Further speculation probably is fruitless. Suffice it simply to state that very low dissolved oxygen concentrations are probably the primary cause of fish death under the ice, but that the effects of low oxygen are augmented by the presence of carbon dioxide, and often of other harmful gases.

## Tolerances and Adaptations

In laboratory determinations of low oxygen tolerance limits of fresh-water fishes, most workers have to a large extent neglected the lower temperature ranges. Even the experiments at higher temperatures, of which there have been many, have produced results in considerable conflict, depending on experimental method, species used, and the effect of various uncontrolled conditions.

Refining and extending a method of field observation used by Smith (1925), Moore (1942) obtained some figures, that are apparently rather dependable, for low-temperature oxygen requirements. The experimental fish were held in live boxes in natural waters of various oxygen tensions; and the results are stated in terms of survival or non-survival for a 48-hour period. Control was fairly adequate; the effects of handling, pH, and $CO_2$ probably were minimal. It was found that the "thresholds of many species of fresh-water fishes lie between 1.0 and 2.0 p.p.m. However, some of the less tolerant species may require up to 3.0 p.p.m. or possibly higher." Even at extremely low oxygen concentrations, death did not occur immediately (in some instances not in four hours), indicating that suffocation at low temperatures requires a comparatively long time.

Moore's figures confirm rather well the conclusion of Thompson (1925) that, at low temperatures, "dissolved oxygen concentrations between zero and two parts per million will kill all kinds of fishes." Data of the present study are entirely inadequate to establish tolerance limits. However, at certain times, dissolved oxygen concentrations of less than two p.p.m. were found, with the apparent survival of many of the fish present. For instance, in Pasinski's Pond, in late February and early March, 1940, some 18 to 20 stations were regularly sampled, assuring a rather adequate coverage of the four acres. For the consecutive sampling dates February 26, 28 and March 1, not one dissolved oxygen value of over 1.5 p.p.m. was found at these stations, and most of the values ranged from 0.0 to 1.0 p.p.m. Although the bluegills died, most of the population of the more hardy bullheads lived. Other scattered recordings of oxygen of from 0.5 to 1.5 p.p.m. were obtained, as in Middle Fish Lake, 1941, Minnis Pond, 1938, and Richmond Lake, 1939 (see Table 10), during periods of low oxygen through which at least a part of the fish population is believed to have survived.

Carbon dioxide tolerances of fishes have been studied by many writers, such as Wells (1918), Powers and associates (Powers, 1938; and other papers), and Black and his associates (Irving, Black, and Safford, 1941; Fry, 1939; etc.). Powers has concluded that fish can satisfactorily absorb oxygen in the presence of carbon dioxide in the concentrations usually found in nature. The factor which in his opinion often causes mortality is a sudden increase in $CO_2$, to which the fish cannot adjust themselves. No special reference is made to the conditions of winter, when abnormally high carbon dioxide tensions may occur.

It has been claimed that fish exhibit avoiding reactions toward low dissolved oxygen (Thompson, 1925) and toward high carbon dioxide (Wells, 1918). However, it was observed many times in the present study that when an open hole is maintained in the ice, at times of low oxygen in the water, the fish will crowd into the open hole, and will remain there until they succumb, even though the oxygen drops to zero, while nearby water still contains some oxygen. For example, in Richmond Lake on February 18, 1940, the surface water in an open hole contained only 0.4 p.p.m. of dissolved oxygen, while that of a station not far away had 1.9 p.p.m. Yet the hole was full of dead and dying fish. Similarly, in Pasinski's Pond, on February 19, 1940, there were hundreds of dying fish in the open hole, and at the same time the oxygen at a station only 40 feet away was 2.8 p.p.m. It is possible that the avoidance reactions of the fish are relatively slight at such low temperatures. On the other hand, it seems rather likely that the tendency for the fish to move to an open hole, and to stay there, is largely conditioned either by a positive reaction toward light or toward open water, or by the opportunity to gulp air at the surface.

It is known that there are considerable differences in the sensitivity of various species of fish to adverse conditions. Various listings of the order of resistance of species have been given. Fry (1939) listed them on the basis of the effect of carbon dioxide upon oxygen utilization. Moore (1942) gave the order in which several species resisted diminished oxygen tension at low temperatures. Though diverging to some degree in their opinions on particular points, almost all authors agree that in general such species as yellow perch and the sunfishes are more sensitive to adverse conditions (e.g., lowered oxygen tension) than those species commonly called rough fish, such as bullheads and carp. It is probable that within species there are relatively tolerant and relatively susceptible physiological races, and that hereditary individual differences in tolerance exist within single populations.

Differences in sensitivity also exist because of differences in age, physiological condition, and (possibly) sex. Moore concluded that older fish can withstand winter oxygen depletion better than can younger ones, since the metabolic rate decreases with age. Fish in poor physiological condition, or those weakened by injury, parasites, or disease no doubt more readily become victims of winter-kill than the more hardy individuals.

Certain fish species have been shown to have special physiological adaptations which enable them to survive conditions that otherwise might be catastrophical. An example is the mud-minnow (<u>Umbra</u>). This fish is the only species known to be present in Bog Lake, where it has maintained itself through countless winters (the stock cannot have been replaced by immigration in recent decades, for the lake has no water connections). During many of those winters, such as that of 1935-36, the lake must have been completely devoid of dissolved oxygen for considerable periods; yet the mud-minnows survived. The explanation probably lies in the ability of this fish to utilize atmospheric oxygen. It has been demonstrated (Geyer and Mann, 1939; and others) that <u>Umbra</u> can exist in water of low oxygen concentration if it is allowed access to the surface, in order to gulp air. It is not very clear just how the fish can obtain air in the presence of an ice cover; but it is possible that cracks in the ice, and air pockets under the ice, allow enough contact with the atmosphere to fulfill the relatively small needs of the fish in cold water. Perhaps also worth considering is the possibility that the mud-minnow may undergo actual hibernation, perhaps buried in the muck of the bottom, for all or part of the winter. Morgan (1939, p. 321) has raised the question of the existence of true winter dormancy in fishes; but at any rate a very sluggish fish would consume very little oxygen.

## Consequences

Heavy winter-kill in a lake may reduce the fish population to such an extent that fishing for the next season or two is very poor, or entirely unproductive. Unfortunately, no really quantitative records are available, for Michigan lakes, regarding the fishing success in the first and second summers following a heavy winter mortality. In fact, the knowledge that a lake has suffered a large loss often keeps most fishermen away from that lake for a year or two, and hence a creel census would be of small value.

Within a certain range, the effect upon the fishing is more or less in proportion to the extent of the kill of the game fish. However, in some lakes, and with a not too heavy loss, a different — perhaps even a desirable — result may obtain. It is known that many Michigan lakes are over-populated with various game fish to the extent that extreme stunting occurs. It is altogether probable that a considerable reduction in numbers of these fish may result in faster growth of the remainder, and hence in fewer, but larger, fish becoming available to the angler.

It appears likely that, following a winter-kill, the fish population recovers to a large degree within a very few years, and eventually becomes restabilized at its original level. Rebuilding of the population may be effected by artificial stocking, by immigration through connecting streams, or by the fecundity of a surviving parent stock. An apparently well substantiated instance of a recovery by the last-named method is that of Goose Lake, in Jackson County. This lake was hit severely by winter suffocation in 1935-36, when it was popularly supposed to have been almost entirely depopulated of fish. Natural reinvasion did not take place because this lake has neither inlet nor outlet. The only recorded plantings of fish between 1936 and 1941 were 10,000 bluegills in 1937, and 20,000 in 1938. Fishing conditions in the lake after the spring of 1936 have been described by Haines (1941). Although admittedly based on a small amount of observation, nevertheless his information is of interest. In 1938, two years after the winter-kill, he found that fishing was still rather poor, and that the bass taken were small. But in 1941, after a total of five years, he made several good catches of large bass.

Species differences in tolerance of fishes to unfavorable winter conditions often bring about a differential winter-kill. In general the game fish are more sensitive than are the rough fish, and several reports from the literature have indicated that the game fish did suffer more damage than the non-game species. As already mentioned, the winter-kill of 1939-40 killed all the bluegills in Pasinski's Pond, but destroyed relatively few of the bullheads. An apparent exception to this general rule was found by Aitken (1938), who reported, "Although many fish died the winter of 1936 they were mostly carp, buffalo, and sheepshead whose loss was probably beneficial to the lakes."

In Table 1 are shown the species which were specifically mentioned in the reports of winter-kill in Michigan lakes. These reports probably were influenced by the propensity of the observer toward noticing game fish, his tendency to neglect to observe minnows and other small fish, and (at times) his inability to recognize other than the game species. Nevertheless the tabulation does distinctly show the game species to be the ones most affected. As Smith (1941) and others have pointed out, this discrimination has the effect of leaving a population, and a brood stock, composed of a large proportion of rough fish. In this manner, species balance between predator fish, game and food fish, and forage fish may be seriously disrupted. It may well be, however, that this balance becomes restored, through the workings of ecological forces, within relatively few years.

Various other animals besides fish sometimes are victims of winter-kill. Kochs (1891) reported the death of very large numbers of frogs; Olson (1932) also stated that frogs are subject to winter suffocation. In the present study, dead tadpoles were observed a few times, but never any dead adult frogs; nor are frogs specifically mentioned in the reports of winter-kill in Michigan lakes.

Many dead snails were observed, particularly at Green Lake, after the break-up of the ice, but it is not known in what proportion they were killed by low oxygen or died from other causes. Similarly, although a few dead mussels, crayfish, and turtles may be seen along the shore of a lake after the ice melts, it is questionable that they are the direct victims of suffocation, since their death in large numbers has seldom been reported.

The plankton invertebrates probably are destroyed in considerable numbers in some waters. Kofoid (1903) recorded the "practical extinction of the plankton" in places in the Illinois River during a winter of heavy fish mortality. However, since many of the plankton animals normally are subject to vast changes in numbers, cyclic or otherwise, and are equipped to weather adverse conditions by means of winter eggs or other resistant forms, it is likely that winter-kill is by no means a complete catastrophe to them.

## Preventive and Remedial Measures

Lake conditions conducive to winter-kill are more fitly subject to prevention than to cure. Once a lake develops an oxygen deficiency to the point where fish are in distress, it is doubtful if artificial means can avert considerable destruction. On the other hand, there are certain measures which, if applied early enough in the winter, may go far toward preventing harmful conditions from arising. In the following discussion not only are these methods considered, along with the extent of their economic feasibility, but also brief attention is given to sundry procedures, proposed or even actually attempted by various workers, which are neither theoretically nor practically sound.

## Flowing Water

If an appreciable flow of water through a lake can be maintained throughout the winter, and if the inflowing water always carries a reasonably large amount of dissolved oxygen, it is quite logical to suppose that the water of the lake (at least that within the path of flow) can thus be kept supplied with oxygen. As mentioned above, Mud Lake furnished an example of a stream's having considerable influence upon the oxygen content of the lake water. Snieszko (1941) stipulated a steady supply of aerated water as a requisite for winter carp ponds; Hubbs and Eschmeyer (1938) discussed the possibility of diverting a natural stream into a lake in order to prevent winter-kill. However, it will generally be impracticable to bring about such a diversion; furthermore, there may not always be the assurance that the stream will remain aerated, since it in turn may arise in another lake where stagnant conditions also develop.

Water from wells perhaps may be utilized as a source of supply for some ponds, but as a rule ground water contains little oxygen and therefore must be artificially aerated before it enters the pond. The results of an experimental use of such a water supply at Pasinski's Pond, discussed above, showed little if any improvement in conditions which could be attributed to the well water, presumably because its flow was relatively small and it was not very high in dissolved oxygen.

## Raised Water Levels

Smith (1941), Hubbs and Eschmeyer, and others have recommended raising the lake level as a means of preventing stagnation by enlarging the inital supply of oxygen. Probably it is feasible to raise the water of many shallow lakes by a foot or two, in the late fall or early winter; whether this additional amount of water can furnish enough oxygen to meet the demands of decaying organic material is rather doubtful. As discussed above, it seems likely that the average lake of the winter-kill type uses, during a long winter, several times the amount of oxygen with which it starts the winter, the balance being made up by photosynthetic production under the ice.

## Holes in the Ice

For no one knows how many decades, fishermen, conservationists, and others have attempted to relieve winter suffocation by cutting holes in the ice. Even scientific writers have recommended the procedure (Wickliff, no date; and others). Presumably these workers subconsciously postulate some such analogy as lifting the trap-door to a dungeon, thus to allow its occupants access to air and to life. Or there may be present the notion, expressed in a newspaper account (Milwaukee Sentinel, 1939), that holes in the ice will "allow the poisonous gases which mean death to the fish to escape." At any rate, despite many published statements in deprecation (Knauthe, 1899; Hubbs and Eschmeyer, 1938; Milwaukee Journal, 1939; Smith, 1941; and others), the practice still has many ardent followers.

The seal of an ice cover is not nearly as perfect as is often supposed. Cracks, pinholes, and air-pockets would relieve any very great pressure that a dissolved gas might build up, and allow the escape of the gas. The very fact that almost invariably the greatest concentrations of methane, hydrogen sulfide, and carbon dioxide are near the bottom rather than near the surface is sufficient proof that it is not the mere presence of ice that prevents their escape from the water. On the other hand, the presence at times of a high degree of supersaturation of dissolved oxygen in the water immediately under the ice may be explained on the basis of the well-known ability of water that is not agitated to retain for a time a large excess of oxygen, whether the surface of the water is covered or exposed.

In the absence of agitation, diffusion of air through the surface film of water is exceedingly slow and small in amount. Any appreciable aeration of the water of a lake by mere contact with the air over the area of a number of holes in the ice is impossible. It is true that if agitation can be accomplished, as by wind, much air can be put into the water. But, as those who have tried it know, the task of removing the ice from any appreciable area of water is herculean indeed (to clear one acre of ice one foot thick would require the removal of 1100 tons of ice). Artificial agitation, by outboard motors or other propeller devices, unless used in impracticable numbers, cannot affect a large enough proportion of the lake's volume to be of any significant aid.

Another popular theory is that fish are benefitted by coming to the surface at open holes and gulping air. However, most fish are fitted primarily to extract their oxygen from the water, and are poorly equipped to utilize atmospheric oxygen. It is held by Powers that gulping may actually be detrimental, because it brings about rapid changes in carbon dioxide tension (Powers, Shields, and Hickman, 1939, p. 243; and other papers). As Hubbs and Eschmeyer,have pointed out (p. 146), those few large species of fish which can use some oxygen from the air, such as bullheads and carp, are of comparatively little value, and perhaps not worth the effort of saving.

Holes cut in the ice may result in actual harm because of their attraction for fish. As described above, fish tend to congregate at an open hole, and may remain there until conditions in that immediate place become fatal to them, even though there is better water not far away. Apparently just such an event took place in Pasinski's Pond, and in Richmond Lake, in the winter of 1939-40.

## Artificial Aeration

Various experiments, in Michigan and elsewhere, in the artificial aeration of ice-bound lakes by means of water or air pumps have been described above, in the section on experimental studies. Almost all of these experimenters have reached the conclusion that pumping methods are wholly inadequate to aerate even a fair-sized body of water. Experiments in Iowa, both by using air blowers and by pumping water into the air were not considered very successful (Aitken, 1938). Pumping operations in Minnesota were "disappointing" (Milwaukee Journal, 1939). Virtually no good was found to have been accomplished by the experimental pumping by the Michigan Institute for Fisheries Research crew in the winter of 1935–36 (Eschmeyer, 1936).

The difficulty with almost any pumping method is in getting aeration for any appreciable distance from the seat of operations; furthermore, the effects of the pumping usually are quite transitory.

Perhaps the possibilities of pumping have not entirely been exhausted, and it may be that some further experimentation is justified. It is possible that efficient air or water pumping over a long period of time could introduce considerable oxygen into a very small body of water, such as a farm pond. Certain precautions should be used, for instance to avoid stirring up bottom materials and thus making them more readily available for bacterial oxidation (Hubbs and Eschmeyer, p. 146). Pumping would have more chance of being effective if started prior to the attainment of extremely bad conditions, rather than after the oxygen is well exhausted. After water has developed an oxygen deficiency, the small amounts of oxygen that are added are quickly consumed. There seems to be little hope that any pumping method will be feasible for large bodies of water, at least after serious conditions have been reached.

## More Vegetation

Since aquatic vegetation is known to be a producer of oxygen, under the proper conditions, it has been proposed (Aitken, 1938) that winter aeration of lakes could be accomplished by increasing the amount of vegetation present. As has been pointed out above, the higher plants usually are responsible for a relatively small proportion of the oxygen production in the winter, at best. During periods of snow coverage, there is little photosynthesis. Often the dead remains of plants become an agent of oxygen consumption. It is therefore doubtful that any aid in alleviating winter stagnation is to be derived from the artificial propagation of plants.

Plankton plants can be increased by the addition of fertilizer to the water; but excess fertilizer, and the remains of plankton algae that die , have a large demand for oxygen. The balance, therefore, is so delicate that tampering is not justified in the light of the present knowledge concerning artificial fertilization.

## Less vegetation

In extremely weedy lakes, it is perhaps more desirable from the standpoint of winter-kill prevention to decrease, rather than increase, the amount of rooted vegetation, since the winter decay of water weeds may use a part of the oxygen supply. There seems to be good indication, for instance, that the very heavy beds of Anacharis in Pasinski's Pond are responsible at times for considerable oxygen utilization. However, the removal of rooted vegetation from a lake presents many difficulties, and probably should not be considered as an economically sound method of accomplishing much toward the prevention of winter-kill. To attempt to remove the plants in winter, when danger is threatened, would be hazzardous, for the bottom materials stirred up would increase the oxygen consumption.

## Snow Removal

It has been pointed out (in the section on results) that there is a definite relationship between the amount of light penetrating the snow and ice cover, the plankton plants, and the dissolved oxygen content of the water. The data of the present study, combined with those of other investigations, definitely prove that the presence or absence of a long-continued snow cover on a lake can mean the difference between safety and doom for the fish. It is therefore apparent — and has been mentioned by several authors (Hubbs and Eschmeyer, 1938; Smith, 1941; and others) — that by far the best single method, from a theoretical viewpoint, of preventing winter-kill is the removal of snow from the ice. Moreover, such removal should not wait until dangerous conditions develop, but should be carried out rather regularly after each major snowfall.

Practically, the method offers many difficulties. Large-scale snow scraping entails the use of power machinery, which is somewhat costly, and which requires fairly heavy ice for safe operation. Hand shovelling is extremely slow and laborious. However, there may be merit in such schemes as that of using road-scraping machinery at times when it otherwise would be idle, or that of making a community project out of clearing the ice of snow for the additional purpose of providing skating. Furthermore, the effort could be somewhat lessened by clearing only strips of ice, with alternating windrows of piled-up snow (which might, however, be scattered back onto the cleared areas by subsequent winds). On the whole it seems likely that, although the method may be feasible for relatively small bodies of water, it could not be applied to all of the large winter-kill lakes of southern Michigan.

An alternate means of reducing the power of the snow cover to shut out light is to melt the snow with a stream or a spray of water. Upon refreezing, this melted snow is much less opaque to the light's rays. Water could be pumped from the lake in a rather large stream at relatively low cost, since the necessary lift would be small. The feasibility of applying this method to any considerable area is largely a matter of conjecture; but the possiblities seem to warrant at least an experimental trial.

## Fish Removal

The removal of fish from a lake subject to winter-kill may be directed toward accomplishing either of two objects. The effect sought may be the diminution of the oxygen demands of the fish by removing a part of them. In such operations the least desirable species may be removed, as in the experiment described by Olson (1932), in which 160,000 pounds of carp were removed from a small lake in the (vain) hope of saving the game fish. As discussed above, the oxygen consumption by fish probably is a very small part of the total oxygen utilization in the water under the ice; and hence the removal of part of the fish will ordinarily have comparatively little effect in maintaining an oxygen supply.

Smith (1941), however, discussed the removal of fish (presumably game fish) for another purpose — that of taking them from the danger of winter suffocation and transferring them to deeper lakes where they will be safe. This procedure is a logical one; and in many instances, when the threat of disaster is really imminent, it is no doubt an advisable thing to do.

## SUMMARY AND CONCLUSIONS

In the past, comparatively few studies have been made of winter conditions in lakes, largely because of the difficulties of winter field work. There are, however, many limnological aspects of lakes in winter which are worthy of observation. A cover of ice and snow brings about striking changes in the water. By interfering not only with gaseous exchange, but also with photosynthesis, this cover may have a great effect on the dissolved gases of the water, particularly on the oxygen balance. Among the disasters which may occur when this balance is adversely upset, the most dramatic and economically most important is the destruction of fish by suffocation.

Winter-kill of fish has been recorded many times in the last half-century, in Europe as well as in North America. In this country, it is of more or less common occurrence in several north central states. In Michigan, it has occurred in many lakes (though in a relatively small proportion of all of the lakes of the state). There have been kills in many winters, the most notable of which, in recent years, was that of 1935-36. During that winter, untold hundreds of thousands of fish perished.

The investigation described by this paper had as its chief objective the securing of information regarding winter-kill, its causes and its consequences. Certain incidental data concerning the general limnology of ice-covered lakes were also obtained.

The lakes studied included a moderately deep, mildly eutrophic lake, not subject to winter-kill; two shallow lakes which are typical of the winter-kill type of southern Michigan; a small, shallow, very rich pond, in which extreme stagnation often arises; and a small acid bog lake. Standard field and laboratory methods were used, with certain modifications necessitated by winter field conditions. Literally thousands of dissolved oxygen determinations were made throughout the three winters, 1937-38, 1939-40, and 1940-41. Routine tests also were made of pH and of methyl orange alkalinity. In 1937–38 and 1940–41, free carbon dioxide was measured; and in 1940–41 a considerable series of measurements of light penetration through snow and ice were made. Also in 1940–41 biochemical oxygen demand was determined for a large number of water samples.

In an experiment, well water was pumped into a pond for two one-week periods, without any notable effect in raising the oxygen of the pond water. Comparative oxygen measurements were made in three ponds, one of which was darkened with paper, and another of which had the snow removed. The different amounts of light penetration resulting were definitely reflected in differences in oxygen tension, though the differences were not very large.

In studying the oxygen trends in the various lakes (Graphs 2 to 14) it was found, as might be expected, that the greatest and most sudden fluctuations occurred in the shallow pond and in the bog lake. The water in the deeper lake remained remarkably constant throughout each winter.

Of the three winters of the investigation, in only that of 1939–40 did serious conditions develop in the lakes under observation. During that winter the ice was covered with snow for a comparatively long time. During the other two winters snow coverage was of rather short duration.

Changes in oxygen concentration, even from week to week, were definitely correlated with changes in the depth of snow on the ice. Measurements of light intensities verified the supposition that only a very small amount of light penetrates through even a few inches of snow. Unquestionably a foot or more of dry snow transmits too little light to actuate photosynthesis.

It is probable that the respiration of fish, other animals, and plants plays an insignificant part in the depletion of the oxygen. The main oxygen consumption comes about through the bacterial decay of organic matter, which is largely derived from dead plankton, and is either suspended or dissolved in the water or lies, in the form of a mucky deposit, on the lake bottom. This bottom deposit also may act indirectly to utilize oxygen, through the anaerobic production of methane and other reducing gases, which in turn are oxidized in the water. The relative importance of each of these organic materials in oxygen utilization is not known, but the correlation of oxygen depletion with general organic richness of the lake is clear-cut. Oxygen consumption apparently is a continuous process throughout the winter, but may be subject to some degree of influence by changes in light conditions, as well as by differences in temperature, etc.

Opposed to oxygen depletion is its production by photosynthesis. In this production, in winter, higher plants are involved to only a minor extent; the chief oxygen output is that of the phytoplankton. The amount of photosynthesis varies greatly, in accordance with the amount of light which penetrates the ice and snow cover.

Winter-kill of fish is principally a matter of suffocation because of a lack of sufficient dissolved oxygen. High concentrations of carbon dioxide or other harmful gases are contributing factors. The oxygen requirements of fish are comparatively low at low temperatures; but nevertheless certain minimal oxygen thresholds exist, beneath which fish cannot indefinitely survive. Different species show differences in tolerance, and hence differential kills occur.

The mortality varies from that of a few fish to the destruction of almost the entire population. Total kill is rare; and, when a residue fish stock is spared, recovery by natural propagation probably is largely completed within a few years, provided a second kill does not occur meanwhile. The detrimental effect upon fishing may be great for the first year or so, however; and the reputation of the lake for fishing is likely to suffer accordingly. The effects of winter-kill may not always be altogether deleterious, however; for the thinning of a large and stunted population may result in increased growth of the surviving fish. A heavy winter-kill may tend to destroy the species balance, by differentially killing the more sensitive species.

Once a lake has developed intense winter stagnation, usually little relief can be secured from the application of artificial measures. Cutting holes in the ice does virtually no good, because air cannot enter the water, by diffusion alone, in any appreciable quantity. These holes may even be harmful, because fish tend to congregate in an open hole and hence to deplete the oxygen in that immediate locality. Nearly all pumping procedures have been found not to be feasible, especially if large bodies of water are involved.

Both the theoretical considerations and the results of experimentation indicate snow removal to be a logical and perhaps feasible method for the prevention of winter-kill. The economic practicability of the method is still largely unknown; for small lakes, particularly those which are important fishing waters, it holds considerable promise.

## SUGGESTIONS FOR FURTHER STUDY AND MANAGEMENT

As has been stressed above, any management program should aim at the prevention, rather than the relief, of extreme winter stagnation; for after serious conditions once have developed there is little that can be done in the way of alleviation. The following management program is sound from a theoretical point of view. Whether or not it is economically feasible probably can be determined only from actual trial. It should be noted that it is recommended primarily for small bodies of water, and probably is not practicable for large lakes.

If control of the water level is possible, the lake or pond should be allowed to enter the winter with a maximum volume of water, thus giving it as large a reserve supply of oxygen as possible. Provision for extra inflowing water during the winter months sometimes is possible; if so, it should be made, particularly if the source of supply is water that is apt to carry abundant oxygen, such as that from a lake not subject to winter-kill or from a large stream.

Snow should be removed from the ice, by scraping or melting. Power or horse-drawn scraping or brushing equipment may be adaptable to the purpose; melting may be effected by a stream of water pumped from the lake. If the entire area cannot be cleared, probably some system of partial removal — such as from alternate strips — would be fairly effective. Very light snowfalls (of a fraction of an inch), which are rather frequent in southern Michigan, do not necessitate any action. Not only is such a small amount of snow insufficient to do much damage, but also it is very likely to be dissipated in rather short time by natural means. But each snowfall of more than an inch or two should be cleared away as soon as possible, not only because it soon can do considerable harm, but also because freshly fallen snow is more easily handled. Experience, plus check determinations of oxygen, will dictate the extent to which snow removal must be carried for any particular body of water.

In some instances, the removal of valuable game fish to a safe body of water before the onset of serious conditions may be advisable. Rescue operations in the winter are difficult and disagreeable work, and should be considered only as an emergency treatment. The need for fish removal in the fall, on the other hand, cannot be determined, for there is no way of foretelling whether the coming winter is to be a severe one or not. Hence fish should be taken in the fall only from those lakes or ponds which are most apt to be affected, or from those which best can spare fish. In other words, there may be certain very productive ponds or small lakes which thus might be considered somewhat as rearing ponds, and from which a certain number of game fish might be transferred each fall to waters more safe from the threat of winter-kill.

Although not recommended, at present, as a practical procedure, pumping water or air still is worthy of a certain amount of further experimental trial, provided the necessary equipment can be assembled. No one pumping method is recommended here above the others. A primary object of the pumping should be the putting of air into the water in as diffuse a form as possible (i.e., as very small bubbles). Vigorous stirring or agitation should be avoided. Finally, it should be borne in mind that the method offers very little hope of successful application to more than small or local areas, and will probably fail to be effective where the danger point has already been reached.

It is extremely advisable, in connection with any program of winter-kill prevention, to maintain throughout the winter a systematic and frequent check on the dissolved oxygen in the water, in order to determine when danger threatens, and to evaluate properly the success of the work. The dissolved oxygen determination is not an extremely difficult procedure, nor does it require an excessive amount of equipment. It is quite feasible for a practical fisheries worker to assemble the apparatus and to perform the test. Or, if this procedure does not seem to be advisable, arrangements often can be made for a fisheries technician or other trained worker to make the oxygen determinations.

Following are suggestions for certain further theoretical studies. They are proposed primarily for possible future investigation by the Institute for Fisheries Research, but may be somewhat useful to others interested in winter limonology.

Further observations of dissolved oxygen changes probably should take the form of an intensive study of one lake throughout a winter, rather than extensive work on several lakes. A considerable saving of time and travel expense would thereby result, and information fully as valuable would be obtained. If it could so be arranged, a desirable procedure would be to combine the oxygen observations with experiments in pumping or snow removal, thus obtaining a comparison of conditions before, during, and after an experiment, and between experimental and control areas. Of the southern Michigan lakes suitable for this project, Green Lake is specifically recommended. Not only is it typical of the winter-kill lakes, but it has the background of the work of the present paper.

Oxygen determinations, probably at several stations, should be made about once a week prior to the first snowfall of consequence. After that, or after the beginning of any experimental work, they should be made at least two or three times weekly.

Measurements of pH, carbon dioxide, or alkalinity are of relatively little value in the present connection, since they are mainly only supplementary to the much better index which is to be had in the oxygen determinations.

Of somewhat more strictly academic interest, and yet very vital to a complete knowledge of winter conditions, are additional measurements of light transmission, and of biochemical oxygen demand. The Institute now has the necessary equipment for this work; the procedures are fairly simple and reliable. It is recommended that, to whatever degree circumstances may permit, considerable more work be done along these lines.

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Table 1.

Reported Instances of Winter-Kill in
Michigan Lakes, 1930-1941.

| County | Lake | Location |  |  | Area, acres | Max. depth, feet | Fish loss | Bg. | Bass | Other Centr. | P. | Pk. | Sue. | Min. | B.H. | Cp. | Dg. | Gar. | Prev. W.K. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | T. | R. | Sec. |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  | 1929-30 |  |  |  |  |  |  |  |  |  |  |  |  |
| Tuscola | Clark | 11 N. | 11 E. | 20, 29 | 40 | 20 | H | ... | x | x | x | ... | x | x | ... | ... | ... | ... | Yes |
|  |  |  |  |  |  |  | 1930-31 |  |  |  |  |  |  |  |  |  |  |  |  |
| Kalkaska | Crawford | 27 N. | 6 W. | 18, 19 | 200 | 10 | ... | ... | ("Pike and other fish") |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  | 1934-35 |  |  |  |  |  |  |  |  |  |  |  |  |
| Kent | Gilbert | 10, 11 N. | 11 W. | 4, 33, 34 | 15 | 16 | H | x | x | x | x | ... | ... | ... | ... | ... | ... | ... | ... |
|  |  |  |  |  |  |  | 1935-36 |  |  |  |  |  |  |  |  |  |  |  |  |
| Barry | Long | 3 N. | 10 W. | 21, 28, 29 | 150 | 3 | H | x | x | ... | x | ... | ... | ... | x | x | ... | ... | ... |
|  | Loon | 1 N. | 7 W. | 28, 33 | 30 | 22 | H | x | x | x | x | x | x | ... | ... | ... | ... | ... | ... |
|  | Otis | 3 N. | 9 W. | 30, 31 | 100 | 4 | H | x | x | x | ... | ... | ... | ... | x | ... | ... | ... | Yes |
| Branch | Long | 6 S. | 6 W. | 18 | 75 | 20 | H | ... | x | ... | ... | ... | ... | ... | ... | ... | ... | ... | Yes |
| Calhoun | Boughton | 1 S. | 6 W. | 14, 23 | 5 | 20 | H | x | ... | x | x | ... | ... | ... | ... | ... | ... | ... | ... |
|  | Spectacle | 3 S. | 4 W. | 4, 5 | 80 | 12 | H | x | x | ... | ... | x | ... | ... | ... | ... | ... | ... | ... |
| Cass | Copley | 5 S. | 14 W. | 25 | 30 | 7 | VH | x | x | ... | x | ... | ... | ... | ... | ... | ... | ... | ... |
|  | Slab | 7 S. | 15 W. | 21 | 20 | 8 | VH | x | x | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Clinton | Park | 5 N. | 1 W. | 28, 29 | 200 | 27 | VH | x | x | x | x | x | x | x | x | ... | x | ... | ... |
| Eaton | Willis | 1 N. | 6 W. | 34 | 20 | ... | H | ... | x | x | x | x | ... | ... | x | ... | ... | ... | ... |
| Hillsdale | Cortwright | 5 S. | 3 W. | 32 | 12 | 12 | H | x | x | ... | ... | ... | ... | ... | ... | x | ... | ... | ... |
| Ingham | Unnamed | 4 N. | 1 W. | 2 | 15 | 10 | L | x | ... | ... | ... | x | ... | x | x | ... | ... | ... | ... |
| Iosco | S. Londo | 23 N. | 5 E. | 29, 30, 31 | 200 | 12 | VH | x | x | x | ... | ... | ... | x | x | ... | ... | ... | ... |
| Iron | Mud | 43 N. | 32 W. | 18 | 60 | 9 | L | ... | ... | ... | x | ... | ... | x | ... | ... | ... | ... | Yes |
| Jackson | Bateese | 1 S. | 1 E. | 9 | 60 | 15 | VH | x | x | x | ... | ... | ... | ... | x | ... | x | ... | ... |
|  | Goose | 2 S. | 1, 2 E. | 24, 19 | 300 | ... | ... | ... | (Not known) |  |  |  |  |  |  |  |  |  |  |
|  | Grass | 2 S. | 2 E. | 29, 30 | 250 | 20 | L | x | x | x | x | x | ... | ... | x | ... | x | ... | ... |
|  | Tim's | 2 S. | 2 E. | 20, 29 | 40 | ... | ... | ... | (Not known) |  |  |  |  |  |  |  |  |  |  |
| Kalamazoo | Austin | 3 S. | 11 W. | 24, 25, 26 | 1,100 | 10 | H | x | x | ... | x | ... | ... | ... | ... | ... | ... | ... | ... |
|  | Dustin | 2 S. | 12 W. | 20 | 35 | 4 | L | x | x | ... | x | ... | ... | ... | ... | ... | ... | ... | Yes |
| Livingston | Brighton | 1, 2 N. | 5, 6 E. | 1, 31, 36 | 200 | ... | H | x | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Manistee | Bar | 22 N. | 16 W. | 17, 19, 30 | 60 | 15 | L | ... | ... | ... | ... | x | ... | ... | ... | x | ... | ... | ... |
| Montcalm | Duck | 10 N. | 5 W. | 10, 11 | 300 | 9 | H | x | x | x | ... | x | ... | ... | ... | ... | ... | ... | ... |
| Oakland | Duck | 3 N. | 7 E. | 11, 12, 14 | 240 | ... | VH | x | x | x | x | x | x | ... | x | ... | ... | ... | ... |
|  | Long | 2 N. | 8 E. | 1 | 300 | 12 | H | x | x | x | x | ... | ... | ... | ... | ... | x | ... | ... |
|  | Round | 3 N. | 8 E. | 35 | 40 | 30 | H | x | x | x | x | ... | ... | ... | x | ... | ... | ... | ... |
|  | White | 3 N. | 7, 8 E. | 12, 13, 7 | 1,000 | 25 | ... | ... | (Not known) |  |  |  |  |  |  |  |  |  |  |
| Ogemaw | Ambrose | 23 N. | 1 E. | 1, 12 | 40 | 10 | H | x | x | x | x | ... | ... | ... | ... | ... | ... | ... | Yes |
|  | Elm | 23 N. | 1 E. | 11 | 20 | 9 | H | x | x | x | ... | x | ... | x | ... | ... | ... | ... | ... |
|  | Wallen | 23 N. | 3 E. | 18 | 12 | 15 | L | x | x | x | x | x | ... | ... | ... | ... | ... | ... | Yes |
| Roscommon | W. Twin | 21, 22 N. | 1 W. | 6, 31 | 100 | 12 | H | x | ... | x | x | ... | x | ... | x | ... | ... | ... | Yes |
| Shiawassee | Colby | 5 N. | 1 E. | 22 | 50 | 20 | H | x | x | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| St. Joseph | Washburn | 6 S. | 9 W. | 15 | 30 | 9 | VH | x | x | x | x | ... | ... | ... | x | ... | x | x | ... |
| Van Buren | Little Brandywine | 1 S. | 14 W. | 27 | 80 | 35 | L | x | ... | x | x | ... | ... | ... | ... | ... | ... | ... | ... |
| Washtenaw | Green | 1 S. | 3 E. | 22, 27, 28 | 80 | 10 | VH | x | x | x | ... | ... | ... | ... | x | ... | x | ... | Yes |
|  | Joslin | 1 S. | 3 E. | 3 | 200 | ... | ... | ... | (Not known) |  |  |  |  |  |  |  |  |  |  |
|  | Mud | 1 S. | 3 E. | 31 | 60 | 5 | VH | x | x | x | x | x | ... | x | x | ... | x | ... | ... |
|  | West | 1 S. | 4 E. | 30 | 100 | 8 | L | x | x | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
|  | Wylie | 1 S. | 4 E. | 25, 35, 36 | 15 | ... | H | ... | ("Many species") |  |  |  |  |  |  |  |  |  |  |

(Continued)

Table 1.

### Reported Instances of Winter-Kill in Michigan Lakes, 1930-41. (Continued)

| County | Lake | Location |  |  | Area, acres | Max. depth, feet | Fish loss | Bg. | Bass | Other Centr. | P. | Pk. | Suc. | Min. | B.H. | Cp. | Dg. | Gar. | Prev. W.K. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | T. | R. | Sec. |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  | 1937-38 |  |  |  |  |  |  |  |  |  |  |  |  |
| Livingston | Beach | 2 N. | 6 E. | 23 | 125 | 20 | ... | ... | (Not known) |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  | 1938-39 |  |  |  |  |  |  |  |  |  |  |  |  |
| Dickinson | Little Bad Water | 40 N. | 30 W. | 11 | 50 | ... | H | ... | x | x | x | x | x | ... | x | ... | ... | ... | ... |
|  |  |  |  |  |  |  | 1939-40 |  |  |  |  |  |  |  |  |  |  |  |  |
| Allegan | Round | 2 N. | 14 W. | 18 | 50 | 12 | VH | ... | (Not known) |  |  |  |  |  |  |  |  |  |  |
| Calhoun | Kinyon | 1 S. | 6 W. | 12 | 100 | ... | ... | ... | (Not known) |  |  |  |  |  |  |  |  |  |  |
| Clare | Cranberry | 19 N. | 4 W. | 12 | 75 | 35 | H | x | x | x | ... | ... | ... | ... | ... | ... | ... | ... | ... |
|  | Crooked | 17 N. | 6 W. | 22 | 150 | 30 | L | x | ... | x | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Kalamazoo | East | 3 S. | 10 W. | 5, 8 | 100 | 5 | VH | x | x | x | ... | ... | ... | x | x | ... | ... | ... | ... |
| Lenawee | Addison Mill Pond | 5 S. | 1 E. | ... | 30 | 10 | L | x | x | x | x | x | x | ... | ... | x | ... | ... | ... |
|  | Grassy | 5 S. | 1, 2 E. | 12, 13, 18 | 25 | 12 | ... | x | x | x | x | ... | ... | x | ... | ... | ... | ... | ... |
|  | Mud | 5 S. | 2 E. | 8 | 8 | 10 | VH | ... | (Not known) |  |  |  |  |  |  |  |  |  |  |
| Livingston | Lime | 3 N. | 5 E. | ... | 30 | 30 | H | x | x | x | x | ... | ... | ... | ... | ... | ... | ... | Yes |
|  | Pasinski's Pond | 2 N. | 5 E. | 5 | 4 | 5 | VH | x | ... | ... | ... | ... | ... | ... | x | ... | ... | ... | Yes |
| Montcalm | Duck | 10 N. | 5 W. | 10, 11 | 300 | 9 | H | x | x | ... | ... | x | ... | ... | x | ... | ... | ... | Yes |
| Oakland | Richmond | 3 N. | 9 E. | 16 | 30 | 10 | H | ... | ... | x | ... | ... | ... | x | x | ... | ... | ... | ... |
| Oscoda | Island | 28 N. | 4 E. | 7, 8, 17 | 60 | 10 | L | x | x | ... | x | ... | ... | ... | ... | ... | ... | ... | ... |
| Roscommon | Mud | 22 N. | 2 W. | 4, 9 | 50 | 10 | H | x | ... | x | ... | x | ... | ... | x | ... | ... | ... | ... |
| St. Joseph | Beaver | 6 S. | 9 W. | 28 | 30 | 20 | H | x | ... | x | x | x | ... | ... | x | ... | ... | ... | Yes |
|  | Kaiser | 6 S. | 12 W. | 20, 28 | 160 | 18 | H | x | ... | x | x | x | ... | x | x | ... | ... | ... | ... |
| Washtenaw | Green | 1 S. | 3 E. | 22, 27, 28 | 80 | 10 | L | ... | ... | x | ... | ... | ... | x | ... | ... | ... | ... | Yes |
|  |  |  |  |  |  |  | 1940-41 |  |  |  |  |  |  |  |  |  |  |  |  |
| Clare | Bungo | 18 N. | 5 W. | 21, 22 | 15 | ... | H | ... | x | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Crawford | May | 28 N. | 4 W. | 35 | 2 | ... | L | ... | x | ... | ... | ... | ... | ... | x | ... | ... | ... | ... |
| Iron | Little Maggie | 42 N. | 33 W. | 29 | 12 | 8 | H | ... | ... | ... | x | ... | x | x | x | ... | ... | ... | ... |
| Kalkaska | Island | 27 N. | 8 W. | 20, 21 | 90 | 22 | H | x | x | ... | x | x | ... | ... | ... | ... | ... | ... | ... |
| Kent | Chapin | 8 N. | 9 W. | 3 | 15 | ... | L | x | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Marquette | Mud | 45 N. | 30 W. | 22 | 40 | ... | H | x | x | ... | ... | x | x | ... | ... | ... | ... | ... | ... |
| Mecosta | Horsehead | 15 N. | 8 W. | 15, 21, 22 | 500 | 50 | ... | ... | (Not known) |  |  |  |  |  |  |  |  |  |  |
|  | Johnson | 15 N. | 8 W. | 9, 10, 15 | 500 | ... | ... | ... | (Not known) |  |  |  |  |  |  |  |  |  |  |
| Missaukee | Crooked | 22, 23 N. | 8 W. | 3, 4, 33 | 300 | ... | VH | x | x | ... | x | x | x | ... | ... | ... | ... | ... | ... |
| Oscoda | Elmer | 28 N. | 1 E. | 13 | 20 | 25 | H | x | ... | x | ... | ... | ... | x | ... | ... | ... | ... | ... |
|  | Helmer | 27 N. | 3 E. | 14 | 6 | 25 | L | x | x | x | x | ... | ... | ... | ... | ... | ... | ... | ... |
|  | Oak | 28 N. | 2 E. | 7, 18 | 40 | 6 | H | x | ... | x | ... | ... | ... | ... | ... | ... | ... | ... | ... |

L = Light
H = Heavy
VH = Very Heavy

Bg. = Bluegill sunfish
B. = Bass (largemouth or smallmouth)
Other Centr. = Other Centrarchids (sunfishes)
P. = Yellow perch
Pk. = Pike and mud pike
Suc.= Suckers
Min.= Minnows (exclusive of carp)

B.H. = Bullheads
Cp. = Carp
Dg. = Dogfish (bowfin)
Gar. = Gar pike

Prev. W.K. = Known winter-kill in previous years.

Table 2.

Principal Lakes Studied; Physical Characteristics.

| Lake | County | Location | Size, Acres | Max. Depth, Feet | In Winter | | Predominant Bottom Materials | Rooted Vegetation, Distribution | Methyl Orange Alkalinity, Usual range, p.p.m. | Class |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Inlet | Outlet | | | | |
| Clear | Jackson | T1, 2S; R2E; Sec. 1, 2, 35, 36 | 140 | 35 | No | No | Marl, mud, pulpy peat | Limited | 150—180 | Early-stage eutrophic |
| Mud | Washtenaw | T1S; R3E; Sec. 31 | 62 | 5 | Yes | Yes | Peat, marl | Widespread | 200—260 | Mid-stage eutrophic |
| Green | Washtenaw | T1S; R3E; Sec. 21, 22, 27, 28 | 78 | 10 | Yes | Yes | Peat, marl | Widespread | 170—210 | Mid-stage eutrophic |
| Richmond | Oakland | T3N; R9E; Sec. 16 | 15 | 10 | No | No | Peat | Widespread | 140—160 | Late-stage eutrophic |
| Pasinski's Pond | Livingston | T2N; R5E; Sec. 5 | 4 | 5 | No | Yes | Peat | Total area | 120—200 | Late-stage eutrophic |
| Bog | Washtenaw | T1S; R3E; Sec. 21 | ¼ | 6 | No | No | Peat | Absent | 5—10 | Dystrophic |

### Table 3.

### Sampling Stations on the Principal Lakes Studied, 1937–1941

| Lake | Station number | Sampled in years | | | Total depth, feet | Depths sampled, feet[1] | Bottom type | Rooted plants |
|---|---|---|---|---|---|---|---|---|
| | | 1937–38 | 1939–40 | 1940–41 | | | | |
| Clear | 1 | x | x | x | 6 | S, 5 | Marl | Sparse |
| | 2 | x | x | ... | 22 | S, 5, 10, 15, 20 | Peaty mud | None |
| | 2a | ... | ... | x | 34 | S, 5, 10, 15, 20, 25, 33 | Peaty mud | None |
| Mud | 1 | x | x | x | 4 | S, 3 | Peaty mud | Medium |
| | 2 | ... | x | ... | 3 | S | Marly mud | Medium |
| | 3 | ... | x | ... | 3 | S | Peat | Dense |
| | 4 | ... | x | ... | 2 | S | Sandy mud | Sparse |
| | Inlet | ... | x | x | 1 | ½ | Fibrous peat | Sparse |
| | Outlet | ... | x | x | 1 | ½ | Peat | None |
| Green | 1 | x | x | x | 3-½ | S, 3 | Peat | Medium |
| | 2 | ... | ... | x | 10 | S, 2, 5, 9 | Peat | None |
| | 3 | ... | ... | x | 3 | S, 2-½ | Marly peat | Sparse |
| | 4 | ... | ... | x | 9 | S, 4, 8 | Peat | None |
| | 5 | ... | ... | x | 3-½ | S, 3 | Peat | Dense |
| | 6 | ... | ... | x | 3-½ | S, 3 | Peat | Medium |
| | Inlet | ... | ... | x | 1 | ½ | Fibrous peat | Sparse |
| | Outlet | ... | ... | x | ... | ½ | ... | ... |
| | O.H.[2] | ... | x | ... | 3 | S | Peat | Medium |
| Bog | 1 | ... | x | x | 6 | S, 1, 2, 3, 4, 5 | Peat | None |
| Richmond | 1 | ... | x | ... | 7 | S, 6 | Peat | None |
| | O.H.[2] | ... | x | ... | 5 | S | Peat | Sparse |
| Pasinski's Pond | 1 to 14 | ... | x | ... | 1 to 3 | S | Peat | Dense |
| | 15 | x | x | x | 4 | S, 3 | Peat | Dense |
| | 16 to 18 | ... | x | ... | 2 to 3 | S | Peat | Dense |
| | 19 | ... | x | ... | 4 | S, 3 | Peat | Dense |
| | 20 | ... | x | x | 4 | S, 3 | Peat | Dense |
| | 21 | ... | x | ... | 4 | S | Peat | Dense |
| | 22 | ... | x | ... | 3-½ | S, 3 | Peat | Dense |
| | 23 | ... | x | ... | 4 | S | Peat | Dense |
| | 24 | ... | x | x | 4 | S, 3-½ | Peat | Dense |
| | 25 | ... | x | ... | 4 | S | Peat | Dense |
| | 26 | ... | x | x | 4-½ | S, 1, 2, 3, 4 | Peat | Dense |
| | 27 | ... | x | x | 4 | S, 3-½ | Peat | Dense |
| | 28 to 33 | ... | x | ... | 2 to 4 | S | Peat | Dense |
| | Outlet | ... | x | ... | 2 | S | Mud | Medium |
| | O.H.[2] | ... | x | ... | 2 | S | Mud | Medium |
| | Pump | ... | x | ... | ... | ... | ... | ... |

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[1] S = "Surface" sample, taken at from 4 to 6 inches below the surface of the water in the hole through the ice. Also called "Top" sample.

