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PRELIMINARY REPORT ON SOME MINNESOTA LAKES AND THEIR PRODUCTIVENESS OF FISH FOOD

MAYNARD S. JOHNSON

I. THE INVESTIGATION OF LAKES

Minnesota's Lake Resources

The lakes of Minnesota constitute one of its valuable natural resources. According to Dole and Wesbrook (1907) "Minnesota contains probably a larger number of lakes than any other state in the Union." It has been estimated that these lakes number about ten thousand. According to Leverett and Sardeson (1919) "the combined area of the lakes within the state is estimated to be about 5,650 square miles, or nearly 7 per cent of the entire area." The economic value of the lakes depends largely on their influence in attracting tourists, through the recreational opportunities they afford. The tourist business of Minnesota, according to figures compiled by the Ten Thousand Lakes Association, amounts to more than 80 million dollars a year and exceeds in value any single field crop produced in the state. One of the most important recreational values of the lakes is the fishing they afford.

Organization and Objectives of the Present Investigation

In view of the number and importance of the lakes, and the growing demands on their fish resources by the increasingly large numbers of tourists, it was decided to begin a biological study of certain lakes with special reference to factors affecting their productivity. The general problem was suggested to the writer by Dr. W. A. Riley, chief of the Division of Entomology and Economic Zoology of the Department of Agriculture of the University of Minnesota, and the plan of procedure was agreed upon in conference with Dr. R. N. Chapman, former chief. The investigation was organized as a project of the Agricultural Experiment Station. As a basis for the selection of suitably representative lakes for biological study it was decided first to make a survey of physical and chemical features of groups of lakes in various parts of the state, and later to pick out lakes of various physical and chemical types for more detailed study. In the conduct of this study the immediate aim was the accumulation of significant data concerning the lakes visited. The expectation was to be able eventually to correlate the physical and chemical conditions in the lakes with the kinds and abundance of bottom fauna and other small animal life and to correlate these with the yield of fish. This report deals chiefly with physical and chemical conditions, and particularly with the distribution of dissolved oxygen and carbon dioxide.

The field work has extended over four summers, 1926-29, inclusive. The field work was done by the writer and one or two assistants. Men who have been engaged in this study as assistants at different times are Sam Kepperly, Ralph King, Francis Munger, Theodore Erickson, and Richard Falkenstein. To all of these the writer wishes to express appreciation of their diligence and cheerful co-operation.

Historical Review, Results of Limnological Studies

It has been generally true that studies of the ocean, both of physical conditions and of organisms, have been made in advance of corresponding studies on bodies of fresh water. The development of limnology (the scientific study of lakes) has to a great extent followed the adoption and adaptation, in fresh-water studies, of quantitative methods originally developed in marine investigations.

One of the more important early papers outlining the broad principles of lake biology was an address given by S. A. Forbes in 1887, "The Lake as a Microcosm." The investigation of Lake Geneva by the Swiss physician, F. A. Forel, and the three volumes of reports of this investigation "Le Leman, Monographie Limnologique" (1892, 1895, 1904) mark the beginning of limnology. Limnological investigations in this country have been chiefly those of E. A. Birge and Chancey Juday on the lakes of Wisconsin. These and other investigations have resulted in a mass of data and have helped toward an understanding of principles underlying conditions and changes observed.

Methods have been developed for the measurement of the transparency of water and of the penetration and absorption of light and heat in pure and natural waters. Density and viscosity changes of water with change of temperature have been determined. Stratification of temperatures and the occurrence of a thermocline in certain lakes has been investigated and explained, and lakes have been classified according to depth and temperature. Heat budgets of lakes (the calories required to raise the lake temperature from the winter minimum to the summer maximum) have been calculated and the effect of the sun and of the wind in warming a lake have been distinguished. Of the substances dissolved in the water, the dissolved gases, especially oxygen and carbon dioxide, have proved to be of greatest biological significance and have received most study. The stratification of these gases in relation to the circulation and stagnation of the water, and in relation to photosynthesis and respiration of the organisms, has been extensively studied. Other dissolved substances, notably carbonates, phosphates, nitrates, and organic nitrogen compounds, also have been investigated, altho to a lesser extent. It is generally supposed that dissolved substances that show a decrease at times of plankton increase are utilized by the plankton. A vast amount of limnological research has been devoted to a study of plankton, especially to seasonal changes in kind and number of organisms, and to their distribution according to depth. Attempts to correlate plankton content of lakes with production of fish on the whole have proved to be not very successful. A scarcity of plankton is likely to be associated with a scarcity of fish, but the converse does not necessarily hold true. Wiebe (1928) declared he was unable to distinguish, on the basis of plankton alone, between unpolluted and badly polluted sections of the Mississippi River. Bottom fauna, being more stable than plankton, is a better measure of year-round conditions in the habitat and the suitability of the habitat for fish.