[2] O.H. = Open hole; i.e., hole in the ice kept open for considerable time.

Table 4.

Thickness of Ice and Snow.
Field Observations on Specified Dates.

1937-38

**Green Lake**

| Date | Ice, inches | Snow Inches | Snow Condition |
|---|---|---|---|
| Dec. 11 | ... | Tr. | ... |
| 28 | 8 | None | ... |
| Jan. 5 | 9 | None | ... |
| 12 | 9 | 1 | ... |
| 19 | 10 | 1 | Crusted |
| 26 | 12 | Tr. | ... |
| Feb. 2 | 12 | None | ... |
| 9 | 5 | None | ... |
| 20 | 3 | Tr. | ... |
| 27 | 2 | 2-3 | Slushy |
| Mar. 8 | Thin | ... | ... |

**Clear Lake**

| Date | Ice, inches | Snow Inches | Snow Condition |
|---|---|---|---|
| Dec. 28 | 10 | None | ... |
| Jan. 5 | 10 | None | ... |
| 12 | 10 | 1½-2 | ... |
| 19 | 12 | ... | ... |
| 26 | 12 | Tr. | ... |
| Feb. 2 | 12 | None | ... |
| 9 | 10 | None | ... |
| 20 | 5 | Tr. | ... |
| 27 | 4 | 3-4 | Slushy |
| Mar. 8 | Thin | ... | ... |

**Mud Lake**

| Date | Ice, inches | Snow Inches | Snow Condition |
|---|---|---|---|
| Dec. 11 | 4 | Tr. | ... |
| 28 | 6 | None | ... |
| Jan. 5 | ... | None | ... |
| 12 | 8 | 1 | ... |
| 19 | 12 | ... | ... |
| 26 | 12 | Tr. | ... |
| Feb. 2 | 12 | None | ... |
| 9 | 7 | None | ... |
| 20 | 4 | Tr. | ... |
| 27 | 4 | 3-4 | ... |
| Mar. 8 | 3 | None | |

**Pasinski's Pond**

| Date | Ice, inches | Snow Inches | Snow Condition |
|---|---|---|---|
| Jan. 1 | 6 | None | ... |
| 8 | 8 | ½ | ... |
| 15 | 8 | 2 | ... |
| 22 | 11 | 2 | ... |
| 30 | 12 | None | ... |
| Feb. 5 | 10 | None | ... |
| 12 | 4 | None | ... |
| 24 | 2 | 1 | ... |
| Mar. 3 | 2 | None | ... |
| 10 | 2 | ... | ... |

Table 4.

## Thickness of Ice and Snow. Field Observations on Specified Dates. (Continued)

1939-40

**Green Lake**

| Date | Ice, inches | Snow Inches | Snow Condition |
|---|---|---|---|
| Jan. 10 | 5 | 2 | ... |
| 17 | 5 | ½ | ... |
| 24 | 10 | ½-1 | ... |
| 31 | 10 | 2 | ... |
| Feb. 8 | 10 | 3 | ... |
| 14 | 10 | 3 | ... |
| 21 | ... | 2 | Crusted |
| 28 | ... | 6 | ... |
| Mar. 8 | 14 | 1-2 | Crusted |
| 11 | 14 | 0-2 | ... |
| 16 | 14 | ½ | New |
| 20 | 12 | 3 | New |
| 23 | ... | 3 | Crusted |
| 27 | 12 | 5 | ... |
| 31 | 8 | ... | ... |
| Apr. 3 | 6 | None | ... |

**Bog Lake**

| Date | Ice, inches | Snow Inches | Snow Condition |
|---|---|---|---|
| Jan. 6 | 2 | 1½-2½ | ... |
| 13 | 3 | 3 | Slushy |
| 20 | 4 | ½ | ... |
| 28 | 5 | 2 | ... |
| Feb. 3 | 5 | 3 | ... |
| 11 | 4 | 4 | Slushy |
| 18 | 4 | 1 | Packed |
| 25 | 4 | 3 | ... |
| Mar. 3 | ... | ... | ... |
| 11 | 4 | 0-1 | ... |
| 16 | 5 | ½ | New |
| 23 | 4 | 3 | Crusted |
| 27 | 6 | 5 | ... |

**Clear Lake**

| Date | Ice, inches | Snow Inches | Snow Condition |
|---|---|---|---|
| Jan. 6 | 4 | 1-1½ | ... |
| 10 | 6 | 2 | ... |
| 13 | 6 | 3 | Slushy |
| 17 | 8 | ½ | ... |
| 20 | 9 | ½ | ... |
| 24 | 12 | ½-1 | ... |
| 28 | 14 | ½-2 | ... |
| 31 | 12 | 2 | ... |
| Feb. 3 | 12 | 3 | ... |
| 8 | 12 | 4 | ... |
| 11 | 12 | 6 | ... |
| 14 | 12 | 3 | Packed |
| 18 | 12 | 2 | Packed |
| 21 | 12 | 2 | Crusted |
| 25 | 14 | 3 | ... |
| 28 | ... | 6 | Crusted |
| Mar. 3 | ... | ... | ... |
| 8 | 14 | 0-2 | Crusted |
| 11 | 14 | 0-1 | ... |
| 16 | 14 | 2-3 | ... |
| 20 | 14 | 3 | New |
| 23 | 14 | 3 | Crusted |
| 27 | 14 | 5 | ... |
| 31 | 10 | None | ... |
| Apr. 3 | 8 | None | ... |

**Mud Lake**

| Date | Ice, inches | Snow Inches | Snow Condition |
|---|---|---|---|
| Jan. 6 | 4 | 1-2 | ... |
| 10 | 5 | 2 | ... |
| 13 | 5 | 2-3 | Slushy |
| 17 | 6 | ½ | ... |
| 20 | 8 | ½ | ... |
| 24 | 10 | ½-1 | ... |
| 28 | 12 | ½-2 | ... |
| 31 | 10 | 2 | ... |
| Feb. 3 | 10 | 3 | ... |
| 8 | 10 | 3-4 | ... |
| 11 | ... | ... | ... |
| 14 | 10 | 3 | Packed |
| 18 | 12 | 2 | Packed |
| 21 | 12 | 2 | Crusted |
| 25 | ... | 2 | ... |
| 28 | ... | 6 | ... |
| Mar. 3 | ... | 2 | Slushy |
| 8 | 12 | 0-2 | Crusted |
| 11 | 12 | 0-2 | ... |
| 16 | 12 | 2 | ... |
| 20 | 10 | 3 | New |
| 23 | 12 | 3 | Crusted |
| 27 | 12 | 5 | ... |
| 31 | 8 | ... | ... |

(Continued)

Table 4.

Thickness of Ice and Snow.
Field Observations On Specified Dates.
(Continued)

1939-40

| Date | Ice, inches | Snow | | Date | Ice, inches | Snow | |
|---|---|---|---|---|---|---|---|
| | | Inches | Condition | | | Inches | Condition |
| | Pasinski's Pond | | | | Hatchery Ponds | | |
| Jan. 7 | 4 | 1 | ... | Jan. 7 | 3 | ½-1 | ... |
| 14 | 4 | None | ... | 14 | 4 | None | ... |
| 21 | 5 | ½ | New | 21 | 9 | Tr. | ... |
| 29 | 8 | 2 | ... | 29 | 12 | 2 | ... |
| Feb. 4 | 8 | 2 | ... | Feb. 4 | 12 | 1 | ... |
| 10 | 12 | 5-6 | ... | 12 | 12 | 3 | Wet |
| 17 | ... | 2 | Crusted | 17 | 12 | 2 | Packed |
| 22 | ... | 2 | Crusted | 19 | ... | 3 | Packed |
| Mar. 8 | ... | 1-2 | Crusted | 26 | ... | 3 | ... |
| 10 | 6 | 0-1 | Crusted | Mar. 1 | ... | 4 | Packed |
| 13 | ... | None | .... | 4 | ... | 2 | Slushy |
| 15 | ... | 0-2 | Crusted | 9 | 10 | 0-1 | Crusted |
| 18 | 10 | None | ... | 18 | 8 | Tr. | ... |
| 22 | 8 | 3 | Slushy | 22 | 10 | 3-6 | New |
| 25 | 10 | 1½ | Packed | 29 | 10 | None | ... |
| 29 | 8 | None | ... | | | | |
| Apr. 1 | 6 | None | ... | | | | |
| 3 | 4 | None | ... | | | | |
| | Richmond Lake | | | | | | |
| Feb. 18 | 12 | 2 | ... | | | | |
| Mar. 4 | 15 | 3 | ... | | | | |
| 9 | 12 | 1-2 | ... | | | | |
| 18 | 14 | None | ... | | | | |
| 22 | 14 | 3 | ... | | | | |
| 29 | 12 | None | ... | | | | |

Table 4.

### Thickness of Ice and Snow.
### Field Observations On Specified Dates.
(Continued)
1940-41

| Date | Ice, inches | Snow Inches | Snow Condition | Date | Ice, inches | Snow Inches | Snow Condition |
|---|---|---|---|---|---|---|---|
| | | **Clear Lake** | | | | **Mud Lake** | |
| Dec. 10 | 1 | None | ... | Dec. 10 | 4 | None | ... |
| 15 | ... | None | ... | 19 | 6 | Tr. | ... |
| 21 | 6 | None | ... | 24 | Thin | None | ... |
| Jan. 1 | Open | ... | ... | Jan. 1 | Open | ... | ... |
| 7 | Thin | None | ... | 7 | 3 | None | ... |
| 12 | 8 | ½-1½ | ... | 14 | 6 | 1 | Crusted |
| 23 | 6 | None | ... | 23 | 6 | None | ... |
| 30 | 10 | 1½ | Crusted | 30 | 8 | 1½ | ... |
| Feb. 6 | 10 | None | ... | Feb. 4 | 10 | None | ... |
| 14 | 8 | None | ... | 11 | 10 | 1-2 | ... |
| 23 | ... | ½-2 | Drifted | 23 | 10 | ½-1 | ... |
| Mar. 2 | 10 | ½-1 | Drifted | Mar. 2 | 10 | ½-1 | Drifted |
| 8 | 10 | Tr. | ... | 8 | 10 | Tr. | ... |
| 13 | 6 | ... | Melting | | | | |
| | | **Green Lake** | | | | **Bog Lake** | |
| Dec. 10 | 4 | None | ... | Dec. 10 | 2 | None | ... |
| 17 | 6 | Tr. | ... | 17 | 3 | Tr. | ... |
| 21 | 5 | None | ... | 21 | 3 | None | ... |
| 24 | 3 | None | ... | Jan. 1 | Thin | ... | ... |
| Jan. 1 | Open | ... | ... | 7 | 2 | Tr. | ... |
| 7 | 4 | None | ... | 14 | 3 | ½-1 | ... |
| 12 | 6 | 1-1½ | ... | 23 | 4 | None | ... |
| 23 | 8 | None | ... | 28 | 5 | 1½ | ... |
| 26 | 8 | None | ... | Feb. 4 | 5 | ½ | ... |
| 28 | 10 | 1-1½ | ... | 11 | 6 | 2 | ... |
| Feb. 9 | 10 | 2 | Dry | 16 | 6 | ½ | New |
| 14 | 6 | None | ... | 25 | 10 | 2 | Crusted |
| 24 | 10 | ½-2 | Drifted | Mar. 2 | 8 | 1½ | Crusted |
| Mar. 2 | 10 | ½-1 | Drifted | 4 | 8 | ½ | New |
| 4 | 10 | ½ | Drifted | 10 | 9 | ... | Hard |
| 8 | 10 | Tr. | ... | 27 | 6 | None | ... |
| | | **Pasinski's Pond** | | | | **Pasinski's Pond (Continued)** | |
| Dec. 12 | 3 | 1-1½ | New | Feb. 8 | 8 | Tr. | ... |
| 19 | 4 | Tr. | ... | 12 | 10 | 1½ | Crusted |
| 26 | 1 | ... | ... | 21 | 8 | Tr. | ... |
| Jan. 5 | Open | ... | ... | 27 | 8 | ½-1 | ... |
| 10 | 4 | 1 | New | Mar. 6 | 10 | ½ | ... |
| 16 | 6 | ½-1 | Crusted | 11 | ... | 3-4 | Wet |
| 24 | 8 | Tr. | ... | | | | |
| 31 | 6 | ½-1 | Wet | | | | |

Table 5.

**Depth of Snow, In Inches, On the Ground At the University Weather Station, Ann Arbor, During the Winter 1935-36.**

| Day | Dec. | Jan. | Feb. | March | April |
|---|---|---|---|---|---|
| 1 | 1 | 3 | 3 | None | None |
| 2 | 1 | 2½ | 3 | ½ | ½ |
| 3 | 1 | 1 | 3 | None | ½ |
| 4 | 1½ | 1 | 7 | " | None |
| 5 | 1 | 1 | 7 | " | 1 |
| 6 | None | 1 | 7 | " | 1 |
| 7 | " | 4 | 7 | " | None |
| 8 | " | 3½ | 7 | " | ½ |
| 9 | " | 6 | 7 | " | None |
| 10 | " | 4½ | 7 | " | " |
| 11 | " | 4½ | 7½ | " | " |
| 12 | " | 3½ | 7 | " | " |
| 13 | 2 | 3 | 8½ | ½ | " |
| 14 | 1 | 3 | 11 | None | " |
| 15 | None | 2 | 8 | " | " |
| 16 | 2 | 2 | 8 | " | ... |
| 17 | 2 | 2 | 9½ | " | ... |
| 18 | 1½ | 4 | 12 | " | ... |
| 19 | 1 | 4 | 12 | " | ... |
| 20 | 1½ | 3½ | 12 | " | ... |
| 21 | 1 | 3½ | 12 | " | ... |
| 22 | 1 | 5 | 9 | " | ... |
| 23 | ½ | 4 | 8 | " | ... |
| 24 | 1 | 4 | 6 | " | ... |
| 25 | 1 | 3½ | None | " | ... |
| 26 | 4 | 3½ | 1 | " | ... |
| 27 | 4 | 3 | None | " | ... |
| 28 | 4 | 3 | " | " | ... |
| 29 | 3½ | 3 | " | " | ... |
| 30 | 3½ | 2½ | ... | " | ... |
| 31 | 3½ | 3 | ... | " | ... |

Table 6.

**Depth of Snow, In Inches, On the Ground At the Ann Arbor Station, and On the Ice On the Various Lakes Studied In Southeastern Michigan, Winters of 1937-38, 1939-40, and 1940-41.**

1937-38

| | December | | January | | February | | March | |
|---|---|---|---|---|---|---|---|---|
| Day | Lakes | Ann Arbor | Lakes | Ann Arbor | Lakes | Ann Arbor | Lakes | Ann Arbor |
| 1 | ... | ... | None | 1 | ... | None | ... | 2 |
| 2 | ... | ... | ... | 1 | None | " | ... | None |
| 3 | ... | ... | ... | 1 | ... | " | None | " |
| 4 | ... | ... | ... | 1 | ... | " | ... | " |
| 5 | ... | ... | None | 1 | None | " | ... | 2 |
| 6 | ... | 2½ | ... | 1 | ... | " | ... | 1 |
| 7 | ... | 2½ | ... | 1 | ... | " | ... | ½ |
| 8 | ... | 2 | ... | 1 | ... | " | None | None |
| 9 | ... | 2 | ... | 1 | None | " | ... | " |
| 10 | ... | 2 | ... | 3 | ... | " | ... | " |
| 11 | Tr. | 2 | ... | 3½ | ... | " | ... | " |
| 12 | ... | 2 | 1-2 | 3 | None | " | ... | " |
| 13 | ... | 2 | ... | 4 | ... | " | ... | " |
| 14 | ... | 2 | ... | 3½ | ... | " | ... | ... |
| 15 | ... | 2 | ... | 4 | ... | " | ... | ... |
| 16 | ... | 3½ | ... | 4 | ... | " | ... | ... |
| 17 | ... | 2½ | ... | 3½ | ... | " | ... | ... |
| 18 | ... | 3 | ... | 3 | ... | " | ... | ... |
| 19 | ... | 3 | 1 | 3 | ... | " | ... | ... |
| 20 | ... | 4 | ... | 2½ | Tr. | 2½ | ... | ... |
| 21 | ... | 4½ | ... | 2½ | ... | 1½ | ... | ... |
| 22 | ... | 4½ | ... | 2½ | ... | 1 | ... | ... |
| 23 | ... | 4½ | ... | 1½ | ... | 3 | ... | ... |
| 24 | ... | 4½ | ... | 1 | 1 | 2½ | ... | ... |
| 25 | ... | 3 | ... | ½ | ... | 2 | ... | ... |
| 26 | ... | 2½ | Tr. | 1 | ... | 3½ | ... | ... |
| 27 | ... | 2½ | ... | 1 | 2-4 | 2½ | ... | ... |
| 28 | None | 2½ | ... | 1½ | ... | 2 | ... | ... |
| 29 | ... | 2 | 1 | 1½ | ... | ... | ... | ... |
| 30 | ... | 2 | None | None | ... | ... | ... | ... |
| 31 | ... | 1½ | ... | " | ... | ... | ... | ... |

Table 6.

**Depth of Snow, In Inches, On the Ground At the Ann Arbor Station, and On the Ice On the Various Lakes Studied in Southeastern Michigan, Winters of 1937-38, 1939-40, and 1940-41.**
**(Continued)**

1939-40

| | January | | February | | March | |
|---|---|---|---|---|---|---|
| Day | Lakes | Ann Arbor | Lakes | Ann Arbor | Lakes | Ann Arbor |
| 1 | ... | 2 | ... | 2½ | 4 | 2 |
| 2 | ... | 2 | ... | 3 | ... | 2 |
| 3 | ... | 2 | 3 | 2½ | 2 | 1 |
| 4 | ... | 2 | 1-2 | 1 | 2-3 | ½ |
| 5 | ... | 2 | ... | 2 | ... | ½ |
| 6 | 1-2½ | 2 | ... | 1½ | ... | ½ |
| 7 | 1 | 2 | ... | 2½ | ... | None |
| 8 | ... | 1½ | 3-4 | 3 | 0-1 | " |
| 9 | ... | 3½ | ... | 7 | 0-1 | " |
| 10 | 2 | 2½ | 5-6 | 7 | 0-1 | " |
| 11 | ... | 3 | 4-6 | 6½ | 0-1 | " |
| 12 | ... | 2 | 3 | 5½ | ... | " |
| 13 | 2-3 | 1½ | ... | 2½ | None | " |
| 14 | None | None | 3 | 2½ | ... | ½ |
| 15 | ... | ½ | ... | 2 | 0-2 | ½ |
| 16 | ... | ½ | ... | 1½ | ½-2 | 1 |
| 17 | ½ | ½ | 2 | 1 | ... | None |
| 18 | ... | 1 | 1-2 | ½ | None | " |
| 19 | ... | 1 | 3 | 2 | ... | " |
| 20 | ½ | 1 | ... | 1 | 3 | 3½ |
| 21 | 0-½ | 1½ | 2 | ½ | ... | 2 |
| 22 | ... | 1 | 2 | ½ | 3-6 | 4 |
| 23 | ... | 1 | ... | ½ | 3 | 2 |
| 24 | ½-1 | 1½ | ... | 2½ | ... | 2 |
| 25 | ... | 2½ | 3 | 1½ | 1½ | 2 |
| 26 | ... | 2½ | 3 | 1½ | ... | 1½ |
| 27 | ... | 3 | ... | 2½ | 5 | 4 |
| 28 | ½-2 | 2½ | 6 | 3 | ... | 3½ |
| 29 | 2 | 2 | 4 | 2 | None | ½ |
| 30 | ... | 3 | ... | ... | ... | None |
| 31 | 2 | 2½ | ... | ... | None | " |

Table 6.

Depth of Snow, In Inches, On the Ground At the Ann Arbor Station, and On the Ice On the Various Lakes Studied In Southeastern Michigan, Winters of 1937-38, 1939-40, and 1940-41
(Continued)

1940-41

| Day | December | | January | | February | | March | |
|---|---|---|---|---|---|---|---|---|
| | Lakes | Ann Arbor | Lakes | Ann Arbor | Lakes | Ann Arbor | Lakes | Ann Arbor |
| 1 | ... | ... | ... | 1½ | ... | ½ | ... | None |
| 2 | ... | ... | ... | None | ... | None | ½-1 | " |
| 3 | ... | ... | ... | " | ... | " | ... | " |
| 4 | ... | ... | ... | " | None | " | ½ | ½ |
| 5 | ... | ... | ... | 1 | ... | " | ... | ½ |
| 6 | ... | ... | ... | 1 | None | " | ... | None |
| 7 | ... | ... | None | 1 | ... | " | ... | " |
| 8 | ... | ... | ... | 1 | ... | " | Tr. | " |
| 9 | ... | ... | ... | 2½ | 2 | ½ | ... | " |
| 10 | None | None | ... | 2 | ... | ½ | ... | " |
| 11 | ... | " | ... | 2 | 1-2 | ½ | 3-4 | 3½ |
| 12 | 1 | ½ | ½-1½ | 2 | 1½ | None | ... | 2½ |
| 13 | ... | None | ... | 1½ | ... | " | ... | 2 |
| 14 | ... | " | 1 | 1½ | None | " | ... | 1 |
| 15 | ... | " | ... | 2½ | ... | " | ... | None |
| 16 | Tr. | " | 1 | 2½ | ... | " | ... | ½ |
| 17 | ... | " | ... | 2 | ... | 2½ | ... | ½ |
| 18 | ... | " | ... | None | ... | 2½ | ... | ½ |
| 19 | Tr. | " | ... | " | ... | 2½ | ... | None |
| 20 | ... | " | ... | " | ... | 2½ | ... | 1 |
| 21 | None | " | ... | " | ... | 2 | ... | None |
| 22 | ... | " | ... | " | ... | 2½ | ... | " |
| 23 | ... | " | None | " | ½-2 | 2½ | ... | " |
| 24 | None | " | ... | " | ½-2 | 1½ | ... | " |
| 25 | ... | " | ... | " | 2 | None | ... | " |
| 26 | ... | " | None | " | ... | " | ... | " |
| 27 | ... | " | ... | 2 | ½ | " | None | " |
| 28 | ... | " | 1½ | 2 | ... | ½ | ... | ... |
| 29 | ... | " | ... | 2 | ... | ... | ... | ... |
| 30 | ... | 3 | 2 | 2 | ... | ... | ... | ... |
| 31 | ... | 2 | 1 | 1½ | ... | ... | ... | ... |

### Table 7.

### Dissolved Oxygen, pH, and Other Chemical Data For the Lakes Studied, 1937-38.

| Lake and Station | Sampling Depth | Date | Temperature | | pH | Free $CO_2$, p.p.m. | Phth. Alkalinity, p.p.m. | M. O. Alkalinity, p.p.m. | Dissolved $O_2$, p.p.m. |
|---|---|---|---|---|---|---|---|---|---|
| | | | °C. | °F. | | | | | |
| Clear Lake, Sta. 1 | Surface | Dec. 28 | 1.1 | 34 | ... | None | ... | ... | ... |
| | | Jan. 5 | 0.0 | 32 | ... | 1 | ... | ... | 14.3 |
| | | 12 | 0.2 | 32½ | ... | None | ... | ... | 14.0 |
| | | 19 | 0.0 | 32 | ... | " | ... | ... | 13.3 |
| | | 26 | 0.1 | 32 | ... | 1 | ... | ... | 13.0 |
| | | Feb. 2 | 0.1 | 32 | ... | 1 | ... | ... | 15.7 |
| | | 9 | 2.0 | 35½ | ... | 1 | ... | ... | 11.2 |
| | | 20 | 0.6 | 33 | ... | 1 | ... | ... | 12.4 |
| | | 27 | 1.0 | 34 | ... | 1 | ... | ... | 12.2 |
| | Bottom | Dec. 28 | 2.3 | 36 | 8.0 | None | ... | 161 | 13.9 |
| | | Jan. 5 | 1.4 | 34½ | 8.2 | 2 | ... | 163 | 9.8 |
| | | 12 | 3.5 | 38½ | 8.2 | None | 5 | 168 | 13.5 |
| | | 19 | 1.6 | 35 | 8.0 | " | ... | 173 | 13.3 |
| | | 26 | 3.9 | 39 | 8.0 | 1 | ... | 163 | 12.6 |
| | | Feb. 2 | 4.1 | 39½ | 8.0 | None | ... | 167 | 12.2 |
| | | 9 | 4.8 | 40½ | 8.0 | " | ... | 170 | 11.5 |
| | | 20 | 5.6 | 42 | 8.0 | " | ... | 161 | 12.1 |
| | | 27 | 5.3 | 41½ | 8.0 | 1 | ... | 166 | 11.2 |
| Sta. 2 | Surface | Jan. 5 | 2.0 | 35½ | ... | ... | ... | ... | ... |
| | | 12 | 0.3 | 32½ | ... | None | ... | ... | 9.6 |
| | | 19 | 0.0 | 32 | ... | " | ... | ... | 13.6 |
| | | 26 | 0.2 | 32½ | ... | " | ... | ... | 13.2 |
| | | Feb. 2 | 0.2 | 32½ | ... | " | ... | ... | 13.9 |
| | | 9 | 1.0 | 34 | ... | 1 | ... | ... | 10.5 |
| | | 20 | 0.6 | 33 | ... | 1 | ... | ... | ... |
| | | 27 | 1.8 | 35 | ... | 1 | ... | ... | ... |
| | 3 feet | Feb. 9 | 5.0 | 41 | ... | ... | ... | ... | ... |
| | | 20 | 6.3 | 43½ | ... | ... | ... | ... | ... |
| | | 27 | 5.5 | 42 | ... | ... | ... | ... | ... |
| | 5 feet | Jan. 5 | 3.4 | 38 | ... | ... | ... | ... | ... |
| | | 12 | 3.3 | 38 | ... | ... | ... | ... | ... |
| | | 19 | 1.1 | 34 | ... | ... | ... | ... | ... |
| | | 26 | 3.3 | 38 | ... | ... | ... | ... | ... |
| | | Feb. 2 | 3.6 | 38½ | ... | ... | ... | ... | ... |
| | | 9 | 5.0 | 41 | ... | ... | ... | ... | ... |
| | | 20 | 6.4 | 43½ | ... | ... | ... | ... | ... |
| | | 27 | 5.9 | 42½ | ... | ... | ... | ... | ... |
| | 10 feet | Jan. 5 | 3.9 | 39 | ... | 2 | ... | ... | 13.1 |
| | | 12 | 3.6 | 38½ | ... | None | ... | ... | 13.1 |
| | | 19 | 3.0 | 37½ | ... | " | ... | ... | 11.8 |
| | | 26 | 4.0 | 39 | ... | " | ... | ... | 11.1 |
| | | Feb. 2 | 4.3 | 39½ | ... | 1 | ... | ... | 11.5 |
| | | 9 | 5.1 | 41 | ... | 1 | ... | ... | 9.8 |
| | | 20 | 5.8 | 42½ | 8.0 | None | ... | 175 | 11.9 |
| | | 27 | 5.9 | 42½ | 8.0 | " | ... | 167 | 11.4 |

(Continued)

Table 7.

Dissolved Oxygen, pH, and Other Chemical Data For the Lakes Studied, 1937-38.
(Continued)

| Lake and Station | Sampling Depth | Date | Temperature |  | pH | Free $CO_2$, p.p.m. | Phth. Alkalinity, p.p.m. | M. O. Alkalinity, p.p.m. | Dissolved $O_2$, p.p.m. |
|---|---|---|---|---|---|---|---|---|---|
|  |  |  | °C. | °F. |  |  |  |  |  |
| Clear Lake, Sta. 2 (Continued) | 15 feet | Jan. 5 | 3.9 | 39 | ... | ... | ... | ... | ... |
|  |  | 12 | 3.9 | 39 | ... | ... | ... | ... | ... |
|  |  | 19 | 4.2 | 39½ | ... | ... | ... | ... | ... |
|  |  | 26 | 4.3 | 39½ | ... | ... | ... | ... | ... |
|  |  | Feb. 2 | 4.9 | 41 | ... | ... | ... | ... | ... |
|  |  | 9 | 5.3 | 41½ | ... | ... | ... | ... | ... |
|  |  | 20 | 5.8 | 42½ | ... | ... | ... | ... | ... |
|  |  | 27 | 5.7 | 42½ | ... | ... | ... | ... | ... |
|  | Bottom | Jan. 5 | 4.4 | 40 | 7.8 | 6 | ... | 179 | 7.7 |
|  |  | 12 | 4.0 | 39 | 8.0 | None | 6 | 172 | 11.7 |
|  |  | 19 | 4.3 | 39½ | 7.8 | 3 | ... | 181 | 8.3 |
|  |  | 26 | 4.8 | 40½ | 7.6 | 2 | ... | 183 | 5.8 |
|  |  | Feb. 2 | 5.3 | 41½ | 7.6 | 2 | ... | 183 | 5.9 |
|  |  | 9 | 5.5 | 42 | 7.6 | 3 | ... | 190 | 3.0 |
|  |  | 20 | 5.7 | 42½ | 7.6 | 1 | ... | 192 | 4.2 |
|  |  | 27 | 5.6 | 42 | 7.8 | 2 | ... | 178 | 10.4 |
| Mud Lake, Sta. 1 | Surface | Dec. 11 | 3.4 | 38 | ... | ... | ... | ... | ... |
|  |  | 28 | 1.1 | 34 | ... | 5 | ... | ... | 8.8 |
|  |  | Jan. 5 | 0.0 | 32 | ... | 5 | ... | ... | 6.8 |
|  |  | 12 | 0.5 | 33 | ... | 6 | ... | ... | 8.6 |
|  |  | 19 | 0.0 | 32 | ... | 8 | ... | ... | 6.9 |
|  |  | 26 | 0.2 | 32½ | ... | 4 | ... | ... | 7.3 |
|  |  | Feb. 2 | 0.0 | 32 | ... | 2 | ... | ... | 10.8 |
|  |  | 9 | 1.4 | 34½ | ... | 1 | ... | ... | 11.1 |
|  |  | 20 | 1.5 | 34½ | ... | 1 | ... | ... | 13.6 |
|  |  | 27 | 0.7 | 33½ | ... | 2 | ... | ... | 11.1 |
|  |  | Mar. 8 | 2.1 | 36 | 7.4 | 2 | ... | 135 | 9.3 |
|  | Bottom | Dec. 11 | 3.6 | 38½ | 7.8 | 3 | ... | 220 | 9.9 |
|  |  | 28 | 3.6 | 38½ | 7.6 | 7 | ... | 245 | 7.6 |
|  |  | Jan. 5 | 0.0 | 32 | 7.4 | 10 | ... | 243 | 6.7 |
|  |  | 12 | 2.9 | 37 | 7.6 | 5 | ... | 264 | 10.5 |
|  |  | 19 | 1.6 | 35 | 7.6 | 7 | ... | 260 | 6.5 |
|  |  | 26 | 4.2 | 39½ | 7.2 | 5 | ... | 208 | 5.3 |
|  |  | Feb. 2 | 2.7 | 37 | 7.4 | 4 | ... | 223 | 8.0 |
|  |  | 9 | 5.4 | 41½ | 7.4 | 2 | ... | 130 | 10.1 |
|  |  | 20 | 4.8 | 40½ | 7.4 | 3 | ... | 145 | 9.8 |
|  |  | 27 | 4.6 | 40½ | 7.6 | 3 | ... | 175 | 9.8 |
|  |  | Mar. 8 | 4.2 | 39½ | 7.6 | 3 | ... | 172 | 9.3 |

(Continued)

Table 7.

Dissolved Oxygen, pH, and Other Chemical Data For the Lakes Studied, 1937-38.
(Continued)

| Lake and Station | Sampling Depth | Date | | Temperature °C. | Temperature °F. | pH | Free $CO_2$, p.p.m. | Phth. Alkalinity, p.p.m. | M. O. Alkalinity, p.p.m. | Dissolved $O_2$, p.p.m. |
|---|---|---|---|---|---|---|---|---|---|---|
| Green Lake, Sta. 1 | Surface | Dec. | 11 | 3.3 | 38 | 8.0 | 2 | ... | 180 | 12.5 |
| | | | 28 | 3.5 | 38½ | 7.8 | 2 | ... | 103 | 13.3 |
| | | Jan. | 5 | 1.8 | 35 | 7.6 | 4 | ... | 204 | 10.5 |
| | | | 12 | 1.5 | 34½ | 7.6 | 2 | ... | 207 | 10.3 |
| | | | 19 | 1.4 | 34½ | 7.6 | 5 | ... | 210 | 10.2 |
| | | | 26 | 0.9 | 33½ | 7.2 | 2 | ... | 79 | 10.6 |
| | | Feb. | 2 | 1.1 | 34 | 7.4 | 2 | ... | 116 | 10.1 |
| | | | 9 | 2.3 | 36 | 7.0 | 1 | ... | 11 | 10.2 |
| | | | 20 | 2.1 | 36 | 7.2 | 1 | ... | 47 | 11.7 |
| | | | 27 | 1.1 | 34 | 7.4 | 1 | ... | 79 | 12.2 |
| | Bottom | Dec. | 11 | 4.4 | 40 | 8.0 | None | ... | ... | 13.6 |
| | | | 28 | 4.1 | 39½ | 7.8 | 5 | ... | 189 | 11.2 |
| | | Jan. | 5 | 3.4 | 38 | 7.6 | 6 | ... | 200 | 10.8 |
| | | | 12 | 3.6 | 38½ | 7.6 | 3 | ... | 207 | 8.9 |
| | | | 19 | 3.9 | 39 | 7.6 | 5 | ... | 210 | 7.0 |
| | | | 26 | 3.3 | 38 | 7.4 | 4 | ... | 170 | 7.4 |
| | | Feb. | 2 | 4.9 | 41 | 7.4 | 3 | ... | 192 | 5.1 |
| | | | 9 | 5.3 | 41½ | 7.8 | 2 | ... | 120 | 8.6 |
| | | | 20 | 5.7 | 42½ | 7.6 | 2 | ... | 123 | 10.1 |
| | | | 27 | 4.9 | 41 | 7.4 | 2 | ... | 138 | 8.2 |
| Pasinski's Pond Sta. 15 | Surface | Jan. | 1 | 0.7 | 33½ | ... | 2 | ... | ... | 13.3 |
| | | | 8 | 0.4 | 32½ | ... | 3 | ... | ... | 17.8 |
| | | | 15 | 0.4 | 32½ | ... | 5 | ... | ... | 9.8 |
| | | | 22 | 1.0 | 34 | ... | 5 | ... | ... | 4.9 |
| | | | 30 | 0.3 | 32½ | ... | 2 | ... | ... | 11.8 |
| | | Feb. | 5 | 0.8 | 33½ | 7.2 | 2 | ... | 108 | 10.7 |
| | | | 12 | 2.5 | 36½ | 7.6 | 1 | ... | 76 | 11.7 |
| | | | 24 | 2.5 | 36½ | 8.2 | None | 5 | 88 | 16.7 |
| | | Mar. | 3 | 2.5 | 36½ | 8.2 | " | 6 | 93 | 17.5 |
| | | | 10 | 1.9 | 35½ | 8.4 | " | 9 | 92 | 13.9 |
| | Bottom | Jan. | 1 | 2.4 | 36½ | 7.6 | 9 | ... | 210 | 7.8 |
| | | | 8 | 2.8 | 37 | 8.0 | 3 | ... | 230 | 15.0 |
| | | | 15 | 2.8 | 37 | 7.4 | 8 | ... | 248 | 9.1 |
| | | | 22 | 2.2 | 36 | 7.4 | 6 | ... | 240 | 3.7 |
| | | | 30 | 2.3 | 36 | 7.4 | 4 | ... | 172 | 7.5 |
| | | Feb. | 5 | 3.1 | 37½ | 7.4 | 3 | ... | 185 | 9.3 |
| | | | 12 | 3.7 | 38½ | 7.4 | 3 | ... | 154 | 10.6 |
| | | | 24 | 4.0 | 39 | 7.6 | 3 | ... | 122 | 12.3 |
| | | Mar. | 3 | 4.3 | 39½ | 7.8 | 1 | ... | 133 | 12.7 |
| | | | 10 | 4.3 | 39½ | 8.0 | None | 4 | 140 | 14.2 |

Table 8.

### Dissolved Oxygen, pH, and Other Chemical Data For the Lakes Studied, 1939-40.

| Lake and station | Sampling depth | Date | pH | Aerated pH | Alveol. pH | Phth. alkalinity, p.p.m. | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|---|---|---|---|
| Clear Lake, Sta. 1 | Surface | Dec. 31 | ... | ... | ... | 2 | 158 | 14.5 |
| | | Jan. 6 | ... | ... | ... | 5 | 160 | 14.6 |
| | | 10 | 8.2 | ... | ... | 4 | 160 | 14.9 |
| | | 13 | 8.0 | ... | ... | 2 | 156 | 14.7 |
| | | 17 | 8.0 | ... | ... | 3 | 154 | 15.5 |
| | | 20 | 8.0 | ... | ... | 4 | 163 | 16.2 |
| | | 24 | 8.1 | ... | ... | 2 | 165 | 15.5 |
| | | 28 | 8.1 | 8.2 | 6.5 | 2 | 168 | 15.4 |
| | | 31 | 8.1 | 8.1 | 6.4 | 2 | 168 | 14.5 |
| | | Feb. 3 | 8.1 | 8.2 | 6.4 | 2 | 167 | 14.5 |
| | | 8 | 8.1 | 8.1 | 6.3 | 2 | 163 | 14.5 |
| | | 11 | 8.1 | ... | ... | 2 | 156 | 14.2 |
| | | 14 | 8.1 | ... | ... | 2 | 168 | 14.4 |
| | | 18 | 8.0 | ... | ... | ... | 164 | 14.2 |
| | | 21 | 8.1 | 8.1 | 6.3 | 2 | 164 | 14.2 |
| | | 25 | 8.1 | 8.2 | ... | 3 | 165 | 14.3 |
| | | 28 | 8.0 | 8.2 | ... | 2 | 168 | 14.9 |
| | | Mar. 3 | 8.0 | 8.1 | 6.4 | ... | 166 | 13.9 |
| | | 8 | 8.0 | ... | ... | 2 | 82 | 13.4 |
| | | 11 | 7.9 | 8.1 | 6.3 | ... | 146 | 13.0 |
| | | 16 | 7.9 | 8.0 | ... | 2 | 163 | 14.0 |
| | | 20 | 6.7 | 6.8 | 5.4 | ... | 18 | 10.9 |
| | | 23 | 6.7 | 6.8 | 5.6 | ... | 28 | 9.0 |
| | | 27 | 8.0 | 8.1 | ... | 2 | 147 | 13.3 |
| | | 31 | 6.8 | 7.4 | ... | ... | 52 | 10.9 |
| | | Apr. 3 | 6.9 | 7.6 | ... | ... | 62 | 11.3 |
| | Bottom | Dec. 31 | ... | ... | ... | 2 | 151 | 14.1 |
| | | Jan. 6 | ... | ... | ... | 3 | 162 | 14.4 |
| | | 10 | 8.2 | ... | ... | 3 | 156 | 14.6 |
| | | 13 | 8.0 | ... | ... | 2 | 153 | 14.9 |
| | | 17 | 8.0 | ... | ... | 3 | 160 | 14.8 |
| | | 20 | ... | ... | ... | ... | ... | 15.8 |
| | | 24 | 8.1 | ... | ... | 2 | 165 | 14.9 |
| | | 28 | 8.1 | 8.1 | 6.4 | 2 | 162 | 15.1 |
| | | 31 | 8.1 | 8.1 | 6.4 | 2 | 165 | 13.5 |
| | | Feb. 3 | 8.1 | 8.2 | 6.3 | 2 | 165 | 13.7 |
| | | 8 | 8.1 | 8.1 | 6.4 | 2 | 165 | 14.2 |
| | | 11 | 8.1 | ... | ... | 3 | 166 | 14.2 |
| | | 14 | 8.0 | ... | ... | ... | 164 | 14.2 |
| | | 18 | 8.0 | ... | ... | 2 | 165 | 14.2 |
| | | 21 | 8.0 | 8.2 | 6.3 | 2 | 163 | 14.3 |
| | | 25 | 8.1 | 8.1 | ... | 3 | 168 | 13.4 |
| | | 28 | 8.1 | 8.1 | ... | 2 | 167 | 14.4 |
| | | Mar. 3 | 8.0 | 8.1 | 6.4 | 2 | 170 | 13.8 |
| | | 8 | 8.0 | ... | ... | 2 | 162 | 13.2 |
| | | 11 | 8.1 | 8.2 | 6.4 | 3 | 165 | 14.4 |
| | | 16 | 8.0 | 8.1 | ... | 2 | 166 | 13.1 |
| | | 20 | 8.0 | 8.1 | 6.4 | 2 | 164 | 13.3 |

(Continued)

Table 8.

**Dissolved Oxygen, pH, and Other Chemical Data For the Lakes Studied, 1939-40.**
(Continued)

| Lake and station | Sampling depth | Date | pH | Aerated pH | Alveol. pH | Phth. alkalinity, p.p.m. | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|---|---|---|---|
| Clear Lake, Sta. 1 (Continued) | Bottom | Mar. 23 | 7.9 | 8.1 | 6.4 | ... | 152 | 12.9 |
| | | 27 | 7.9 | 8.1 | ... | ... | 165 | 11.9 |
| | | 31 | 7.9 | 8.1 | ... | ... | 160 | 12.4 |
| | | Apr. 3 | 7.9 | 8.1 | ... | ... | 158 | 12.0 |
| Sta. 2 | Surface | Dec. 31 | ... | ... | ... | ... | ... | 14.5 |
| | | Jan. 6 | ... | ... | ... | 5 | 158 | 14.7 |
| | | 10 | 8.2 | ... | ... | 2 | 160 | 15.1 |
| | | 13 | 8.0 | ... | ... | 2 | 151 | 14.6 |
| | | 17 | 8.0 | ... | ... | 2 | 160 | 16.0 |
| | | 20 | 8.0 | ... | ... | 5 | 165 | 15.5 |
| | | 24 | 8.1 | 8.2 | 6.4 | 4 | 168 | 15.5 |
| | | 28 | 8.1 | 8.1 | 6.5 | 2 | 165 | 15.5 |
| | | 31 | 8.1 | 8.2 | 6.5 | 2 | 166 | 14.0 |
| | | Feb. 3 | 8.1 | 8.1 | 6.4 | 2 | 168 | 14.0 |
| | | 8 | 8.1 | 8.1 | 6.3 | 2 | 160 | 14.1 |
| | | 11 | 8.0 | ... | ... | 2 | 147 | 13.4 |
| | | 14 | 8.0 | ... | ... | 2 | 158 | 14.1 |
| | | 18 | 8.0 | ... | ... | 2 | 172 | 14.2 |
| | | 21 | 8.0 | 8.1 | 6.3 | ... | 152 | 13.6 |
| | | 25 | 8.0 | 8.1 | ... | 2 | 165 | 14.1 |
| | | 28 | 8.1 | 8.2 | ... | 2 | 168 | 14.9 |
| | | Mar. 3 | 8.0 | 8.1 | 6.3 | 2 | 165 | 13.8 |
| | | 8 | 6.9 | ... | ... | ... | 40 | 14.2 |
| | | 11 | 6.9 | 7.7 | 5.9 | ... | 54 | 13.2 |
| | | 16 | 7.0 | 7.6 | 6.3 | ... | 107 | 15.5 |
| | | 20 | 6.7 | 6.7 | 5.3 | ... | 12 | 11.3 |
| | | 23 | 6.7 | 6.9 | 5.2 | ... | 10 | 7.2 |
| | | 27 | 7.0 | 7.8 | 5.9 | ... | 65 | 9.7 |
| | | 31 | 6.9 | 7.5 | ... | ... | 45 | 10.2 |
| | | Apr. 3 | 6.8 | 6.9 | ... | ... | 28 | 9.9 |
| | 5 feet | Dec. 31 | ... | ... | ... | ... | ... | 14.2 |
| | | Jan. 6 | ... | ... | ... | 1 | 156 | 14.5 |
| | | 10 | 8.2 | ... | ... | 4 | 157 | 14.5 |
| | | 13 | ... | ... | ... | ... | ... | 14.4 |
| | | 17 | ... | ... | ... | ... | ... | 14.7 |
| | | 20 | ... | ... | ... | ... | ... | 14.7 |
| | | 24 | ... | ... | ... | ... | ... | 15.3 |
| | | 28 | ... | ... | ... | ... | ... | 15.1 |
| | | 31 | ... | ... | ... | ... | ... | 13.8 |
| | | Feb. 3 | ... | ... | ... | ... | ... | 13.9 |
| | | 8 | ... | ... | ... | ... | ... | 14.2 |
| | | 11 | ... | ... | ... | ... | ... | 14.2 |
| | | 14 | ... | ... | ... | ... | ... | 13.9 |
| | | 18 | ... | ... | ... | ... | ... | 13.5 |
| | | 21 | ... | ... | ... | ... | ... | 13.7 |
| | | 25 | ... | ... | ... | ... | ... | 13.3 |
| | | 28 | ... | ... | ... | ... | ... | 13.6 |

(Continued)

Table 8.

Dissolved Oxygen, pH, and Other Chemical Data For the Lakes Studied, 1939-40.
(Continued)

| Lake and station | Sampling depth | Date | pH | Aerated pH | Alveol. pH. | Phth. alkalinity p.p.m. | M. O. alkalinity p.p.m. | $O_2$ p.p.m. |
|---|---|---|---|---|---|---|---|---|
| Clear Lake, Sta. 2 (Continued) | 5 feet | Mar. 3 | ... | ... | ... | ... | ... | 12.9 |
| | | 8 | ... | ... | ... | ... | ... | 12.6 |
| | | 11 | 7.8 | 8.1 | 6.4 | ... | 164 | 11.0 |
| | | 16 | ... | ... | ... | ... | ... | 12.2 |
| | | 20 | ... | ... | ... | ... | ... | 11.5 |
| | | 23 | ... | ... | ... | ... | ... | 10.7 |
| | | 27 | ... | ... | ... | ... | ... | 10.5 |
| | | 31 | 7.7 | 8.1 | ... | ... | 164 | 10.8 |
| | | Apr. 3 | 7.6 | 7.9 | ... | ... | 143 | 10.0 |
| | 10 feet | Dec. 31 | ... | ... | ... | ... | ... | 14.1 |
| | | Jan. 6 | ... | ... | ... | 4 | 157 | 14.2 |
| | | 10 | 8.2 | ... | ... | 3 | 157 | 14.0 |
| | | 13 | 8.0 | ... | ... | 2 | 156 | 13.7 |
| | | 17 | 8.0 | ... | ... | 2 | 155 | 13.4 |
| | | 20 | 8.0 | ... | ... | 4 | 158 | 14.2 |
| | | 24 | 8.1 | ... | ... | 2 | 161 | 13.9 |
| | | 28 | 8.1 | ... | ... | 3 | 163 | 14.8 |
| | | 31 | 8.1 | 8.1 | 6.5 | 2 | 165 | 13.2 |
| | | Feb. 3 | 8.0 | 8.1 | 6.4 | ... | 166 | 12.3 |
| | | 8 | 8.0 | 8.1 | 6.4 | ... | 168 | 12.0 |
| | | 11 | 8.0 | ... | ... | ... | 166 | 12.0 |
| | | 14 | 7.8 | ... | ... | ... | 165 | 11.9 |
| | | 18 | 7.8 | ... | ... | ... | 165 | 11.6 |
| | | 21 | 7.8 | 8.1 | 6.3 | ... | 170 | 11.5 |
| | | 25 | 7.7 | 8.0 | ... | ... | 167 | 9.8 |
| | | 28 | 7.7 | 8.0 | ... | ... | 171 | 9.7 |
| | | Mar. 3 | 7.6 | 8.1 | 6.4 | ... | 171 | 10.0 |
| | | 8 | 7.8 | ... | ... | ... | 168 | 9.4 |
| | | 11 | 7.7 | 8.1 | 6.4 | ... | 172 | 7.9 |
| | | 16 | 7.6 | 8.0 | ... | ... | 174 | 9.0 |
| | | 20 | 7.7 | 8.1 | 6.4 | ... | 168 | 9.7 |
| | | 23 | 7.6 | 8.1 | 6.4 | ... | 165 | 8.8 |
| | | 27 | 7.6 | 8.1 | ... | ... | 166 | 8.8 |
| | | 31 | 7.6 | 8.1 | ... | ... | 168 | 9.4 |
| | | Apr. 3 | 7.6 | 8.0 | ... | ... | 171 | 8.1 |
| | 15 feet | Dec. 31 | ... | ... | ... | ... | ... | 14.0 |
| | | Jan. 6 | ... | ... | ... | 5 | 159 | 13.1 |
| | | 10 | 8.2 | ... | ... | 2 | 157 | 12.9 |
| | | 13 | ... | ... | ... | ... | ... | 11.9 |
| | | 17 | ... | ... | ... | ... | ... | 11.9 |
| | | 20 | ... | ... | ... | ... | ... | 12.4 |
| | | 24 | ... | ... | ... | ... | ... | 14.7 |
| | | 28 | ... | ... | ... | ... | ... | 15.5 |
| | | 31 | ... | ... | ... | ... | ... | 11.4 |

(Continued)

Table 8.

Dissolved Oxygen, pH, and Other Chemical Data For the Lakes Studied, 1939-40 (Continued)

| Lake and station | Sampling depth | Date | pH | Aerated pH | Alveol. pH | Phth. alkalinity, p.p.m. | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|---|---|---|---|
| Clear Lake, Sta. 2 (Continued) | 15 feet | Feb. 3 | ... | ... | ... | ... | ... | 10.5 |
| | | 8 | ... | ... | ... | ... | ... | 10.2 |
| | | 11 | ... | ... | ... | ... | ... | 8.6 |
| | | 14 | ... | ... | ... | ... | ... | 8.4 |
| | | 18 | ... | ... | ... | ... | ... | 8.7 |
| | | 21 | ... | ... | ... | ... | ... | 8.2 |
| | | 25 | ... | ... | ... | ... | ... | 6.9 |
| | | 28 | ... | ... | ... | ... | ... | 7.4 |
| | | Mar. 3 | ... | ... | ... | ... | ... | 6.9 |
| | | 8 | ... | ... | ... | ... | ... | 6.5 |
| | | 11 | ... | ... | ... | ... | ... | 7.3 |
| | | 16 | ... | ... | ... | ... | ... | 7.0 |
| | | 20 | ... | ... | ... | ... | ... | 7.8 |
| | | 23 | ... | ... | ... | ... | ... | 8.1 |
| | | 27 | ... | ... | ... | ... | ... | 7.1 |
| | | 31 | ... | ... | ... | ... | ... | 8.4 |
| | | Apr. 3 | ... | ... | ... | ... | ... | 7.4 |
| | Bottom | Dec. 31 | ... | ... | ... | 3 | 156 | 13.7 |
| | | Jan. 6 | ... | ... | ... | 3 | 164 | 12.6 |
| | | 10 | 8.2 | ... | ... | 2 | 160 | 12.3 |
| | | 13 | 8.0 | ... | ... | 2 | 153 | 10.8 |
| | | 17 | 8.0 | ... | ... | ... | 165 | 9.9 |
| | | 20 | 8.0 | ... | ... | ... | 166 | 10.8 |
| | | 24 | 8.0 | 8.1 | 6.3 | ... | 170 | 11.1 |
| | | 28 | 7.8 | 8.1 | 6.5 | ... | 172 | 9.9 |
| | | 31 | 7.7 | 8.1 | 6.4 | ... | 172 | 9.0 |
| | | Feb. 3 | 7.7 | 8.1 | 6.4 | ... | 175 | 8.7 |
| | | 8 | 7.7 | 8.1 | 6.4 | ... | 175 | 6.6 |
| | | 11 | 7.6 | ... | ... | ... | 178 | 7.3 |
| | | 14 | 7.5 | ... | ... | ... | 180 | 8.1 |
| | | 18 | 7.6 | ... | ... | ... | 177 | 5.9 |
| | | 21 | 7.6 | 8.1 | 6.4 | ... | 181 | 7.2 |
| | | 25 | 7.6 | 8.0 | ... | ... | 178 | 4.4 |
| | | 28 | 7.6 | 8.0 | ... | ... | 177 | 7.5 |
| | | Mar. 3 | 7.4 | 8.1 | 6.5 | ... | 182 | 4.8 |
| | | 8 | 7.5 | ... | ... | ... | 182 | 3.6 |
| | | 11 | 7.4 | 8.1 | 6.4 | ... | 181 | 6.1 |
| | | 16 | 7.3 | 7.8 | ... | ... | 182 | 3.9 |
| | | 20 | 7.4 | 8.1 | 6.4 | ... | 182 | 4.0 |
| | | 23 | 7.5 | 8.1 | 6.5 | ... | 177 | 6.6 |
| | | 27 | 7.4 | 8.0 | 6.5 | ... | 181 | 5.8 |
| | | 31 | 7.4 | 8.1 | ... | ... | 178 | 5.6 |
| | | Apr. 3 | 7.3 | 8.0 | ... | ... | 178 | 4.0 |

(Continued)

Table 8.

Dissolved Oxygen, pH, and Other Chemical Data For the Lakes Studied, 1939-40.
(Continued)

| Lake and station | Sampling depth | Date | pH | Aerated pH | Alveol. pH | Phth. alkalinity, p.p.m. | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|---|---|---|---|
| Mud Lake<br>Sta. 1 | Surface | Dec. 31 | ... | ... | ... | 5 | 210 | 17.6 |
| | | Jan. 6 | 7.6 | ... | ... | ... | 232 | 12.3 |
| | | 10 | 8.0 | ... | ... | ... | 226 | 11.6 |
| | | 13 | 8.0 | ... | ... | ... | 190 | 10.8 |
| | | 17 | 7.6 | ... | ... | ... | 195 | 12.4 |
| | | 20 | 8.0 | ... | ... | ... | 245 | 14.5 |
| | | 24 | 7.6 | 8.1 | 6.5 | ... | 213 | 11.2 |
| | | 28 | 7.5 | 8.0 | 6.4 | ... | 220 | 11.6 |
| | | 31 | 7.6 | 8.1 | 6.5 | ... | 212 | 9.8 |
| | | Feb. 3 | 7.5 | 8.1 | 6.6 | ... | 219 | 8.7 |
| | | 8 | 7.6 | 8.1 | 6.4 | ... | 218 | 8.6 |
| | | 11 | 7.4 | ... | ... | ... | 220 | 8.9 |
| | | 14 | 7.4 | ... | ... | ... | 215 | 9.1 |
| | | 18 | 7.5 | ... | ... | ... | 212 | 9.4 |
| | | 21 | 7.6 | 8.1 | 6.5 | ... | 203 | 9.7 |
| | | 25 | 7.4 | 8.0 | ... | ... | 225 | 8.9 |
| | | 28 | 7.6 | 8.1 | ... | ... | 225 | 9.5 |
| | | Mar. 3 | 7.4 | 8.1 | 6.5 | ... | 216 | 9.7 |
| | | 8 | 7.4 | ... | ... | ... | 93 | 12.6 |
| | | 11 | 7.3 | 8.1 | 6.5 | ... | 208 | 9.8 |
| | | 16 | 7.4 | 7.9 | ... | ... | 219 | 10.5 |
| | | 20 | 6.9 | 7.5 | 5.8 | ... | 50 | 10.0 |
| | | 23 | 6.9 | 8.0 | 6.2 | ... | 110 | 9.3 |
| | | 27 | 7.4 | 8.1 | ... | ... | 192 | 9.0 |
| | | 31 | 6.8 | 7.7 | ... | ... | 35 | 8.0 |
| | Bottom | Dec. 31 | ... | ... | ... | 3 | 210 | 16.1 |
| | | Jan. 6 | ... | ... | ... | ... | ... | 9.4 |
| | | 10 | 8.0 | ... | ... | ... | 255 | 8.9 |
| | | 13 | ... | ... | ... | ... | ... | 9.4 |
| | | 17 | ... | ... | ... | ... | ... | 9.0 |
| | | 20 | ... | ... | ... | ... | ... | 10.0 |
| | | 24 | ... | ... | ... | ... | ... | 6.7 |
| | | 28 | 7.3 | 8.1 | 6.5 | ... | 249 | 9.4 |
| | | 31 | ... | ... | ... | ... | ... | 8.1 |
| | | Feb. 3 | ... | ... | ... | ... | ... | 7.5 |
| | | 8 | ... | ... | ... | ... | ... | 6.8 |
| | | 11 | ... | ... | ... | ... | ... | 7.3 |
| | | 14 | ... | ... | ... | ... | ... | 4.5 |
| | | 18 | ... | ... | ... | ... | ... | 7.9 |
| | | 21 | ... | ... | ... | ... | ... | 7.8 |
| | | 25 | ... | ... | ... | ... | ... | 7.9 |
| | | 28 | ... | ... | ... | ... | ... | 8.8 |

(Continued)

Table 8.

Dissolved Oxygen, pH, and Other Chemical Data For the Lakes Studied, 1939-40.
(Continued)

| Lake and station | Sampling depth | Date | pH | Aerated pH | Alveol. pH | Phth. alkalinity, p.p.m. | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|---|---|---|---|
| Mud Lake, Sta. 1 (Continued) | Bottom | Mar. 3 | ... | ... | ... | ... | ... | 5.5 |
| | | 8 | ... | ... | ... | ... | ... | 8.3 |
| | | 11 | 7.3 | 8.1 | 6.5 | ... | 225 | 8.3 |
| | | 16 | 7.4 | 7.8 | ... | ... | 220 | 9.7 |
| | | 20 | 7.0 | 8.0 | 6.3 | ... | 157 | 7.7 |
| | | 23 | ... | ... | ... | ... | ... | 8.1 |
| | | 27 | ... | ... | ... | ... | ... | 8.2 |
| | | 31 | ... | ... | ... | ... | ... | 7.2 |
| Sta. 2 | Surface | Dec. 31 | ... | ... | ... | 3 | 227 | ... |
| | | Jan. 6 | 8.0 | ... | ... | ... | 250 | 12.1 |
| | | 10 | 8.0 | ... | ... | ... | 250 | 9.4 |
| | | 13 | 8.0 | ... | ... | ... | 240 | 9.9 |
| | | 17 | 7.6 | ... | ... | ... | 224 | 9.8 |
| | | 20 | 8.0 | ... | ... | ... | 256 | 12.2 |
| | | 24 | 7.4 | 8.1 | 6.5 | ... | 231 | 4.4 |
| | | 28 | 7.3 | 8.2 | 6.6 | ... | 260 | 3.3 |
| | | 31 | 7.3 | 8.1 | 6.5 | ... | 235 | 1.2 |
| | | Feb. 3 | 7.4 | 8.1 | 6.5 | ... | 225 | 1.5 |
| | | 8 | 7.3 | 8.1 | 6.4 | ... | 198 | 0.8 |
| | | 11 | 7.3 | ... | ... | ... | 200 | 0.9 |
| | | 14 | 7.3 | ... | ... | ... | 200 | 1.7 |
| | | 18 | ... | ... | ... | ... | ... | 1.0 |
| | | 21 | 7.3 | 8.1 | 6.4 | ... | 177 | 2.9 |
| | | 25 | ... | ... | ... | ... | ... | 3.8 |
| | | 28 | 7.3 | 8.0 | ... | ... | 216 | 1.2 |
| | | Mar. 3 | 7.5 | 8.1 | 6.5 | ... | 189 | 9.3 |
| | | 8 | 7.3 | ... | ... | ... | 83 | 12.6 |
| | | 11 | 7.5 | 8.1 | 6.4 | ... | 186 | 7.1 |
| | | 16 | 7.2 | 7.9 | ... | ... | 200 | 12.2 |
| | | 20 | 7.0 | 8.0 | 6.2 | ... | 113 | 13.6 |
| | | 23 | 7.4 | 7.8 | 6.1 | ... | 78 | 9.4 |
| | | 27 | ... | ... | ... | ... | ... | 10.2 |
| | | 31 | 6.9 | 6.9 | ... | ... | 14 | 11.9 |
| Sta. 3 | Surface | Dec. 31 | ... | ... | ... | ... | ... | 17.0 |
| | | Jan. 6 | 8.0 | ... | ... | 2 | 230 | 13.6 |
| | | 10 | 8.0 | ... | ... | ... | 242 | 12.4 |
| | | 13 | 8.0 | ... | ... | ... | 240 | 6.6 |
| | | 17 | 7.6 | ... | ... | ... | 229 | 11.9 |
| | | 20 | 7.8 | ... | ... | ... | 246 | 12.8 |
| | | 24 | ... | ... | ... | ... | ... | 10.5 |
| | | 28 | 7.3 | 8.1 | 6.6 | ... | 286 | 9.4 |
| | | 31 | 7.3 | 8.2 | 6.6 | ... | 275 | 6.8 |

(Continued)

Table 8.

Dissolved Oxygen, pH, and Other Chemical Data For the Lakes Studied, 1939-40.
(Continued)

| Lake and station | Sampling depth | Date | pH | Aerated pH | Alveol. pH | Phth. alkalinity, p.p.m. | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|---|---|---|---|
| Mud Lake, Sta. 3 (Continued) | Surface | Feb. 3 | 7.3 | 8.1 | 6.5 | ... | 268 | 7.0 |
| | | 8 | 7.3 | 8.1 | 6.5 | ... | 227 | 4.6 |
| | | 11 | ... | ... | ... | ... | ... | 3.8 |
| | | 14 | 7.2 | ... | ... | ... | 230 | 1.8 |
| | | 18 | ... | ... | ... | ... | ... | 3.0 |
| | | 21 | ... | ... | ... | ... | ... | 8.0 |
| | | 25 | ... | ... | ... | ... | ... | 2.5 |
| | | 28 | ... | ... | ... | ... | ... | 0.9 |
| | | Mar. 3 | 6.9 | 8.1 | 6.5 | ... | 262 | 2.7 |
| | | 8 | 7.0 | ... | ... | ... | 110 | 9.7 |
| | | 11 | ... | ... | ... | ... | ... | 12.5 |
| | | 16 | 7.0 | 7.8 | ... | ... | 223 | 8.6 |
| | | 20 | 7.0 | 7.8 | 6.1 | ... | 88 | 10.6 |
| | | 23 | 6.9 | 8.0 | 6.3 | ... | 128 | 8.7 |
| | | 27 | ... | ... | ... | ... | ... | 4.5 |
| | | 31 | 6.9 | 7.4 | ... | ... | 66 | 10.0 |
| Sta. 4 | Surface | Dec. 31 | ... | ... | ... | 4 | 208 | 16.3 |
| | | Jan. 6 | 7.8 | ... | ... | ... | 247 | 10.7 |
| | | 10 | 8.0 | ... | ... | ... | 252 | 11.2 |
| | | 13 | 8.0 | ... | ... | ... | 224 | 9.8 |
| | | 17 | 7.6 | ... | ... | ... | 198 | 11.5 |
| | | 20 | 8.0 | ... | ... | ... | 261 | 12.3 |
| | | 24 | 7.6 | 8.1 | 6.5 | ... | 235 | 10.0 |
| | | 28 | 7.5 | 8.1 | 6.5 | ... | 237 | 11.2 |
| | | 31 | 7.6 | 8.1 | 6.6 | ... | 237 | 9.1 |
| | | Feb. 3 | 7.5 | 8.1 | 6.5 | ... | 231 | 7.1 |
| | | 8 | 7.4 | 8.1 | 6.4 | ... | 217 | 6.2 |
| | | 11 | 7.4 | ... | ... | ... | 211 | 6.2 |
| | | 14 | 7.4 | ... | ... | ... | 213 | 6.4 |
| | | 18 | 7.2 | ... | ... | ... | 238 | 4.3 |
| | | 21 | 7.3 | 8.1 | 6.5 | ... | 212 | 6.0 |
| | | 25 | 7.3 | 8.0 | ... | ... | 234 | 4.6 |
| | | 28 | 7.3 | 8.0 | ... | ... | 226 | 5.4 |
| | | Mar. 3 | 7.4 | 8.2 | 6.6 | ... | 216 | 7.8 |
| | | 8 | 7.7 | ... | ... | ... | 104 | 13.1 |
| | | 11 | 8.1 | 8.1 | 6.4 | 2 | 149 | 19.4 |
| | | 16 | 7.7 | 8.1 | ... | ... | 207 | 13.2 |
| | | 20 | 6.8 | 7.0 | 5.6 | ... | 30 | 14.2 |
| | | 23 | 7.0 | 7.8 | 6.2 | ... | 108 | 10.6 |
| | | 27 | 7.4 | 8.0 | ... | ... | 198 | 6.0 |
| | | 31 | 6.9 | 7.3 | ... | ... | 40 | 10.2 |

(Continued)

Table 8.

Dissolved Oxygen, pH, and Other Chemical Data For the Lakes Studied, 1939-40.
(Continued)

| Lake and location | Sampling depth | Date | pH | Aerated pH | Alveol. pH | Phth. alkalinity, p.p.m. | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|---|---|---|---|
| **Mud Lake, Inlet** | **Surface** | Jan. 24 | 7.8 | 8.2 | 6.5 | ... | 205 | 12.5 |
| | | 31 | 7.9 | 8.1 | 6.6 | ... | ... | 10.2 |
| | | Feb. 3 | 7.6 | 8.1 | 6.5 | ... | 213 | 9.5 |
| | | 8 | 7.6 | 8.1 | 6.4 | ... | 210 | 9.4 |
| | | 11 | 7.5 | ... | ... | ... | 217 | 8.6 |
| | | 14 | 7.4 | ... | ... | ... | 216 | 9.3 |
| | | 18 | 7.6 | ... | ... | ... | 220 | 9.7 |
| | | 21 | 7.4 | 8.1 | 6.5 | ... | 218 | 9.6 |
| | | 25 | 7.4 | 8.0 | ... | ... | 224 | 9.5 |
| | | 28 | 7.5 | 8.0 | ... | ... | 220 | 9.8 |
| | | Mar. 3 | 7.5 | 8.1 | 6.5 | ... | 215 | 9.6 |
| | | 8 | 7.4 | ... | ... | ... | 213 | 9.6 |
| | | 11 | 7.4 | 8.2 | 6.5 | ... | 222 | 9.8 |
| | | 16 | 7.5 | 8.0 | ... | ... | 214 | 11.0 |
| | | 20 | 7.1 | 8.1 | 6.5 | ... | 197 | 8.9 |
| | | 23 | 7.2 | 8.1 | 6.5 | ... | 200 | 9.3 |
| | | 27 | 7.3 | 8.0 | ... | ... | 190 | 7.9 |
| | | 31 | 7.3 | 7.8 | ... | ... | 101 | 10.0 |
| **Outlet** | Surface | Jan. 24 | 7.6 | 8.2 | 6.6 | ... | 275 | 11.6 |
| | | 31 | 7.3 | 8.1 | 6.6 | ... | 264 | 7.3 |
| | | Feb. 3 | 7.3 | 8.1 | 6.5 | ... | 260 | 6.1 |
| | | 8 | 7.3 | 8.1 | 6.5 | ... | 240 | 4.8 |
| | | 11 | 7.4 | ... | ... | ... | 261 | 4.0 |
| | | 14 | 7.2 | ... | ... | ... | 225 | 4.4 |
| | | 18 | 7.2 | ... | ... | ... | 250 | 3.2 |
| | | 21 | 7.2 | 8.2 | 6.5 | ... | 213 | 4.1 |
| | | 25 | 7.3 | 8.0 | ... | ... | 237 | 5.4 |
| | | 28 | 7.3 | 8.0 | ... | ... | 237 | 5.3 |
| | | Mar. 3 | 7.3 | 8.1 | 6.6 | ... | 224 | 5.3 |
| | | 8 | 7.3 | ... | ... | ... | 215 | 8.2 |
| | | 11 | 7.2 | 8.1 | 6.5 | ... | 213 | 8.2 |
| | | 16 | 7.0 | 7.8 | ... | ... | 226 | 9.8 |
| | | 20 | 7.0 | 8.0 | 6.5 | ... | 175 | 11.3 |
| | | 23 | 7.0 | 8.1 | 6.5 | ... | 167 | 8.9 |
| | | 27 | 7.2 | 8.0 | ... | ... | 205 | 6.3 |
| **Green Lake, Sta. 1** | Surface | Jan. 10 | 8.2 | ... | ... | 2 | 180 | 15.7 |
| | | 17 | 8.0 | ... | ... | ... | 172 | 14.9 |
| | | 24 | 7.8 | 8.1 | 6.5 | ... | 196 | 12.9 |
| | | 31 | 7.7 | 8.1 | 6.5 | ... | 202 | 12.4 |
| | | Feb. 8 | 7.6 | 8.1 | 6.4 | ... | 192 | 10.3 |
| | | 14 | 7.5 | ... | ... | ... | 157 | 9.6 |
| | | 21 | 7.4 | 8.1 | 6.5 | ... | 196 | 7.0 |
| | | 28 | 7.4 | 8.0 | ... | ... | 214 | 4.7 |

(Continued)

Table 8.

Dissolved Oxygen, pH, and Other Chemical Data For
the Lakes Studied, 1939-40.
(Continued)

| Lake and station | Sampling depth | Date | pH | Aerated pH | Alveol. pH | Phth. alkalinity, p.p.m. | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|---|---|---|---|
| **Green Lake, Sta. 1 (Continued)** | **Surface** | **Mar.** 8 | 7.2 | 8.1 | 6.5 | ... | 187 | 1.8 |
| | | 11 | 7.2 | 8.1 | 6.5 | ... | 187 | 1.5 |
| | | 16 | 7.0 | 7.8 | ... | ... | 201 | 2.7 |
| | | 20 | 6.9 | 7.8 | 6.1 | ... | 90 | 8.1 |
| | | 23 | 6.9 | 8.0 | 6.2 | ... | 104 | 5.5 |
| | | 27 | 7.1 | 8.0 | ... | ... | 200 | 2.7 |
| | | 31 | 6.8 | 6.9 | ... | ... | 26 | 9.7 |
| | | Apr. 3 | 6.8 | 6.8 | ... | ... | 9 | 8.0 |
| | Bottom | Jan. 10 | 8.0 | ... | ... | ... | 186 | 12.4 |
| | | 17 | ... | ... | ... | ... | ... | 10.7 |
| | | 24 | 7.9 | 8.1 | 6.5 | ... | 200 | 12.8 |
| | | 31 | 7.6 | 8.1 | 6.5 | ... | 212 | 10.3 |
| | | Feb. 8 | 7.6 | 8.1 | 6.4 | ... | 210 | 5.3 |
| | | 14 | 7.3 | ... | ... | ... | 206 | 6.8 |
| | | 21 | 7.4 | 8.1 | 6.5 | ... | 211 | 2.8 |
| | | 28 | 7.4 | 8.0 | ... | ... | 217 | 2.7 |
| | | Mar. 8 | 7.2 | 8.2 | 6.5 | ... | 200 | 0.7 |
| | | 11 | 7.3 | 8.1 | 6.5 | ... | 206 | 0.7 |
| | | 16 | 7.1 | 7.8 | ... | ... | 210 | 0.9 |
| | | 20 | 7.0 | 8.2 | 6.5 | ... | 188 | 1.2 |
| | | 23 | 7.1 | 8.1 | 6.5 | ... | 187 | 1.1 |
| | | 27 | 7.2 | 8.1 | ... | ... | 203 | 1.1 |
| | | 31 | 6.9 | 7.8 | ... | ... | 82 | 2.1 |
| | | Apr. 3 | 7.4 | 8.0 | ... | ... | 156 | 4.9 |
| **Open Hole** | **Surface** | **Mar.** 8 | ... | ... | ... | ... | ... | 1.6 |
| | | 11 | 7.3 | 8.1 | 6.5 | ... | 193 | 0.8 |
| | | 16 | 7.0 | 7.8 | ... | ... | 203 | 0.7 |
| **Bog Lake** | **Surface** | Jan. 6 | ... | ... | ... | ... | 7 | 11.6 |
| | | 13 | ... | ... | ... | ... | 6 | 14.0 |
| | | 20 | 6.4 | ... | ... | ... | 8 | 11.3 |
| | | 28 | 5.6 | 6.5 | ... | ... | 5 | 7.1 |
| | | Feb. 3 | 5.5 | 6.8 | ... | ... | 8 | 2.2 |
| | | 11 | 5.6 | ... | ... | ... | 6 | 1.6 |
| | | 18 | 6.5 | ... | ... | ... | 7 | 8.1 |
| | | 25 | 5.5 | 6.7 | ... | ... | 7 | 2.4 |
| | | Mar. 3 | 5.5 | 6.8 | ... | ... | 5 | 0.6 |
| | | 11 | 5.8 | 6.8 | ... | ... | 6 | 10.5 |
| | | 16 | 5.9 | 6.8 | ... | ... | 7 | 15.0 |
| | | 23 | 6.0 | 6.8 | ... | ... | 7 | 14.4 |
| | | 27 | 6.1 | 6.8 | ... | ... | 7 | 15.3 |

(Continued)

Table 8.

Dissolved Oxygen, pH, and Other Chemical Data For the Lakes Studied, 1939-40.
(Continued)

| Lake and station | Sampling depth | Date | pH | Aerated pH | Alveol. pH | Phth. alkalinity, p.p.m. | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|---|---|---|---|
| Bog Lake (Continued) | 1 foot | Jan. 13 | ... | ... | ... | ... | 8 | 12.2 |
| | | 20 | 5.6 | ... | ... | ... | 5 | 11.0 |
| | | 28 | 5.7 | 6.5 | ... | ... | 5 | 5.9 |
| | | Feb. 3 | 5.5 | 6.8 | ... | ... | 5 | 2.0 |
| | | 11 | 5.6 | ... | ... | ... | 6 | 0.5 |
| | | 18 | 6.2 | ... | ... | ... | 5 | 4.7 |
| | | 25 | 5.6 | 6.8 | ... | ... | 5 | 2.1 |
| | | Mar. 3 | 5.6 | 6.8 | ... | ... | 5 | 0.2 |
| | | 11 | 5.9 | 6.8 | ... | ... | 5 | 10.4 |
| | | 16 | 5.9 | 6.7 | ... | ... | 6 | 14.8 |
| | | 23 | 6.0 | 6.6 | ... | ... | 6 | 14.2 |
| | | 27 | 6.1 | 6.7 | ... | ... | 5 | 14.5 |
| | 2 feet | Jan. 6 | ... | ... | ... | ... | 9 | 4.4 |
| | | 13 | ... | ... | ... | ... | 6 | 8.6 |
| | | 20 | 5.4 | ... | ... | ... | 5 | 3.3 |
| | | 28 | 5.6 | 6.5 | ... | ... | 6 | 3.2 |
| | | Feb. 3 | 5.5 | 6.7 | ... | ... | 5 | 0.5 |
| | | 11 | 5.8 | ... | ... | ... | 5 | 0.2 |
| | | 18 | 6.0 | ... | ... | ... | 5 | 3.1 |
| | | 25 | 5.5 | 6.7 | ... | ... | 5 | 1.0 |
| | | Mar. 3 | 5.5 | 6.8 | ... | ... | 5 | 0.2 |
| | | 11 | 5.7 | 6.8 | ... | ... | 6 | 5.2 |
| | | 16 | 5.7 | 6.8 | ... | ... | 6 | 6.5 |
| | | 23 | 5.8 | 6.7 | ... | ... | 6 | 8.3 |
| | | 27 | 5.8 | 6.9 | ... | ... | 5 | 3.4 |
| | 3 feet | Jan. 13 | ... | ... | ... | ... | 5 | 4.8 |
| | | 20 | ... | ... | ... | ... | ... | 4.9 |
| | | 28 | 5.5 | ... | ... | ... | 5 | 1.0 |
| | | Feb. 3 | 5.5 | 6.8 | ... | ... | 8 | 0.2 |
| | | 11 | 5.8 | ... | ... | ... | 5 | 0.5 |
| | | 18 | 6.0 | ... | ... | ... | 5 | 0.9 |
| | | 25 | 5.6 | 6.8 | ... | ... | 5 | 0.2 |
| | | Mar. 3 | 5.6 | 6.8 | ... | ... | 6 | 0.0 |
| | | 11 | 5.7 | 6.8 | ... | ... | 6 | 1.2 |
| | | 16 | 5.5 | 6.7 | ... | ... | 6 | 2.8 |
| | | 23 | 5.8 | 6.6 | ... | ... | 6 | 3.9 |
| | | 27 | 5.6 | 6.8 | ... | ... | 6 | 1.9 |

(Continued)

Table 8.

Dissolved Oxygen, pH, and Other Chemical Data For the Lakes Studied, 1939-40.
(Continued)

| Lake and station | Sampling depth | Date | pH | Aerated pH | Alveol. pH | Phth. alkalinity, p.p.m. | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|---|---|---|---|
| Bog Lake (Continued) | 4 feet | Jan. 6 | ... | ... | ... | ... | 9 | 1.0 |
| | | 13 | ... | ... | ... | ... | 6 | 0.8 |
| | | 20 | 5.4 | ... | ... | ... | 6 | 3.3 |
| | | 28 | 5.5 | ... | ... | ... | 6 | 0.5 |
| | | Feb. 3 | 5.5 | 6.8 | ... | ... | 6 | 0.3 |
| | | 11 | 5.7 | ... | ... | ... | 5 | 0.0 |
| | | 18 | 5.9 | ... | ... | ... | 7 | 0.9 |
| | | 25 | 5.6 | 6.8 | ... | ... | 6 | 1.2 |
| | | Mar. 3 | 5.5 | 6.9 | ... | ... | 9 | 0.0 |
| | | 11 | 5.7 | 6.8 | ... | ... | 7 | 2.2 |
| | | 16 | 5.6 | 6.7 | ... | ... | 7 | 2.0 |
| | | 23 | 5.8 | 6.7 | ... | ... | 8 | 2.1 |
| | | 27 | 5.8 | 6.9 | ... | ... | 8 | 1.9 |
| | 5 feet | Jan. 6 | ... | ... | ... | ... | 10 | 0.4 |
| | | 13 | ... | ... | ... | ... | 6 | 0.6 |
| | | 20 | 5.4 | ... | ... | ... | 5 | 0.7 |
| | | 28 | 5.5 | 6.5 | ... | ... | 6 | 0.6 |
| | | Feb. 3 | 5.5 | 6.8 | ... | ... | 6 | 0.0 |
| | | 11 | 5.6 | ... | ... | ... | 5 | 0.0 |
| | | 18 | 5.9 | ... | ... | ... | 7 | 0.3 |
| | | 25 | 5.6 | 6.7 | ... | ... | 7 | 0.6 |
| | | Mar. 3 | 5.6 | 6.8 | ... | ... | 8 | 0.0 |
| | | 11 | 5.7 | 6.9 | ... | ... | 11 | 0.0 |
| | | 16 | 5.6 | 6.8 | ... | ... | 12 | 0.0 |
| | | 23 | 5.6 | 6.8 | ... | ... | 11 | 0.6 |
| | | 27 | 5.7 | 6.8 | ... | ... | 12 | 0.2 |
| Pasinski's Pond, Sta. 1 | Surface | Feb. 10 | 7.3 | 7.8 | ... | ... | 151 | 0.7 |
| | | 12 | 7.3 | ... | ... | ... | ... | 1.0 |
| | | 14 | 7.3 | 8.0 | 6.4 | ... | 176 | 0.3 |
| | | 17 | 7.3 | ... | ... | ... | ... | 1.0 |
| | | 19 | 7.3 | ... | ... | ... | ... | 0.7 |
| | | 22 | 7.3 | ... | ... | ... | ... | 1.6 |
| | | 26 | 7.3 | ... | ... | ... | ... | 0.3 |
| | | 28 | ... | ... | ... | ... | ... | 0.3 |
| | | Mar. 1 | 7.2 | ... | ... | ... | ... | 1.4 |
| | | 4 | 7.0 | ... | ... | ... | ... | 0.0 |
| | | 8 | 6.9 | ... | ... | ... | ... | 2.0 |
| | | 10 | ... | ... | ... | ... | ... | 1.0 |
| | | 13 | 6.9 | ... | ... | ... | ... | 0.3 |
| | | 15 | 7.0 | ... | ... | ... | ... | 1.1 |
| | | 18 | 7.1 | ... | ... | ... | ... | 1.3 |
| | | 22 | 6.9 | ... | ... | ... | ... | 1.1 |
| | | 25 | 6.9 | ... | ... | ... | ... | 1.7 |
| | | 29 | 6.9 | 7.2 | 5.8 | ... | 37 | 8.5 |
| | | Apr. 1 | 6.7 | ... | ... | ... | 22 | 7.8 |

(Continued)

Table 8.

Dissolved Oxygen, pH, and Other Chemical Data For the Lakes Studied, 1939-40. (Continued)

| Lake and station | Sampling depth | Date | pH | Aerated pH | Alvool. pH | Phth. alkalinity, p.p.m. | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|---|---|---|---|
| Pasinski's Pond Sta. 15 | Surface | Dec. 23 | ... | ... | ... | ... | ... | 15.3 |
| | | Jan. 7 | ... | ... | ... | 26 | 140 | 19.1 |
| | | 14 | ... | ... | ... | 6 | 73 | 13.7 |
| | | 21 | ... | ... | ... | 9 | 147 | 14.9 |
| | | 29 | 8.1 | 8.1 | 6.4 | 2 | 150 | 9.9 |
| | | Feb. 4 | 7.4 | 8.0 | 6.3 | ... | 155 | 3.7 |
| | | 10 | 7.4 | 7.7 | 6.6 | ... | 155 | 0.5 |
| | | 12 | 7.3 | ... | ... | ... | ... | 0.8 |
| | | 14 | 7.3 | 8.1 | 6.4 | ... | 156 | 1.6 |
| | | 17 | 7.4 | ... | ... | ... | ... | 2.2 |
| | | 19 | 7.4 | ... | ... | ... | ... | 2.4 |
| | | 22 | ... | ... | ... | ... | ... | 1.0 |
| | | 26 | 7.3 | ... | ... | ... | ... | 1.3 |
| | | 28 | ... | ... | ... | ... | ... | 0.6 |
| | | Mar. 1 | 7.2 | ... | ... | ... | ... | 0.6 |
| | | 4 | 6.9 | ... | ... | ... | ... | 0.2 |
| | | 8 | 6.9 | ... | ... | ... | ... | 3.3 |
| | | 10 | 6.9 | 8.0 | 6.4 | ... | 153 | 0.9 |
| | | 13 | 6.9 | ... | ... | ... | ... | 0.9 |
| | | 15 | 6.9 | ... | ... | ... | ... | 0.3 |
| | | 18 | 7.0 | 7.8 | 6.4 | ... | 153 | 0.6 |
| | | 22 | 6.9 | ... | ... | ... | ... | 2.0 |
| | | 25 | 6.9 | ... | ... | ... | ... | 1.7 |
| | | 29 | 6.9 | 7.9 | 6.4 | ... | 87 | 5.9 |
| | | Apr. 1 | 6.8 | 6.9 | ... | ... | 15 | 8.1 |
| | | 3 | 6.9 | 7.6 | ... | ... | 38 | 6.9 |
| | Bottom | Dec. 23 | 8.4 | ... | ... | 20 | 115 | 16.1 |
| | | Jan. 7 | ... | ... | ... | 20 | 138 | 17.3 |
| | | 14 | ... | ... | ... | 13 | 125 | 14.9 |
| | | 21 | ... | ... | ... | 10 | 147 | 14.1 |
| | | 29 | 8.0 | 8.1 | 6.4 | ... | 148 | 7.0 |
| | | Feb. 4 | 7.4 | 8.0 | 6.3 | ... | 156 | 3.3 |
| | | 10 | 7.4 | ... | ... | ... | ... | 0.5 |
| | | 12 | ... | ... | ... | ... | ... | 2.2 |
| | | 14 | ... | ... | ... | ... | ... | 0.8 |
| | | 17 | 7.3 | ... | ... | ... | ... | 0.8 |
| | | 19 | 7.3 | ... | ... | ... | ... | 0.5 |
| | | 22 | 7.2 | ... | ... | ... | ... | 0.7 |
| | | 26 | 7.1 | ... | ... | ... | ... | 0.2 |
| | | 28 | ... | ... | ... | ... | ... | 0.2 |

(Continued)

Table 8.

Dissolved Oxygen, pH, and Other Chemical Data For the Lakes Studied, 1939-40.
(Continued)

| Lake and station | Sampling depth | Date | pH | Aerated pH | Alveol. pH | Phth. alkalinity, p.p.m. | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|---|---|---|---|
| **Pasinski's Pond, Sta. 15 (Continued)** | **Bottom** | **Mar.** 1 | 7.0 | ... | ... | ... | ... | 0.0 |
| | | 4 | 6.9 | ... | ... | ... | ... | 0.1 |
| | | 8 | 6.9 | ... | ... | ... | ... | 0.1 |
| | | 10 | 6.9 | 8.1 | 6.5 | ... | 192 | 0.2 |
| | | 13 | 6.9 | ... | ... | ... | ... | 0.0 |
| | | 15 | 6.9 | 8.1 | 6.5 | ... | 193 | 0.0 |
| | | 18 | 6.9 | 7.9 | 6.5 | ... | 198 | 0.2 |
| | | 22 | 6.9 | ... | ... | ... | ... | 0.2 |
| | | 25 | 6.9 | ... | ... | ... | ... | 0.1 |
| | | 29 | 6.9 | 8.1 | 6.5 | ... | 168 | 0.0 |
| | | **Apr.** 1 | 6.9 | 7.8 | ... | ... | 158 | 0.0 |
| | | 3 | 6.9 | 7.8 | ... | ... | 165 | 1.6 |
| **Sta. 20** | **Surface** | **Feb.** 10 | ... | ... | ... | ... | ... | 1.0 |
| | | 12 | ... | ... | ... | ... | ... | 0.8 |
| | | 14 | ... | ... | ... | ... | ... | 0.4 |
| | | 17 | ... | ... | ... | ... | ... | 0.4 |
| | | 19 | ... | ... | ... | ... | ... | 1.5 |
| | | 22 | ... | ... | ... | ... | ... | 1.4 |
| | | 26 | ... | ... | ... | ... | ... | 1.4 |
| | | 28 | ... | ... | ... | ... | ... | 1.3 |
| | | **Mar.** 1 | ... | ... | ... | ... | ... | 0.7 |
| | | 4 | ... | ... | ... | ... | ... | 0.9 |
| | | 8 | ... | ... | ... | ... | ... | 3.5 |
| | | 10 | ... | ... | ... | ... | ... | 0.4 |
| | | 13 | ... | ... | ... | ... | ... | 0.4 |
| | | 15 | ... | ... | ... | ... | ... | 0.2 |
| | | 18 | ... | ... | ... | ... | ... | 1.4 |
| | | 22 | ... | ... | ... | ... | ... | 0.7 |
| | | 25 | ... | ... | ... | ... | ... | 1.2 |
| | | 29 | ... | ... | ... | ... | ... | 2.9 |
| | | **Apr.** 1 | ... | ... | ... | ... | ... | 7.1 |
| **Sta. 24** | **Surface** | **Feb.** 10 | 7.3 | ... | ... | ... | ... | 1.4 |
| | | 12 | 7.4 | ... | ... | ... | ... | 4.8 |
| | | 14 | ... | ... | ... | ... | ... | 1.9 |
| | | 17 | 7.3 | ... | ... | ... | ... | 0.7 |
| | | 19 | 7.3 | ... | ... | ... | ... | 1.2 |
| | | 22 | 7.3 | ... | ... | ... | ... | 1.0 |
| | | 26 | 7.2 | ... | ... | ... | ... | 0.3 |
| | | 28 | ... | ... | ... | ... | ... | 0.3 |
| | | **Mar.** 1 | 7.3 | ... | ... | ... | ... | 0.5 |
| | | 4 | 7.0 | ... | ... | ... | ... | 0.7 |
| | | 8 | 6.9 | ... | ... | ... | ... | 3.4 |
| | | 10 | 6.9 | ... | ... | ... | ... | 1.0 |
| | | 13 | 6.9 | ... | ... | ... | ... | 0.4 |
| | | 15 | 6.9 | ... | ... | ... | ... | 0.4 |

(Continued)

Table 8.

Dissolved Oxygen, pH, and Other Chemical Data For the Lakes Studied, 1939-40.
(Continued)

| Lake and station | Sampling depth | Date | pH | Aerated pH | Alveol. pH | Phth. alkalinity, p.p.m. | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|---|---|---|---|
| Pasinski's Pond, Sta. 24 (Continued) | Surface | Mar. 18 | 6.9 | ... | ... | ... | ... | 0.6 |
| | | 22 | 6.9 | ... | ... | ... | ... | 1.1 |
| | | 25 | 6.9 | ... | ... | ... | ... | 0.9 |
| | | 29 | 6.8 | ... | ... | ... | ... | 9.9 |
| | | Apr. 1 | 6.8 | ... | ... | ... | ... | 8.3 |
| | | 3 | ... | ... | ... | ... | ... | 7.1 |
| Sta. 26 | Surface | Feb. 10 | 7.5 | 7.8 | ... | ... | 156 | 3.6 |
| | | 12 | 7.6 | ... | ... | ... | ... | 6.5 |
| | | 14 | 7.3 | 8.1 | 6.4 | ... | 160 | 1.5 |
| | | 17 | 7.3 | ... | ... | ... | ... | 1.7 |
| | | 19 | 7.3 | ... | ... | ... | ... | 0.6 |
| | | 22 | 7.3 | ... | ... | ... | ... | 0.7 |
| | | 26 | 7.1 | ... | ... | ... | ... | 0.4 |
| | | 28 | ... | ... | ... | ... | ... | 0.6 |
| | | Mar. 1 | 7.0 | ... | ... | ... | ... | 1.1 |
| | | 4 | 6.9 | ... | ... | ... | ... | 1.2 |
| | | 8 | 6.8 | ... | ... | ... | ... | 5.8 |
| | | 10 | 6.8 | 7.7 | 6.0 | ... | 62 | 4.0 |
| | | 13 | 6.8 | ... | ... | ... | ... | 1.0 |
| | | 15 | 6.9 | ... | ... | ... | ... | 0.3 |
| | | 18 | 6.9 | ... | ... | ... | ... | 1.2 |
| | | 22 | 6.8 | ... | ... | ... | ... | 5.1 |
| | | 25 | 6.9 | ... | ... | ... | ... | 1.0 |
| | | 29 | 6.8 | 6.9 | 5.6 | ... | 20 | 10.7 |
| | | Apr. 1 | 6.7 | 6.9 | ... | ... | 17 | 8.1 |
| | | 3 | 6.9 | 7.6 | ... | ... | 58 | 5.9 |
| | Bottom | Feb. 12 | 7.4 | ... | ... | ... | ... | 1.9 |
| | | 14 | ... | ... | ... | ... | ... | 1.0 |
| | | 17 | 7.2 | ... | ... | ... | ... | 0.5 |
| | | 19 | 7.3 | ... | ... | ... | ... | 0.1 |
| | | 22 | 7.3 | ... | ... | ... | ... | 0.4 |
| | | 26 | 7.1 | ... | ... | ... | ... | 0.0 |
| | | 28 | ... | ... | ... | ... | ... | 0.0 |
| | | Mar. 1 | 7.0 | ... | ... | ... | ... | 0.4 |
| | | 4 | 6.9 | ... | ... | ... | ... | 0.0 |
| | | 8 | 6.8 | ... | ... | ... | ... | 0.0 |
| | | 10 | 6.8 | 8.1 | 6.5 | ... | 195 | 0.1 |
| | | 13 | 6.8 | ... | ... | ... | ... | 0.0 |
| | | 15 | 6.9 | ... | ... | ... | ... | 0.0 |
| | | 18 | 6.8 | ... | ... | ... | ... | 0.0 |
| | | 22 | 6.7 | ... | ... | ... | ... | 0.0 |
| | | 25 | 6.7 | ... | ... | ... | ... | 0.1 |
| | | 29 | 6.7 | 7.9 | 6.5 | ... | 184 | 0.1 |
| | | Apr. 1 | 6.6 | ... | ... | ... | ... | 0.2 |
| | | 3 | 6.6 | 7.6 | 6.4 | ... | 190 | 0.2 |

(Continued)

Table 8.

Dissolved Oxygen, pH, and Other Chemical Data For the Lakes Studied, 1939-40. (Continued)

| Lake and station | Sampling depth | Date | pH | Aerated pH | Alveol. pH | Phth. alkalinity, p.p.m. | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|---|---|---|---|
| Pasinski's Pond, Sta. 27 | Surface | Feb. 12 | 8.5 | ... | ... | ... | ... | 12.3 |
| | | 14 | ... | ... | ... | ... | ... | 2.4 |
| | | 17 | 7.3 | ... | ... | ... | ... | 0.7 |
| | | 19 | 7.3 | ... | ... | ... | ... | 0.9 |
| | | 22 | 7.3 | ... | ... | ... | ... | 0.9 |
| | | 26 | 7.1 | ... | ... | ... | ... | 0.6 |
| | | 28 | ... | ... | ... | ... | ... | 1.3 |
| | | Mar. 1 | 7.0 | ... | ... | ... | ... | 1.2 |
| | | 4 | 6.8 | ... | ... | ... | ... | 4.4 |
| | | 8 | 6.8 | ... | ... | ... | ... | 9.4 |
| | | 10 | 6.8 | 7.8 | 6.3 | ... | 109 | 5.4 |
| | | 13 | 6.8 | ... | ... | ... | ... | 1.0 |
| | | 15 | 6.9 | ... | ... | ... | ... | 0.9 |
| | | 18 | 6.9 | ... | ... | ... | ... | 2.2 |
| | | 22 | 6.8 | ... | ... | ... | ... | 5.0 |
| | | 25 | 6.9 | ... | ... | ... | ... | 1.2 |
| | | 29 | 6.7 | ... | ... | ... | ... | 11.2 |
| | | Apr. 1 | 6.9 | ... | ... | ... | ... | 8.5 |
| | | 3 | 6.9 | 7.6 | ... | ... | 65 | 4.0 |
| Open Hole | Surface | Feb. 19 | 7.3 | ... | ... | ... | ... | 0.9 |
| | | 22 | 7.3 | ... | ... | ... | ... | 0.2 |
| | | Mar. 1 | 7.2 | ... | ... | ... | ... | 2.6 |
| | | 4 | 6.9 | ... | ... | ... | ... | 0.7 |
| | | 8 | 6.9 | ... | ... | ... | ... | 1.4 |
| Richmond L., Sta. 1 | Surface | Feb. 18 | ... | ... | ... | ... | ... | 1.9 |
| | | 22 | 6.9 | 8.1 | 6.4 | ... | 150 | 0.7 |
| | | Mar. 4 | 6.9 | ... | ... | ... | ... | 0.6 |
| | | 9 | ... | ... | ... | ... | ... | 2.8 |
| | | 18 | 6.9 | 8.1 | 6.4 | ... | 151 | 1.0 |
| | | 22 | 6.9 | 7.8 | 6.3 | ... | 140 | 2.3 |
| | | 29 | 6.9 | 7.8 | 6.2 | ... | 113 | 4.3 |
| | Bottom | Feb. 18 | ... | ... | ... | ... | ... | 0.3 |
| | | 22 | ... | ... | ... | ... | ... | 0.1 |
| | | Mar. 4 | 6.9 | 8.0 | 6.5 | ... | 160 | 0.2 |
| | | 9 | 6.9 | 8.0 | 6.4 | ... | 156 | 0.1 |
| | | 18 | 6.9 | ... | ... | ... | ... | 0.0 |
| | | 22 | 6.9 | 8.0 | 6.5 | ... | 157 | 0.3 |
| | | 29 | 6.9 | 8.1 | 6.5 | ... | 148 | 0.0 |
| Open Hole | Surface | Feb. 18 | 6.9 | 8.1 | 6.4 | ... | 153 | 0.4 |
| | | 22 | 6.9 | ... | ... | ... | 151 | 1.1 |
| | | Mar. 4 | 6.9 | ... | ... | ... | ... | 1.0 |
| | | 9 | 6.9 | ... | ... | ... | 156 | 0.1 |

Table 9.