II. PHYSIOGRAPHY OF SOME GROUPS OF MINNESOTA LAKES

Necessity of Physiographic Study

In undertaking an investigation of the productiveness of Minnesota lakes, it was necessary, first of all, to learn something about the nature of the lakes themselves. A knowledge of conditions existing in the lakes was considered no less important than a knowledge of the kinds and numbers of organisms there. Only few of the data required were available from published sources. Township plat maps showed the location of lakes as well as their size and shape, but gave no indication of depth. Even the information given was not wholly dependable, as several of the lakes shown on the maps were dried up completely, and some were so shrunken that their size and shape were no longer as shown on the maps. Maps showing depth were available for only a few lakes. The lakes of Ramsey County had been sounded under the direction of the county surveyor, and maps published with depth contour lines. United States government maps were available showing depths of Lake Pepin, Lake Minnetonka, Mille Lacs Lake, and the borders of Red Lake. Accurate depth data for other lakes were entirely wanting. Estimates of depth of lakes, made by resort proprietors and other interested persons, proved notably unreliable. The tendency was greatly to over-estimate the depth. As to stratification of temperatures, dissolved gases, and the like, there seemed to be no published data.

Groups of Minnesota Lakes Investigated

As it was manifestly impossible to obtain the desired physical and chemical data for all the lakes, a survey was planned of groups of lakes in different parts of the state. In accordance with this plan determinations of depth, temperature, dissolved gases, and carbonate have been made for practically all the lakes on which boats could be obtained in Ramsey, Washington, Anoka, Hennepin, and Wright Counties, in the east central part of the state, and in Douglas County, in the west central part. As none of these lakes are large, Ottertail Lake and Mille Lacs Lake were visited, as examples of medium and large lakes. Whitefish Lake, a smaller lake just west of Mille Lacs and connected with it, was also included in the survey. The entire summer of 1928, and time in other seasons, has been devoted to a biological study of Lake Pepin, with special reference to its bottom fauna. This lake differs from the others studied in being a river lake (an expansion of the Mississippi River).

Minnesota owes its wealth of lakes to the numerous ridges or moraines formed successively at the borders of the receding ice sheet that covered most of the state at the time of the latest glacial invasion (Leverett and Sardeson, 1919). The entire southeastern corner of the state and the extreme southwestern tip are without lakes because they were not reached by the latest, or "young" glaciation. Northwestern Minnesota was the floor of a great glacial lake (Lake Agassiz), and is now without lakes because of its flatness. In the northern parts of Cook, Lake, and St. Louis Counties are large areas of rock. The explanation, according to Leverett and Sardeson (1917) is that "the ice sheet removed the soil and subsoil, laying bare the underlying hard rock. Before the ice melted in this region it had carried the loose material away. Since that time there has been some weathering of the rock, but at most places not enough to give a good workable soil." This rocky region contains numerous lakes.

The groups of lakes already investigated are typical of the fertile-land regions. The lakes of the rocky, non-fertile region of northeastern Minnesota are not (1929) represented in this survey, and should be made the first objective of any continuation of it.

Physical and Chemical Measurements

The physiographic study was designed to be a general survey of groups of lakes, rather than a detailed study of a few. The object was to get a few of the most significant facts about as many lakes as possible in the designated areas.

Tracings were made from county and township plat books, in advance of visits, showing the outlines of the lakes in the selected areas. Sometimes lakes that were impressive on the map were much less so when seen. Numbers of the lakes proved to be very shallow, choked with emergent vegetation, and with little or no open water. A few lakes appearing on the maps had disappeared. Generally, however, the lakes were essentially as shown on the map.

Upon arriving at the lake, a boat was obtained if possible and the map was oriented with the lake and landmarks were noted. Sometimes it was necessary to make changes in the lake outline on the map, if bays had shortened or points had lengthened or islands appeared owing to lowering of the water level. Any such changes were drawn on the map, as accurately as possible without surveying instruments. The approximate areas of the lakes were estimated by checking the maps against a superimposed scale subdivided into fractions of a square mile. When it was necessary to change the outline of the lake on the map, because of changed contours resulting from lowered water level, only the open-water areas (those not choked with emerging vegetation) were included in the recorded estimate.