Dissolved Oxygen, pH, and Other Chemical Data For the Lakes Studied, 1940-41.

| Lake and station | Sampling depth | Date | pH | Aerated pH | Alveol. pH | $CO_2$, p.p.m. | Phth. alkalinity, p.p.m. | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|---|---|---|---|---|
| Clear Lake, Sta. 1 | Surface | Dec. 15 | 8.1 | ... | ... | ... | 3 | 152 | 14.5 |
| | | 21 | 7.7 | ... | ... | 2 | ... | 91 | 14.8 |
| | | Jan. 12 | 8.3 | ... | ... | ... | 10 | 142 | 12.8 |
| | | 23 | 8.1 | ... | ... | ... | 3 | 145 | ... |
| | | 30 | 8.1 | ... | ... | ... | 3 | 145 | 14.2 |
| | | Feb. 6 | 8.1 | ... | ... | ... | 2 | 140 | 13.7 |
| | | 14 | 8.1 | ... | ... | ... | 2 | 123 | 13.2 |
| | | 18 | ... | ... | ... | ... | ... | ... | 12.3 |
| | | 23 | 7.8 | ... | ... | 1 | ... | 112 | 15.6 |
| | | Mar. 2 | 8.2 | ... | ... | ... | 6 | 141 | 14.4 |
| | | 8 | 8.1 | ... | ... | ... | 5 | 122 | 13.8 |
| | | 13 | 7.7 | ... | ... | 2 | ... | 25 | 7.0 |
| | Bottom | Dec. 15 | 8.2 | ... | ... | ... | 4 | 148 | 14.3 |
| | | 21 | 8.1 | ... | ... | ... | 2 | 140 | 13.9 |
| | | Jan. 12 | 8.1 | ... | ... | ... | 3 | 133 | 12.7 |
| | | 23 | 8.0 | ... | ... | ... | ... | 143 | 14.1 |
| | | 30 | 8.1 | ... | ... | ... | 3 | 145 | 13.8 |
| | | Feb. 6 | 8.1 | ... | ... | ... | 3 | 148 | 14.1 |
| | | 14 | 8.2 | ... | ... | ... | 5 | 152 | 14.0 |
| | | 23 | 8.1 | ... | ... | ... | 3 | 150 | 13.9 |
| | | Mar. 2 | 8.2 | ... | ... | ... | 6 | 148 | 14.7 |
| | | 8 | 8.2 | ... | ... | ... | 6 | 145 | 14.8 |
| | | 13 | 8.2 | ... | ... | ... | 4 | 146 | 15.2 |
| Sta. 2a | Surface | Dec. 15 | 8.2 | ... | ... | ... | 3 | 142 | 14.2 |
| | | 21 | 7.9 | ... | ... | 1 | ... | 103 | 14.5 |
| | | Jan. 12 | 8.2 | ... | ... | ... | 5 | 140 | 13.2 |
| | | 23 | 8.1 | ... | ... | ... | 3 | 144 | 14.2 |
| | | 30 | 8.1 | ... | ... | ... | 3 | 143 | 14.3 |
| | | Feb. 6 | 8.1 | ... | ... | ... | 4 | 140 | 13.8 |
| | | 14 | 8.1 | ... | ... | ... | 3 | 115 | 12.5 |
| | | 23 | 8.1 | ... | ... | ... | 1 | 130 | 14.7 |
| | | Mar. 2 | 7.8 | ... | ... | ... | ... | 117 | 13.5 |
| | | 8 | 7.7 | ... | ... | 1 | ... | 63 | 15.4 |
| | | 13 | 7.6 | ... | ... | 2 | ... | 43 | 9.6 |
| | 5 feet | Dec. 15 | ... | ... | ... | ... | ... | ... | 14.0 |
| | | 21 | ... | ... | ... | ... | ... | ... | 13.5 |
| | | Jan. 12 | 8.1 | ... | ... | ... | 4 | 136 | 12.5 |
| | | 23 | ... | ... | ... | ... | ... | ... | 14.1 |
| | | 30 | ... | ... | ... | ... | ... | ... | 14.1 |
| | | Feb. 6 | ... | ... | ... | ... | ... | ... | 13.9 |
| | | 14 | ... | ... | ... | ... | ... | ... | 14.1 |
| | | 23 | ... | ... | ... | ... | ... | ... | 13.8 |
| | | Mar. 2 | ... | ... | ... | ... | ... | ... | 14.4 |
| | | 8 | ... | ... | ... | ... | ... | ... | 14.1 |
| | | 13 | ... | ... | ... | ... | ... | ... | 14.8 |

(Continued)

Table 9.

Dissolved Oxygen, pH, and Other Chemical Data For the Lakes Studied, 1940-41.
(Continued)

| Lake and station | Sampling depth | Date | pH | Aerated pH | Alveol. pH | $CO_2$, p.p.m. | Phth. alkalinity, p.p.m. | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|---|---|---|---|---|
| Clear Lake, Sta. 2a, (Continued) | 10 feet | Dec. 15 | 8.2 | ... | ... | ... | 3 | 142 | 13.9 |
| | | 21 | 8.1 | ... | ... | ... | 2 | 142 | 13.6 |
| | | Jan. 12 | 8.2 | ... | ... | ... | 6 | 138 | 13.1 |
| | | 23 | 8.0 | ... | ... | ... | 2 | 144 | 14.1 |
| | | 30 | 8.1 | ... | ... | ... | 3 | 144 | 14.3 |
| | | Feb. 6 | 8.1 | ... | ... | ... | 3 | 146 | 14.1 |
| | | 14 | 8.1 | ... | ... | ... | 4 | 152 | 14.2 |
| | | 23 | 8.1 | ... | ... | ... | 3 | 153 | 13.7 |
| | | Mar. 2 | 8.1 | ... | ... | ... | 4 | 149 | 14.2 |
| | | 8 | 8.2 | ... | ... | ... | 4 | 150 | 14.1 |
| | | 13 | 8.2 | ... | ... | ... | 5 | 147 | 15.6 |
| | 15 feet | Dec. 15 | ... | ... | ... | ... | ... | ... | 14.2 |
| | | 21 | ... | ... | ... | ... | ... | ... | 12.0 |
| | | Jan. 12 | 8.1 | ... | ... | ... | 4 | 141 | 12.2 |
| | | 23 | ... | ... | ... | ... | ... | ... | 14.5 |
| | | 30 | ... | ... | ... | ... | ... | ... | 13.8 |
| | | Feb. 6 | ... | ... | ... | ... | ... | ... | 13.7 |
| | | 14 | ... | ... | ... | ... | ... | ... | 13.4 |
| | | 23 | ... | ... | ... | ... | ... | ... | 13.5 |
| | | Mar. 2 | ... | ... | ... | ... | ... | ... | 13.3 |
| | | 8 | ... | ... | ... | ... | ... | ... | 14.4 |
| | | 13 | ... | ... | ... | ... | ... | ... | 15.6 |
| | 20 feet | Dec. 15 | 8.0 | ... | ... | ... | 2 | 148 | 12.7 |
| | | 21 | 8.0 | ... | ... | ... | ... | 152 | 11.0 |
| | | Jan. 12 | 8.2 | ... | ... | ... | 5 | 139 | 11.3 |
| | | 23 | 7.7 | ... | ... | 3 | ... | 146 | 10.0 |
| | | 30 | 8.0 | 8.1 | 6.5 | ... | 2 | 147 | 11.5 |
| | | Feb. 6 | 7.8 | ... | ... | 2 | ... | 153 | 11.2 |
| | | 14 | 7.8 | ... | ... | 3 | ... | 163 | 10.2 |
| | | 23 | 8.0 | ... | ... | ... | ... | 161 | 10.0 |
| | | Mar. 2 | 7.8 | ... | ... | 4 | ... | 157 | 10.4 |
| | | 8 | 7.8 | ... | ... | 1 | ... | 153 | 12.5 |
| | | 13 | 8.1 | ... | ... | ... | 3 | 152 | 14.1 |
| | 25 feet | Dec. 15 | ... | ... | ... | ... | ... | ... | 6.4 |
| | | 21 | ... | ... | ... | ... | ... | ... | 9.2 |
| | | Jan. 12 | 8.0 | ... | ... | ... | 2 | 142 | 10.9 |
| | | 23 | ... | ... | ... | ... | ... | ... | 3.4 |
| | | 30 | ... | ... | ... | ... | ... | ... | 9.6 |
| | | Feb. 6 | ... | ... | ... | ... | ... | ... | 3.7 |
| | | 14 | ... | ... | ... | ... | ... | ... | 9.9 |
| | | 23 | ... | ... | ... | ... | ... | ... | 8.0 |
| | | Mar. 2 | ... | ... | ... | ... | ... | ... | 9.7 |
| | | 8 | ... | ... | ... | ... | ... | ... | 10.6 |
| | | 13 | ... | ... | ... | ... | ... | ... | 11.9 |

(Continued)

Table 9.

Dissolved Oxygen, pH, and Other Chemical Data For the Lakes Studied, 1940-41.
(Continued)

| Lake and station | Sampling depth | Date | pH | Aerated pH | Alveol. pH | $CO_2$, p.p.m. | Phth. alkalinity, p.p.m. | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|---|---|---|---|---|
| Clear Lake, Sta. 2a, (Continued) | Bottom | Dec. 15 | 7.6 | 8.0 | ... | ... | ... | 158 | 4.7 |
| | | 21 | 7.7 | ... | ... | 3 | ... | 157 | 5.7 |
| | | Jan. 12 | 7.6 | ... | ... | 2 | ... | 144 | 6.4 |
| | | 23 | 7.6 | ... | ... | 3 | ... | 157 | 7.8 |
| | | 30 | 7.6 | 8.1 | 6.5 | 3 | ... | 157 | 7.9 |
| | | Feb. 6 | 7.5 | ... | ... | 4 | ... | 163 | 6.7 |
| | | 14 | 7.6 | ... | ... | 3 | ... | 170 | 7.0 |
| | | 23 | 7.7 | ... | ... | 3 | ... | 175 | 4.5 |
| | | Mar. 2 | 7.4 | ... | ... | 3 | ... | 167 | 4.4 |
| | | 8 | 7.5 | ... | ... | 4 | ... | 169 | 5.4 |
| | | 13 | 7.6 | ... | ... | 4 | ... | 168 | 5.3 |
| Mud Lake, Sta. 1 | Surface | Dec. 10 | 7.4 | 8.0 | ... | ... | ... | 175 | ... |
| | | 19 | 7.6 | 8.0 | 6.1 | ... | ... | 127 | 12.3 |
| | | Jan. 7 | 7.7 | ... | ... | 3 | ... | 170 | 14.3 |
| | | 14 | 7.6 | 8.0 | 6.5 | 4 | ... | 175 | 12.3 |
| | | 23 | 7.4 | ... | ... | 4 | ... | 170 | 13.3 |
| | | 30 | 7.6 | 8.1 | 6.6 | 3 | ... | 169 | 13.5 |
| | | Feb. 4 | 7.6 | 8.1 | 6.7 | 4 | ... | 185 | 13.0 |
| | | 11 | 7.6 | ... | ... | 4 | ... | 190 | 13.2 |
| | | 23 | 7.6 | ... | ... | 3 | ... | 182 | 12.8 |
| | | Mar. 2 | 7.3 | ... | ... | 4 | ... | 156 | 10.4 |
| | | 8 | 6.9 | ... | ... | 3 | ... | 111 | 14.0 |
| | Bottom | Dec. 10 | 7.5 | 8.0 | ... | ... | ... | 180 | ... |
| | | 19 | 7.6 | 8.1 | 6.4 | ... | ... | 185 | 10.2 |
| | | Jan. 7 | 7.6 | ... | ... | 4 | ... | 170 | 13.8 |
| | | 14 | 7.5 | 8.2 | 6.6 | 4 | ... | 170 | 11.0 |
| | | 23 | 7.4 | ... | ... | 4 | ... | 174 | 11.1 |
| | | 30 | 7.5 | 8.1 | 6.6 | 5 | ... | 186 | 12.6 |
| | | Feb. 4 | 7.4 | 8.1 | 6.6 | 4 | ... | 191 | 10.8 |
| | | 11 | 7.5 | ... | ... | 4 | ... | 197 | 12.1 |
| | | 23 | 7.6 | ... | ... | 4 | ... | 200 | 12.5 |
| | | Mar. 2 | 7.6 | ... | ... | 6 | ... | 197 | 12.1 |
| | | 8 | 7.3 | ... | ... | 4 | ... | 200 | 11.5 |
| Inlet | Surface | Dec. 10 | 7.5 | 8.0 | ... | ... | ... | 162 | ... |
| | | 19 | 7.7 | 8.1 | 6.3 | ... | ... | 156 | 12.5 |
| | | Jan. 7 | 7.6 | ... | ... | 3 | ... | 165 | 13.0 |
| | | 14 | 7.6 | 8.0 | 6.6 | 3 | ... | 165 | 12.3 |
| | | 23 | 7.4 | ... | ... | 4 | ... | 171 | 12.3 |
| | | 30 | 7.6 | 8.1 | 6.6 | 4 | ... | 180 | 11.8 |
| | | Feb. 4 | 7.6 | 8.1 | 6.7 | 4 | ... | 197 | 11.1 |
| | | 11 | 7.4 | ... | ... | 4 | ... | 193 | 10.4 |
| | | 23 | 7.4 | ... | ... | 4 | ... | 196 | 10.4 |
| | | Mar. 2 | 7.6 | ... | ... | 4 | ... | 196 | 11.4 |
| | | 8 | 7.4 | ... | ... | 4 | ... | 181 | 11.1 |

(Continued)

Table 9.

Dissolved Oxygen, pH, and Other Chemical Data For
the Lakes Studied, 1940-41.
(Continued)

| Lake and station | Sampling depth | Date | pH | Aerated pH | Alveol. pH | CO$_2$, p.p.m. | Phth. alkalinity, p.p.m. | M. O. alkalinity, p.p.m. | O$_2$, p.p.m. |
|---|---|---|---|---|---|---|---|---|---|
| Mud Lake, Outlet | Surface | Dec. 10 | 7.6 | 8.0 | ... | ... | ... | 178 | ... |
| | | 19 | 7.6 | 8.1 | 6.4 | ... | ... | 177 | 12.1 |
| | | Jan. 7 | 7.7 | ... | ... | 3 | ... | 163 | 14.0 |
| | | 14 | 7.6 | 8.1 | 6.6 | 3 | ... | 165 | 13.7 |
| | | 23 | 7.5 | ... | ... | 4 | ... | 170 | 13.0 |
| | | 30 | 7.6 | 8.1 | 6.6 | 4 | ... | 182 | 14.5 |
| | | Feb. 4 | 7.7 | 8.1 | 6.6 | 4 | ... | 190 | 13.9 |
| | | 11 | 7.6 | ... | ... | 3 | ... | 193 | 14.5 |
| | | 23 | 7.6 | ... | ... | 4 | ... | 191 | 14.7 |
| | | Mar. 2 | 7.6 | ... | ... | 4 | ... | 192 | 14.3 |
| | | 8 | 7.5 | ... | ... | 4 | ... | 160 | 13.3 |
| Green Lake, Sta. 1 | Surface | Dec. 10 | 7.5 | 8.1 | ... | ... | ... | 132 | ... |
| | | 17 | 7.6 | 7.9 | 6.1 | ... | ... | 80 | 12.5 |
| | | 21 | 7.7 | ... | ... | 2 | ... | 80 | 12.1 |
| | | Jan. 7 | 7.6 | ... | ... | 4 | ... | 141 | 13.3 |
| | | 12 | 7.7 | ... | ... | 3 | ... | 141 | 12.1 |
| | | 23 | 7.6 | ... | ... | 2 | ... | 147 | 13.5 |
| | | 28 | 7.7 | ... | ... | 3 | ... | 156 | 13.3 |
| | | Feb. 9 | 7.6 | 8.1 | 6.7 | 4 | ... | 148 | 9.6 |
| | | 14 | 7.6 | ... | ... | 3 | ... | 61 | 9.7 |
| | | 24 | 7.6 | ... | ... | 2 | ... | 161 | 10.6 |
| | | Mar. 2 | 7.7 | ... | ... | 4 | ... | 144 | 10.9 |
| | | 8 | 7.4 | ... | ... | 2 | ... | 106 | 10.8 |
| | Bottom | Dec. 10 | 7.8 | 8.1 | ... | ... | ... | 143 | ... |
| | | 17 | 7.8 | 8.0 | ... | ... | ... | 140 | 10.9 |
| | | 21 | 7.8 | ... | ... | 4 | ... | 138 | 10.2 |
| | | Jan. 7 | 7.7 | ... | ... | 3 | ... | 140 | 13.4 |
| | | 12 | 7.7 | ... | ... | 2 | ... | 135 | 12.1 |
| | | 23 | 7.5 | ... | ... | 3 | ... | 147 | 13.0 |
| | | 28 | 7.6 | ... | ... | 3 | ... | 152 | 12.7 |
| | | Feb. 9 | 7.6 | 8.2 | 6.7 | 4 | ... | 160 | 10.2 |
| | | 14 | 7.5 | ... | ... | 4 | ... | 165 | 9.7 |
| | | 24 | 7.6 | ... | ... | 3 | ... | 160 | 10.8 |
| | | Mar. 2 | 7.6 | ... | ... | 4 | ... | 164 | 10.9 |
| | | 8 | 7.6 | ... | ... | 5 | ... | 152 | 10.2 |
| Sta. 2 | Surface | Dec. 10 | 7.8 | 8.0 | ... | ... | ... | 130 | ... |
| | | 17 | 7.8 | 8.0 | 6.2 | ... | ... | 133 | 12.4 |
| | | 21 | 7.9 | ... | ... | 2 | ... | 119 | 12.0 |
| | | Jan. 7 | 7.6 | ... | ... | 4 | ... | 142 | 13.2 |
| | | 12 | 7.7 | ... | ... | 2 | ... | 141 | 12.8 |
| | | 23 | 7.3 | ... | ... | 3 | ... | 90 | 12.3 |
| | | 28 | 7.6 | ... | ... | 2 | ... | 152 | 11.6 |

(Continued)

Table 9.

Dissolved Oxygen, pH, and Other Chemical Data For the Lakes Studied, 1940-41.
(Continued)

| Lake and station | Sampling depth | Date | pH | Aerated pH | Alveol. pH | $CO_2$, p.p.m. | Phth. alkalinity, p.p.m. | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|---|---|---|---|---|
| Green Lake, Sta. 2 (Continued) | Surface | Feb. 9 | 7.5 | 8.1 | 6.6 | 4 | ... | 152 | 9.4 |
| | | 14 | 7.5 | ... | ... | 3 | ... | 65 | 10.5 |
| | | 18 | ... | ... | ... | ... | ... | ... | 12.2 |
| | | 24 | 7.4 | ... | ... | 4 | ... | 163 | 9.2 |
| | | Mar. 2 | 7.4 | ... | ... | 3 | ... | 139 | 8.2 |
| | | 8 | 7.6 | ... | ... | 2 | ... | 67 | 12.6 |
| | 2 feet | Jan. 23 | ... | ... | ... | ... | ... | ... | 10.3 |
| | | 28 | 7.6 | ... | ... | 4 | ... | 149 | 10.8 |
| | | Feb. 9 | ... | ... | ... | ... | ... | ... | 10.3 |
| | | 14 | 7.6 | ... | ... | 4 | ... | 163 | 10.2 |
| | | 18 | ... | ... | ... | ... | ... | ... | 9.8 |
| | | 24 | 7.6 | ... | ... | 4 | ... | 169 | 9.0 |
| | | Mar. 2 | 7.5 | ... | ... | 4 | ... | 164 | 8.9 |
| | | 8 | 7.4 | ... | ... | 4 | ... | 144 | 10.1 |
| | 5 feet | Dec. 10 | 7.7 | 8.0 | ... | ... | ... | 140 | ... |
| | | 17 | ... | ... | ... | ... | ... | ... | 9.9 |
| | | 21 | 7.7 | ... | ... | 3 | ... | 144 | 9.5 |
| | | Jan. 7 | 7.7 | ... | ... | 3 | ... | 140 | 13.3 |
| | | 12 | 7.7 | ... | ... | 4 | ... | 138 | 12.7 |
| | | 23 | 7.0 | ... | ... | 5 | ... | 148 | 8.0 |
| | | 28 | 7.6 | ... | ... | 3 | ... | 148 | 10.1 |
| | | Feb. 9 | 7.5 | 8.1 | 6.4 | 4 | ... | 162 | 10.3 |
| | | 14 | 7.4 | ... | ... | 5 | ... | 172 | 7.8 |
| | | 18 | ... | ... | ... | ... | ... | ... | 9.0 |
| | | 24 | 7.4 | ... | ... | 4 | ... | 166 | 8.7 |
| | | Mar. 2 | 7.6 | ... | ... | 4 | ... | 163 | 8.9 |
| | | 8 | ... | ... | ... | ... | ... | ... | 11.2 |
| | 9 feet | Dec. 10 | 7.5 | 8.0 | ... | ... | ... | 156 | ... |
| | | 17 | 7.5 | 8.0 | 6.3 | ... | ... | 161 | 5.8 |
| | | 21 | 7.1 | ... | ... | 5 | ... | 160 | 4.8 |
| | | Jan. 7 | 7.6 | ... | ... | 3 | ... | 140 | 12.4 |
| | | 12 | 7.3 | ... | ... | 3 | ... | 150 | 8.8 |
| | | 23 | 7.0 | ... | ... | 7 | ... | 164 | 3.3 |
| | | 28 | 7.0 | 8.2 | 6.6 | 9 | ... | 170 | 3.8 |
| | | Feb. 9 | 6.9 | 8.1 | 6.6 | 7 | ... | 176 | 6.8 |
| | | 14 | 7.0 | ... | ... | 4 | ... | 177 | 3.9 |
| | | 18 | ... | ... | ... | ... | ... | ... | 5.5 |
| | | 24 | 7.0 | ... | ... | 7 | ... | 175 | 5.0 |
| | | Mar. 2 | 7.2 | ... | ... | 7 | ... | 170 | 5.7 |
| | | 8 | 7.0 | ... | ... | 4 | ... | 169 | 6.7 |

(Continued)

Table 9.

Dissolved Oxygen, pH, and Other Chemical Data For the Lakes Studied, 1940-41.
(Continued)

| Lake and station | Sampling depth | Date | pH | Aerated pH | Alveol. pH | $CO_2$, p.p.m. | Phth. alkalinity, p.p.m. | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|---|---|---|---|---|
| Green Lake, Sta. 3 | Surface | Dec. 17 | 7.7 | 8.0 | ... | ... | ... | 120 | 13.7 |
| | | 21 | 8.1 | ... | ... | ... | 2 | 75 | 14.0 |
| | | 24 | 7.9 | 8.0 | 6.1 | 1 | ... | 94 | 13.7 |
| | | Jan. 7 | 7.6 | ... | ... | 3 | ... | 142 | 13.1 |
| | | 12 | 7.9 | ... | ... | ... | ... | 135 | 12.7 |
| | | 23 | 7.6 | ... | ... | 3 | ... | 147 | 12.5 |
| | | 28 | 8.0 | ... | ... | ... | ... | 155 | 14.7 |
| | | Feb. 9 | ... | ... | ... | ... | ... | ... | 13.1 |
| | | 24 | 7.7 | ... | ... | 4 | ... | 176 | 11.0 |
| | | Mar. 2 | 7.6 | ... | ... | 4 | ... | 174 | 12.0 |
| | | 8 | 7.3 | ... | ... | 3 | ... | 116 | 10.3 |
| | Bottom | Dec. 17 | 7.8 | 8.1 | ... | ... | ... | 150 | 14.3 |
| | | 21 | 8.0 | ... | ... | ... | ... | 152 | 12.6 |
| | | 24 | 7.9 | 8.1 | 6.5 | 2 | ... | 150 | 12.6 |
| | | Jan. 7 | 7.6 | ... | ... | 3 | ... | 140 | 13.1 |
| | | 12 | 7.7 | ... | ... | 3 | ... | 140 | 12.3 |
| | | 23 | 7.6 | ... | ... | 4 | ... | 145 | 11.9 |
| | | 28 | 7.7 | ... | ... | 3 | ... | 158 | 13.0 |
| | | Feb. 9 | 7.6 | 8.2 | 6.7 | 4 | ... | 164 | 11.8 |
| | | 24 | 7.6 | ... | ... | 4 | ... | 173 | 10.8 |
| | | Mar. 2 | 7.7 | ... | ... | 4 | ... | 175 | 11.8 |
| | | 8 | 7.5 | ... | ... | 4 | ... | 162 | 11.5 |
| Sta. 4 | Surface | Dec. 17 | 7.6 | 8.0 | ... | ... | ... | 127 | 11.9 |
| | | 21 | 7.8 | ... | ... | 3 | ... | 127 | 12.6 |
| | | 24 | 7.6 | 8.0 | 6.2 | 3 | ... | 120 | 12.6 |
| | | Jan. 7 | 7.6 | ... | ... | 3 | ... | 133 | 13.1 |
| | | 12 | 7.8 | ... | ... | 2 | ... | 137 | ... |
| | | 23 | 7.6 | ... | ... | 3 | ... | 145 | 13.1 |
| | | 28 | 7.5 | ... | ... | 3 | ... | 154 | 11.1 |
| | | Feb. 9 | 7.5 | 8.1 | 6.5 | 4 | ... | 143 | 10.6 |
| | | 14 | 7.4 | ... | ... | 3 | ... | 70 | 10.6 |
| | | 24 | 7.7 | ... | ... | 3 | ... | 162 | 11.2 |
| | | Mar. 2 | 7.6 | ... | ... | 4 | ... | 155 | 11.7 |
| | | 4 | 6.9 | ... | ... | 1 | ... | 25 | 12.1 |
| | | 8 | 7.4 | ... | ... | 3 | ... | 92 | 11.5 |
| | 4 feet | Jan. 28 | 7.4 | 8.1 | 6.6 | 6 | ... | 147 | 10.8 |
| | | Feb. 24 | 7.5 | ... | ... | 3 | ... | 171 | 11.0 |
| | | Mar. 2 | ... | ... | ... | ... | ... | ... | 12.3 |
| | | 4 | 7.7 | ... | ... | ... | ... | ... | 12.1 |
| | | 8 | ... | ... | ... | ... | ... | ... | 11.6 |

(Continued)

Table 9.

Dissolved Oxygen, pH, and Other Chemical Data For the Lakes Studied, 1940-41.
(Continued)

| Lake and station | Sampling depth | Date | pH | Aerated pH | Alveol. pH | $CO_2$, p.p.m. | Phth. alkalinity, p.p.m. | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|---|---|---|---|---|
| Green Lake, Sta. 4, (Continued) | Bottom | Dec. 17 | 7.6 | 8.0 | ... | ... | ... | 158 | 10.6 |
| | | 21 | 7.1 | ... | ... | 6 | ... | 149 | 10.1 |
| | | 24 | 7.4 | 8.0 | 6.5 | 4 | ... | 150 | 8.8 |
| | | Jan. 7 | 7.6 | ... | ... | 4 | ... | 134 | 11.9 |
| | | 12 | 7.6 | ... | ... | 3 | ... | 150 | 8.5 |
| | | 23 | 7.2 | ... | ... | 7 | ... | 164 | 3.9 |
| | | 28 | 7.3 | 8.2 | 6.5 | 7 | ... | 155 | 4.6 |
| | | Feb. 9 | 7.3 | 8.1 | 6.6 | 5 | ... | 166 | 6.0 |
| | | 14 | 7.0 | ... | ... | 6 | ... | 177 | 4.5 |
| | | 24 | 7.5 | ... | ... | 4 | ... | 168 | 9.7 |
| | | Mar. 2 | 7.4 | ... | ... | 6 | ... | 179 | 8.4 |
| | | 4 | 7.6 | ... | ... | 4 | ... | 173 | 9.8 |
| | | 8 | 7.6 | ... | ... | 5 | ... | 167 | 9.9 |
| Sta. 5 | Surface | Jan. 7 | 7.6 | ... | ... | 3 | ... | 139 | 13.9 |
| | | 12 | 7.7 | ... | ... | 2 | ... | 140 | 12.9 |
| | | 23 | 7.5 | ... | ... | 3 | ... | 151 | 12.0 |
| | | 28 | 7.6 | 8.2 | 6.6 | 3 | ... | 150 | 11.4 |
| | | Feb. 9 | 7.6 | 8.1 | 6.6 | 3 | ... | 136 | 8.6 |
| | | 14 | 7.4 | ... | ... | 4 | ... | 46 | 9.2 |
| | | 24 | 7.8 | ... | ... | 2 | ... | 156 | 10.3 |
| | | Mar. 2 | 8.0 | ... | ... | ... | 2 | 144 | 11.0 |
| | | 8 | 8.1 | ... | ... | ... | 2 | 121 | 12.5 |
| | Bottom | Jan. 7 | 7.8 | ... | ... | 3 | ... | 132 | 13.8 |
| | | 12 | 7.7 | ... | ... | 2 | ... | 140 | 12.2 |
| | | 23 | 7.6 | ... | ... | 3 | ... | 150 | 11.2 |
| | | 28 | 7.6 | ... | ... | 4 | ... | 148 | 11.0 |
| | | Feb. 9 | 7.7 | 8.1 | 6.4 | 4 | ... | 158 | 9.2 |
| | | 14 | 7.6 | ... | ... | 3 | ... | 150 | 9.3 |
| | | 24 | 7.9 | ... | ... | 3 | ... | 162 | 10.4 |
| | | Mar. 2 | 8.0 | ... | ... | ... | 1 | 159 | 11.1 |
| | | 8 | 8.2 | ... | ... | ... | 4 | 148 | 12.2 |
| Sta. 6 | Surface | Jan. 23 | 7.6 | ... | ... | 4 | ... | 140 | 13.0 |
| | | 28 | 8.0 | 8.1 | 6.5 | ... | 2 | 141 | 13.6 |
| | Bottom | Jan. 23 | 7.4 | ... | ... | 4 | ... | 150 | 11.2 |
| | | 28 | 7.6 | 8.2 | 6.4 | 4 | ... | 153 | 9.8 |

(Continued)

Table 9.

Dissolved Oxygen, pH, and Other Chemical Data For the Lakes Studied, 1940-41.
(Continued)

| Lake and station | Sampling depth | Date | pH | Aerated pH | Alveol. pH | $CO_2$, p.p.m. | Phth. alkalinity, p.p.m. | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|---|---|---|---|---|
| Green Lake, Inlet | Surface | Dec. 17 | 6.8 | 7.9 | 6.2 | ... | ... | 126 | 10.3 |
| | | 21 | 7.1 | ... | ... | 4 | ... | 143 | 9.5 |
| | | 24 | 7.2 | 7.9 | 6.4 | 7 | ... | 160 | 8.5 |
| | | Jan. 7 | 6.9 | ... | ... | 10 | ... | 205 | 2.8 |
| | | 12 | 6.9 | ... | ... | 14 | ... | 207 | 2.6 |
| | | 23 | 6.9 | ... | ... | 14 | ... | 200 | 5.7 |
| | | 28 | 6.8 | 8.1 | 6.6 | 22 | ... | 214 | 2.1 |
| | | Feb. 9 | 6.8 | 8.0 | 6.6 | 14 | ... | 233 | 2.8 |
| | | 14 | 7.3 | ... | ... | 4 | ... | 88 | 11.2 |
| | | 24 | 6.9 | ... | ... | 17 | ... | 240 | 3.2 |
| | | Mar. 2 | 6.9 | ... | ... | 14 | ... | 220 | 4.0 |
| | | 4 | 6.8 | ... | ... | 3 | ... | 46 | 12.0 |
| | | 8 | 7.0 | ... | ... | 11 | ... | 182 | 4.9 |
| Outlet | Surface | Dec. 17 | 6.7 | 7.4 | 5.5 | ... | ... | 22 | 12.6 |
| | | 21 | 7.6 | ... | ... | 4 | ... | 45 | 12.1 |
| | | 24 | 7.3 | 7.8 | 5.7 | 4 | ... | 66 | 10.9 |
| | | Jan. 7 | 7.7 | ... | ... | 3 | ... | 140 | 14.3 |
| | | 12 | 7.7 | ... | ... | 3 | ... | 135 | 12.8 |
| | | 23 | 7.6 | ... | ... | 3 | ... | 150 | 12.7 |
| | | 28 | 7.5 | 8.2 | 6.5 | 4 | ... | 150 | 10.9 |
| | | Feb. 9 | 7.6 | 8.1 | 6.6 | 2 | ... | 159 | 9.3 |
| | | 14 | 8.0 | ... | ... | 2 | ... | 140 | 11.7 |
| | | 24 | 8.1 | ... | ... | ... | 4 | 163 | 12.9 |
| | | Mar. 2 | 8.2 | ... | ... | ... | 3 | 150 | 13.0 |
| | | 8 | 8.2 | ... | ... | ... | 5 | 151 | 13.3 |
| Bog Lake | Surface | Dec. 10 | 6.1 | 6.7 | ... | ... | ... | 7 | ... |
| | | 17 | 6.2 | 6.5 | 5.3 | ... | ... | 5 | 15.9 |
| | | 21 | 6.6 | ... | ... | 2 | ... | 6 | 16.1 |
| | | Jan. 7 | 6.6 | ... | ... | 4 | ... | 6 | 16.7 |
| | | 14 | 6.0 | 6.8 | 5.4 | 4 | ... | 5 | 14.0 |
| | | 23 | 6.0 | ... | ... | 4 | ... | 5 | 20.2 |
| | | 28 | 5.9 | 6.3 | 5.2 | 4 | ... | 7 | 17.7 |
| | | Feb. 4 | 5.8 | 6.5 | 5.3 | 4 | ... | 7 | 18.4 |
| | | 11 | 5.8 | ... | ... | 4 | ... | 12 | 21.0 |
| | | 16 | 5.9 | ... | ... | 4 | ... | 6 | 18.7 |
| | | 18 | ... | ... | ... | ... | ... | ... | 18.2 |
| | | 25 | 5.9 | ... | ... | 4 | ... | 8 | 20.5 |
| | | Mar. 2 | 5.9 | ... | ... | 7 | ... | 4 | 15.3 |
| | | 4 | 6.0 | ... | ... | 5 | ... | 8 | 13.9 |
| | | 10 | 5.8 | ... | ... | 8 | ... | 4 | 14.9 |
| | | 27 | 5.8 | ... | ... | 4 | ... | 7 | 17.8 |

Table 9.

**Dissolved Oxygen, pH, and Other Chemical Data For the Lakes Studied, 1940-41.**
**(Continued)**

| Lake and station | Sampling depth | Date | pH | Aerated pH | Alveol. pH | $CO_2$, p.p.m. | Phth. alkalinity, p.p.m. | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|---|---|---|---|---|
| Bog **Lake** | **1 foot** | **Dec.** 10 | 5.7 | ... | ... | ... | ... | 5 | ... |
| | | 17 | 6.2 | 6.5 | ... | ... | ... | 5 | 13.2 |
| | | 21 | 6.8 | ... | ... | 2 | ... | 8 | 14.5 |
| | | **Jan.** 7 | 6.5 | ... | ... | 12 | ... | 6 | 13.0 |
| | | 14 | 5.8 | 6.9 | 5.4 | 9 | ... | 5 | 7.8 |
| | | 23 | 6.0 | ... | ... | 4 | ... | 5 | 18.3 |
| | | 28 | 5.8 | ... | ... | 6 | ... | 5 | 17.6 |
| | | **Feb.** 4 | 5.8 | 6.5 | 5.3 | 5 | ... | 5 | 16.0 |
| | | 11 | 5.7 | ... | ... | 4 | ... | 5 | 17.1 |
| | | 16 | 5.8 | ... | ... | 4 | ... | 6 | 17.6 |
| | | 18 | ... | ... | ... | ... | ... | ... | 18.0 |
| | | 25 | 5.7 | ... | ... | 7 | ... | 6 | 18.5 |
| | | **Mar.** 2 | 5.7 | ... | ... | 9 | ... | 6 | 15.2 |
| | | 4 | 6.2 | ... | ... | 5 | ... | 7 | 13.4 |
| | | 10 | 5.6 | ... | ... | 9 | ... | 4 | 15.4 |
| | | 27 | 5.8 | ... | ... | 4 | ... | 4 | 17.8 |
| | **2 feet** | **Dec.** 10 | 5.6 | ... | ... | ... | ... | 6 | ... |
| | | 17 | 5.7 | 6.8 | ... | ... | ... | 14 | 4.5 |
| | | 21 | 5.8 | ... | ... | 13 | ... | 12 | 0.7 |
| | | **Jan.** 7 | 5.9 | ... | ... | 14 | ... | 6 | 6.5 |
| | | 14 | 5.8 | 6.9 | 5.2 | 14 | ... | 6 | 1.5 |
| | | 23 | 5.4 | ... | ... | 16 | ... | 7 | 2.1 |
| | | 28 | 5.7 | 6.5 | 5.3 | 14 | ... | 6 | 6.7 |
| | | **Feb.** 4 | 5.5 | 6.5 | 5.3 | 14 | ... | 6 | 7.4 |
| | | 11 | 5.4 | ... | ... | 19 | ... | 5 | 2.3 |
| | | 16 | 5.6 | ... | ... | 14 | ... | 5 | 9.5 |
| | | 18 | ... | ... | ... | ... | ... | ... | 4.8 |
| | | 25 | 5.6 | ... | ... | 10 | ... | 7 | 11.1 |
| | | **Mar.** 2 | 5.7 | ... | ... | 10 | ... | 6 | 7.0 |
| | | 4 | 5.6 | ... | ... | 15 | ... | 5 | 6.4 |
| | | 10 | 5.7 | ... | ... | 5 | ... | 5 | 14.5 |
| | | 27 | 5.9 | ... | ... | 4 | ... | 7 | 17.1 |
| | **3 feet** | **Dec.** 10 | 5.6 | ... | ... | ... | ... | 6 | ... |
| | | 17 | 5.6 | 6.7 | ... | ... | ... | 5 | 1.7 |
| | | 21 | 5.6 | ... | ... | 17 | ... | 7 | 0.4 |
| | | Jan. 7 | 5.9 | ... | ... | 19 | ... | 6 | 1.5 |
| | | 14 | 5.7 | 6.7 | 5.2 | 21 | ... | 5 | 2.1 |
| | | 23 | 5.4 | ... | ... | 23 | ... | 7 | 0.6 |
| | | 28 | 5.5 | 6.5 | 5.4 | 21 | ... | 6 | 1.8 |
| | | Feb. 4 | 5.5 | 6.5 | 5.2 | 19 | ... | 7 | 1.9 |
| | | 11 | 5.4 | ... | ... | 22 | ... | 6 | 0.7 |
| | | 16 | 5.5 | ... | ... | 15 | ... | 8 | 3.0 |
| | | 18 | ... | ... | ... | ... | ... | ... | 1.8 |
| | | 25 | 5.6 | ... | ... | 16 | ... | 6 | 4.5 |

(Continued)

Table 9.

Dissolved Oxygen, pH, and Other Chemical Data For the Lakes Studied, 1940-41.
(Continued)

| Lake and station | Sampling depth | Date | pH | Aerated pH | Alveol. pH | $CO_2$, p.p.m. | Phth. alkalinity, p.p.m. | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|---|---|---|---|---|
| Bog Lake (Continued) | 3 feet | Mar. 2 | 5.8 | ... | ... | 17 | ... | 4 | 2.8 |
| | | 4 | 5.8 | ... | ... | ... | ... | ... | 2.8 |
| | | 10 | 5.4 | ... | ... | 21 | ... | 5 | 4.0 |
| | | 27 | 5.6 | ... | ... | 6 | ... | 5 | 9.0 |
| | 4 feet | Dec. 10 | 5.6 | ... | ... | ... | ... | 6 | ... |
| | | 17 | 5.6 | 6.8 | ... | ... | ... | 14 | 0.6 |
| | | 21 | 5.7 | ... | ... | 18 | ... | 8 | 0.1 |
| | | Jan. 7 | 5.7 | ... | ... | 22 | ... | 7 | 0.9 |
| | | 14 | 5.7 | 6.6 | ... | 22 | ... | 6 | 0.5 |
| | | 23 | 5.4 | ... | ... | 23 | ... | 7 | 0.3 |
| | | 28 | 5.4 | 6.4 | 5.3 | 24 | ... | 6 | 0.7 |
| | | Feb. 4 | 5.5 | 6.5 | 5.2 | 21 | ... | 6 | 0.6 |
| | | 11 | 5.4 | ... | ... | 23 | ... | 6 | 0.2 |
| | | 16 | 5.5 | ... | ... | 18 | ... | 5 | 1.5 |
| | | 18 | ... | ... | ... | ... | ... | ... | 0.4 |
| | | 25 | 5.5 | ... | ... | 22 | ... | 7 | 1.3 |
| | | Mar. 2 | 5.7 | ... | ... | 22 | ... | 5 | 0.2 |
| | | 4 | 5.8 | ... | ... | ... | ... | ... | 1.0 |
| | | 10 | 5.5 | ... | ... | 21 | ... | 7 | 1.3 |
| | | 27 | 5.4 | ... | ... | 19 | ... | 5 | 3.7 |
| | 5 feet | Dec. 10 | 5.6 | ... | ... | ... | ... | 6 | ... |
| | | 17 | 5.7 | 6.8 | 5.3 | ... | ... | 10 | 0.3 |
| | | 21 | 5.7 | ... | ... | 21 | ... | 7 | 0.2 |
| | | Jan. 7 | 5.7 | ... | ... | 22 | ... | 7 | 0.6 |
| | | 14 | 5.7 | 6.8 | 5.4 | 21 | ... | 6 | 0.1 |
| | | 23 | 5.4 | ... | ... | 23 | ... | 8 | 0.0 |
| | | 28 | 5.5 | ... | ... | 22 | ... | 8 | 0.0 |
| | | Feb. 4 | 5.5 | 6.5 | 5.3 | 23 | ... | 9 | 0.0 |
| | | 11 | 5.4 | ... | ... | 25 | ... | 6 | 0.1 |
| | | 16 | 5.6 | ... | ... | 18 | ... | 6 | 1.2 |
| | | 18 | ... | ... | ... | ... | ... | ... | 0.4 |
| | | 25 | 5.5 | ... | ... | 27 | ... | 7 | 0.0 |
| | | Mar. 2 | 5.6 | ... | ... | 23 | ... | 7 | 0.0 |
| | | 4 | 5.6 | ... | ... | ... | ... | ... | 0.6 |
| | | 10 | 5.5 | ... | ... | 24 | ... | 6 | 0.0 |
| | | 27 | 5.4 | ... | ... | 25 | ... | 6 | 1.5 |

(Continued)

## Table 9.

### Dissolved Oxygen, pH, and Other Chemical Data For the Lakes Studied, 1940-41. (Continued)

| Lake and station | Sampling depth | Date | pH | Aerated pH | Alveol. pH | $CO_2$, p.p.m. | Phth. alkalinity, p.p.m. | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|---|---|---|---|---|
| Pasinski's Pond, Sta. 15 | Surface | Dec. 12 | 8.8+ | 8.8+ | 6.0 | ... | 11 | 90 | 12.5 |
| | | 19 | 8.8+ | 8.5 | 6.1 | ... | 7 | 74 | 13.0 |
| | | Jan. 10 | 8.8+ | ... | ... | ... | 15 | 99 | 18.0 |
| | | 16 | 8.8+ | ... | ... | ... | 13 | 103 | 17.5 |
| | | 24 | 8.8+ | ... | ... | ... | 18 | 106 | 21.9 |
| | | 31 | 8.8+ | ... | ... | ... | 16 | 112 | 20.8 |
| | | Feb. 8 | 8.8 | ... | ... | ... | 10 | 123 | 17.8 |
| | | 12 | 8.6 | ... | ... | ... | 13 | 123 | 19.9 |
| | | 21 | 8.8 | ... | ... | ... | 15 | 123 | 21.5 |
| | | 27 | 8.8+ | ... | ... | ... | 12 | 129 | 22.0 |
| | | Mar. 6 | 8.8 | ... | ... | ... | 8 | 92 | 21.5 |
| | Bottom | Dec. 12 | 8.3 | ... | ... | ... | 3 | 96 | 6.9 |
| | | 19 | 8.3 | ... | ... | ... | 2 | 102 | 7.5 |
| | | Jan. 10 | 8.2 | ... | ... | ... | 3 | 103 | 13.4 |
| | | 16 | 7.3 | ... | ... | 4 | ... | 106 | 8.1 |
| | | 24 | 8.0 | ... | ... | ... | ... | 110 | 16.4 |
| | | 31 | 7.3 | ... | ... | 4 | ... | 120 | 5.3 |
| | | Feb. 8 | 7.7 | ... | ... | 4 | ... | 125 | 13.6 |
| | | 12 | 7.6 | ... | ... | 4 | ... | 135 | 9.9 |
| | | 21 | 8.3 | ... | ... | ... | 7 | 134 | 15.9 |
| | | 27 | 7.6 | ... | ... | 4 | ... | 134 | 12.9 |
| | | Mar. 6 | 7.2 | ... | ... | 4 | ... | 135 | 13.2 |
| Sta. 20 | Surface | Dec. 19 | ... | ... | ... | ... | ... | ... | 10.2 |
| | | Jan. 10 | 8.8+ | ... | ... | ... | 13 | 101 | 15.5 |
| | | 16 | 8.2 | ... | ... | ... | 2 | 102 | 13.2 |
| | | 24 | 8.7 | ... | ... | ... | 10 | 104 | 17.3 |
| | | 31 | 8.8 | ... | ... | ... | 12 | 110 | 19.5 |
| | | Feb. 8 | 8.7 | ... | ... | ... | 12 | 118 | 17.7 |
| | | 12 | 8.7 | ... | ... | ... | 10 | 123 | 18.2 |
| | | 21 | 8.0 | ... | ... | ... | 3 | 125 | 13.0 |
| | | 27 | 7.7 | ... | ... | 4 | ... | 132 | 14.3 |
| | | Mar. 6 | 8.8 | ... | ... | ... | 8 | 111 | 20.7 |
| | Bottom | Jan. 10 | 8.4 | ... | ... | ... | 6 | 103 | 15.2 |
| | | 16 | 7.2 | ... | ... | 4 | ... | 105 | 4.8 |
| | | 24 | 8.0 | ... | ... | ... | ... | 108 | 12.8 |
| | | 31 | 7.6 | ... | ... | 3 | ... | 118 | 8.5 |
| | | Feb. 8 | 8.1 | ... | ... | ... | 3 | 123 | 13.7 |
| | | 12 | 7.6 | ... | ... | 4 | ... | 135 | 6.6 |
| | | 21 | 6.9 | ... | ... | 5 | ... | 134 | 8.9 |
| | | 27 | 6.9 | ... | ... | 5 | ... | 134 | 8.1 |
| | | Mar. 6 | 7.0 | ... | ... | 5 | ... | 133 | 14.0 |

(Continued)

Table 9.

Dissolved Oxygen, pH, and Other Chemical Data For the Lakes Studied, 1940-41.
(Continued)

| Lake and station | Sampling depth | Date | pH | Aerated pH | Alveol. pH | $CO_2$, p.p.m. | Phth. alkalinity, p.p.m. | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|---|---|---|---|---|
| **Pasinski's Pond, Sta. 24** | **Surface** | **Dec.** 12 | 8.8+ | 8.8+ | 6.0 | ... | 15 | 95 | 14.8 |
| | | 19 | ... | ... | ... | ... | ... | ... | 14.1 |
| | | **Jan.** 10 | 8.8+ | ... | ... | ... | 14 | 103 | 17.4 |
| | | 16 | 8.8+ | ... | ... | ... | 17 | 105 | 20.3 |
| | | 24 | 8.8+ | ... | ... | ... | 20 | 104 | 24.2 |
| | | 31 | 8.8+ | ... | ... | ... | 20 | 112 | 25.1 |
| | | **Feb.** 8 | 8.8+ | ... | ... | ... | 16 | 123 | 19.7 |
| | | 12 | 8.8+ | ... | ... | ... | 17 | 132 | 23.7 |
| | | 21 | 8.8+ | ... | ... | ... | 16 | 126 | 21.8 |
| | | 27 | 8.8+ | ... | ... | ... | 17 | 134 | 24.8 |
| | | **Mar.** 6 | 8.8+ | ... | ... | ... | 8 | 62 | 21.3 |
| | **Bottom** | **Dec.** 12 | 8.6 | 8.4 | 6.1 | ... | 5 | 100 | 8.0 |
| | | 19 | ... | ... | ... | ... | ... | ... | 7.2 |
| | | **Jan.** 10 | 7.8 | ... | ... | 2 | ... | 106 | 12.4 |
| | | 16 | 7.1 | ... | ... | 4 | ... | 106 | 7.6 |
| | | 24 | 7.7 | ... | ... | 4 | ... | 120 | 12.0 |
| | | 31 | 7.6 | ... | ... | 3 | ... | 127 | 9.1 |
| | | Feb. 8 | 8.3 | ... | ... | ... | 4 | 130 | 15.1 |
| | | 12 | 7.8 | ... | ... | 2 | ... | 133 | 13.3 |
| | | 21 | 8.4 | ... | ... | ... | 7 | 135 | 20.6 |
| | | 27 | 8.4 | ... | ... | ... | 9 | 132 | 20.2 |
| | | **Mar.** 6 | 7.6 | ... | ... | 4 | ... | 130 | 12.0 |
| Sta. 26 | **Surface** | **Dec.** 12 | 8.8+ | 8.8+ | 6.0 | ... | 15 | 96 | 13.5 |
| | | 19 | 8.8+ | 8.8+ | 6.1 | ... | 13 | 84 | 15.1 |
| | | **Jan.** 10 | 8.8+ | ... | ... | ... | 14 | 103 | 17.1 |
| | | 16 | 8.7 | ... | ... | ... | 16 | 108 | 17.8 |
| | | 24 | 8.8 | ... | ... | ... | 17 | 115 | 19.9 |
| | | 31 | 8.8+ | ... | ... | ... | 24 | 124 | 28.0 |
| | | **Feb.** 8 | 8.8+ | ... | ... | ... | 23 | 129 | 21.3 |
| | | 12 | 8.8+ | ... | ... | ... | 27 | 131 | 24.1 |
| | | 18 | ... | ... | ... | ... | ... | ... | 25.2 |
| | | 21 | 8.8+ | ... | ... | ... | 26 | 137 | 24.8 |
| | | 27 | 8.8+ | ... | ... | ... | 23 | 138 | 26.2 |
| | | **Mar.** 6 | 8.8 | ... | ... | ... | 5 | 56 | 20.1 |
| | | 11 | 8.8 | ... | ... | ... | 5 | 54 | 16.7 |
| | **1 foot** | **Jan.** 10 | ... | ... | ... | ... | ... | ... | 16.6 |
| | | 16 | ... | ... | ... | ... | ... | ... | 18.3 |
| | | 24 | ... | ... | ... | ... | ... | ... | 19.9 |
| | | 31 | ... | ... | ... | ... | ... | ... | 27.2 |
| | | **Feb.** 8 | ... | ... | ... | ... | ... | ... | 21.5 |
| | | 12 | ... | ... | ... | ... | ... | ... | 24.5 |
| | | 18 | ... | ... | ... | ... | ... | ... | 25.8 |
| | | 21 | ... | ... | ... | ... | ... | ... | 24.0 |
| | | 27 | 8.8+ | ... | ... | ... | 22 | 138 | 26.5 |
| | | **Mar.** 6 | 8.8 | ... | ... | ... | 8 | 58 | 20.3 |
| | | 11 | 8.8+ | ... | ... | ... | 12 | 81 | 19.6 |

**(Continued)**

Table 9.

Dissolved Oxygen, pH, and Other Chemical Data For the Lakes Studied, 1940-41.
(Continued)

| Lake and station | Sampling depth | Date | pH | Aerated pH | Alveol. pH | $CO_2$, p.p.m. | Phth. alkalinity, p.p.m. | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|---|---|---|---|---|
| Pasinski's Pond, Sta. 26, (Continued) | 2 feet | Jan. 10 | 8.4 | ... | ... | ... | 5 | 104 | 14.7 |
| | | 16 | 8.3 | ... | ... | ... | 4 | 109 | 13.8 |
| | | 24 | 8.7 | ... | ... | ... | 13 | 113 | 17.1 |
| | | 31 | 8.8 | ... | ... | ... | 15 | 120 | 19.2 |
| | | Feb. 8 | 8.8+ | ... | ... | ... | 17 | 127 | 19.6 |
| | | 12 | 8.8+ | ... | ... | ... | 21 | 135 | 21.0 |
| | | 18 | ... | ... | ... | ... | ... | ... | 21.7 |
| | | 21 | 8.8+ | ... | ... | ... | 21 | 134 | 22.6 |
| | | 27 | 8.8+ | ... | ... | ... | 21 | 135 | 24.4 |
| | | Mar. 6 | 8.8 | ... | ... | ... | 19 | 118 | 24.1 |
| | | 11 | 8.8+ | ... | ... | ... | 17 | 99 | 22.9 |
| | 3 feet | Jan. 10 | ... | ... | ... | ... | ... | ... | 14.3 |
| | | 16 | ... | ... | ... | ... | ... | ... | 11.9 |
| | | 24 | ... | ... | ... | ... | ... | ... | 16.9 |
| | | 31 | ... | ... | ... | ... | ... | ... | 13.7 |
| | | Feb. 8 | ... | ... | ... | ... | ... | ... | 18.7 |
| | | 12 | ... | ... | ... | ... | ... | ... | 18.4 |
| | | 18 | ... | ... | ... | ... | ... | ... | 20.9 |
| | | 21 | ... | ... | ... | ... | ... | ... | 23.1 |
| | | 27 | 8.8+ | ... | ... | ... | 22 | 132 | 24.1 |
| | | Mar. 6 | 8.8 | ... | ... | ... | 13 | 132 | 20.1 |
| | | 11 | 8.6 | ... | ... | ... | 11 | 113 | 22.3 |
| | Bottom | Dec. 12 | 8.6 | 8.4 | 6.1 | ... | 4 | 103 | 8.6 |
| | | 19 | 8.6 | 8.6 | 6.1 | ... | 8 | 105 | 9.8 |
| | | Jan. 10 | 7.6 | ... | ... | 3 | ... | 113 | 12.7 |
| | | 16 | 7.6 | ... | ... | 3 | ... | 110 | 12.1 |
| | | 24 | 8.4 | ... | ... | ... | 10 | 122 | 15.5 |
| | | 31 | 8.1 | ... | ... | ... | 2 | 127 | 11.1 |
| | | Feb. 8 | 8.8+ | ... | ... | ... | 13 | 128 | 17.6 |
| | | 12 | 8.1 | ... | ... | ... | 2 | 132 | 14.9 |
| | | 18 | ... | ... | ... | ... | ... | ... | 19.2 |
| | | 21 | 8.8+ | ... | ... | ... | 17 | 133 | 21.8 |
| | | 27 | 8.8+ | ... | ... | ... | 14 | 144 | 21.4 |
| | | Mar. 6 | 8.7 | ... | ... | ... | 7 | 131 | 19.8 |
| | | 11 | 8.6 | ... | ... | ... | 9 | 116 | 21.6 |
| Sta. 27 | Surface | Dec. 12 | 8.8+ | 8.8+ | 6.1 | ... | 19 | 90 | 16.0 |
| | | 19 | ... | ... | ... | ... | ... | ... | 13.5 |
| | | Jan. 10 | 8.8+ | ... | ... | ... | 14 | 105 | 17.6 |
| | | 16 | 8.8 | ... | ... | ... | 15 | 102 | 16.9 |
| | | 24 | 8.8+ | ... | ... | ... | 23 | 116 | 22.6 |
| | | 31 | 8.8+ | ... | ... | ... | 23 | 117 | 24.3 |
| | | Feb. 8 | 8.8 | ... | ... | ... | 13 | 124 | 18.7 |
| | | 12 | 8.8+ | ... | ... | ... | 27 | 132 | 24.8 |
| | | 21 | 8.8+ | ... | ... | ... | 16 | 135 | 21.2 |
| | | 27 | 8.8+ | ... | ... | ... | 16 | 130 | 22.2 |
| | | Mar. 6 | 8.1 | ... | ... | ... | 1 | 54 | 18.1 |

(Continued)

Table 9.

### Dissolved Oxygen, pH, and Other Chemical Data For the Lakes Studied, 1940-41. (Continued)

| Lake and station | Sampling depth | Date | pH | Aerated pH | Alveol. pH | $CO_2$, p.p.m. | Phth. alkalinity, p.p.m. | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|---|---|---|---|---|
| Pasinski's Pond, | Bottom | Dec. 12 | 8.8 | 8.8 | 6.2 | ... | 13 | 103 | 11.2 |
| Sta. 27, | | 19 | ... | ... | ... | ... | ... | ... | 10.2 |
| (Continued) | | Jan. 10 | 8.3 | ... | ... | ... | 4 | 104 | 14.0 |
| | | 16 | 7.6 | ... | ... | 2 | ... | 105 | 7.1 |
| | | 24 | 8.1 | ... | ... | ... | 2 | 115 | 12.2 |
| | | 31 | 8.1 | ... | ... | ... | ... | 115 | 12.7 |
| | | Feb. 8 | 8.1 | ... | ... | ... | 3 | 136 | 15.9 |
| | | 12 | 7.7 | ... | ... | 3 | ... | 133 | 11.3 |
| | | 21 | 8.4 | ... | ... | ... | 8 | 136 | 16.2 |
| | | 27 | 8.2 | ... | ... | ... | 4 | 131 | 14.3 |
| | | Mar. 6 | 8.4 | ... | ... | ... | 6 | 127 | 20.9 |

Table 10.

**Dissolved Oxygen and Other Chemical Data; Miscellaneous Lakes;**
**1937-38, 1949-40, 1940-41.**

| Date | Lake | Station | Depth | pH | Aerated pH | Alveol. pH | $CO_2$, p.p.m. | Phth. alkalinity, p.p.m. | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | (1937-38) | | | | | |
| Jan. 23, 1938 | Minnis Pond | Sta. 1 | Surf. | ... | ... | ... | 9 | ... | ... | ... |
| | | | 2½ feet | 7.4 | ... | ... | 10 | ... | 330 | 0.3 |
| | | Open Hole | Surf. | ... | ... | ... | 8 | ... | ... | 0.0 |
| | | | 2 feet | ... | ... | ... | 8 | ... | ... | 0.1 |
| Jan. 29, 1938 | Fowler L. | Sta. 1 | Surf. | 7.4 | ... | ... | 2 | ... | 100 | 10.4 |
| | | | 10 feet | ... | ... | ... | 4 | ... | ... | ... |
| | | | 20 feet | 7.4 | ... | ... | 5 | ... | 252 | 5.8 |
| | | | | | (1939-40) | | | | | |
| Dec. 26, 1939 | West L. | Sta. 1 | Surf. | 8.4 | ... | ... | ... | 3 | 175 | 14.6 |
| | | | 4 feet | 8.4 | ... | ... | ... | 3 | 175 | 14.2 |
| Feb. 24, 1940 | Grass L. | Sta. 1 | Surf. | 7.6 | 8.2 | 6.5 | ... | ... | 230 | 10.2 |
| | | | 4 feet | 7.4 | 8.1 | 6.5 | ... | ... | 253 | 4.0 |
| | Bateese L. | Sta. 1 | Surf. | 7.7 | 8.2 | 6.5 | ... | ... | 188 | 12.0 |
| | | | 6 feet | ... | ... | ... | ... | ... | ... | 6.7 |
| | | | 11 feet | 7.3 | 8.1 | 6.5 | ... | ... | 195 | 5.0 |
| | Park L. | Sta. 1 | Surf. | 7.3 | 8.2 | 6.5 | ... | ... | 226 | 5.3 |
| | | | 6 feet | ... | ... | ... | ... | ... | ... | 5.2 |
| | | | 11 feet | 7.2 | 8.2 | 6.5 | ... | ... | 241 | 2.3 |
| Mar. 3, 1940 | West L. | Sta. 2 | Surf. | 7.3 | 8.1 | 6.5 | ... | ... | 240 | 6.2 |
| | | | 3 feet | 7.1 | 8.1 | 6.6 | ... | ... | 248 | 3.6 |
| Mar. 13, 1940 | Deep L. | Sta. 1 | Surf. | 8.1 | ... | ... | ... | 2 | 94 | 13.9 |
| | | | 5 feet | 7.9 | ... | ... | ... | ... | 87 | 13.0 |
| | | | 10 feet | ... | ... | ... | ... | ... | ... | 12.0 |
| | | | 15 feet | ... | ... | ... | ... | ... | ... | 11.9 |

(Continued)

Table 10.

### Dissolved Oxygen and Other Chemical Data; Miscellaneous Lakes; 1937-38, 1939-40, 1940-41.

(Continued)

| Date | Lake | Station | Depth | pH | Aerated pH | Alveol. pH | $CO_2$, p.p.m. | Phth. alkalinity, p.p.m. | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|---|---|---|---|---|---|
| Mar. 13, 1940 (Continued) | Deep L. | Sta. 1 | 20 feet | 7.6 | ... | ... | ... | ... | 90 | 10.8 |
| | | | 30 feet | ... | ... | ... | ... | ... | ... | 7.5 |
| | | | 40 feet | ... | ... | ... | ... | ... | ... | 5.8 |
| | | | 50 feet | ... | ... | ... | ... | ... | ... | 3.7 |
| | | | 62 feet | 6.9 | ... | ... | ... | ... | 97 | 2.9 |
| | | | | | (1940-41) | | | | | |
| Feb. 27, 1941 | Richmond L. | Sta. 1 | Surf. | 7.5 | ... | ... | 5 | ... | 111 | 16.6 |
| | | | 6 feet | 6.9 | ... | ... | 5 | ... | 117 | 11.2 |
| Mar. 5, 1941 | S. Londo L. (Iosco Co.) | Sta. 1 | Surf. | 6.8 | 8.1 | 6.6 | 15 | ... | 153 | 0.4 |
| | | | 2 feet | 6.8 | ... | ... | ... | ... | ... | 0.3 |
| | | | 6 feet | 6.8 | 8.1 | 6.6 | 16 | ... | 143 | Tr. |
| | | Sta. 2 | Surf. | 6.8 | 8.1 | 6.7 | 18 | ... | 149 | 0.4 |
| | | | 3 feet | 6.8 | ... | ... | ... | ... | ... | 0.1 |
| | | | 6 feet | 6.8 | ... | ... | ... | ... | ... | Tr. |
| | | | 9 feet | 6.8 | ... | ... | ... | ... | ... | Tr. |
| Mar. 20, 1941 | E. Fish L. | Sta. 1 | Surf. | 7.5 | 7.8 | ... | 2 | ... | 175 | 10.3 |
| | | | 5 feet | ... | ... | ... | ... | ... | ... | 8.9 |
| | | | 10 feet | ... | ... | ... | ... | ... | ... | 8.8 |
| | | | 15 feet | ... | ... | ... | ... | ... | ... | 7.7 |
| | | | 20 feet | 7.5 | 7.7 | ... | 3 | ... | 188 | 8.1 |
| | | | 25 feet | ... | ... | ... | ... | ... | ... | 6.8 |
| | | | 30 feet | ... | ... | ... | ... | ... | ... | 5.0 |
| | | | 35 feet | ... | ... | ... | ... | ... | ... | 2.6 |
| | | | 39 feet | 7.3 | 7.8 | ... | 4 | ... | 205 | 2.5 |
| | | Inlet | Surf. | 7.7 | 7.9 | ... | 2 | ... | 183 | 11.8 |
| | | Outlet | Surf. | 7.5 | 7.9 | ... | 2 | ... | 178 | 10.0 |

(Continued)

Table 10.

### Dissolved Oxygen and Other Chemical Data; Miscellaneous Lakes; 1937-38, 1939-40, 1940-41.

(Continued)

| Date | Lake | Station | Depth | pH | Aerated pH | Alveol. pH | $CO_2$, p.p.m. | Phth. alkalinity, p.p.m. | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|---|---|---|---|---|---|
| Mar. 21, 1941 | Middle Fish L. | Sta. 1 | Surf. | 7.0 | 7.7 | ... | 7 | ... | 167 | 0.3 |
| | | | 1 foot | ... | ... | ... | ... | ... | ... | 0.2 |
| | | | 2 feet | 7.0 | 7.8 | ... | 6 | ... | 165 | 0.2 |
| | | | 3 feet | ... | ... | ... | ... | ... | ... | Tr. |
| | | | 4 feet | 7.1 | 7.7 | ... | 5 | ... | 180 | 0.0 |
| | | | 5 feet | ... | ... | ... | ... | ... | ... | 0.0 |
| | W. Fish L. | Sta. 1 | Surf. | 7.2 | 7.9 | ... | 5 | ... | 176 | 4.3 |
| | | | 1 foot | ... | ... | ... | ... | ... | ... | 4.2 |
| | | | 2 feet | ... | ... | ... | ... | ... | ... | 5.2 |
| | | | 3 feet | 7.1 | 7.9 | ... | 6 | ... | 176 | 2.8 |
| | | | 4 feet | ... | ... | ... | ... | ... | ... | 1.9 |
| | | | 5 feet | ... | ... | ... | ... | ... | ... | 0.9 |
| | | | 6 feet | ... | ... | ... | ... | ... | ... | 0.7 |
| | | | 7½ feet | 7.0 | 7.8 | ... | 7 | ... | 185 | Tr. |
| Mar. 22, 1941 | Island L. (Oscoda Co.) | Sta. 1 | Surf. | 7.0 | 8.0 | ... | 13 | ... | 203 | 0.2 |
| | | | 2 feet | ... | ... | ... | ... | ... | ... | Tr. |
| | | | 4 feet | 7.0 | 7.8 | ... | 14 | ... | 215 | 0.0 |
| | | Sta. 2 | Surf. | 7.0 | 8.0 | ... | 10 | ... | 208 | 0.3 |
| | | | 2 feet | ... | ... | ... | ... | ... | ... | 0.0 |
| | | | 3 feet | 7.0 | 8.0 | ... | 14 | ... | 211 | 0.0 |

## Table 11.

### Vertical Distribution of Temperatures; Clear Lake, Station 2; 1937-38

| Date | Depth | Temperature °C. | Temperature °F. |
|---|---|---|---|
| Jan. 5, 1938 | Surf. | 2.0 | 35½ |
| | 5' | 3.4 | 38 |
| | 10' | 3.9 | 39 |
| | 15' | 3.9 | 39 |
| | 20' | 4.4 | 40 |
| Jan. 12, 1938 | Surf. | 0.3 | 32½ |
| | 5' | 3.3 | 38 |
| | 10' | 3.6 | 38½ |
| | 15' | 3.9 | 39 |
| | 20' | 4.0 | 39 |
| Jan. 19, 1938 | Surf. | 0.0 | 32 |
| | 5' | 1.1 | 34 |
| | 10' | 3.0 | 37½ |
| | 15' | 4.2 | 39½ |
| | 20' | 4.3 | 39½ |
| Jan. 26, 1938 | Surf. | 0.2 | 32½ |
| | 5' | 3.3 | 38 |
| | 10' | 4.0 | 39 |
| | 15' | 4.3 | 39½ |
| | 20' | 4.8 | 40½ |
| Feb. 2, 1938 | Surf. | 0.2 | 32½ |
| | 5' | 3.6 | 38½ |
| | 10' | 4.3 | 39½ |
| | 15' | 4.9 | 41 |
| | 20' | 5.3 | 41½ |
| Feb. 9, 1938 | Surf. | 1.0 | 34 |
| | 3' | 5.0 | 41 |
| | 5' | 5.0 | 41 |
| | 10' | 5.1 | 41 |
| | 15' | 5.3 | 41½ |
| | 20' | 5.5 | 42 |
| Feb. 20, 1938 | Surf. | 0.6 | 33 |
| | 3' | 6.3 | 43½ |
| | 5' | 6.4 | 43½ |
| | 10' | 5.8 | 42½ |
| | 15' | 5.8 | 42½ |
| | 20' | 5.7 | 42½ |
| Feb. 27, 1938 | Surf. | 1.8 | 35 |
| | 3' | 5.5 | 42 |
| | 5' | 5.9 | 42½ |
| | 10' | 5.9 | 42½ |
| | 15' | 5.7 | 42½ |
| | 20' | 5.6 | 42 |

### Table 12.

### Vertical Distribution of pH, Alkalinity and Dissolved Oxygen, Clear Lake, Station 2; 1939-40.

| Date | Depth | pH | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|
| Dec. 31, 1939 | Surf. | ... | ... | 14.5 |
| | 5 feet | ... | ... | 14.2 |
| | 10 feet | ... | ... | 14.1 |
| | 15 feet | ... | ... | 14.0 |
| | 20 feet | ... | 156 | 13.7 |
| Jan. 6, 1940 | Surf. | ... | 158 | 14.7 |
| | 5 feet | ... | 156 | 14.5 |
| | 10 feet | ... | 157 | 14.2 |
| | 15 feet | ... | 159 | 13.1 |
| | 20 feet | ... | 164 | 12.6 |
| Jan. 10, 1940 | Surf. | 8.2 | 160 | 15.1 |
| | 5 feet | ... | ... | 14.5 |
| | 10 feet | 8.2 | 157 | 14.0 |
| | 15 feet | ... | ... | 12.9 |
| | 20 feet | 8.2 | 160 | 12.3 |
| Jan. 13, 1940 | Surf. | 8.0 | 151 | 14.6 |
| | 5 feet | ... | ... | 14.4 |
| | 10 feet | 8.0 | 156 | 13.7 |
| | 15 feet | ... | ... | 11.9 |
| | 20 feet | 8.0 | 160 | 10.8 |
| Jan. 17, 1940 | Surf. | 8.0 | 160 | 16.0 |
| | 5 feet | ... | ... | 14.7 |
| | 10 feet | 8.0 | 155 | 13.4 |
| | 15 feet | ... | ... | 11.9 |
| | 20 feet | 8.0 | 165 | 9.9 |
| Jan. 20, 1940 | Surf. | 8.0 | 165 | 15.5 |
| | 5 feet | ... | ... | 14.7 |
| | 10 feet | 8.0 | 158 | 14.2 |
| | 15 feet | ... | ... | 12.4 |
| | 20 feet | 8.0 | 166 | 10.8 |
| Jan. 24, 1940 | Surf. | 8.1 | 168 | 15.5 |
| | 5 feet | ... | ... | 15.3 |
| | 10 feet | 8.1 | 161 | 13.9 |
| | 15 feet | ... | ... | 14.7 |
| | 20 feet | 8.0 | 170 | 11.1 |
| Jan. 28, 1940 | Surf. | 8.1 | 165 | 15.5 |
| | 5 feet | ... | ... | 15.1 |
| | 10 feet | 8.1 | 163 | 14.8 |
| | 15 feet | ... | ... | 15.5 |
| | 20 feet | 7.8 | 172 | 9.9 |

(Continued)

Table 12.

### Vertical Distribution of pH, Alkalinity, and Dissolved Oxygen, Clear Lake, Station 2; 1939-40. (Continued)

| Date | Depth | pH | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|
| Jan. 31, 1940 | Surf. | 8.1 | 166 | 14.0 |
| | 5 feet | ... | ... | 13.8 |
| | 10 feet | 8.1 | 165 | 13.2 |
| | 15 feet | ... | ... | 11.4 |
| | 20 feet | 7.7 | 172 | 9.0 |
| Feb. 3, 1940 | Surf. | 8.1 | 168 | 14.0 |
| | 5 feet | ... | ... | 13.9 |
| | 10 feet | 8.0 | 166 | 12.3 |
| | 15 feet | ... | ... | 10.5 |
| | 20 feet | 7.7 | 175 | 8.7 |
| Feb. 8, 1940 | Surf. | 8.1 | 160 | 14.1 |
| | 5 feet | ... | ... | 14.2 |
| | 10 feet | 8.0 | 168 | 12.0 |
| | 15 feet | ... | ... | 10.2 |
| | 20 feet | 7.7 | 175 | 6.6 |
| Feb. 11, 1940 | Surf. | 8.0 | 147 | 13.4 |
| | 5 feet | ... | ... | 14.2 |
| | 10 feet | 8.0 | 166 | 12.0 |
| | 15 feet | ... | ... | 8.6 |
| | 20 feet | 7.6 | 178 | 7.3 |
| Feb. 14, 1940 | Surf. | 8.0 | 158 | 14.1 |
| | 5 feet | ... | ... | 13.9 |
| | 10 feet | 7.8 | 165 | 11.9 |
| | 15 feet | ... | ... | 8.4 |
| | 20 feet | 7.5 | 180 | 8.1 |
| Feb. 18, 1940 | Surf. | 8.0 | 172 | 14.2 |
| | 5 feet | ... | ... | 13.5 |
| | 10 feet | 7.8 | 165 | 11.6 |
| | 15 feet | ... | ... | 8.7 |
| | 20 feet | 7.6 | 177 | 5.9 |
| Feb. 21, 1940 | Surf. | 8.0 | 152 | 13.6 |
| | 5 feet | ... | ... | 13.7 |
| | 10 feet | 7.8 | 170 | 11.5 |
| | 15 feet | ... | ... | 8.2 |
| | 20 feet | 7.6 | 181 | 7.2 |
| Feb. 25, 1940 | Surf. | 8.0 | 165 | 14.1 |
| | 5 feet | ... | ... | 13.3 |
| | 10 feet | 7.7 | 167 | 9.8 |
| | 15 feet | ... | ... | 6.9 |
| | 20 feet | 7.6 | 178 | 4.4 |

(Continued)

Table 12.

Vertical Distribution of pH, Alkalinity, and
Dissolved Oxygen, Clear Lake,
Station 2; 1939-40.
(Continued)

| Date | Depth | pH | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|
| Feb. 28, 1940 | Surf. | 8.1 | 168 | 14.9 |
| | 5 feet | ... | ... | 13.6 |
| | 10 feet | 7.7 | 171 | 9.7 |
| | 15 feet | ... | ... | 7.4 |
| | 20 feet | 7.6 | 177 | 7.5 |
| Mar. 3, 1940 | Surf. | 8.0 | 165 | 13.8 |
| | 5 feet | ... | ... | 12.9 |
| | 10 feet | 7.6 | 171 | 10.0 |
| | 15 feet | ... | ... | 6.9 |
| | 20 feet | 7.4 | 182 | 4.5 |
| Mar. 8, 1940 | Surf. | 6.9 | 40 | 14.2 |
| | 5 feet | ... | ... | 12.6 |
| | 10 feet | 7.8 | 168 | 9.4 |
| | 15 feet | ... | ... | 6.5 |
| | 20 feet | 7.5 | 182 | 3.6 |
| Mar. 11, 1940 | Surf. | 6.9 | 54 | 13.2 |
| | 5 feet | 7.8 | 164 | 11.0 |
| | 10 feet | 7.7 | 172 | 7.9 |
| | 15 feet | ... | ... | 7.3 |
| | 20 feet | 7.4 | 181 | 6.1 |
| Mar. 16, 1940 | Surf. | 7.0 | 107 | 15.5 |
| | 5 feet | ... | ... | 12.2 |
| | 10 feet | 7.6 | 174 | 9.0 |
| | 15 feet | ... | ... | 7.0 |
| | 20 feet | 7.3 | 182 | 3.9 |
| Mar. 20, 1940 | Surf. | 6.7 | 12 | 11.3 |
| | 5 feet | ... | ... | 11.5 |
| | 10 feet | 7.7 | 168 | 9.7 |
| | 15 feet | ... | ... | 7.8 |
| | 20 feet | 7.4 | 182 | 4.0 |
| Mar. 23, 1940 | Surf. | 6.7 | 10 | 7.2 |
| | 5 feet | ... | ... | 10.7 |
| | 10 feet | 7.6 | 165 | 8.8 |
| | 15 feet | ... | ... | 8.1 |
| | 20 feet | 7.5 | 177 | 6.6 |
| Mar. 27, 1940 | Surf. | 7.0 | 65 | 9.7 |
| | 5 feet | ... | ... | 10.5 |
| | 10 feet | 7.6 | 166 | 8.8 |
| | 15 feet | ... | ... | 7.1 |
| | 20 feet | 7.4 | 181 | 5.8 |

(Continued)

Table 12.

Vertical Distribution of pH, Alkalinity, and
Dissolved Oxygen, Clear Lake,
Station 2; 1939-40.
(Continued)

| Date | Depth | pH | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|
| Mar. 31, 1940 | Surf. | 6.9 | 45 | 10.2 |
| | 5 feet | 7.7 | 164 | 10.8 |
| | 10 feet | 7.6 | 168 | 9.4 |
| | 15 feet | ... | ... | 8.4 |
| | 20 feet | 7.4 | 178 | 5.6 |
| Apr. 3, 1940 | Surf. | 6.8 | 28 | 9.9 |
| | 5 feet | 7.6 | 143 | 10.0 |
| | 10 feet | 7.6 | 171 | 8.1 |
| | 15 feet | ... | ... | 7.4 |
| | 20 feet | 7.3 | 178 | 4.0 |

Table 13.

Vertical Distribution of pH, Alkalinity, and
Dissolved Oxygen, Clear Lake,
Station 2a; 1940-41.

| Date | Depth | pH | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|
| Dec. 15, 1940 | Surf. | 8.2 | 142 | 14.2 |
| | 5 feet | ... | ... | 14.0 |
| | 10 feet | 8.2 | 142 | 13.9 |
| | 15 feet | ... | ... | 14.2 |
| | 20 feet | 8.0 | 148 | 12.7 |
| | 25 feet | ... | ... | 6.4 |
| | 33 feet | 7.6 | 158 | 4.7 |
| Dec. 21, 1940 | Surf. | 7.9 | 103 | 14.5 |
| | 5 feet | ... | ... | 13.5 |
| | 10 feet | 8.1 | 142 | 13.6 |
| | 15 feet | ... | ... | 12.0 |
| | 20 feet | 8.0 | 152 | 11.0 |
| | 25 feet | ... | ... | 9.2 |
| | 33 feet | 7.7 | 157 | 5.7 |
| Jan. 12, 1941 | Surf. | 8.2 | 140 | 13.2 |
| | 5 feet | 8.1 | 136 | 12.5 |
| | 10 feet | 8.2 | 138 | 13.1 |
| | 15 feet | 8.1 | 141 | 12.2 |
| | 20 feet | 8.2 | 139 | 11.3 |
| | 25 feet | 8.0 | 142 | 10.9 |
| | 33 feet | 7.6 | 144 | 6.4 |
| Jan. 23, 1941 | Surf. | 8.1 | 144 | 14.2 |
| | 5 feet | ... | ... | 14.1 |
| | 10 feet | 8.0 | 144 | 14.1 |
| | 15 feet | ... | ... | 14.5 |
| | 20 feet | 7.7 | 146 | 10.0 |
| | 25 feet | ... | ... | 8.4 |
| | 33 feet | 7.6 | 157 | 7.8 |
| Jan. 30, 1941 | Surf. | 8.1 | 143 | 14.3 |
| | 5 feet | ... | ... | 14.1 |
| | 10 feet | 8.1 | 144 | 14.3 |
| | 15 feet | ... | ... | 13.8 |
| | 20 feet | 8.0 | 147 | 11.5 |
| | 25 feet | ... | ... | 9.6 |
| | 33 feet | 7.6 | 157 | 7.9 |
| Feb. 6, 1941 | Surf. | 8.1 | 140 | 13.8 |
| | 5 feet | ... | ... | 13.9 |
| | 10 feet | 8.1 | 146 | 14.1 |
| | 15 feet | ... | ... | 13.7 |
| | 20 feet | 7.8 | 153 | 11.2 |
| | 25 feet | ... | ... | 8.7 |
| | 33 feet | 7.5 | 163 | 6.7 |

(Continued)

Table 13.

Vertical Distribution of pH, Alkalinity, and
Dissolved Oxygen, Clear Lake,
Station 2a; 1940-41.
(Continued)

| Date | Depth | pH | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|
| Feb. 14, 1941 | Surf. | 8.1 | 115 | 12.5 |
| | 5 feet | ... | ... | 14.1 |
| | 10 feet | 8.1 | 152 | 14.2 |
| | 15 feet | ... | ... | 13.4 |
| | 20 feet | 7.8 | 163 | 10.2 |
| | 25 feet | ... | ... | 9.9 |
| | 33 feet | 7.6 | 170 | 7.0 |
| Feb. 23, 1941 | Surf. | 8.1 | 130 | 14.7 |
| | 5 feet | ... | ... | 13.8 |
| | 10 feet | 8.1 | 153 | 13.7 |
| | 15 feet | ... | ... | 13.5 |
| | 20 feet | 8.0 | 161 | 10.0 |
| | 25 feet | ... | ... | 8.0 |
| | 33 feet | 7.7 | 175 | 4.5 |
| Mar. 2, 1941 | Surf. | 7.8 | 117 | 13.5 |
| | 5 feet | ... | ... | 14.4 |
| | 10 feet | 8.1 | 149 | 14.2 |
| | 15 feet | ... | ... | 13.3 |
| | 20 feet | 7.8 | 157 | 10.4 |
| | 25 feet | ... | ... | 9.7 |
| | 33 feet | 7.4 | 167 | 4.4 |
| Mar. 8, 1941 | Surf. | 7.7 | 63 | 15.4 |
| | 5 feet | ... | ... | 14.1 |
| | 10 feet | 8.2 | 150 | 14.1 |
| | 15 feet | ... | ... | 14.4 |
| | 20 feet | 7.8 | 153 | 12.5 |
| | 25 feet | ... | ... | 10.6 |
| | 33 feet | 7.5 | 169 | 5.4 |
| Mar. 13, 1941 | Surf. | 7.6 | 43 | 9.6 |
| | 5 feet | ... | ... | 14.8 |
| | 10 feet | 8.2 | 147 | 15.6 |
| | 15 feet | ... | ... | 15.6 |
| | 20 feet | 8.1 | 152 | 14.1 |
| | 25 feet | ... | ... | 11.9 |
| | 33 feet | 7.6 | 168 | 5.3 |

Table 14.

Vertical Distribution of Dissolved Oxygen, etc.; Green Lake, Station 2; 1940-41.

| Date | Depth | pH | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|
| Dec. 10, 1940 | Surf. | 7.8 | 130 | ... |
| | 5 feet | 7.7 | 140 | ... |
| | 9 feet | 7.5 | 156 | ... |
| Dec. 17, 1940 | Surf. | 7.8 | 133 | 12.4 |
| | 5 feet | ... | ... | 9.9 |
| | 9 feet | 7.5 | 161 | 5.8 |
| Dec. 21, 1940 | Surf. | 7.9 | 119 | 12.0 |
| | 5 feet | 7.7 | 144 | 9.5 |
| | 9 feet | 7.1 | 160 | 4.8 |
| Jan. 7, 1941 | Surf. | 7.6 | 142 | 13.2 |
| | 5 feet | 7.7 | 140 | 13.3 |
| | 9 feet | 7.6 | 140 | 12.4 |
| Jan. 12, 1941 | Surf. | 7.7 | 141 | 12.8 |
| | 5 feet | 7.7 | 138 | 12.7 |
| | 9 feet | 7.3 | 150 | 8.8 |
| Jan. 23, 1941 | Surf. | 7.3 | 90 | 12.3 |
| | 2 feet | ... | ... | 10.3 |
| | 5 feet | 7.0 | 148 | 8.0 |
| | 9 feet | 7.0 | 164 | 3.3 |
| Jan. 28, 1941 | Surf. | 7.6 | 152 | 11.6 |
| | 2 feet | 7.6 | 149 | 10.8 |
| | 5 feet | 7.6 | 148 | 10.1 |
| | 9 feet | 7.0 | 170 | 3.8 |
| Feb. 2, 1941 | Surf. | ... | ... | 11.2 |
| | 2 feet | ... | ... | 11.3 |
| | 5 feet | ... | ... | 8.8 |
| | 9 feet | ... | ... | 3.2 |
| Feb. 9, 1941 | Surf. | 7.5 | 152 | 9.4 |
| | 2 feet | ... | ... | 10.3 |
| | 5 feet | 7.5 | 162 | 10.3 |
| | 9 feet | 6.9 | 176 | 6.8 |
| Feb. 14, 1941 | Surf. | 7.5 | 65 | 10.5 |
| | 2 feet | 7.6 | 163 | 10.2 |
| | 5 feet | 7.4 | 172 | 7.8 |
| | 9 feet | 7.0 | 177 | 3.9 |
| Feb. 18, 1941 | Surf. | ... | ... | 12.2 |
| | 2 feet | ... | ... | 9.8 |
| | 5 feet | ... | ... | 9.0 |
| | 9 feet | ... | ... | 5.5 |

(Continued)

## Table 14.

### Vertical Distribution of Dissolved Oxygen, etc.; Green Lake, Station 2; 1940-41.
### (Continued)

| Date | Depth | pH | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|
| Feb. 24, 1941 | Surf. | 7.4 | 163 | 9.2 |
| | 2 feet | 7.6 | 169 | 9.0 |
| | 5 feet | 7.4 | 166 | 8.7 |
| | 9 feet | 7.0 | 175 | 5.0 |
| Mar. 2, 1941 | Surf. | 7.4 | 139 | 8.2 |
| | 2 feet | 7.5 | 164 | 8.9 |
| | 5 feet | 7.6 | 163 | 8.9 |
| | 9 feet | 7.2 | 170 | 5.7 |
| Mar. 8, 1941 | Surf. | 7.6 | 67 | 12.6 |
| | 2 feet | 7.4 | 144 | 10.1 |
| | 5 feet | ... | ... | 11.2 |
| | 9 feet | 7.0 | 169 | 6.7 |

## Table 15.

### Vertical Distribution of pH, Alkalinity, and Dissolved Oxygen, Bog Lake; 1939-40.

| Date | Depth | pH | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|
| Jan. 6, 1940 | Surf. | ... | 7 | 11.6 |
| | 1 foot | ... | ... | ... |
| | 2 feet | ... | 9 | 4.4 |
| | 3 feet | ... | ... | ... |
| | 4 feet | ... | 9 | 1.0 |
| | 5 feet | ... | 10 | 0.4 |
| Jan. 13, 1940 | Surf. | ... | 6 | 14.0 |
| | 1 foot | ... | 8 | 12.2 |
| | 2 feet | ... | 6 | 8.6 |
| | 3 feet | ... | 5 | 4.8 |
| | 4 feet | ... | 6 | 0.8 |
| | 5 feet | ... | 6 | 0.6 |
| Jan. 20, 1940 | Surf. | 6.4 | 8 | 11.3 |
| | 1 foot | 5.6 | 5 | 11.0 |
| | 2 feet | 5.4 | 5 | 3.3 |
| | 3 feet | ... | ... | 4.9 |
| | 4 feet | 5.4 | 6 | 3.3 |
| | 5 feet | 5.4 | 5 | 0.7 |
| Jan. 28, 1940 | Surf. | 5.6 | 5 | 7.1 |
| | 1 foot | 5.7 | 5 | 5.9 |
| | 2 feet | 5.6 | 6 | 3.2 |
| | 3 feet | 5.5 | 5 | 1.0 |
| | 4 feet | 5.5 | 6 | 0.5 |
| | 5 feet | 5.5 | 6 | 0.6 |
| Feb. 3, 1940 | Surf. | 5.5 | 8 | 2.2 |
| | 1 foot | 5.5 | 5 | 2.0 |
| | 2 feet | 5.5 | 5 | 0.5 |
| | 3 feet | 5.5 | 8 | 0.2 |
| | 4 feet | 5.5 | 6 | 0.3 |
| | 5 feet | 5.5 | 6 | 0.0 |
| Feb. 11, 1940 | Surf. | 5.6 | 6 | 1.6 |
| | 1 foot | 5.6 | 6 | 0.5 |
| | 2 feet | 5.8 | 5 | 0.2 |
| | 3 feet | 5.8 | 5 | 0.5 |
| | 4 feet | 5.7 | 5 | 0.0 |
| | 5 feet | 5.6 | 5 | 0.0 |
| Feb. 18, 1940 | Surf. | 6.5 | 7 | 8.1 |
| | 1 foot | 6.2 | 5 | 4.7 |
| | 2 feet | 6.0 | 5 | 3.1 |
| | 3 feet | 6.0 | 5 | 0.9 |
| | 4 feet | 5.9 | 7 | 0.9 |
| | 5 feet | 5.9 | 7 | 0.3 |

(Continued)

Table 15.

Vertical Distribution of pH, Alkalinity, and Dissolved Oxygen, Bog Lake; 1939-40.
(Continued)

| Date | Depth | pH | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|
| Feb. 25, 1940 | Surf. | 5.5 | 7 | 2.4 |
| | 1 foot | 5.6 | 5 | 2.1 |
| | 2 feet | 5.5 | 5 | 1.0 |
| | 3 feet | 5.6 | 5 | 0.2 |
| | 4 feet | 5.6 | 6 | 1.2 |
| | 5 feet | 5.6 | 7 | 0.6 |
| Mar. 3, 1940 | Surf. | 5.5 | 5 | 0.6 |
| | 1 foot | 5.6 | 5 | 0.2 |
| | 2 feet | 5.5 | 5 | 0.2 |
| | 3 feet | 5.6 | 6 | 0.0 |
| | 4 feet | 5.5 | 9 | 0.0 |
| | 5 feet | 5.6 | 8 | 0.0 |
| Mar. 11, 1940 | Surf. | 5.8 | 6 | 10.5 |
| | 1 foot | 5.9 | 5 | 10.4 |
| | 2 feet | 5.7 | 6 | 5.2 |
| | 3 feet | 5.7 | 6 | 1.2 |
| | 4 feet | 5.7 | 7 | 2.2 |
| | 5 feet | 5.7 | 11 | 0.0 |
| Mar. 16, 1940 | Surf. | 5.9 | 7 | 15.0 |
| | 1 foot | 5.9 | 6 | 14.8 |
| | 2 feet | 5.7 | 6 | 6.5 |
| | 3 feet | 5.5 | 6 | 2.8 |
| | 4 feet | 5.6 | 7 | 2.0 |
| | 5 feet | 5.6 | 12 | 0.0 |
| Mar. 23, 1940 | Surf. | 6.0 | 7 | 14.4 |
| | 1 foot | 6.0 | 6 | 14.2 |
| | 2 feet | 5.8 | 6 | 8.3 |
| | 3 feet | 5.8 | 6 | 3.9 |
| | 4 feet | 5.8 | 8 | 2.1 |
| | 5 feet | 5.6 | 11 | 0.6 |
| Mar. 27, 1940 | Surf. | 6.1 | 7 | 15.3 |
| | 1 foot | 6.1 | 5 | 14.5 |
| | 2 feet | 5.8 | 5 | 3.4 |
| | 3 feet | 5.6 | 6 | 1.9 |
| | 4 feet | 5.8 | 8 | 1.9 |
| | 5 feet | 5.7 | 12 | 0.2 |

Table 16.

Vertical Distribution of pH, Carbon Dioxide, Alkalinity, and Dissolved Oxygen, Bog Lake, 1940-41.

| Date | Depth | pH | $CO_2$, p.p.m. | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|---|
| Dec. 10, 1940 | Surf. | 6.1 | ... | 7 | ... |
| | 1 foot | 5.7 | ... | 5 | ... |
| | 2 feet | 5.6 | ... | 6 | ... |
| | 3 feet | 5.6 | ... | 6 | ... |
| | 4 feet | 5.6 | ... | 6 | ... |
| | 5 feet | 5.6 | ... | 6 | ... |
| Dec. 17, 1940 | Surf. | 6.2 | ... | 5 | 15.9 |
| | 1 foot | 6.2 | ... | 5 | 13.2 |
| | 2 feet | 5.7 | ... | 14 | 4.5 |
| | 3 feet | 5.6 | ... | 5 | 1.7 |
| | 4 feet | 5.6 | ... | 14 | 0.6 |
| | 5 feet | 5.7 | ... | 10 | 0.3 |
| Dec. 21, 1940 | Surf. | 6.6 | 2 | 6 | 16.1 |
| | 1 foot | 6.8 | 2 | 8 | 14.5 |
| | 2 feet | 5.8 | 13 | 12 | 0.7 |
| | 3 feet | 5.6 | 17 | 7 | 0.4 |
| | 4 feet | 5.7 | 18 | 8 | 0.1 |
| | 5 feet | 5.7 | 21 | 7 | 0.2 |
| Jan. 7, 1941 | Surf. | 6.6 | 4 | 6 | 16.7 |
| | 1 foot | 6.5 | 12 | 6 | 13.0 |
| | 2 feet | 5.9 | 14 | 6 | 6.5 |
| | 3 feet | 5.9 | 19 | 6 | 1.5 |
| | 4 feet | 5.7 | 22 | 7 | 0.9 |
| | 5 feet | 5.7 | 22 | 7 | 0.6 |
| Jan. 14, 1941 | Surf. | 6.0 | 4 | 5 | 14.0 |
| | 1 foot | 5.8 | 9 | 5 | 7.8 |
| | 2 feet | 5.8 | 14 | 6 | 1.5 |
| | 3 feet | 5.7 | 21 | 5 | 2.1 |
| | 4 feet | 5.7 | 22 | 6 | 0.5 |
| | 5 feet | 5.7 | 21 | 6 | 0.1 |
| Jan. 23, 1941 | Surf. | 6.0 | 4 | 5 | 20.2 |
| | 1 foot | 6.0 | 4 | 5 | 18.3 |
| | 2 feet | 5.4 | 16 | 7 | 2.1 |
| | 3 feet | 5.4 | 23 | 7 | 0.6 |
| | 4 feet | 5.4 | 23 | 7 | 0.3 |
| | 5 feet | 5.4 | 23 | 8 | 0.0 |
| Jan. 28, 1941 | Surf. | 5.9 | 4 | 7 | 17.7 |
| | 1 foot | 5.8 | 6 | 5 | 17.6 |
| | 2 feet | 5.7 | 14 | 6 | 6.7 |
| | 3 feet | 5.5 | 21 | 6 | 1.8 |
| | 4 feet | 5.4 | 24 | 6 | 0.7 |
| | 5 feet | 5.5 | 22 | 8 | 0.0 |

(Continued)

## Table 16.

### Vertical Distribution of pH, Carbon Dioxide, Alkalinity, and Dissolved Oxygen, Bog Lake, 1940-41.

(Continued)

| Date | Depth | pH | $CO_2$, p.p.m. | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|---|
| Feb. 4, 1941 | Surf. | 5.8 | 4 | 7 | 18.4 |
| | 1 foot | 5.8 | 5 | 5 | 16.0 |
| | 2 feet | 5.5 | 14 | 6 | 7.4 |
| | 3 feet | 5.5 | 19 | 7 | 1.9 |
| | 4 feet | 5.5 | 21 | 6 | 0.6 |
| | 5 feet | 5.5 | 23 | 9 | 0.0 |
| Feb. 11, 1941 | Surf. | 5.8 | 4 | 12 | 21.0 |
| | 1 foot | 5.7 | 4 | 5 | 17.1 |
| | 2 feet | 5.4 | 19 | 5 | 2.3 |
| | 3 feet | 5.4 | 22 | 6 | 0.7 |
| | 4 feet | 5.4 | 23 | 6 | 0.2 |
| | 5 feet | 5.4 | 25 | 6 | 0.1 |
| Feb. 16, 1941 | Surf. | 5.9 | 4 | 6 | 18.7 |
| | 1 foot | 5.8 | 4 | 6 | 17.6 |
| | 2 feet | 5.6 | 14 | 5 | 9.5 |
| | 3 feet | 5.5 | 15 | 8 | 3.0 |
| | 4 feet | 5.5 | 18 | 5 | 1.5 |
| | 5 feet | 5.6 | 18 | 6 | 1.2 |
| Feb. 18, 1941 | Surf. | ... | ... | ... | 18.2 |
| | 1 foot | ... | ... | ... | 18.0 |
| | 2 feet | ... | ... | ... | 4.8 |
| | 3 feet | ... | ... | ... | 1.8 |
| | 4 feet | ... | ... | ... | 0.4 |
| | 5 feet | ... | ... | ... | 0.4 |
| Feb. 25, 1941 | Surf. | 5.9 | 4 | 8 | 20.5 |
| | 1 foot | 5.7 | 7 | 6 | 18.5 |
| | 2 feet | 5.6 | 10 | 7 | 11.1 |
| | 3 feet | 5.6 | 16 | 6 | 4.5 |
| | 4 feet | 5.5 | 22 | 7 | 1.3 |
| | 5 feet | 5.5 | 27 | 7 | 0.0 |
| Mar. 2, 1941 | Surf. | 5.9 | 7 | 4 | 15.3 |
| | 1 foot | 5.7 | 9 | 6 | 15.2 |
| | 2 feet | 5.7 | 10 | 6 | 7.0 |
| | 3 feet | 5.8 | 17 | 4 | 2.8 |
| | 4 feet | 5.7 | 22 | 5 | 0.2 |
| | 5 feet | 5.6 | 23 | 7 | 0.0 |
| Mar. 4, 1941 | Surf. | 6.0 | 5 | 8 | 13.9 |
| | 1 foot | 6.2 | 5 | 7 | 13.4 |
| | 2 feet | 5.6 | 15 | 5 | 6.4 |
| | 3 feet | 5.8 | ... | ... | 2.8 |
| | 4 feet | 5.8 | ... | ... | 1.0 |
| | 5 feet | 5.6 | ... | ... | 0.6 |

(Continued)

Table 16.