Except in the case of the relatively few lakes for which published maps showing depth were available, soundings were made at equal intervals along lines back and forth across the lake. Not enough soundings were obtained in this way or not accurately enough located, to justify drawing depth contour lines, but they were ample for indicating the approximate maximum depth, and the approximate amount and position of deep and shallow water areas. It is thought that the methods used were the quickest and best for the objects in view. The soundings were made with a weight (a flatiron) attached to the end of a line of window-sash cord marked in feet. In some lakes a part of the bottom was of such soft mud that the weight continued to sink and no sharp boundary appeared between water and mud. Readings were taken as soon as the line slackened, before it had time to settle. In connection with the soundings, notes were made of the character of the bottom, particularly if it was unusually solid or unusually soft; and sometimes note was made of conspicuous patches of vegetation.

In most of the lakes visited, transparency of the water was measured by the use of a Secchi's disk. Samples of water were taken with a modified Kemmerer water bottle, and put in small-mouthed glass-stoppered sample bottles of approximately 250 cc. capacity, with due precautions against exposure to the air. Temperatures were read from a thermometer placed in the sample bottles as they were being filled from the sampler. Determinations of oxygen, free carbon dioxide, and "fixed" carbon dioxide (carbonate) were made according to the methods described by Gemmerer, Bovard, and Boorman (1923). These analytical methods are essentially those used by Birge and Juday (1911). The strong acid and the hydroxide-iodide mixture were added to the oxygen sample bottles immediately. The titrations for the oxygen determinations and the free and fixed carbon dioxide determinations, were made on shore, usually within a few hours of the time the samples were taken.

In each lake a series of water samples was taken from different depths. The deepest or most exposed part of the lake was chosen for sampling. In lakes that were quite definitely marked off into distinct parts, more than one series of samples was ordinarily taken.

As is to be expected under summer conditions, oxygen and carbon dioxide show great variation with depth, the oxygen decreasing and the carbon dioxide increasing at increased depths. The rate and extent of this change depends in part on the depth and the area of the lake. Oxygen is added to the upper layers of water by absorption from the air and by photosynthesis, and carbon dioxide is at the same time consumed. In the deeper layers, and especially at the bottom, carbon dioxide is added to the water by decay of organic matter, and at the same time oxygen is consumed. The upper layers of water are warmer and lighter than the lower layers and so resist the tendency of the wind to mix them. Owing to the influence of photosynthesis, in utilization of carbon dioxide and liberation of oxygen, the upper layers of a lake with abundant plankton algae may differ greatly in their content of these two gases between night and day, between a cloudy and a sunny day, or between morning and afternoon of the same day. As a result of photosynthesis, the upper layers of a lake may readily become supersaturated with oxygen and depleted of carbon dioxide during a sunny day, whereas the reverse might be true in the early morning or on a cloudy day. In general, larger, deeper lakes do not develop supersaturation of dissolved oxygen to the same extent as smaller shallower ones. Likewise, in larger lakes there is less likely to be a depletion of oxygen in the deeper water. In the larger lakes the wind has a greater sweep and so the water is mixed to a greater depth. Some of the smaller lakes visited were entirely oxygen-free in August at depths below 40 feet. Many small lakes do not have enough oxygen for fish to live at depths below 15 feet during the latter part of the summer. The larger lakes are exposed to the mixing effect of wind action and have plenty of oxygen at greater depths. Tanner's Lake, Washington County, for instance, on August 10, 1926, had 2 cc. of oxygen per liter at a depth of 20 feet and none at 30 feet, as compared with 6 cc. at the surface. Mille Lacs Lake, on August 30, had 5 cc. of oxygen per liter at 25 feet as compared with 6.1 cc. at the surface. Lake Minnetonka, of moderate size, has a total area of 21 square miles, but is divided into numerous bays and arms that are in effect distinct small lakes. The deepest lake visited was Lake Carlos, in Douglas County, where a maximum depth of 153 feet was found. When this lake was visited, July 23, 1927, the water at a depth of 125 feet contained 3.5 cc. of oxygen per liter. Because of the great mass of water below the thermocline in this lake, the reserve of oxygen was not seriously depleted by the decay of organic matter at the bottom. A small lake in Washington County (Goose Lake), was exceptional in the very low carbonate content of the water. The fixed carbon dioxide was 5.5 cc. per liter, as compared with an average of more than 20 cc. per liter for the other lakes of the county.

Table 1 shows, in condensed form, the principal results of analyses of water. The principles outlined in the preceding paragraph are amply illustrated by the data in the table. Space does not permit the presentation of the complete records of soundings, notes on the vegetation and character of the bottom, the time of day, or conditions under which the water samples were collected. These data are on file at the University, and may be consulted by anyone interested. The maximum depth found in each lake is given in the table.