Vertical Distribution of pH, Carbon Dioxide, Alkalinity, and Dissolved Oxygen, Bog Lake, 1940-41. (Continued)

| Date | Depth | pH | $CO_2$, p.p.m. | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|---|
| Mar. 10, 1941 | Surf. | 5.8 | 8 | 4 | 14.9 |
| | 1 foot | 5.6 | 9 | 4 | 15.4 |
| | 2 feet | 5.7 | 5 | 5 | 14.5 |
| | 3 feet | 5.4 | 21 | 5 | 4.0 |
| | 4 feet | 5.5 | 21 | 7 | 1.3 |
| | 5 feet | 5.5 | 24 | 6 | 0.0 |
| Mar. 27, 1941 | Surf. | 5.8 | 4 | 7 | 17.8 |
| | 1 foot | 5.8 | 4 | 4 | 17.8 |
| | 2 feet | 5.9 | 4 | 7 | 17.1 |
| | 3 feet | 5.6 | 6 | 5 | 9.0 |
| | 4 feet | 5.4 | 19 | 5 | 3.7 |
| | 5 feet | 5.4 | 25 | 6 | 1.5 |

Table 17.

### Vertical Distribution of pH, Alkalinity, and Dissolved Oxygen, Pasinski's Pond, Station 26; 1940-41.

| Date | Depth | pH | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|
| Dec. 12, 1940 | Surf. | 8.8+ | 96 | 13.5 |
| | 4 feet | 8.6 | 103 | 8.6 |
| Dec. 19, 1940 | Surf. | 8.8+ | 84 | 15.1 |
| | 4 feet | 8.6 | 105 | 9.8 |
| Jan. 10, 1941 | Surf. | 8.8+ | 103 | 17.1 |
| | 1 foot | ... | ... | 16.6 |
| | 2 feet | 8.4 | 104 | 14.7 |
| | 3 feet | ... | ... | 14.3 |
| | 4 feet | 7.6 | 113 | 12.7 |
| Jan. 16, 1941 | Surf. | 8.7 | 108 | 17.8 |
| | 1 foot | ... | ... | 18.3 |
| | 2 feet | 8.3 | 109 | 13.8 |
| | 3 feet | ... | ... | 11.9 |
| | 4 feet | 7.6 | 110 | 12.1 |
| Jan. 24, 1941 | Surf. | 8.8 | 115 | 19.9 |
| | 1 foot | ... | ... | 19.9 |
| | 2 feet | 8.7 | 113 | 17.1 |
| | 3 feet | ... | ... | 16.9 |
| | 4 feet | 8.4 | 122 | 15.5 |
| Jan. 31, 1941 | Surf. | 8.8+ | 124 | 28.0 |
| | 1 foot | ... | ... | 27.2 |
| | 2 feet | 8.8 | 120 | 19.2 |
| | 3 feet | ... | ... | 13.7 |
| | 4 feet | 8.1 | 127 | 11.1 |
| Feb. 8, 1941 | Surf. | 8.8+ | 129 | 21.3 |
| | 1 foot | ... | ... | 21.5 |
| | 2 feet | 8.8+ | 127 | 19.6 |
| | 3 feet | ... | ... | 18.7 |
| | 4 feet | 8.8+ | 128 | 17.6 |
| Feb. 12, 1941 | Surf. | 8.8+ | 131 | 24.1 |
| | 1 foot | ... | ... | 24.5 |
| | 2 feet | 8.8+ | 135 | 21.0 |
| | 3 feet | ... | ... | 18.4 |
| | 4 feet | 8.1 | 132 | 14.9 |
| Feb. 18, 1941 | Surf. | ... | ... | 25.2 |
| | 1 foot | ... | ... | 25.8 |
| | 2 feet | ... | ... | 21.7 |
| | 3 feet | ... | ... | 20.9 |
| | 4 feet | ... | ... | 19.2 |

(Continued)

## Table 17.

## Vertical Distribution of pH, Alkalinity, and Dissolved Oxygen, Pasinski's Pond, Station 26; 1940-41. (Continued)

| Date | Depth | pH | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|
| Feb. 21, 1941 | Surface | 8.8+ | 137 | 24.8 |
| | 1 foot | ... | ... | 24.0 |
| | 2 feet | 8.8+ | 134 | 22.6 |
| | 3 feet | ... | ... | 23.1 |
| | 4 feet | 8.8+ | 133 | 21.8 |
| Feb. 27, 1941 | Surf. | 8.8+ | 138 | 26.2 |
| | 1 foot | 8.8+ | 138 | 26.5 |
| | 2 feet | 8.8+ | 135 | 24.4 |
| | 3 feet | 8.8+ | 132 | 24.1 |
| | 4 feet | 8.8+ | 144 | 21.4 |
| Mar. 6, 1941 | Surf. | 8.8 | 56 | 20.1 |
| | 1 foot | 8.8 | 58 | 20.3 |
| | 2 feet | 8.8 | 118 | 24.1 |
| | 3 feet | 8.8 | 132 | 20.1 |
| | 4 feet | 8.7 | 131 | 19.8 |
| Mar. 11, 1941 | Surf. | 8.8 | 54 | 16.7 |
| | 1 foot | 8.8+ | 81 | 19.6 |
| | 2 feet | 8.8+ | 99 | 22.9 |
| | 3 feet | 8.6 | 113 | 22.3 |
| | 4 feet | 8.6 | 116 | 21.6 |

Table 18.

Dissolved Oxygen, Two-hour Intervals for 48 Hours,
Green Lake; Jan. 17-19, 1941.
Oxygen in p.p.m.

| Day | Hour | Air temp., °F. | Sky | Station 6 6-inch depth | Station 6 3-foot depth | Station 2 6-inch depth | Station 2 2-foot depth | Station 2 5-foot depth | Station 2 9-foot depth |
|---|---|---|---|---|---|---|---|---|---|
| Friday | 5 P.M. | 38 | Overcast | 12.7 | 12.6 | 13.6 | 13.3 | 9.8 | 6.0 |
| | 7 P.M. | 38 | " | 13.0 | 13.2 | 13.4 | 12.7 | 9.3 | 6.1 |
| | 9 P.M. | 38 | Lt. rain | 13.4 | 12.7 | 12.8 | 13.0 | 9.7 | 4.6 |
| | 11 P.M. | 37 | Mist | 13.2 | 12.6 | 12.7 | 12.7 | 8.1 | 3.4 |
| Saturday | 1 A.M. | 34 | Overcast | 13.2 | 12.7 | 12.5 | 12.2 | 8.4 | 4.4 |
| | 3 A.M. | 31 | Lt. snow | 13.2 | 12.6 | 12.5 | 12.0 | 8.4 | 4.1 |
| | 5 A.M. | 30 | Pt. Cl. | 13.4 | 11.6 | 12.3 | 12.2 | 8.0 | 4.5 |
| | 7 A.M. | 29 | Pt. Cl. | 12.7 | 12.6 | 12.7 | 12.6 | 8.1 | 4.3 |
| | 9 A.M. | 26 | Cloudy | 13.1 | 12.8 | 13.0 | 12.7 | 7.2 | 4.7 |
| | 11 A.M. | 23½ | " | 13.3 | 12.7 | 12.8 | 13.5 | 8.9 | 3.7 |
| | 1 P.M. | 23½ | " | 12.9 | 12.1 | 12.6 | 13.1 | 8.6 | 4.7 |
| | 3 P.M. | ... | Pt. Cl. | 12.8 | 12.5 | 12.9 | 13.0 | 8.6 | 3.7 |
| | 5 P.M. | 21 | Cloudy | 13.0 | 11.6 | 13.2 | 11.9 | 8.7 | 5.4 |
| | 7 P.M. | 20 | " | 13.0 | 12.8 | 12.7 | 13.0 | 9.2 | 4.7 |
| | 9 P.M. | 18 | " | 12.8 | 12.8 | 13.2 | 13.1 | 8.4 | 5.5 |
| | 11 P.M. | 16 | Pt. Cl. | 13.0 | 11.2 | 13.4 | 13.2 | 10.5 | 6.0 |
| Sunday | 1 A.M. | 16½ | Cloudy | 13.3 | 12.6 | 13.6 | 13.3 | 8.7 | 6.6 |
| | 3 A.M. | 16 | Pt. Cl. | 13.5 | 12.6 | 13.7 | 13.7 | 9.2 | 4.3 |
| | 5 A.M. | 16 | Overcast | 14.0 | 12.8 | 14.1 | 13.1 | 9.2 | 5.7 |
| | 7 A.M. | 17 | Cloudy | 14.4 | 12.7 | 14.2 | 13.4 | 8.2 | 7.1 |
| | 9 A.M. | 17 | Pt. Cl. | 14.1 | 12.7 | 14.0 | 12.9 | 8.1 | 4.9 |
| | 11 A.M. | 19½ | Clear | 14.0 | 12.2 | 14.3 | 13.2 | 9.2 | 5.0 |
| | 1 P.M. | 20 | Pt. Cl. | 13.8 | 12.5 | 13.6 | 13.1 | 8.9 | 7.3 |
| | 3 P.M. | 21 | Pt. Cl. | 14.0 | 12.3 | 14.1 | 13.5 | 8.4 | 7.6 |

## Table 19.

pH, Two-hour Intervals for 48 Hours,
Green Lake; Jan. 17-19, 1941.

| | | Station 6 | | Station 2 | | | |
|---|---|---|---|---|---|---|---|
| Day | Hour | 6-inch depth | 3-foot depth | 6-inch depth | 2-foot depth | 5-foot depth | 9-foot depth |
| Friday | 5 P.M. | 6.9 | 7.7 | 7.8 | 7.8 | 7.5 | 7.3 |
| | 7 P.M. | 7.5 | 7.7 | 7.4 | 7.6 | 7.5 | 7.4 |
| | 9 P.M. | 7.3 | 7.7 | 7.6 | 7.7 | 7.6 | 7.3 |
| | 11 P.M. | 7.5 | 7.7 | 7.6 | 7.7 | 7.5 | 7.3 |
| Saturday | 1 A.M. | 7.2 | 7.7 | 7.7 | 7.7 | 7.6 | 7.3 |
| | 3 A.M. | 7.3 | 7.7 | 7.6 | 7.7 | 7.6 | 7.3 |
| | 5 A.M. | 6.8 | 7.6 | 7.6 | 7.7 | 7.5 | 7.2 |
| | 7 A.M. | 7.6 | 7.6 | 7.6 | 7.6 | 7.4 | 7.3 |
| | 9 A.M. | 7.6 | 7.6 | 7.6 | 7.6 | 7.0 | 7.0 |
| | 11 A.M. | 7.5 | 7.7 | 7.6 | 7.8 | 7.4 | 6.9 |
| | 1 P.M. | 7.6 | 7.6 | 7.6 | 7.6 | 7.4 | 7.0 |
| | 3 P.M. | 7.5 | 7.6 | 7.6 | 7.6 | 7.4 | 7.0 |
| | 5 P.M. | 7.6 | 7.8 | 7.6 | 7.6 | 7.4 | 6.9 |
| | 7 P.M. | 7.6 | 7.7 | 7.5 | 7.7 | 7.4 | 6.9 |
| | 9 P.M. | 7.5 | 7.7 | 7.5 | 7.7 | 7.4 | 6.9 |
| | 11 P.M. | 7.5 | 7.5 | 7.5 | 7.7 | 7.5 | 6.9 |
| Sunday | 1 A.M. | 7.6 | 7.7 | 7.6 | 7.7 | 7.5 | 7.0 |
| | 3 A.M. | 7.5 | 7.7 | 7.5 | 7.6 | 7.4 | 6.9 |
| | 5 A.M. | 7.4 | 7.6 | 7.5 | 7.6 | 7.3 | 6.9 |
| | 7 A.M. | 7.4 | 7.6 | 7.5 | 7.6 | 7.4 | 7.0 |
| | 9 A.M. | 7.4 | 7.6 | 7.5 | 7.6 | 7.2 | 7.0 |
| | 11 A.M. | 7.4 | ... | 7.4 | 7.6 | 7.2 | 7.0 |
| | 1 P.M. | 7.6 | 7.6 | 7.6 | 7.6 | 7.2 | 7.0 |
| | 3 P.M. | 7.6 | 7.7 | 7.6 | 7.6 | 7.4 | 7.0 |

Table 20.

Dissolved Oxygen and Temperature Profiles;
Green Lake; February 2, 1941.

| Station | Dist. from Inlet, feet | Depth | Temperature °F. | Temperature °C. | $O_2$, p.p.m. |
|---|---|---|---|---|---|
| Inlet | 0 | 1 inch | 32 | 0.0 | 4.3 |
| | | 6 inches | 35 | 1.7 | 4.1 |
| | 200 | 2 inches | 32 | 0.0 | 13.2 |
| | | 1 foot | 32 | 0.0 | 13.5 |
| | | 2 feet | 36 | 2.2 | 12.5 |
| | 300 | 2 inches | 32 | 0.0 | 12.3 |
| | | 1 foot | 33 | 0.6 | 12.2 |
| | | 2 feet | 35½ | 1.9 | 11.4 |
| | | 3 feet | 37 | 2.8 | 11.4 |
| | | 4 feet | 37 | 2.8 | 11.4 |
| | 400 | 2 inches | 32 | 0.0 | 12.4 |
| | | 1 foot | 33 | 0.6 | 11.9 |
| | | 2 feet | 35½ | 1.9 | 11.3 |
| | | 3 feet | 36½ | 2.5 | 11.7 |
| | | 4 feet | 37½ | 3.0 | 11.6 |
| | | 5 feet | 37½ | 3.0 | 11.3 |
| | | 6 feet | 38 | 3.3 | 10.3 |
| | | 7 feet | 38 | 3.3 | 8.6 |
| | | 8 feet | 39 | 3.9 | 8.1 |
| Sta. 4 | 625 | 2 inches | 32 | 0.0 | 13.7 |
| | | 1 foot | 33 | 0.6 | 12.9 |
| | | 2 feet | 37 | 2.8 | 11.2 |
| | | 3 feet | 37½ | 3.0 | 10.8 |
| | | 4 feet | 38 | 3.3 | 9.5 |
| | | 5 feet | 38 | 3.3 | 9.1 |
| | | 6 feet | 38 | 3.3 | 7.6 |
| | | 7 feet | 38 | 3.3 | 5.8 |
| | | 8 feet | 38 | 3.3 | 5.2 |
| | 925 | 2 inches | 32 | 0.0 | 12.0 |
| | | 1 foot | 32 | 0.0 | 12.2 |
| | | 2 feet | 36 | 2.2 | 12.3 |
| | | 3 feet | 37½ | 3.0 | 11.3 |
| | | 4 feet | 38 | 3.3 | 10.3 |
| | | 5 feet | 38 | 3.3 | 7.9 |
| Sta. 2 | 1,350 | 4 inches | 32 | 0.0 | 11.2 |
| | | 1 foot | 32 | 0.0 | 11.0 |
| | | 2 feet | 36½ | 2.5 | 11.3 |
| | | 3 feet | 37½ | 3.0 | 11.2 |
| | | 4 feet | 38 | 3.3 | 10.4 |
| | | 5 feet | 38 | 3.3 | 8.8 |
| | | 6 feet | 38 | 3.3 | 7.8 |
| | | 7 feet | 38 | 3.3 | 6.7 |
| | | 8 feet | 38½ | 3.6 | 4.6 |
| | | 8½ feet | 39 | 3.9 | 3.2 |

(Continued)

Table 20.

## Dissolved Oxygen and Temperature Profiles; Green Lake; February 2, 1941.
(Continued)

| Station | Dist. from Inlet, feet | Depth | Temperature | | $O_2$, p.p.m. |
|---|---|---|---|---|---|
| | | | °F. | °C. | |
| | 1,600 | 2 inches | 32 | 0.0 | 10.8 |
| | | 1 foot | 33 | 0.6 | 10.9 |
| | | 2 feet | 36 | 2.2 | 10.6 |
| | | 3 feet | 37 | 2.8 | 10.4 |
| | | 4 feet | 37 | 2.8 | 10.5 |
| | | 5 feet | 38 | 3.3 | 9.7 |
| Sta. 1 | 1,950 | 2 inches | 32 | 0.0 | 12.1 |
| | | 1 foot | 32 | 0.0 | 11.8 |
| | | 2 feet | 36 | 2.2 | 10.5 |
| | | 3 feet | 37 | 2.8 | 10.1 |
| | 2,400 | 2 inches | 32 | 0.0 | 11.9 |
| | | 1 foot | 32 | 0.0 | 11.8 |
| | | 2 feet | 37 | 2.8 | 10.5 |
| Sta. 5 | 2,900 | 2 inches | 32 | 0.0 | 11.3 |
| | | 1 foot | 33 | 0.6 | 11.0 |
| | | 2 feet | 36½ | 2.5 | 9.7 |
| | | 3 feet | 37 | 2.8 | 8.6 |
| Outlet | 3,275 | 2 inches | 32 | 0.0 | 12.7 |
| | | 1 foot | 33 | 0.6 | 12.6 |
| | | 2 feet | 37 | 2.8 | 9.2 |
| | | 3 feet | 38 | 3.3 | 9.0 |
| | | 4 feet | 38 | 3.3 | 9.0 |

## Table 21.

**Biochemical Oxygen Demand (B.O.D.), Five Days at 20° C. Samples from Various Lakes, 1940-41. Data Expressed in p.p.m.**

| Lake | Station number | Depth | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | 12/21 | 1/7 | 1/23 | 1/28 | 2/9 | 2/18 | 3/11 |
| Green | 1 | Surface | 2.9 | 2.0 | ... | 3.0 | 2.3 | ... | ... |
| | | Bottom | 1.7 | 2.4 | ... | 2.3 | 1.8 | ... | ... |
| | 2 | Surface | 1.5 | 1.9 | 1.9 | 3.8 | 1.5 | 2.0 | ... |
| | | 2 feet | ... | ... | 1.6 | 2.0 | 2.1 | ... | 2.0 |
| | | 5 feet | 2.0 | 2.6 | 0.3 | 2.6 | 2.1 | 2.2 | ... |
| | | 9 feet | 0.0 | 1.9 | 3.0 | 1.9 | 1.1 | 2.1 | ... |
| | 3 | Surface | 3.2 | 3.1 | ... | 3.3 | 2.4 | ... | ... |
| | | Bottom | 2.7 | 2.9 | ... | 3.9 | 3.2 | ... | ... |
| | 4 | Surface | 2.9 | 1.8 | ... | 2.8 | 3.3 | ... | ... |
| | | 4 feet | ... | ... | ... | 2.2 | ... | ... | ... |
| | | 8 feet | 2.3 | 0.8 | ... | 0.0 | 3.1 | ... | ... |
| | 5 | Surface | ... | 3.1 | ... | 2.6 | 1.4 | ... | ... |
| | | Bottom | ... | 2.9 | ... | 2.9 | 1.8 | ... | ... |
| | Inlet | | 2.0 | 0.0 | 1.5 | 0.8 | 1.0 | ... | ... |
| | Outlet | | 1.7 | 4.0 | ... | 2.7 | 2.5 | ... | ... |
| | | | 12/19 | 1/7 | 1/14 | 1/28 | 1/30 | 2/4 | 2/11 |
| Mud | 1 | Surface | 2.1 | 3.1 | 1.4 | 2.6 | 3.7 | 2.6 | 3.9 |
| | | Bottom | 1.3 | 2.2 | 1.4 | 1.9 | 2.2 | 2.1 | 2.4 |
| | Inlet | | 2.1 | 2.1 | 2.7 | 2.0 | 2.2 | 1.5 | 1.3 |
| | Outlet | | 2.1 | 2.1 | 2.6 | 2.3 | 4.3 | 2.4 | 2.6 |
| | | | 12/21 | 1/12 | 1/23 | 1/30 | 2/6 | 2/18 | 3/11 |
| Clear | 1 | Surface | ... | 1.2 | ... | 3.8 | 2.9 | 1.6 | ... |
| | | Bottom | ... | 0.5 | 1.8 | 1.7 | 2.1 | ... | 1.2 |
| | 2a | Surface | 2.3 | 0.8 | 2.2 | 4.3 | 3.2 | ... | ... |
| | | 5 feet | ... | 0.6 | 1.5 | 2.4 | 1.8 | ... | ... |
| | | 10 feet | 1.5 | 0.8 | 1.6 | 3.6 | 2.3 | ... | ... |
| | | 15 feet | ... | 0.6 | 1.7 | 1.8 | 1.0 | ... | ... |
| | | 20 feet | 1.6 | 0.0 | 2.8 | 1.2 | 1.9 | ... | ... |
| | | 25 feet | ... | 0.0 | 1.4 | 0.9 | 1.3 | ... | ... |
| | | 33 feet | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | ... | ... |

Table 21.

Biochemical Oxygen Demand (B.O.D.), Five Days at 20° C.
Samples from Various Lakes, 1940-41. Data Expressed in p.p.m.
(Continued)

| Lake | Station number | Depth | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 12/21 | 1/7 | 1/14 | 1/23 | 2/4 | 2/11 | 2/18 | 3/11 | |
| Bog | | Surface | 13.4 | 15.2 | 9.8 | 10.0 | 13.2 | 8.8 | 12.0 | 22.0+ | |
| | | 1 foot | 8.4 | 8.2 | 5.2 | 18.3 | 7.3 | 8.4 | ... | ... | |
| | | 2 feet | 1.4 | 5.6 | 2.2 | 5.1 | 7.0+ | 2.0+ | 4.2 | 7.2 | |
| | | 3 feet | 1.8 | 1.8 | 4.0 | 3.9 | 5.6 | 3.0 | ... | ... | |
| | | 4 feet | 2.2 | 3.6 | 2.8 | 4.6 | 3.8 | 3.8 | ... | ... | |
| | | 5 feet | 2.2 | 2.6 | 3.4 | 4.2 | 4.2 | 3.4 | 6.2 | 2.9 | |
| | | | 12/19 | 1/10 | 1/16 | 1/24 | 1/31 | 2/8 | 2/12 | 2/18 | 3/11 |
| Pasinski's Pond | 15 | Surface | 3.0 | 15.0 | 42.0 | 10.6 | 14.7 | 6.8 | 12.0 | ... | ... |
| | | Bottom | 1.3 | 2.5 | 5.7 | 11.2 | 2.6 | 5.7 | 2.7 | ... | ... |
| | 24 | Surface | ... | 7.6 | 6.2 | 5.2 | 10.0 | 11.0 | 20.2 | ... | ... |
| | | Bottom | ... | 1.1 | 5.5 | 4.8 | 4.0 | 5.9 | 7.9 | ... | ... |
| | 26 | Surface | 4.2 | 11.5 | 11.0 | 2.8 | 8.3 | 2.5 | 36.3 | 6.4 | 22.0+ |
| | | 1 foot | ... | 4.4 | 4.5 | 2.4 | 9.2 | 9.4 | 34.3 | ... | ... |
| | | 2 feet | ... | 4.2 | 3.1 | 6.1 | 5.3 | 7.6 | 20.1 | 10.0 | 8.4 |
| | | 3 feet | ... | 4.0 | 2.8 | 5.8 | 2.6 | 11.0 | 15.7 | ... | ... |
| | | 4 feet | 1.5 | 1.7 | 4.9 | 4.4 | 1.4 | 10.9 | 6.1 | 7.5 | 5.4 |
| | 27 | Surface | ... | 12.9 | 7.1 | 4.3 | 21.8 | 4.8 | 24.2 | ... | ... |
| | | Bottom | ... | 4.7 | 0.0 | 3.6 | 5.2 | 6.3 | 3.6 | ... | ... |
| | 20 | Surface | ... | 6.7 | 9.1 | 10.1 | 10.0 | 8.1 | 20.6 | ... | ... |
| | | Bottom | ... | 3.2 | 0.0 | 4.8 | 3.6 | 5.2 | 3.2 | ... | ... |

## Table 22.

### Biochemical Oxygen Demand (B.O.D.), Five Days at 0° C. Samples from Various Lakes, 1941. Data Expressed in p.p.m.

| Lake | Station number | Depth | | | | |
|---|---|---|---|---|---|---|
| | | | 2/9 | 2/18 | 3/11 | |
| Green | 1 | Surface | 0.6 | ... | ... | |
| | | Bottom | 0.8 | ... | ... | |
| | 2 | Surface | 0.7 | 0.0 | ... | |
| | | 2 feet | 1.3 | ... | 0.5 | |
| | | 5 feet | 0.8 | 0.3 | ... | |
| | | 9 feet | 0.0 | 0.4 | ... | |
| | 3 | Surface | 1.2 | ... | ... | |
| | | Bottom | 1.8 | ... | ... | |
| | 4 | Surface | 0.6 | ... | ... | |
| | | Bottom | 3.3 | ... | ... | |
| | 5 | Surface | 0.5 | ... | ... | |
| | | Bottom | 0.6 | ... | ... | |
| | Inlet | | 0.6 | ... | ... | |
| | Outlet | | 0.9 | ... | ... | |
| | | | 2/4 | 2/11 | | |
| Mud | 1 | Surface | 0.5 | 1.2 | | |
| | | Bottom | 0.6 | 1.4 | | |
| | Inlet | | 0.0 | 0.6 | | |
| | Outlet | | 1.0 | 1.3 | | |
| | | | 2/6 | 2/18 | 3/11 | |
| Clear | 1 | Surface | 0.0 | 0.0 | ... | |
| | | Bottom | 0.5 | ... | 0.0 | |
| | 2a | Surface | 0.0 | ... | ... | |
| | | 5 feet | 0.4 | ... | ... | |
| | | 10 feet | 0.4 | ... | ... | |
| | | 15 feet | 0.0 | ... | ... | |
| | | 20 feet | 0.3 | ... | ... | |
| | | 25 feet | 0.7 | ... | ... | |
| | | 33 feet | 0.0 | ... | ... | |
| | | | 2/4 | 2/11 | 2/18 | 3/11 |
| Bog | | Surface | 3.9 | 4.1 | 2.4 | 9.4 |
| | | 1 foot | 1.1 | 6.1 | ... | ... |
| | | 2 feet | 5.4 | 1.4 | 1.2 | 2.8 |
| | | 3 feet | 0.0 | 0.0 | ... | ... |
| | | 4 feet | 0.0 | 0.0 | ... | ... |
| | | 5 feet | 0.0 | 0.0 | 1.0 | 1.4 |

Table 22.

Biochemical Oxygen Demand (B.O.D.), Five Days at 0° C.
Samples from Various Lakes, 1941. Data Expressed in p.p.m.
(Continued)

| Lake | Station number | Depth | 2/8 | 2/12 | 2/18 | 3/11 |
|---|---|---|---|---|---|---|
| Pasinski's Pond | 15 | Surface | 1.1 | 5.7 | ... | ... |
| | | Bottom | 3.0 | 1.9 | ... | ... |
| | 20 | Surface | 2.7 | 7.8 | ... | ... |
| | | Bottom | 2.6 | 0.5 | ... | ... |
| | 24 | Surface | 3.4 | 9.4 | ... | ... |
| | | Bottom | 3.9 | 8.4 | ... | ... |
| | 26 | Surface | 0.0 | 16.1 | 1.1 | 22.7 |
| | | 1 foot | 0.0 | 15.3 | ... | ... |
| | | 2 feet | 3.0 | 7.5 | 2.8 | 4.0 |
| | | 3 feet | 2.8 | 5.8 | ... | ... |
| | | 4 feet | 2.5 | 2.9 | 2.5 | 2.2 |
| | 27 | Surface | 4.1 | 11.8 | ... | ... |
| | | Bottom | 4.1 | 1.9 | ... | ... |

## Table 23.

### Biochemical Oxygen Demand (B.O.D.), 60 Days at 0° C.
### Samples Taken March 11, 1941. Data Expressed in p.p.m.

| Lake | Station | Depth | Days | B.O.D., p.p.m. | Lake | Station | Depth | Days | B.O.D., p.p.m. |
|---|---|---|---|---|---|---|---|---|---|
| Clear | 1 | 3 feet | 5 | 0.0 | Green | 2 | 3 feet | 5 | 0.5 |
|  |  |  | 10 | 1.6 |  |  |  | 10 | 1.7 |
|  |  |  | 15 | 2.1 |  |  |  | 15 | 1.8 |
|  |  |  | 20 | 1.3 |  |  |  | 20 | 1.8 |
|  |  |  | 30 | 0.2 |  |  |  | 30 | 2.2 |
|  |  |  | 40 | 2.8 |  |  |  | 40 | 7.0 |
|  |  |  | 50 | 1.9 |  |  |  | 50 | 5.4 |
|  |  |  | 60 | 2.6 |  |  |  | 60 | 5.4 |
| Bog |  | Surface | 5 | 9.4 | Pasinski's Pond | 26 | Surface | 5 | 22.5 |
|  |  |  | 10 | 20.0 |  |  |  | 10 | 29.6 |
|  |  |  | 15 | 27.6 |  |  |  |  |  |
|  |  |  | 20 | 31.6 |  |  | 2 feet | 5 | 4.0 |
|  |  |  |  |  |  |  |  | 10 | 4.0 |
|  |  | 2 feet | 5 | 2.8 |  |  |  | 15 | 7.4 |
|  |  |  | 10 | 4.9 |  |  |  | 20 | 9.5 |
|  |  |  | 15 | 5.4 |  |  |  | " | 14.6 |
|  |  |  | 20 | 6.5 |  |  |  | 30 | 15.2 |
|  |  |  | 30 | 8.3 |  |  |  | 40 | 18.4 |
|  |  |  | 40 | 9.5 |  |  |  | 50 | 18.0 |
|  |  |  | " | 15.4 |  |  |  |  |  |
|  |  |  | 50 | ... |  |  | 4 feet | 5 | 2.2 |
|  |  |  | 60 | 20.4 |  |  |  | 10 | 4.3 |
|  |  |  |  |  |  |  |  | 15 | 5.2 |
|  |  | 5 feet | 5 | 1.4 |  |  |  | 20 | 5.0 |
|  |  |  | 10 | 4.4 |  |  |  | 30 | 6.9 |
|  |  |  | 15 | 6.2 |  |  |  | 40 | 6.7 |
|  |  |  | 20 | 5.8 |  |  |  | 50 | 6.7 |
|  |  |  | 30 | 8.8 |  |  |  | " | 11.6 |
|  |  |  | 40 | 10.8 |  |  |  |  |  |
|  |  |  | 50 | 7.6 |  |  |  |  |  |

Table 24.

Light Transmission Through Water, Ice, and Snow.
Field Measurements at Certain Lakes, 1941.

Results expressed in foot-candles incident on photometer target, and in percentage transmission.

| Date, 1941 | Ice | | Snow | | Depth[1] | Intensity, foot-candles | Percentage transmission | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Thickness, inches | Condition | Thickness, inches | Condition | | | No filter | Red | Green | Blue |
| **Clear Lake** | | | | | | | | | | |
| Feb. 23 | 7-½ | Clear | None | | Air | 8000 | ... | ... | ... | ... |
| | | | | | Ice | 6700 | 84 | ... | ... | ... |
| | | | | | 1' | 5400 | 68 | ... | ... | ... |
| | | | | | 2' | 4560 | 57 | ... | ... | ... |
| | | | | | 3' | 3800 | 48 | ... | ... | ... |
| | | | | | 6' | 1920 | 24 | ... | ... | ... |
| | | | | | 9' | 1360 | 17 | ... | ... | ... |
| | | | | | 12' | 820 | 10.2 | ... | ... | ... |
| | | | | | 15' | 580 | 7.2 | ... | ... | ... |
| | | | | | 18' | 400 | 5.0 | ... | ... | ... |
| | | | | | 21' | 300 | 3.8 | ... | ... | ... |
| | | | | | 24' | 206 | 2.6 | ... | ... | ... |
| | | | | | 27' | 142 | 1.8 | ... | ... | ... |
| | | | | | 30' | 112 | 1.4 | ... | ... | ... |
| | 7 | Clear | 7/8 — 1 | Dry, light | Air | 7300 | ... | ... | ... | ... |
| | | | | | Ice | 182 | 2.5 | ... | ... | ... |
| | (Same) | | (Snow removed) | | Air | 7000 | ... | ... | ... | ... |
| | | | | | Ice | 3800 | 54 | ... | ... | ... |
| Mar. 13 | 6 | — | None | | Air | 4800 | ... | ... | ... | ... |
| | | | | | Ice | 2540 | 53 | 53 | 53 | 54 |
| | | | | | 3' | 1400 | 29 | 27 | 32 | 28 |
| | | | | | 6' | 1000 | 21 | 16 | 23 | 13 |
| | | | | | 9' | 690 | 14.4 | 9.8 | 16 | 7.4 |
| | | | | | 12' | 490 | 10.2 | 6.0 | 12 | 4.0 |
| | | | | | 15' | 340 | 7.1 | 4.0 | 8.7 | 2.4 |
| | | | | | 18' | 250 | 5.2 | 2.6 | 6.6 | 1.5 |
| | | | | | 21' | 188 | 3.9 | 1.7 | 5.0 | 0.9 |
| | | | | | 24' | 138 | 2.9 | 1.2 | 3.7 | 0.5 |
| | | | | | 27' | 100 | 2.1 | 0.8 | 2.8 | 0.3 |
| | | | | | 30' | 76 | 1.6 | 0.5 | 2.2 | 0.2 |
| | | | | | 32' | 55 | 1.1 | 0.4 | 1.6 | 0.2 |
| **Green Lake** | | | | | | | | | | |
| Mar. 13 | 5 | Fairly clear | None | | Air | 2120 | ... | ... | ... | ... |
| | | | | | Ice | 1250 | 59 | 57 | 59 | 58 |

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[1] Below upper surface of ice.

Table 24.

Light Transmission Through Water, Ice, and Snow.
Field Measurements at Certain Lakes, 1941.
(Continued)
Results expressed in foot-candles incident on photometer target,
and in percentage transmission.

| Date, 1941 | Ice |  | Snow |  | Depth[1] | Intensity, foot-candles | Percentage transmission |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  | Thickness, inches | Condition | Thickness, inches | Condition |  |  | No filter | Red | Green | Blue |
|  |  |  |  | **Mud Lake** |  |  |  |  |  |  |
| Feb. 23 | 8-½ | Clear | None |  | Air | 3200 | ... | ... | ... | ... |
|  |  |  |  |  | Ice | 2150 | 67 | ... | ... | ... |
|  | 7-½ | Partly cloudy | None |  | Air | 3700 | ... | ... | ... | ... |
|  |  |  |  |  | Ice | 820 | 22 | ... | ... | ... |
|  | 10-¾ | Very cloudy | None |  | Air | 4700 | ... | ... | ... | ... |
|  |  |  |  |  | Ice | 340 | 7.2 | ... | ... | ... |
|  | 6-½ | Clear | 2 - 2½ | Crusted | Air | 5550 | ... | ... | ... | ... |
|  |  |  |  |  | Ice | 55 | 1.0 | ... | ... | ... |
|  | (Same) |  | (Snow removed) |  | Air | 5900 | ... | ... | ... | ... |
|  |  |  |  |  | Ice | 3100 | 53 | ... | ... | ... |
|  |  |  |  | **Bog Lake** |  |  |  |  |  |  |
| Feb. 25 | 9-½ | Milky | 1-⅞ | Dry, light | Air | 9200 | ... | ... | ... | ... |
|  |  |  |  |  | Ice | 106 | 1.15 | ... | ... | ... |
|  | (Same) |  | (Snow removed) |  | Air | 9300 | ... | ... | ... | ... |
|  |  |  |  |  | Ice | 1340 | 14.4 | ... | ... | ... |
|  | 9-½ | Milky | 1-⅞ | Dry | Air | 9440 | ... | ... | ... | ... |
|  |  |  |  |  | Ice | 154 | 1.63 | ... | ... | ... |
|  |  |  |  |  | 2' | 100 | 1.06 | ... | ... | ... |
|  |  |  |  |  | 3' | 27 | 0.29 | ... | ... | ... |
|  |  |  |  |  | 4' | 12.4 | 0.13 | ... | ... | ... |
|  |  |  |  |  | 5' | 7.0 | 0.07 | ... | ... | ... |
| Mar. 13 | 10 | Soft on top | 1 | Slushy | Air | 3450 | ... | ... | ... | ... |
|  |  |  |  |  | Ice | 138 | 4.0 | 4.5 | 4.0 | 2.5 |
|  |  |  |  |  | 13" | ... | ... | ... | ... | 0.19 |
|  |  |  |  |  | 15" | .... | ... | ... | ... | 0.19 |
|  |  |  |  |  | 24" | 17 | 0.49 | 1.14 | 0.42 | ... |
|  | (Same) |  | (Snow removed) |  | Air | 2500 | ... | ... | ... | ... |
|  |  |  |  |  | Ice | 340 | 13.6 | 15.8 | 14.4 | 8.3 |
|  |  |  |  |  | 13" | ... | ... | ... | ... | 2.1 |
|  |  |  |  |  | 16" | ... | ... | ... | ... | 0.46 |
|  |  |  |  |  | 24" | 50 | 2.0 | 3.0 | 1.9 | 0.02 |

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[1] Below upper surface of ice.

Table 24.

Light Transmission Through Water, Ice, and Snow.
Field Measurements at Certain Lakes, 1941.
(Continued)
Results expressed in foot-candles incident on photometer target, and in percentage transmission.

| Date, 1941 | Ice | | Snow | | Depth[1] | Intensity, foot-candles | Percentage transmission | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Thickness, inches | Condition | Thickness, inches | Condition | | | No filter | Red | Green | Blue |
| South Londo Lake | | | | | | | | | | |
| Mar. 5 | 24 | Partly cloudy | 10 | Dry | Air | 7600 | ... | ... | ... | ... |
| | | | | | Ice | 4.0 | 0.05 | ... | .... | ... |
| | | (Same) | (Snow removed) | | Air | 7600 | ... | ... | ... | ... |
| | | | | | Ice | 580 | 7.6 | ... | ... | ... |
| East Fish Lake | | | | | | | | | | |
| Mar. 20 | 14 | Partly cloudy | 5 | Dry | Air | 4650 | ... | ... | ... | ... |
| | | | | | Ice | 10.5 | 0.23 | 0.21 | 0.30 | 0.23 |
| | | | | | 3' | 10.5 | 0.23 | ... | ... | ... |
| | | | | | 6' | 9.0 | 0.19 | 0.13 | 0.24 | 0.15 |
| | | | | | 9' | 7.2 | 0.15 | 0.09 | 0.18 | 0.09 |
| | | | | | 12' | 5.5 | 0.12 | 0.07 | 0.14 | 0.07 |
| | | | | | 15' | 4.5 | 0.10 | 0.05 | 0.11 | 0.06 |
| | | | | | 18' | 3.8 | 0.08 | 0.04 | 0.10 | 0.04 |
| | | | | | 21' | 3.2 | 0.07 | 0.03 | 0.07 | 0.04 |
| | | | | | 24' | 2.7 | 0.06 | 0.03 | 0.06 | 0.03 |
| | | | | | 27' | 2.2 | 0.05 | 0.02 | 0.05 | 0.03 |
| | | | | | 30' | 1.6 | 0.03 | 0.02 | 0.04 | 0.02 |
| | | (Same) | (Snow removed) | | Air | 4950 | ... | ... | ... | ... |
| | | | | | Ice | 470 | 9.5 | 9.3 | 10.8 | 7.4 |
| Middle Fish Lake | | | | | | | | | | |
| Mar. 21 | 16 | Fairly clear | 6 | Crusted | Air | 9900 | ... | ... | ... | ... |
| | | | | | Ice | 9.3 | 0.09 | 0.10 | 0.11 | 0.05 |
| | | | | | 19" | 8.5 | 0.09 | 0.10 | 0.11 | 0.05 |
| | | | | | 22" | 7.8 | 0.08 | 0.09 | 0.10 | 0.04 |
| | | | | | 28" | 7.2 | 0.07 | 0.09 | 0.10 | 0.03 |
| | | (Same) | (Snow removed) | | Air | 10600 | ... | ... | ... | ... |
| | | | | | Ice | 1220 | 11.5 | 11.3 | 12.2 | 8.1 |
| | | | | | 19" | 1020 | 9.6 | 10.1 | 11.5 | 5.7 |
| | | | | | 22" | 930 | 8.8 | 8.8 | 10.2 | 3.6 |
| | | | | | 28" | 720 | 6.8 | 7.1 | 7.5 | 1.9 |

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[1] Below upper surface of ice.

Table 24.

### Light Transmission Through Water, Ice, and Snow.
### Field Measurements at Certain Lakes, 1941.
### (Continued)

**Results expressed in foot-candles incident on photometer target, and in percentage transmission.**

| Date, 1941 | Ice |  | Snow |  | Depth[1] | Intensity, foot-candles | Percentage transmission |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  | Thickness, inches | Condition | Thickness, inches | Condition |  |  | No filter | Red | Green | Blue |
| **West Fish Lake** |  |  |  |  |  |  |  |  |  |  |
| Mar. 21 | 16 | Fairly clear | 6-½ | Crusted | Air | 10400 | ... | ... | ... | ... |
|  |  |  |  |  | Ice | 9.4 | 0.09 | 0.07 | 0.13 | 0.12 |
|  |  |  |  |  | 2' | 8.7 | 0.08 | 0.07 | ... | 0.11 |
|  |  |  |  |  | 3' | 7.5 | 0.07 | 0.06 | ... | 0.06 |
|  |  |  |  |  | 4' | 6.8 | 0.07 | 0.05 | ... | 0.04 |
|  |  |  |  |  | 5' | 6.2 | 0.06 | 0.05 | 0.10 | 0.03 |
|  |  |  |  |  | 6' | 6.0 | 0.06 | 0.04 | 0.08 | 0.02 |
|  |  |  |  |  | 7' | 5.2 | 0.05 | 0.04 | 0.06 | 0.01 |
|  |  |  |  |  | 8' | 4.2 | 0.04 | 0.03 | 0.06 | 0.01 |

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[1] Below upper surface of ice.

Table 25.

Light Transmission Through Ice.
Field Measurements at Certain Lakes, 1941.

| Lake | Date, 1941 | Ice |  | Percentage transmission |  |  |  |
|---|---|---|---|---|---|---|---|
|  |  | Thickness, inches | Condition | No filter | Red | Green | Blue |
| Clear | Feb. 23 | 7-½ | Clear | 84 | ... | ... | ... |
| Mud | Feb. 23 | 8-½ | Clear | 67 | ... | ... | ... |
| Green | Mar. 13 | 5 | Fairly clear | 59 | 57 | 59 | 58 |
| Clear | Feb. 23 | 7 | Clear | 54 | ... | ... | ... |
| Mud | Feb. 23 | 6-½ | Clear | 53 | ... | ... | ... |
| Clear | Mar. 13 | 6 | Fairly clear | 53 | 53 | 53 | 54 |
| Mud | Feb. 23 | 7-½ | Partly cloudy | 22 | ... | ... | ... |
| Bog | Mar. 13 | 10 | Soft on top | 14 | 16 | 14 | 8.3 |
| Bog | Feb. 25 | 9-½ | Milky | 14 | ... | ... | ... |
| N. Fish | Mar. 21 | 16 | Fairly clear | 11.5 | 11.3 | 12.2 | 8.1 |
| R. Fish | Mar. 20 | 14 | Partly cloudy | 9.5 | 9.3 | 10.8 | 7.4 |
| S. Londo | Mar. 5 | 24 | Partly cloudy | 7.6 | ... | ... | ... |
| Mud | Feb. 23 | 10-¾ | Very cloudy | 7.2 | ... | ... | ... |

Table 26.

Light Transmission Through Snow.
Field Measurements at Certain of the Lakes Studied, 1941.
Percentage Transmission Obtained by Calculation (see text).

| Lake | Date, 1941 | Snow | | | | | |
|---|---|---|---|---|---|---|---|
| | | Thickness, inches | Condition | No filter | Red | Green | Blue |
| Bog | Mar. 13 | 1 | Slushy | 29 | 28 | 28 | 30 |
| Bog | Feb. 25 | 1–7/8 | Dry, light | 8.0 | ... | ... | ... |
| Clear | Feb. 23 | 7/8 – 1 | Dry, light | 4.6 | ... | ... | ... |
| E. Fish | Mar. 20 | 5 | Dry | 2.5 | 1.9 | 2.5 | 2.4 |
| Mud | Feb. 23 | 2 – 2–1/2 | Crusted | 1.9 | ... | ... | ... |
| M. Fish | Mar. 21 | 6 | Crusted | 0.8 | 0.9 | 0.9 | 0.6 |
| S. Londo | Mar. 5 | 10 | Dry | 0.7 | ... | ... | ... |

Table 27.

Light Transmission Through Snow, Laboratory Experiments, 1941. The Source of Light was an Incandescent Bulb.

| Date, 1941 | Snow, Condition | Depth, inches | Percentage Transmission | | | |
|---|---|---|---|---|---|---|
| | | | No filter | Red | Green | Blue |
| Feb. 22 | Somewhat wet | ½ | 15 | ... | ... | ... |
| | | 1 | 1.1 | ... | ... | ... |
| | | 2 | 0.54 | ... | ... | ... |
| | | 4 | tr. | ... | ... | ... |
| Mar. 23 | Fairly dry; lumpy | 1 | 3.4 | ... | ... | ... |
| | | 2 | 1.1 | ... | ... | ... |
| | | 3 | 0.21 | ... | ... | ... |
| | | 4 | tr. | ... | ... | ... |
| Mar. 23 | Dry; screened | 1 | 5.6 | 2.5 | 3.3 | 4.0 |
| | | 2 | 0.81 | 1.1 | 0.72 | tr. |
| | | 3 | 0.04 | 0.15 | 0.14 | 0.0 |
| | | 4 | tr. | tr. | tr. | 0.0 |

Table 28.

Dissolved Oxygen; Pasinski's Pond; 1940.
All Values are in p.p.m.
All are "Surface" Samples.

| Station number | Feb. 10 (A.M.) | Feb. 10 (P.M.) | Feb. 11 | Feb. 12 | Feb. 14 | Feb. 17 | Feb. 19 | Feb. 22 | Feb. 26 | Feb. 28 | Mar. 1 | Mar. 4 | Mar. 8 | Mar. 10 | Mar. 13 | Mar. 15 | Mar. 18 | Mar. 22 | Mar. 25 | Mar. 29 | Apr. 1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ←pump in operation→ | | | | | | | | | ←pump in operation→ | | | | | | | | | | |
| 1 | 0.7 | 2.6 | 0.2 | 1.0 | 0.3 | 1.0 | 0.7 | 1.6 | 0.3 | 0.3 | 1.4 | 0.0 | 2.0 | 1.0 | 0.3 | 1.1 | 1.3 | 1.1 | 1.7 | 8.5 | ... |
| 2 | 0.3 | 0.2 | 0.1 | 1.0 | 0.8 | 1.3 | 1.1 | 1.0 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 3 | 0.1 | 0.1 | 0.6 | 0.7 | 0.9 | 0.9 | 2.8 | 1.1 | 0.3 | 0.3 | 0.9 | 1.6 | 1.5 | 0.3 | 0.3 | 0.2 | 2.1 | ... | ... | 9.5 | 7.8 |
| 4 | 0.3 | 1.2 | 0.4 | 2.0 | 1.1 | 0.7 | 1.7 | 0.5 | 0.7 | ... | 0.0 | ... | 1.2 | 1.2 | ... | ... | ... | ... | ... | ... | ... |
| 5 | 0.1 | 0.4 | 0.2 | 0.5 | ... | 0.8 | 0.8 | 1.6 | 0.3 | ... | 0.3 | ... | 2.3 | 1.9 | ... | ... | ... | ... | ... | ... | ... |
| 6 | 0.2 | 0.2 | 0.5 | 0.7 | 0.6 | 0.6 | 0.6 | 1.9 | 0.3 | 0.5 | 0.8 | 0.3 | 3.1 | 2.2 | 0.2 | 0.4 | 2.2 | 0.9 | 1.2 | 11.4 | ... |
| 7 | 0.2 | 0.4 | 0.5 | 1.4 | 1.3 | 0.7 | 0.6 | 1.4 | ... | ... | 0.0 | 0.2 | 1.8 | 3.0 | ... | ... | ... | ... | ... | ... | ... |
| 8 | 0.2 | 0.1 | 1.7 | 0.6 | 0.9 | 0.4 | 0.8 | 1.3 | 0.2 | 0.7 | 0.0 | 0.5 | 3.5 | 2.9 | 0.1 | 0.6 | 1.8 | 1.1 | 1.5 | 10.1 | 9.1 |
| 9 | 0.7 | 0.4 | 0.3 | 0.6 | 0.6 | 0.8 | 0.9 | 1.9 | 0.5 | 0.6 | 0.2 | 0.7 | 2.0 | 1.0 | 0.2 | 0.3 | 2.0 | 0.9 | ... | 11.0 | ... |
| 10 | 0.3 | 1.0 | 0.5 | 1.4 | 1.5 | 0.6 | 1.0 | 0.6 | 0.2 | 0.2 | 1.2 | 0.7 | 0.6 | 0.9 | 0.9 | 1.0 | 2.8 | 1.6 | 0.9 | 8.1 | ... |
| 11 | 1.3 | 0.4 | 0.9 | 1.7 | 1.3 | 0.8 | 0.7 | 1.3 | 0.2 | ... | 1.0 | 0.9 | 1.3 | 1.4 | ... | ... | ... | ... | ... | ... | ... |
| 12 | 0.1 | 1.5 | 2.3 | 1.9 | 1.7 | 0.8 | 1.0 | 0.9 | 0.1 | 1.5 | 0.7 | 0.7 | 1.3 | 1.9 | 0.5 | 0.5 | 0.3 | 2.6 | 1.6 | 6.0 | 8.2 |
| 13 | 0.5 | 0.4 | 1.6 | 2.4 | 1.0 | 1.0 | 0.3 | 1.0 | 0.1 | 0.9 | 0.4 | 0.4 | 0.8 | 1.5 | 0.4 | 0.2 | 0.5 | ... | ... | 8.6 | ... |
| 14 | 0.2 | 0.8 | 0.8 | 1.3 | 0.8 | 0.7 | 1.3 | 1.0 | 0.2 | ... | 0.0 | 0.0 | 1.5 | 0.4 | ... | 0.9 | ... | ... | ... | ... | ... |
| 15 | 0.5 | 1.5 | 0.8 | 0.8 | 1.6 | 2.2 | 2.4 | 1.0 | 1.3 | 0.6 | 0.6 | 0.2 | 3.3 | 0.9 | 0.9 | 0.3 | 0.6 | 2.0 | 1.7 | 5.9 | 8.1 |
| 16 | 1.0 | 2.0 | 0.4 | 0.7 | 0.8 | 1.3 | 2.2 | 0.6 | 1.3 | ... | 0.2 | 2.2 | 1.8 | 0.3 | ... | 0.5 | ... | ... | ... | ... | ... |
| 17 | 0.9 | 0.7 | 0.4 | 0.4 | 1.0 | 0.8 | 1.3 | 1.2 | 0.2 | 0.5 | 0.2 | 0.3 | 2.1 | 2.2 | 0.6 | 1.0 | 1.2 | 1.6 | 2.2 | 5.3 | 7.2 |
| 18 | 0.4 | 0.8 | 0.2 | 1.6 | 1.2 | 1.0 | 1.9 | 0.8 | 0.9 | ... | 0.5 | 1.0 | 4.2 | 1.3 | ... | 0.4 | ... | ... | ... | ... | ... |
| 19 | 0.6 | 1.3 | 0.7 | 0.9 | 1.6 | 1.3 | 2.8 | 0.9 | 1.4 | 0.5 | 0.9 | 1.6 | 5.2 | 1.8 | 0.2 | 0.6 | 1.2 | 1.6 | 1.5 | 6.1 | 8.3 |
| 20 | 1.0 | 0.6 | 0.3 | 0.8 | 0.4 | 0.4 | 1.5 | 1.4 | 1.4 | 1.3 | 0.7 | 0.9 | 3.5 | 0.4 | 0.4 | 0.2 | 1.4 | 0.7 | 1.2 | 2.9 | 7.1 |
| 21 | 0.3 | 0.3 | 0.5 | 1.4 | 0.6 | 0.5 | 2.6 | 0.8 | 0.8 | ... | 1.2 | 0.5 | 1.8 | 1.2 | ... | 0.9 | ... | ... | ... | ... | ... |
| 22 | 0.5 | 0.9 | 0.9 | 2.8 | 1.8 | 1.4 | 1.6 | 1.0 | 0.4 | 0.7 | 0.3 | 3.0 | 4.7 | 0.6 | 0.7 | 0.4 | 1.1 | ... | ... | 3.5 | 8.2 |
| 23 | 0.4 | 0.2 | 0.5 | 1.7 | 1.0 | 1.6 | 0.7 | 1.2 | 1.0 | 0.4 | 1.3 | 3.5 | 2.4 | 1.6 | 0.4 | 0.3 | 1.2 | ... | ... | 9.6 | 7.7 |
| 24 | ... | 1.4 | 2.1 | 4.8 | 1.9 | 0.7 | 1.2 | 1.0 | 0.3 | 0.3 | 0.5 | 0.7 | 3.4 | 1.0 | 0.4 | 0.4 | 0.6 | 1.1 | 0.9 | 9.9 | 8.3 |
| 25 | ... | 1.1 | 2.3 | 2.8 | 1.0 | 1.7 | 1.9 | 1.7 | 0.5 | 0.3 | 1.0 | 0.8 | 1.3 | 1.4 | 1.7 | 0.5 | 1.2 | ... | ... | 10.1 | 7.0 |
| 26 | 3.6 | 7.7 | 8.0 | 6.5 | 1.5 | 1.7 | 0.6 | 0.7 | 0.4 | 0.6 | 1.1 | 1.2 | 5.8 | 4.0 | 1.0 | 0.3 | 1.2 | 5.1 | 1.0 | 10.7 | 8.1 |
| 27 | ... | 11.0 | 9.7 | 12.3 | 2.4 | 0.7 | 0.9 | 0.9 | 0.6 | 1.3 | 1.2 | 4.4 | 9.4 | 5.4 | 1.0 | 0.9 | 2.1 | 5.0 | 1.2 | 11.2 | 8.5 |
| 28 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 5.5 | 0.4 | 0.5 | 1.6 | 6.5 | 1.7 | 11.2 | 8.6 |
| 29 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 10.4 | 6.0 | 1.9 | 9.7 | 6.8 | 1.4 | 11.9 | 8.3 |
| 30 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 0.8 | 6.2 | 9.4 | 6.3 | 1.6 | 0.5 | 1.3 | ... | ... | 11.3 | 7.9 |
| 31 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 1.0 | 6.3 | 5.9 | 4.1 | 0.6 | 0.7 | 0.7 | ... | ... | ... | ... |
| 32 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 0.4 | 0.9 | 3.2 | 3.1 | 0.7 | 0.4 | 1.2 | ... | ... | ... | ... |
| 33 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 7.2 | 4.6 | 0.2 | 0.5 | 3.1 | ... | ... | ... | ... |
| Outlet | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 0.0 | 0.2 | 5.6 | 3.2 | 2.5 | 0.7 | 3.6 | 3.1 | 0.4 | 10.8 | 7.7 |
| Open Hole | ... | ... | ... | ... | ... | ... | 0.9 | 0.2 | ... | ... | ... | 0.7 | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Pump | 2.0 | 1.8 | 1.7 | 1.3 | 1.4 | 1.4 | ... | ... | ... | ... | 2.0 | 1.3 | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| "Trough" | ... | 5.3 | 5.1 | ... | 6.1 | 4.0 | ... | ... | ... | ... | 3.6 | 3.5 | ... | ... | ... | ... | ... | ... | ... | ... | ... |

Table 29.

Dissolved Oxygen, pH, and Other Chemical Data; Hatchery Ponds; 1939-40.

| Pond | Station | Date | pH | Aerated pH | Alveol. pH | Phth. alkalinity, p.p.m. | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|---|---|---|---|
| Pond 8 | Weir | Dec. 23 | ... | ... | ... | 3 | 165 | 14.0 |
| | | Jan. 7 | ... | ... | ... | ... | ... | 12.9 |
| | | 14 | 8.0 | ... | ... | ... | 156 | 13.3 |
| | | 21 | 8.0 | ... | ... | 2 | 173 | 14.0 |
| | | 29 | 8.1 | 8.1 | 6.4 | ... | 168 | 12.3 |
| | | Feb. 4 | 8.0 | 8.1 | 6.4 | ... | 171 | 13.0 |
| | | 12 | 8.0 | ... | ... | ... | 172 | 12.6 |
| | | 17 | 8.0 | ... | ... | ... | ... | 14.1 |
| | | 19 | ... | ... | ... | ... | ... | 12.9 |
| | | 22 | 7.8 | 8.1 | 6.4 | ... | 172 | 12.5 |
| | | 26 | 8.0 | ... | ... | ... | 173 | 12.6 |
| | | Mar. 1 | 7.8 | ... | ... | ... | 169 | 12.1 |
| | | 4 | 7.7 | 8.1 | ... | ... | 162 | 11.4 |
| | | 9 | 7.6 | 8.0 | 6.4 | ... | 158 | 11.4 |
| | | 13 | 7.8 | ... | ... | ... | 176 | 11.9 |
| | | 18 | 7.8 | 8.1 | 6.5 | ... | 178 | 12.0 |
| | | 22 | 7.7 | ... | ... | ... | 128 | 10.9 |
| | | 29 | 6.8 | 7.0 | 5.4 | ... | 16 | 13.2 |
| | Center | Jan. 7 | ... | ... | ... | 1 | 171 | 13.3 |
| | | 14 | 8.0 | ... | ... | ... | 154 | 13.3 |
| | | 21 | 8.0 | ... | ... | 2 | 178 | 14.3 |
| | | 29 | 8.0 | 8.1 | 6.4 | 2 | 172 | 12.6 |
| | | Feb. 4 | 8.0 | 8.1 | 6.4 | ... | 170 | 13.0 |
| | | 12 | 8.0 | ... | ... | ... | 170 | 12.9 |
| | | 17 | 8.0 | ... | ... | ... | 173 | 13.6 |
| | | 19 | 8.1 | ... | ... | 2 | 162 | 12.9 |
| | | 22 | 7.8 | 8.1 | 6.4 | ... | 172 | 12.8 |
| | | 26 | 7.8 | ... | ... | ... | 173 | 12.8 |
| | | Mar. 1 | 7.8 | ... | ... | ... | 175 | 12.0 |
| | | 4 | 7.6 | 8.0 | ... | ... | 134 | 13.5 |
| | | 9 | 7.7 | 8.1 | 6.5 | ... | 169 | 11.7 |
| | | 13 | 7.8 | ... | ... | ... | 178 | 12.5 |
| | | 18 | 7.8 | 8.1 | 6.5 | ... | 168 | 12.1 |
| | | 29 | 7.2 | 7.4 | 5.9 | ... | 46 | 12.5 |
| Pond 9 | Weir | Dec. 23 | ... | ... | ... | 3 | 162 | 13.9 |
| | | Jan. 7 | ... | ... | ... | ... | ... | 13.1 |
| | | 14 | 8.0 | ... | ... | ... | 155 | 13.0 |
| | | 21 | 8.0 | ... | ... | 2 | 180 | 14.5 |
| | | 29 | 8.1 | 8.1 | 6.4 | 2 | 172 | 12.8 |
| | | Feb. 4 | 8.1 | 8.1 | 6.4 | ... | 174 | 13.3 |
| | | 12 | 8.0 | ... | ... | ... | 172 | 12.8 |
| | | 17 | 8.0 | ... | ... | ... | ... | 13.3 |
| | | 19 | ... | ... | ... | ... | ... | 13.5 |
| | | 22 | 8.0 | 8.0 | 6.3 | ... | 145 | 14.3 |
| | | 26 | 8.1 | ... | ... | 2 | 173 | 14.2 |

(Continued)

## Table 29.

### Dissolved Oxygen, pH, and Other Chemical Data; Hatchery Ponds; 1939-40.

(Continued)

| Pond | Station | Date | pH | Aerated pH | Alveol. pH | Phth. alkalinity, p.p.m. | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|---|---|---|---|
| Pond 9, (Continued) | Weir | Mar. 1 | 7.9 | ... | ... | ... | 168 | 13.1 |
| | | 4 | 7.8 | 8.0 | ... | ... | 161 | 12.1 |
| | | 9 | 7.8 | 8.1 | 6.4 | ... | 130 | 13.4 |
| | | 13 | 8.2 | ... | ... | 2 | 137 | 17.5 |
| | | 18 | 8.2 | 8.2 | 6.5 | 3 | 157 | 17.1 |
| | | 22 | 7.7 | 7.7 | 6.0 | ... | 62 | 16.8 |
| | | 29 | 6.9 | 6.9 | 5.5 | ... | 23 | 13.1 |
| | Center | Jan. 7 | ... | ... | ... | 2 | 170 | 13.1 |
| | | 14 | 8.0 | ... | ... | ... | 159 | 13.2 |
| | | 21 | 8.0 | ... | ... | 2 | 179 | 13.9 |
| | | 29 | 8.0 | 8.1 | 6.4 | ... | 170 | 12.5 |
| | | Feb. 4 | 8.0 | 8.1 | 6.4 | ... | 173 | 13.0 |
| | | 12 | 8.0 | ... | ... | ... | 168 | 12.6 |
| | | 17 | 8.0 | ... | ... | ... | 173 | 13.5 |
| | | 19 | 7.9 | ... | ... | ... | 164 | 13.3 |
| | | 22 | 7.6 | 7.7 | 5.9 | ... | 66 | 14.5 |
| | | 26 | 7.9 | ... | ... | ... | 176 | 12.8 |
| | | Mar. 1 | 7.8 | ... | ... | ... | 164 | 12.1 |
| | | 4 | 7.7 | 8.0 | ... | ... | 131 | 12.5 |
| | | 9 | 7.6 | 7.7 | 6.0 | ... | 80 | 13.4 |
| | | 13 | 8.1 | ... | ... | 2 | 152 | 16.2 |
| | | 18 | 7.8 | 8.1 | 6.5 | ... | 168 | 13.4 |
| | | 29 | 6.8 | 6.8 | 5.2 | ... | 8 | 12.4 |
| Pond 10 | Weir | Dec. 23 | ... | ... | ... | 3 | 162 | 14.1 |
| | | Jan. 7 | ... | ... | ... | ... | ... | 14.0 |
| | | 14 | 8.0 | ... | ... | ... | 152 | 13.3 |
| | | 21 | 8.0 | ... | ... | 2 | 178 | 14.0 |
| | | 29 | 8.0 | 8.1 | 6.4 | ... | 168 | 12.4 |
| | | Feb. 4 | 8.0 | 8.1 | 6.4 | ... | 172 | 13.1 |
| | | 12 | 8.0 | ... | ... | ... | 168 | 12.6 |
| | | 17 | 8.1 | ... | ... | ... | ... | 14.8 |
| | | 19 | ... | ... | ... | ... | ... | 13.7 |
| | | 22 | 8.1 | 8.1 | 6.4 | ... | 153 | 16.9 |
| | | 26 | 8.1 | ... | ... | 2 | 167 | 16.3 |
| | | Mar. 1 | 8.0 | ... | ... | ... | 168 | 13.7 |
| | | 4 | 8.0 | 8.1 | ... | 2 | 162 | 13.6 |
| | | 9 | 8.0 | 8.0 | 6.4 | ... | 131 | 15.7 |
| | | 13 | 8.3 | ... | ... | 7 | 160 | 18.3 |
| | | 18 | 8.3 | 8.2 | 6.5 | 5 | 166 | 19.4 |
| | | 22 | 8.0 | 8.1 | 6.4 | ... | 123 | 16.0 |
| | | 29 | 8.2 | 8.2 | ... | 2 | 146 | 16.2 |
| | Center | Jan. 7 | ... | ... | ... | ... | 174 | 13.7 |
| | | 14 | 8.0 | ... | ... | ... | 145 | 13.2 |
| | | 21 | 8.0 | ... | ... | 2 | 178 | 14.0 |
| | | 29 | 8.0 | 8.1 | 6.4 | ... | 172 | 12.4 |

(Continued)

Table 29.

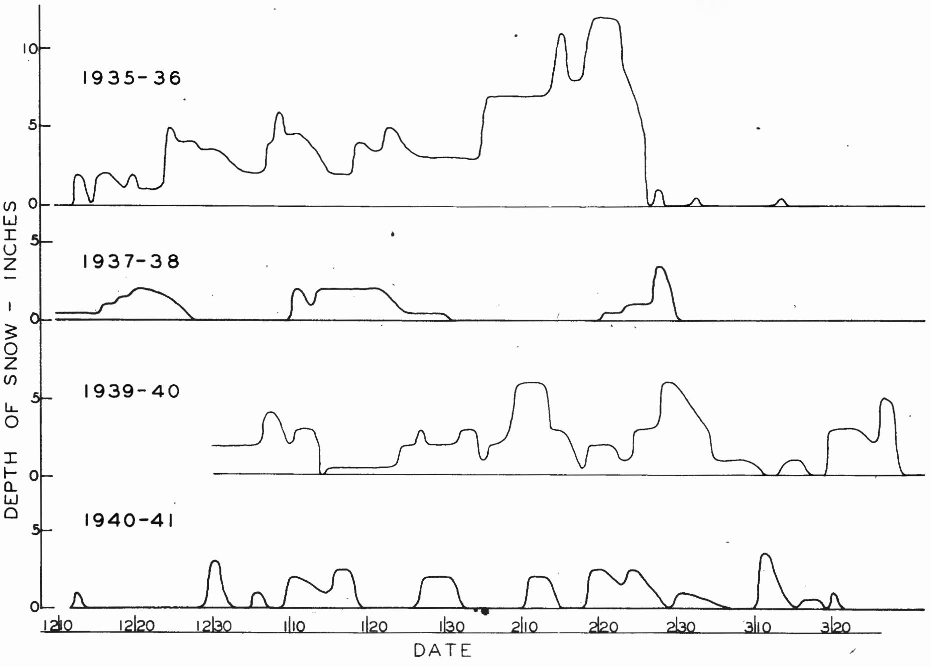
Dissolved Oxygen, pH, and Other Chemical Data;
Hatchery Ponds; 1939-40.
(Continued)

| Pond | Station | Date | pH | Aerated pH | Alveol. pH | Phth. alkalinity, p.p.m. | M. O. alkalinity, p.p.m. | $O_2$, p.p.m. |
|---|---|---|---|---|---|---|---|---|
| Pond 10, (Continued) | Center | Feb. 4 | 8.0 | 8.1 | 6.4 | ... | 170 | 12.7 |
| | | 12 | 8.0 | ... | ... | ... | 155 | 12.6 |
| | | 17 | 8.1 | ... | ... | ... | 164 | 14.6 |
| | | 19 | 7.4 | ... | ... | ... | 113 | 13.2 |
| | | 22 | 7.8 | 8.0 | 6.2 | ... | 115 | 14.6 |
| | | 26 | 8.0 | ... | ... | ... | 163 | 13.8 |
| | | Mar. 1 | 8.0 | ... | ... | ... | 166 | 13.3 |
| | | 4 | 7.8 | 8.0 | ... | ... | 129 | 12.9 |
| | | 9 | 8.0 | 8.1 | 6.5 | 2 | 146 | 14.8 |
| | | 13 | 8.3 | ... | ... | 5 | 161 | 18.0 |
| | | 18 | 8.2 | 8.2 | 6.5 | 5 | 162 | 15.9 |
| | | 29 | 8.0 | 8.1 | ... | ... | 173 | 14.8 |
| River | | Feb. 4 | 8.0 | 8.1 | 6.4 | ... | 171 | 12.3 |
| | | 12 | 8.0 | ... | ... | ... | 172 | 12.9 |
| | | 17 | ... | ... | ... | 2 | 172 | 14.0 |
| | | 19 | 7.9 | ... | ... | ... | 165 | 12.4 |
| | | 22 | 7.8 | 8.1 | 6.5 | ... | 176 | 12.4 |
| | | 26 | 7.9 | ... | ... | ... | 174 | 12.4 |
| | | Mar. 1 | 7.8 | ... | ... | ... | 170 | 12.4 |
| | | 4 | 7.7 | 8.1 | ... | ... | 165 | 11.7 |
| | | 9 | 7.7 | 8.1 | 6.5 | ... | 172 | 12.2 |
| | | 13 | 8.0 | ... | ... | ... | 175 | 13.0 |
| | | 18 | 7.6 | 8.1 | 6.5 | ... | 174 | 11.6 |
| | | 22 | 7.8 | 8.1 | 6.5 | ... | 178 | 11.8 |
| | | 29 | 7.7 | 8.0 | ... | ... | 178 | 10.8 |

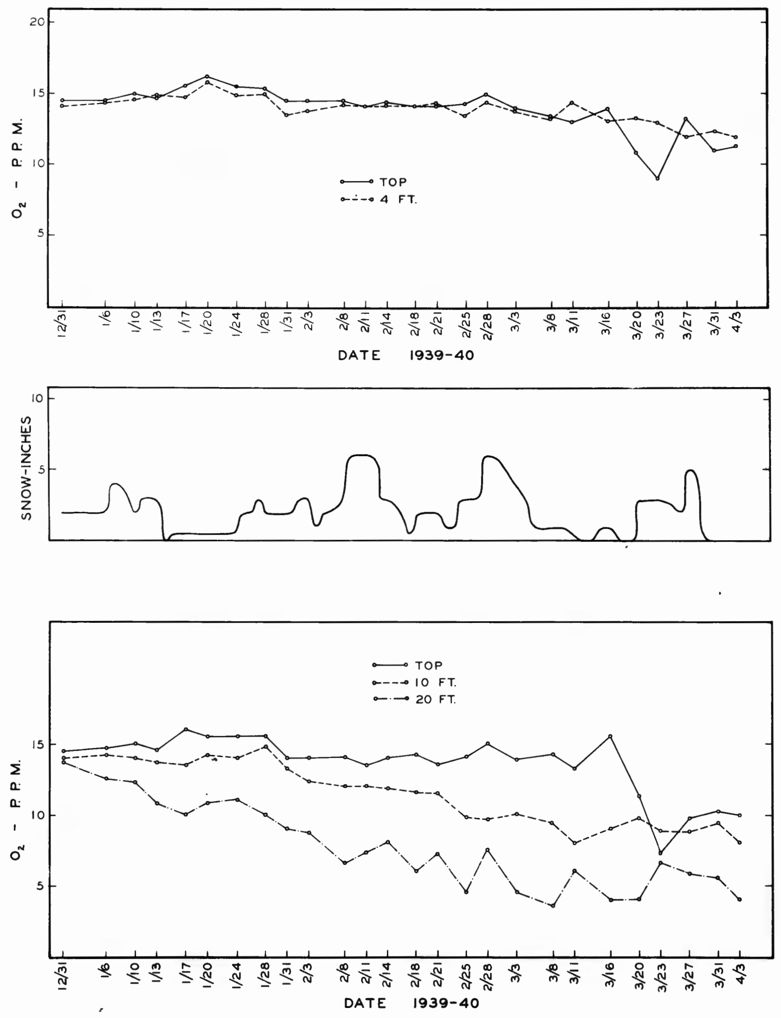
Table 30.

Oxygen Requirements of Various Fishes at Low Temperatures

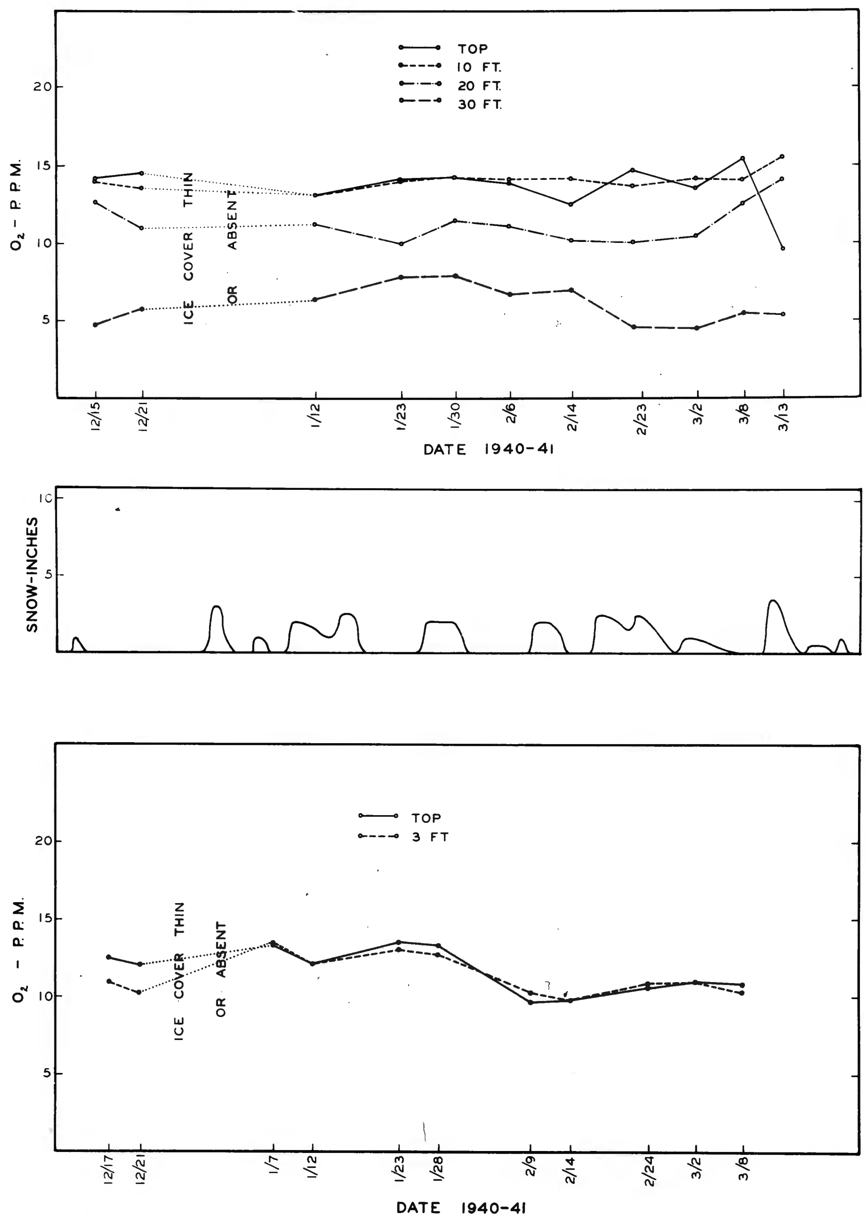
| Fish | Temp., °C. | $O_2$ consumed, cc/kg/hr. | Author |
|---|---|---|---|
| Brown trout | 4–7° | 102.5 | Gardner and Leetham (1914) |
| Goldfish | 2° | 14.8 | Regnard (1891) |
| Goldfish | 5–6° | 16.07 | Gardner and King (1923) |
| Tench | 0° | 6.05 | Linstedt (1914) |
| Pike (*Esox lucius*) | 5–6° | 24.44 | Gardner and King (1923) |
| Eel | 5–6° | 9.28 | Gardner and King (1923) |



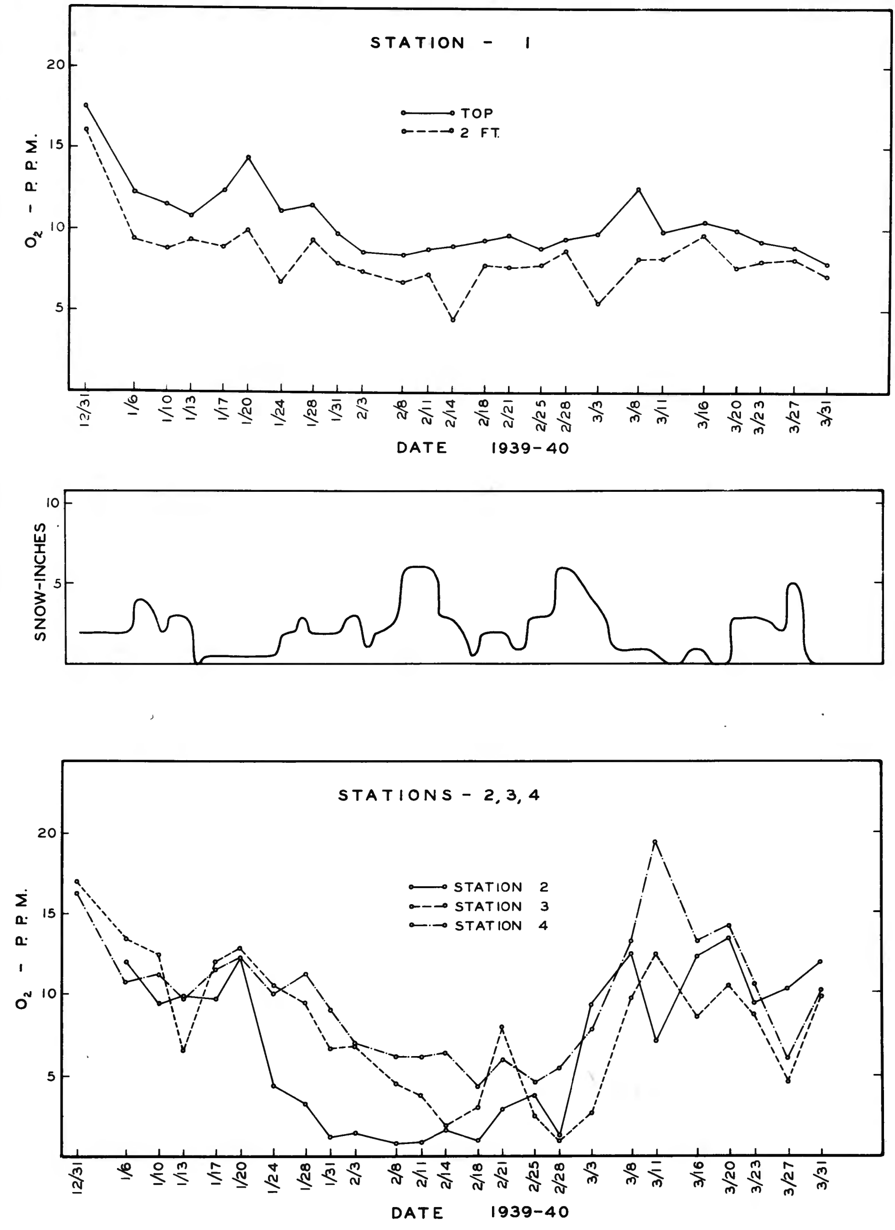
Graph 1. Depth of snow, in the area studied, during the periods of ice cover, 1935-36, 1937-38, 1939-40, and 1940-41.



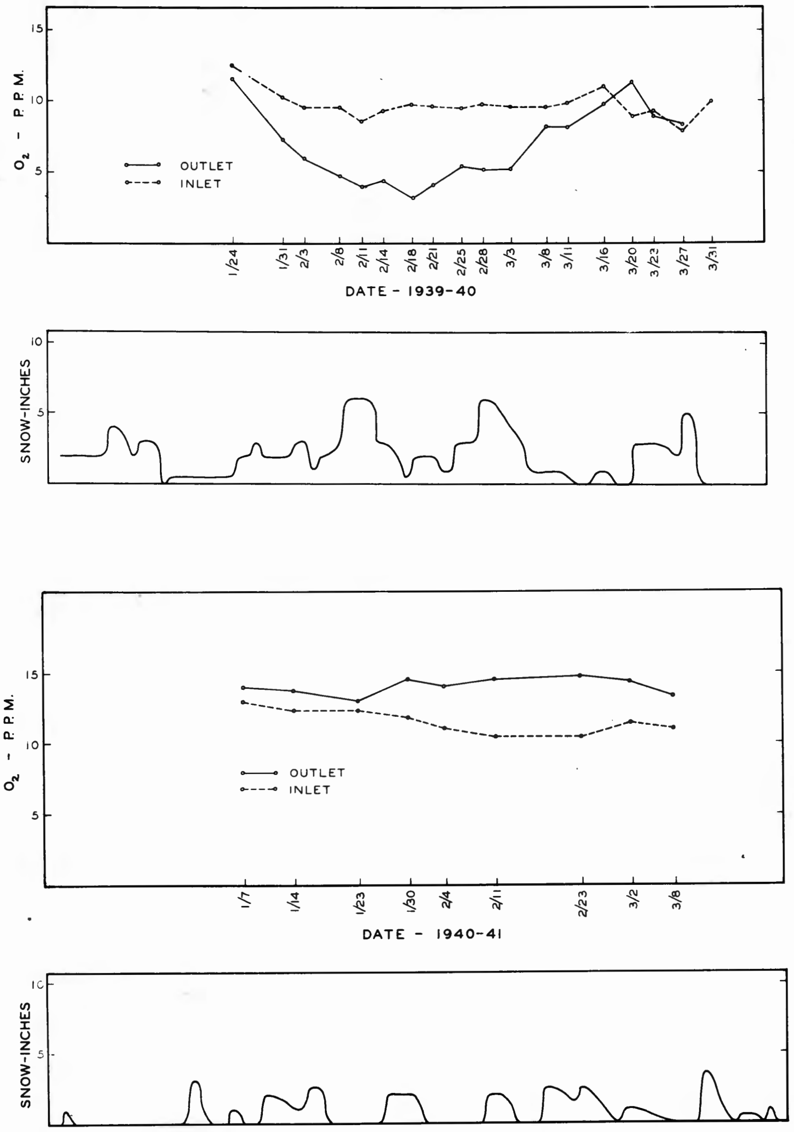
Graph 2. Dissolved oxygen, Clear Lake, 1939-40.
Upper — Station 1.
Lower — Station 2.



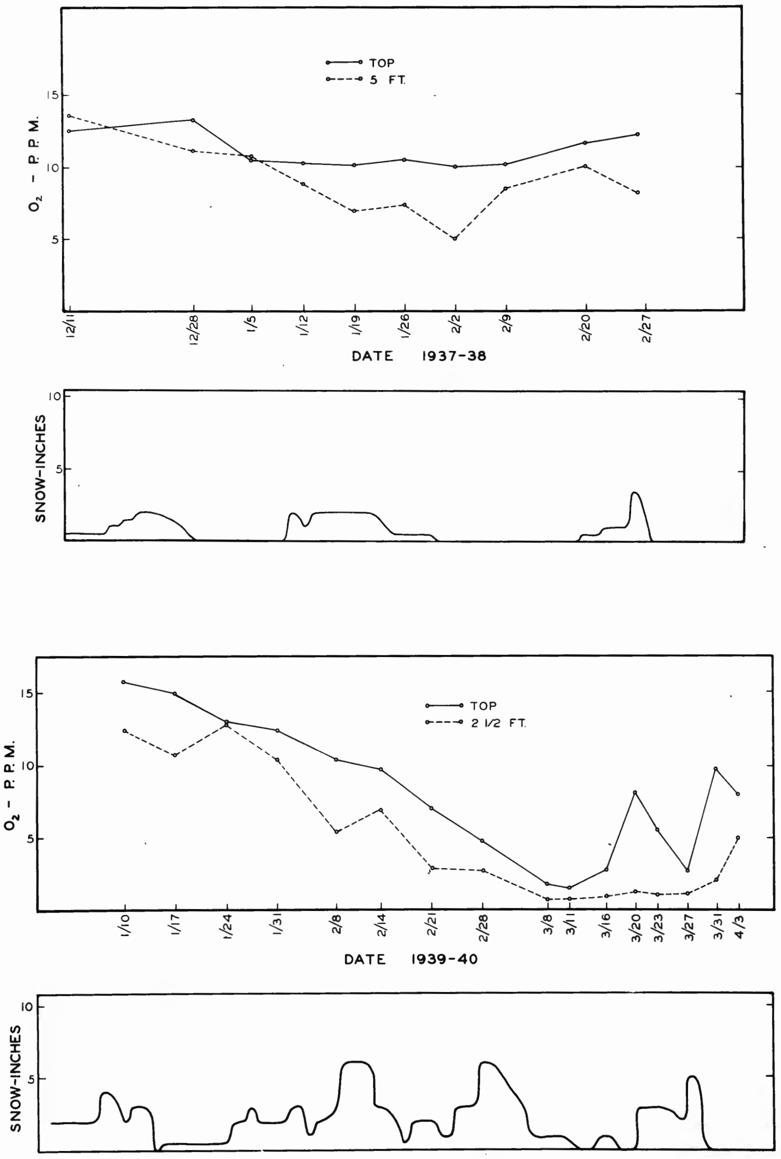
Graph 3. Dissolved oxygen, ~~Clear~~ Green Lake, 1940-41.
Upper -- Station 2a.
Lower -- Station 1.



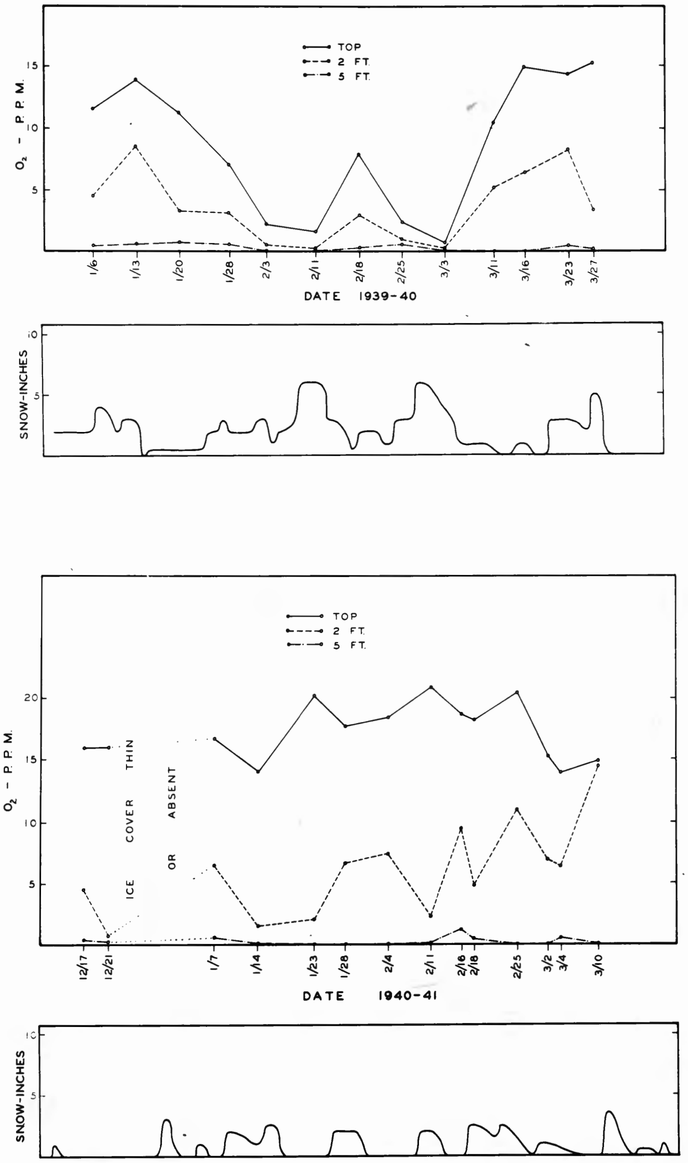
Graph 4. Dissolved oxygen, Mud Lake, 1939-40.



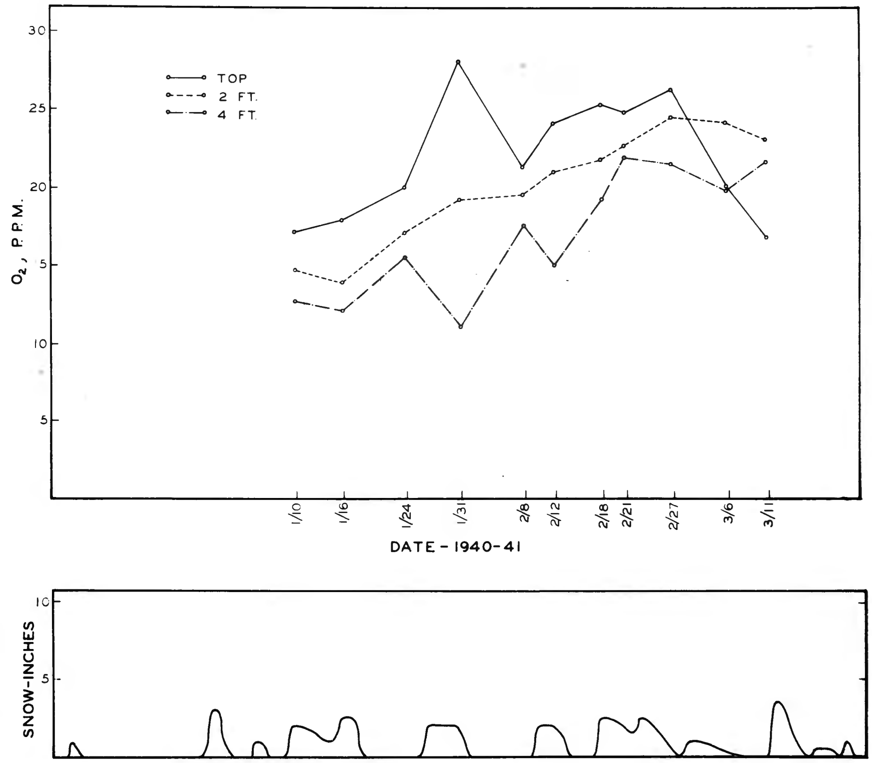
Graph 5. Dissolved oxygen, Mud Lake. Inlet and outlet, 1939-40 and 1940-41.



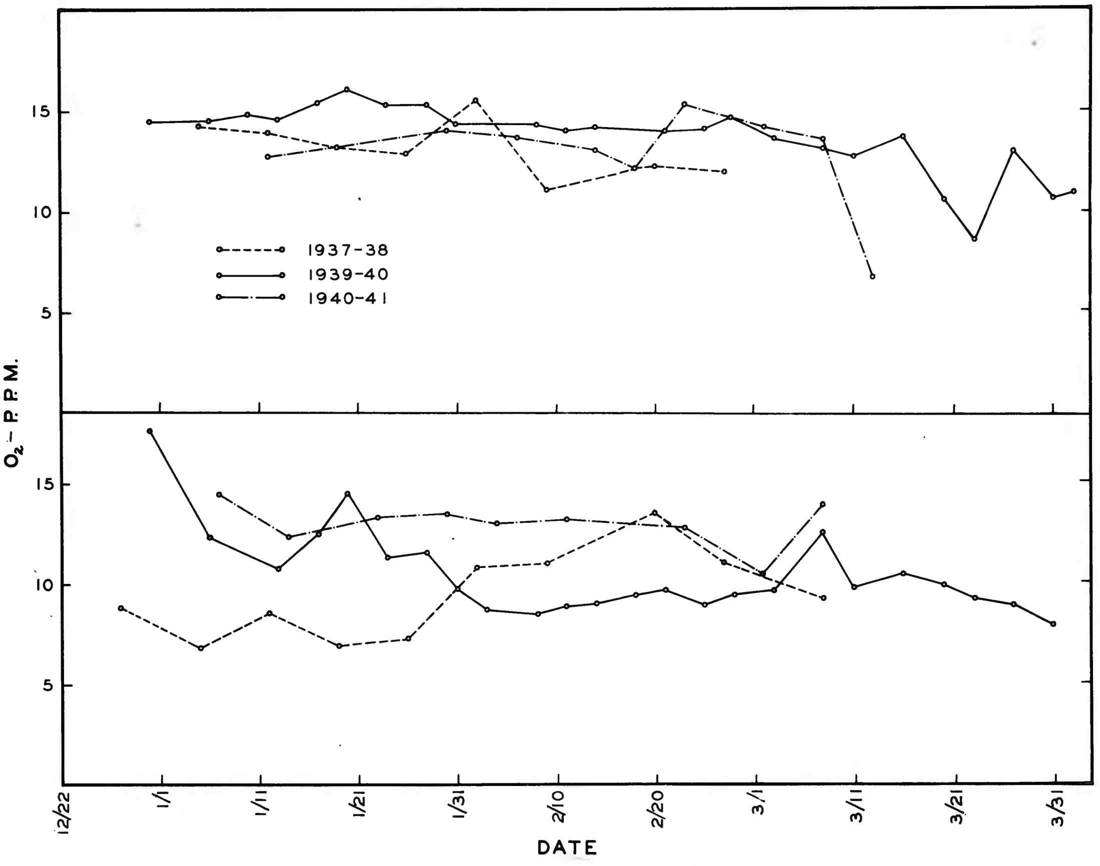
Graph 6. Dissolved oxygen, Green Lake, Station 1.
1937-38 and 1939-40.



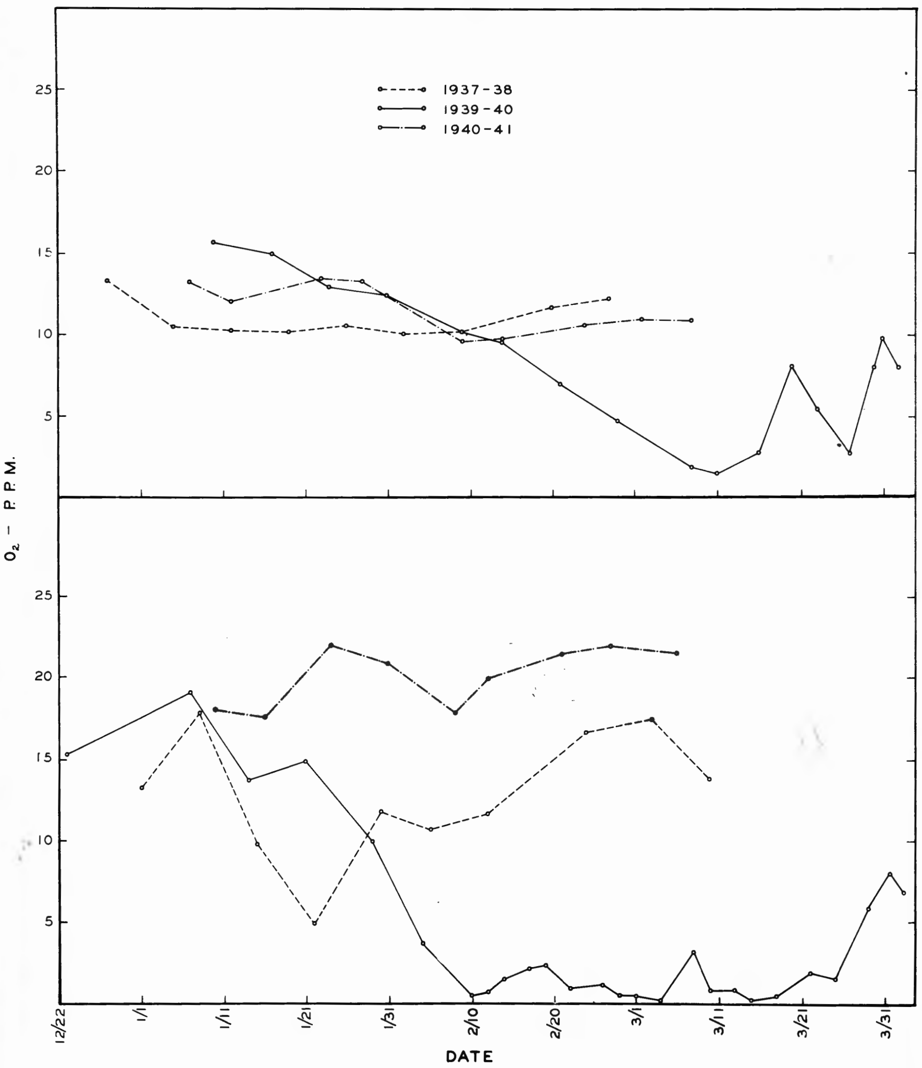
Graph 7. Dissolved oxygen, Bog Lake, 1939-40 and 1940-41.



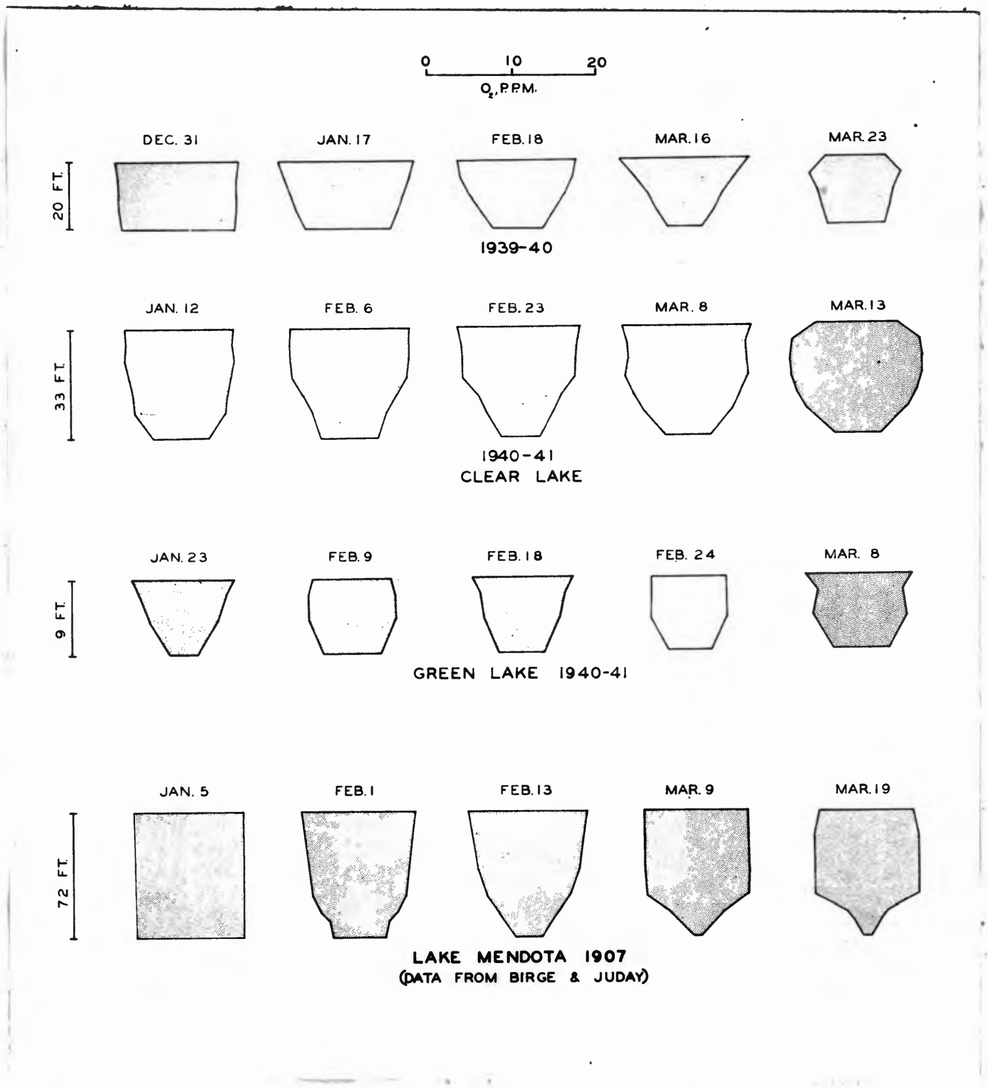
Graph 8. Dissolved oxygen, Pasinski's Pond.
Station 26, 1940-41.



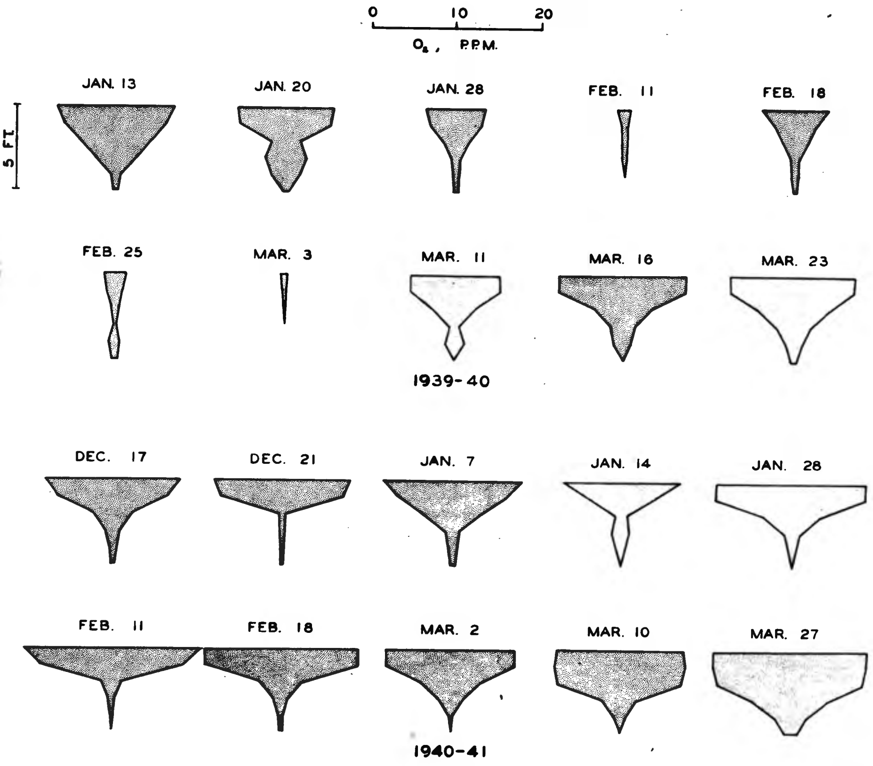
Graph 9. Dissolved oxygen, 1937-38, 1939-40, and 1940-41.
Upper -- Clear Lake, Station 1, Surface.
Lower -- Mud Lake, Station 1, Surface.



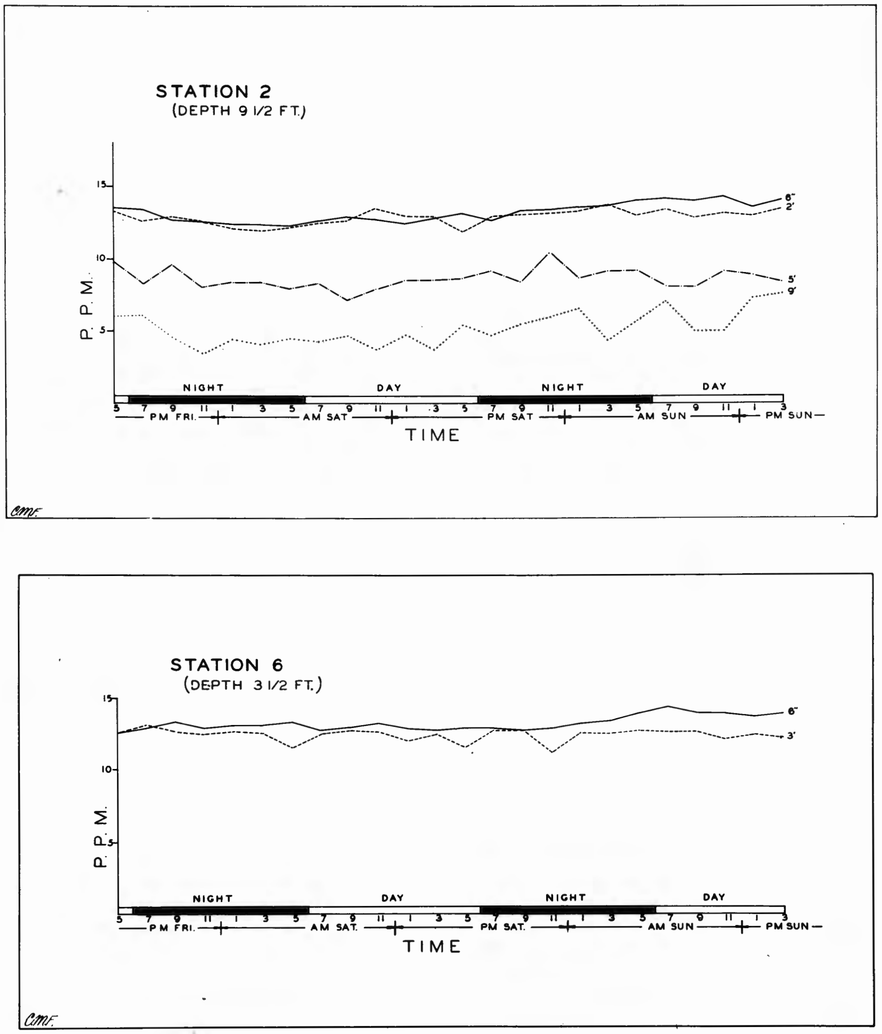
Graph 10. Dissolved oxygen, 1937-38, 1939-40, and 1940-41.
Upper — Green Lake, Station 1, Surface.
Lower — Pasinski's Pond, Station 15, Surface.



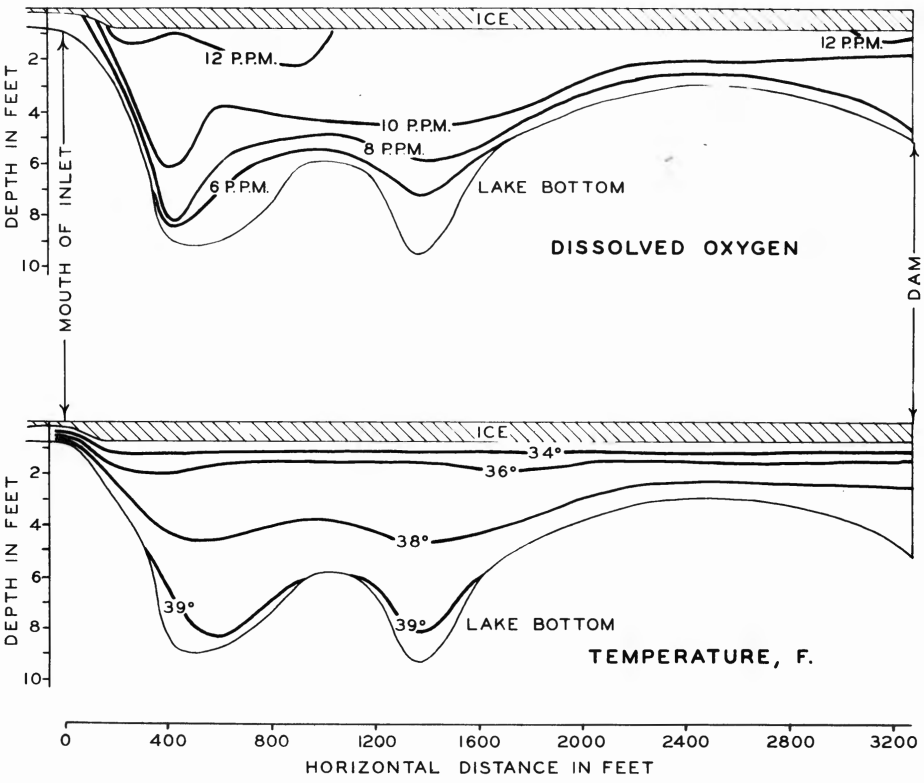
Graph 11. Dissolved oxygen, vertical distribution. Clear Lake, Green Lake, and Lake Mendota. Selected dates.



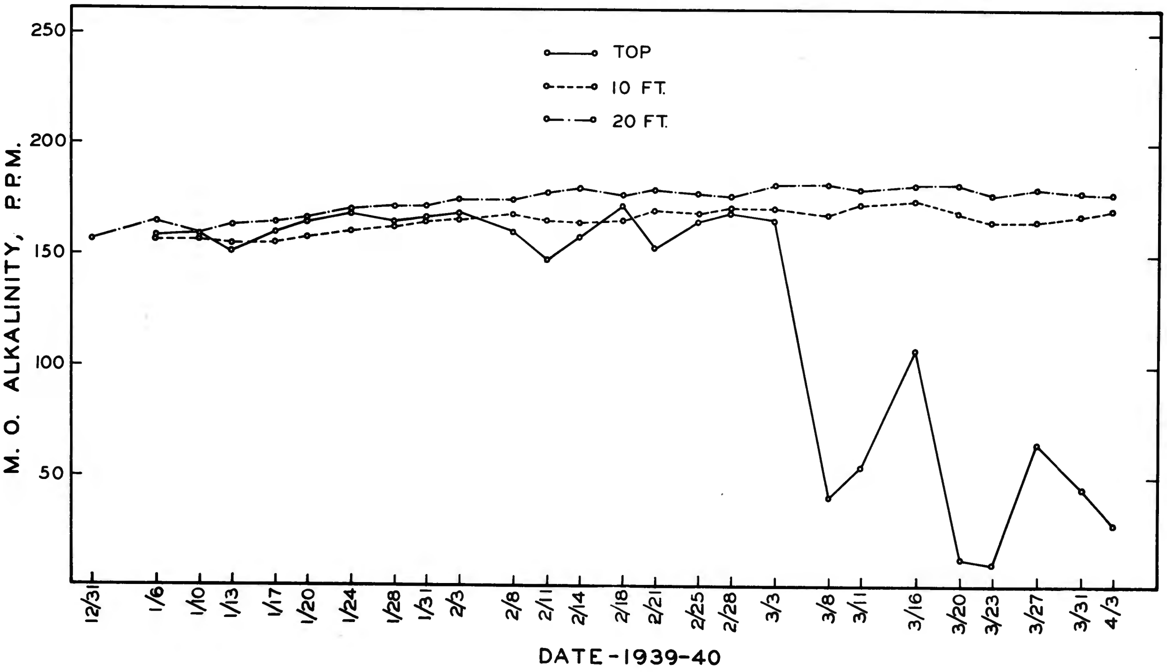
Graph 12. Dissolved oxygen, vertical distribution. Bog Lake, 1939-40 and 1940-41. Selected dates.



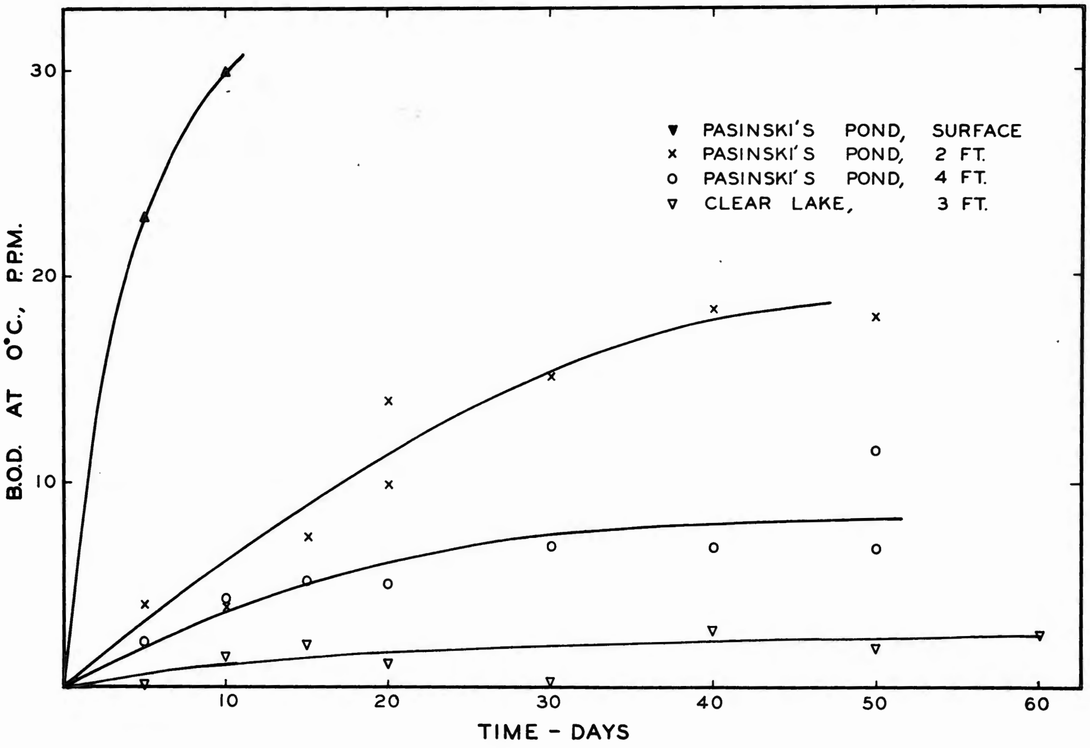
Graph 13. Dissolved oxygen, Green Lake, 48-hour period, January 17-19, 1941. (Samples at two-hour intervals)



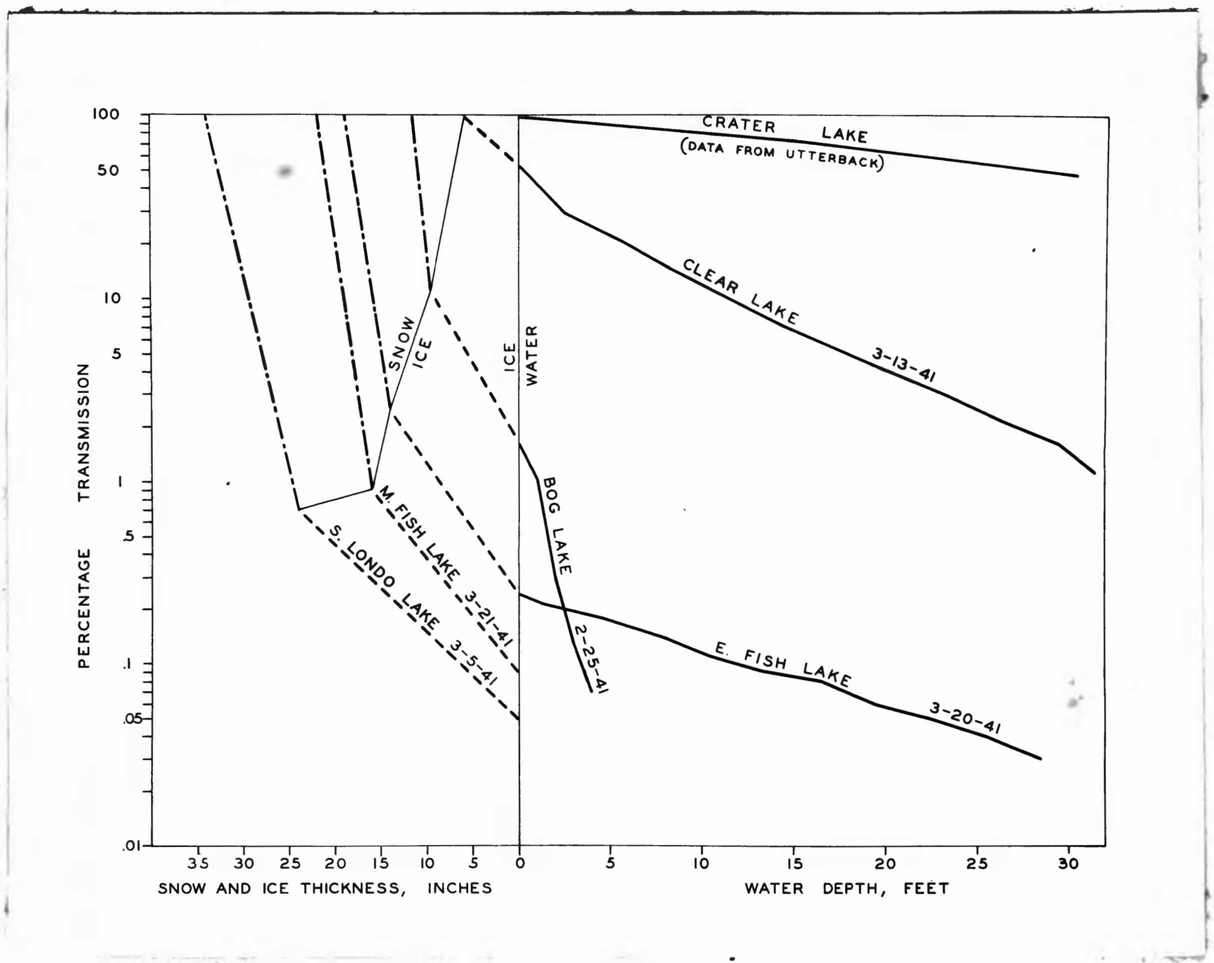
Graph **14.** Dissolved oxygen and temperature profiles, Green Lake, February 2, 1941. Cross-section of the lake somewhat generalized.



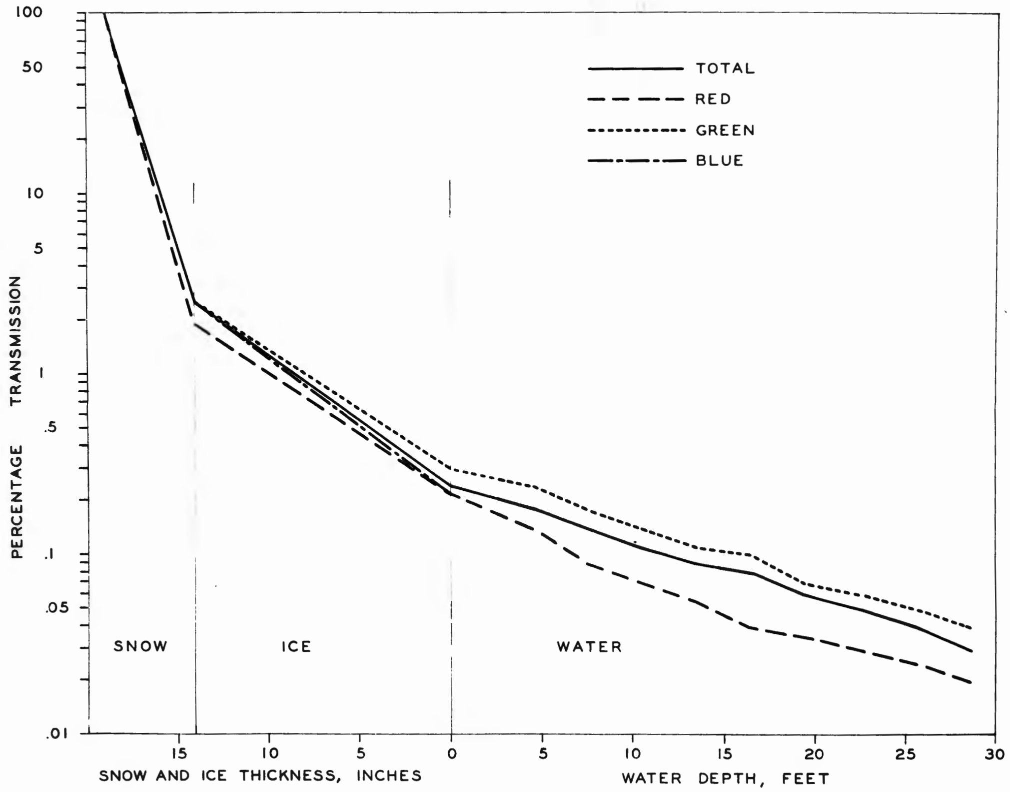
Graph 15. Methyl orange alkalinity. Clear Lake,
Station 2, 1939-40.



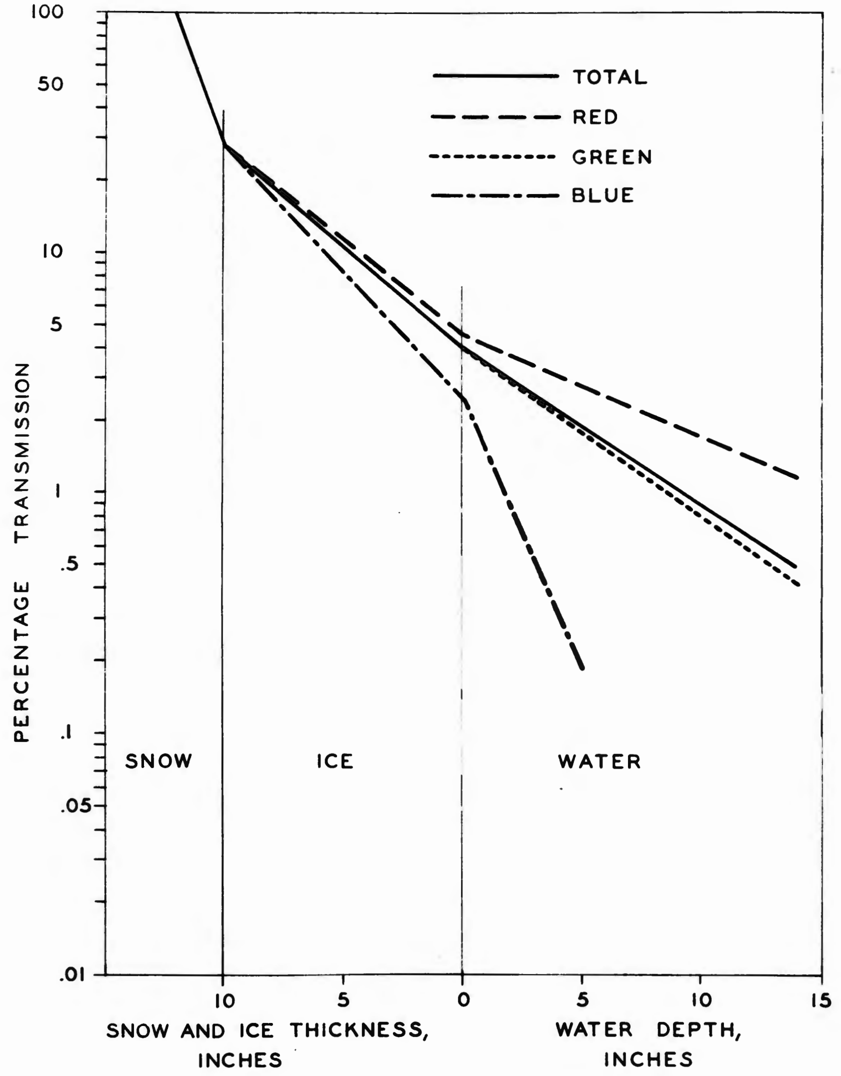
Graph 16. Biochemical oxygen demand at 0° C.



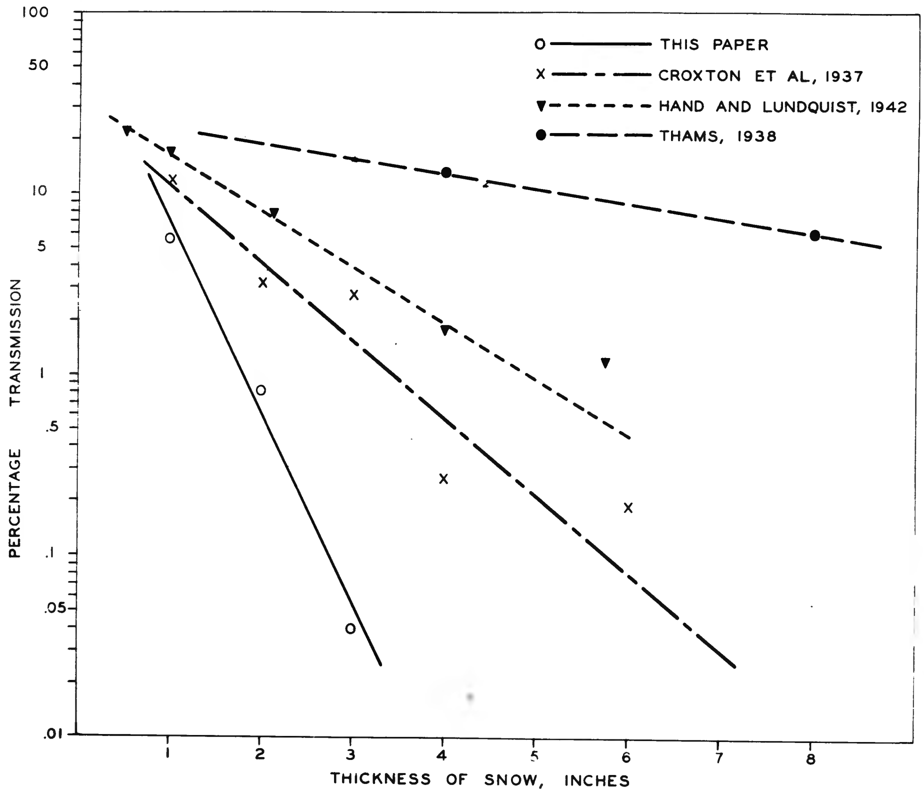
Graph 17. Percentage transmission of light through snow, ice, and water, various lakes.



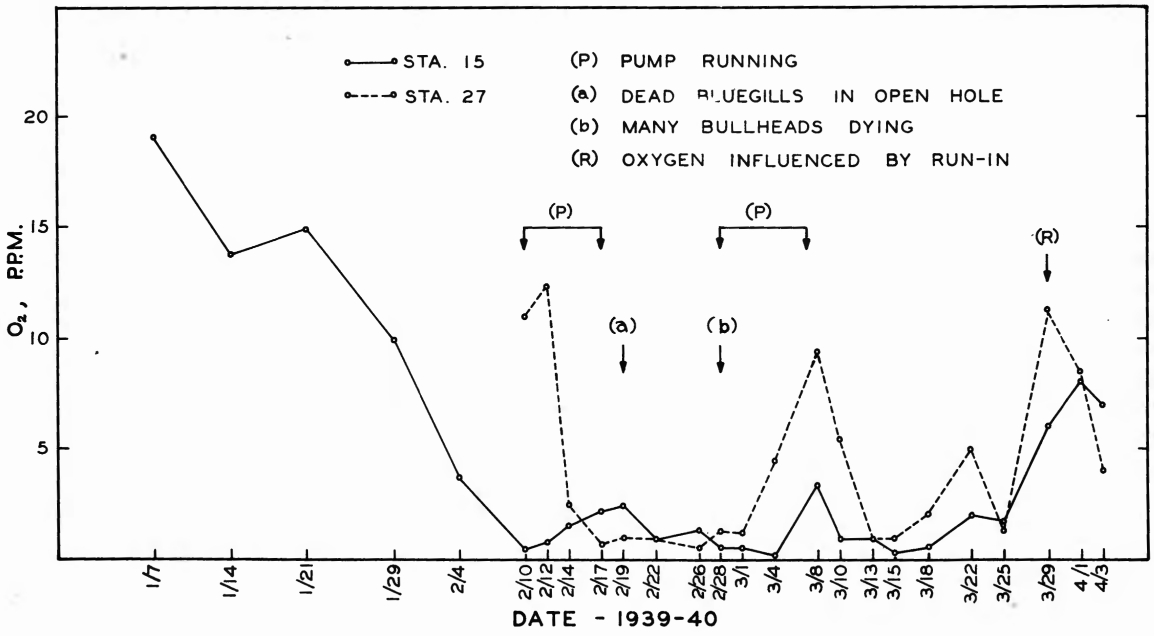
Graph 18. Percentage transmission of light through snow, ice, and water, East Fish Lake, March 20, 1941.



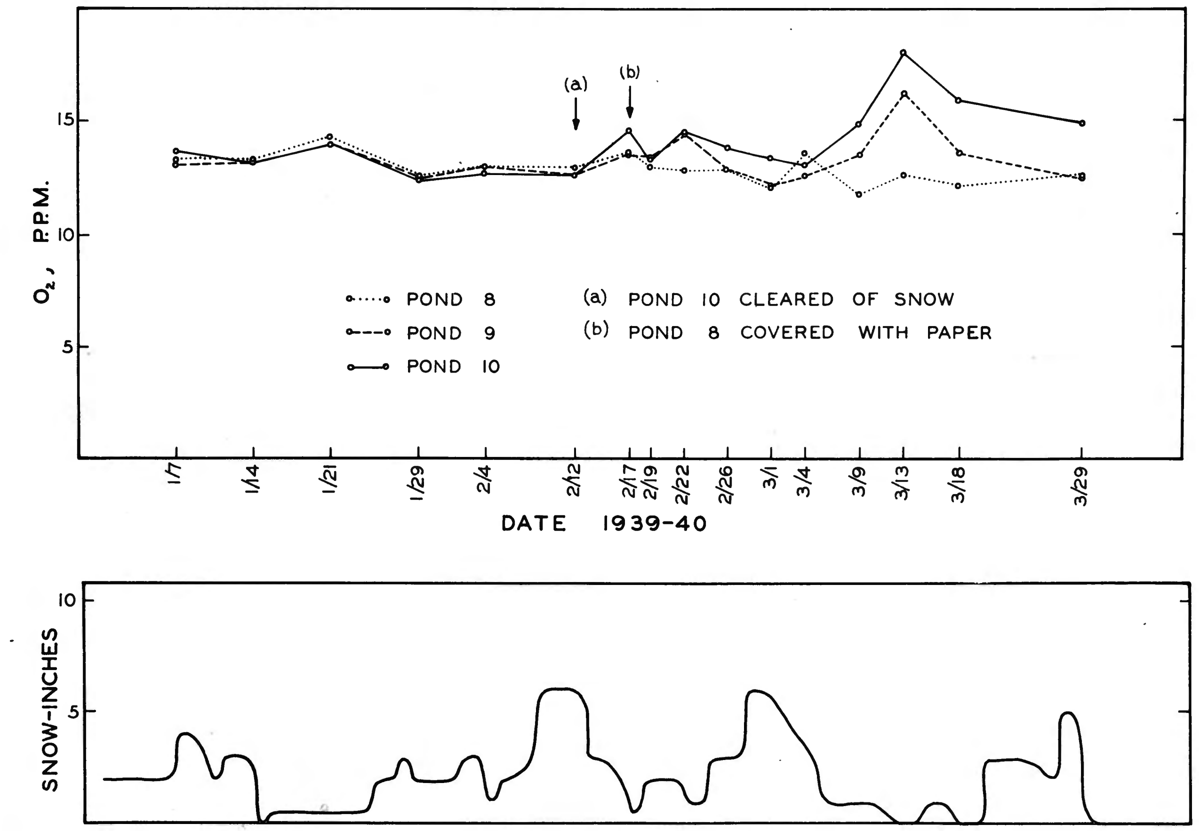
Graph 19. Percentage transmission of light through snow, ice, and water, Bog Lake, March 15, 1941.



Graph 20. Percentage transmission of light through snow. Data from authors.



Graph 21. Dissolved oxygen, effect of pumping water. Pasinski's Pond, Stations 15 and 27, Surface samples. 1939-40.



Graph 22. Dissolved oxygen, snow-clearing experiment.
Hatchery experimental ponds, 1939-40.

## APPENDIX

### THE EFFECT OF CERTAIN SAMPLING PROCEDURES UPON DISSOLVED OXYGEN VALUES

An experiment to determine the possible diurnal variation in dissolved oxygen in the water of an ice-covered lake (described in the text of this paper under "Special observations, Green Lake") gave results apparently somewhat ambiguous (Table 18, and Graph 14). It seemed possible that these results might have been influenced by the method of sampling. The sampling procedure, repeated each two hours, was as follows. The samples were taken consecutively from four depths, 6 inches, and 2, 5, and 9 feet, starting with the uppermost. The sampler was so constructed that during the sampling operation it emitted, in a stream of bubbles, all of the contained air (roughly, 1.5 liters). It was considered possible that this stream of bubbles, when a sample was being taken at a lower depth, might agitate the water above, and hence change the characteristics of a subsequent sample taken in an upper layer. Furthermore, the passing of the sampler up and down through the layers of water might, in itself, have a disturbing effect.

In the routine work of the survey, this error was assumed to be negligible; for ordinarily no station was sampled oftener than once a day, and the usual interval was two to four days. It seems altogether likely that during such a period the water again would return to its normal condition of stratification, and that the effect of the agitation would disappear. When only two hours intervened between samples, however, a considerable error seemed possible.

In order to estimate the magnitude of this error, and to test the effect of various sampling techniques, the following experiments were performed. All of the trials were run at a single sampling station, at the sampling depths stated above.

I, January 17–19, 1941. — The 48-hour run referred to above constitutes Number I of this series of experiments.

II, January 26, 1941. — The four depths were sampled in rotation, from the uppermost to the lowermost one; then immediately the process was repeated. After five sets of samples had been taken in this manner, a new hole was cut in the ice and five new sets of samples from each depth were taken. The time consumed by the entire procedure was less than two hours.

III, February 2, 1941. — The same procedure as in Experiment II was followed, except that the sampler was modified to the extent of having a rubber hose leading from its air exhaust tube to the atmosphere. Thus, while the effect of moving the sampler up and down through the water remained, that of bubbling air through the water was obviated.

IV, January 26, 1941. — Without using the rubber hose, five consecutive samples were taken at the 6-inch depth, then five at the next lower depth, and so forth. In this way, no layer of water was disturbed by either the sampler or air bubbles before all of the samples from that layer had been obtained. The total sampling time was about one-half hour.

Dissolved oxygen in all of the samples of these experiments was determined by the rapid Winkler method, as described under "Methods."

The dissolved oxygen values are given in Table A. They are arranged in the order in which the samples were taken. All figures are in parts per million. Mean values are calculated to the nearest 0.05 p.p.m. The standard deviation from the mean is given for each series, as is also the maximum deviation, from the mean, of any individual sample in the series. The series are numbered in the table to correspond with the descriptions above.

Since these experiments were performed on different dates, the absolute values for dissolved oxygen are not subject to comparison. Rather it is the

Table A. Effect of sampling procedure on dissolved-oxygen determinations. Green Lake, Station 2. At the bottom of each column are the mean, the standard deviation, and the maximum deviation, each estimated to the nearest 0.05 p.p.m. See explanation below.

$O_2$ (p.p.m.), Method I, at depth (feet):

| 0.5 | 2 | 5 | 9 |
|---|---|---|---|
| 13.6 | 13.3 | 9.8 | 6.0 |
| 13.4 | 12.7 | 9.6 | 6.1 |
| 12.8 | 13.0 | 9.7 | 4.6 |
| 12.7 | 12.7 | 8.1 | 3.4 |
| 12.5 | 12.2 | 8.4 | 4.4 |
| 12.5 | 12.0 | 8.4 | 4.1 |
| 12.3 | 12.2 | 8.0 | 4.5 |
| 12.7 | 12.6 | 8.1 | 4.3 |
| 13.0 | 12.7 | 7.2 | 4.7 |
| 12.8 | 13.5 | 8.9 | 3.7 |
| 12.6 | 13.1 | 8.6 | 4.7 |
| 12.9 | 13.0 | 8.6 | 3.7 |
| 13.2 | 11.9 | 8.7 | 5.4 |
| 12.7 | 13.0 | 9.2 | 4.7 |
| 13.2 | 13.1 | 8.4 | 5.5 |
| 13.4 | 13.2 | 10.5 | 6.0 |
| 13.6 | 13.3 | 8.7 | 6.6 |
| 13.7 | 13.7 | 9.2 | 4.3 |
| 14.1 | 13.1 | 9.2 | 5.7 |
| 14.2 | 13.4 | 8.2 | 7.1 |
| 14.0 | 12.9 | 8.1 | 4.9 |
| 14.3 | 13.2 | 9.2 | 5.0 |
| 13.6 | 13.1 | 8.9 | 7.3 |
| 14.1 | 13.5 | 8.4 | 7.6 |
| 13.25 | 12.95 | 8.75 | 5.20 |
| 0.60 | 0.45 | 0.70 | 1.20 |
| 1.05 | 1.05 | 1.75 | 2.40 |

$O_2$ (p.p.m.), Method II, at depth (feet):

| 0.5 | 2 | 5 | 9 |
|---|---|---|---|
| 11.1 | 9.8 | 11.9 | 4.9 |
| 10.9 | 10.9 | 12.2 | 5.5 |
| 11.6 | 12.1 | 12.4 | 4.8 |
| 11.6 | 11.7 | 11.8 | 5.9 |
| 11.1 | 10.9 | 11.2 | 3.7 |
| 10.9 | 10.8 | 11.9 | 5.8 |
| 11.2 | 11.9 | 12.1 | 5.3 |
| 11.1 | 10.9 | 11.5 | 4.9 |
| 10.9 | 11.1 | 11.4 | 4.4 |
| 11.1 | 11.4 | 11.6 | 4.4 |
| 11.15 | 11.15 | 11.80 | 4.95 |
| 0.25 | 0.65 | 0.35 | 0.65 |
| 0.45 | 1.35 | 0.60 | 1.25 |

$O_2$ (p.p.m.), Method III, at depth (feet):

| 0.5 | 2 | 5 | 9 |
|---|---|---|---|
| 10.9 | 11.0 | 9.7 | 4.8 |
| 10.7 | 10.8 | 9.7 | 5.9 |
| 11.0 | 11.3 | 9.4 | 4.6 |
| 10.9 | 10.9 | 9.6 | 6.5 |
| 10.8 | 11.0 | 9.4 | 5.9 |
| 10.9 | 11.1 | 9.4 | 4.4 |
| 10.9 | 10.9 | 9.3 | 4.1 |
| 10.8 | 11.2 | 9.6 | 6.3 |
| 10.9 | 11.2 | 9.0 | 5.2 |
| 10.8 | 10.7 | 9.3 | 5.7 |
| 10.85 | 11.00 | 9.45 | 5.35 |
| 0.10 | 0.20 | 0.20 | 0.80 |
| 0.15 | 0.30 | 0.45 | 1.25 |

$O_2$ (p.p.m.), Method IV, at depth (feet):

| 0.5 | 2 | 5 | 9 |
|---|---|---|---|
| 10.9 | 10.9 | 12.1 | 6.0 |
| 10.8 | 10.8 | 11.8 | 6.9 |
| 10.9 | 11.0 | 11.8 | 6.7 |
| 10.8 | 10.8 | 12.1 | 6.5 |
| 10.9 | 11.0 | 11.8 | 6.1 |
| 10.85 | 10.90 | 11.90 | 6.45 |
| 0.05 | 0.10 | 0.15 | 0.35 |
| 0.05 | 0.10 | 0.20 | 0.45 |

Method I — Samples at two-hour intervals for 48 hours. January 17–19, 1941.

Method II — The four depths sampled in rotation. January 26, 1941.

Method III — As in (I), but sampler equipped with outlet hose. February 2, 1941.

Method IV — Five consecutive samples at each depth. January 26, 1941.

See text for further explanation.

amount and manner of fluctuation of values within each experiment that is significant.

It is realised that a possible fallacy in statistical treatment of the data of II and III may arise because of the fact that each of these series of ten samples is in reality a combination of two sub-series of five samples each; since the sampling operation was transferred to a new hole midway in the series. Actually, however, this error is small; because (1) the mean for each sub-series is very nearly the same as the mean for the whole series, and (2) the fluctuations in value are without any apparent trend in either direction.

The data at hand appear to support the following conclusions:

1. The magnitude of deviations from the mean is significantly larger [1] for the samples obtained at two-hour intervals for forty-eight hours than it is even for samples obtained in rapid rotation, as in Experiment II (see Table B). Therefore the fluctuations in dissolved oxygen during the forty-eight hour run can be only partly accounted for by imperfection of sampling technique, and their trends must have in part some other explanation. Changes due to natural causes over the forty-eight hour period were no doubt responsible for some of the fluctuations in the oxygen values for a given depth in Experiment 1. Thus, for the 6-inch depth, and early series of four values (12.8, 12.7, 12.5, 12.5) no doubt was significantly different from a later period when four successive values at the same depth were 14.1, 14.2, 14.0, and 14.3.

2. There is, however, a certain amount of fluctuation in the dissolved oxygen value at any particular depth from one time to another, if during that time the water at that depth has been disturbed by passage through it of the sampler or of a stream of air bubbles. This effect, of course, is most apparent when the time interval between samples is short, and is believed to be insigni-

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[1] An exception to this statement is furnished by the samples taken at 2 feet. For this, and other similar discrepancies, there is no explanation available.

**Table B.** Effect of sampling procedure upon dissolved-oxygen values (deviations from the mean). Green Lake, Station 2. See text.

| Depth (feet) | Standard deviation, p.p.m. of $O_2$, using method: | | | | Maximum deviation, p.p.m. of $O_2$, using method: | | | |
|---|---|---|---|---|---|---|---|---|
| | I | II | III | IV | I | II | III | IV |
| 0.5 | 0.60 | 0.25 | 0.10 | 0.05 | 1.05 | 0.45 | 0.15 | 0.05 |
| 2 | 0.45 | 0.65 | 0.20 | 0.10 | 1.05 | 1.35 | 0.30 | 0.10 |
| 5 | 0.70 | 0.35 | 0.20 | 0.15 | 1.75 | 0.60 | 0.45 | 0.20 |
| 9 | 1.20 | 0.65 | 0.80 | 0.35 | 2.40 | 1.25 | 1.25 | 0.45 |

ficant when more than a few hours intervene. The fluctuations show no apparent trend, toward either higher or lower dissolved oxygen, but have a more or less random distribution.

3. Deviations are significantly smaller when air bubbles are not allowed to pass through the water (Experiment III); hence a definite part of the fluctuation of Experiment II can be attributed to the air bubbles. Bubbles of this size are not readily absorbed by the water; and, furthermore, there is no distinct trend toward increased dissolved oxygen from the first sample of a series to the last. Therefore the effect of the air bubbles must be largely a mechanical one; i.e., one of agitation.

4. There is, also, a definite effect of the mere motion of the sampler through the water; since the deviations in Experiment IV are significantly less than those of Experiment III.

5. When the procedure of Experiment IV is used; i.e., when no sample is taken from a layer of water which has recently been disturbed by the sampler; the fluctuations in the dissolved oxygen value of the samples are little, if any, greater than those of the normal experimental error of the dissolved oxygen method (about 0.0 — 0.2 p.p.m.). This statement holds true only for samples from the uppermost layers.

6. Samples from the lower layers show relatively wide fluctuations, even when the sampling is done by the method of Experiment IV. This situation is exactly the reverse of what might be expected if the fluctuations were caused entirely by the disturbances mentioned above; for the effect of these disturbances would be the greatest in the upper layers of water, and at a minimum at the lowest sampling depth, a depth beyond which the sampler has not passed. The explanation is rather simple. The slope of the dissolved oxygen curve (for that particular station and time) is much greater in the lower water than near

the surface. Thus on January 26, the decline in oxygen in the 6- to 9-foot layer was almost 2 p.p.m. per foot of depth, whereas in the surface to 4-foot layer there was practically no change. Any errors caused by not accurately reading the sampling line therefore are much greater for samples taken in the lower depths than for those taken near the surface.

The wide variations in oxygen values for the lower levels (which are evident regardless of the time interval between samples and of the sampling method employed) may be due in part to natural causes rather than to experimental errors. Slight tilting of the water strata might cause sharp changes in the dissolved oxygen values at any given point.