III. BOTTOM FAUNA OF SOME MINNESOTA LAKES

Lakes Selected for This Study

In the summer of 1929, bottom samples were collected from small lakes near St. Paul. These were visited in the lake survey begun in 1926, and were selected for special study because of the contrasting features they afforded, as well as their proximity to the University. The organisms have been separated and tabulated for the samples from only eight of these lakes, as follows:

Small shallow lakes. Oxygen present at bottom.
- Turtle Lake
- Goose Lake

Small shallow lakes. Oxygen deficient at bottom.
- Lake Gervais
- Lake Jane

Small lakes. Oxygen absent from bottom.
- Tanner's Lake
- McCarrons' Lake

Fairly deep lakes. Oxygen absent from bottom.
- Lake Phalen
- Lake Elmo

Aside from the differences indicated by this classification according to depth and dissolved oxygen, these lakes present others. Turtle Lake has a sand bottom. Goose Lake has shores of sand and gravel, and, as has been mentioned, is notable for the very low carbonate content of the water. Lake Jane has only a little sandy shore, most of the shore and bottom being of soft black mud. Almost the entire shore of Lake Elmo consists of very soft grayish yellow mud. The last two lakes mentioned are almost unapproachable except by docks extending out to water deep enough to float a boat.

The summer of 1928 was spent in a study of Lake Pepin, with special reference to the large numbers of chironomid midges occurring there. Lake Pepin is an enlargement of the Mississippi River, formed by the natural damming of that river by the delta of the Chippewa River. This lake is about 20 miles long and averages about 2 miles wide. No current is noticeable in the main part of the lake. Lake Pepin has a fairly uniform depth of about 30 feet. The shores are mostly sand and gravel, and the bottom is mud. A considerable series of bottom samples was taken at Lake Pepin, and is of interest for comparison with the samples from the lakes near St. Paul.

Method of Study

The bottom samples were taken with an Ekman dredge. The jaws are operated by springs and are arranged to close when a weight or messenger is dropped along the line. The dredge used had a cross-section of 6 x 6 inches and so each sample represented 36 square inches of lake bottom. The dredge was not entirely satisfactory in some respects. It was easily clogged by bits of sand or grit. When samples were obtained from sand bottom they were usually scanty, and so the organisms of sand bottom probably are not fully represented in the results obtained.

The samples were sifted in a brass sieve, 20 meshes to the inch. The macroscopic organisms and debris of various sorts remained in the sieve; the mud passed through. In the bottom samples from Lake Pepin the organisms were separated at once from the debris, and preserved in bottles of formalin. In those from the lakes near St. Paul, the entire residue from the sifting was preserved in formalin in half-pint milk bottles, and brought to the laboratory to be sorted later. The latter method shortens the time required for the collection of samples, but greatly lengthens the time required for the separation of organisms, and is not recommended.

The samples from Lake Pepin were mostly from the deeper water, beyond the zone of vegetation. The samples from the lakes near St. Paul were taken, so far as practicable, according to the following plan:

Two samples each

a. from deepest part of lake.
b. from shallower vegetationless zone in A is below thermocline.
c. from submerged vegetation (out of sight).
d. from emerging vegetation (or reaching within a foot or two of the surface).

Organisms Obtained

Mostly amphipods, chironomids, and Corethra were contained in the samples from the lakes near St. Paul. Mostly chironomids (nearly all of the one species *Chironomus plumosus*) and sphaerid molluscs were in the samples from Lake Pepin. Annelids were occasional and irregular in all the lakes. Small numbers of mayfly and damselfly nymphs or caddis larvae appeared in samples from shallower parts of several of the lakes near St. Paul. Their non-appearance in samples from other lakes is possibly a mere chance of sampling, as the numbers are small in any case. When numbers are small, statements of non-occurrence or calculations of abundance are likely to be misleading. It is for this reason that the tabulation of bottom organisms obtained is in number of organisms per sample, rather than the calculated number per square yard. In several samples, quite by chance, a crayfish was caught. The sample was of 36 square inches, or 1/36 of a square yard, but that does not mean that the lake or any part of it contained 36 crayfish per square yard.

It is of interest to note that a fairly abundant amphipod from Lake Jane and a bit of sponge from Goose Lake seem not to fit, even approximately, into any available key, and may be new. Specimens have been turned over to Dr. Eddy, of the University Zoology Department, for further study.

Comparison of Samples

Various European investigators have taken the lead in classifying lakes according to the kind and abundance of bottom fauna, and in calculating ratios between amount of bottom fauna and yield of fish. Thus Alm (1922) distinguishes six types of Swedish lakes as follows: Plumosus type (*Chironomus plumosus*), Oligochaete type, Tanypus type, Corethra type, Amphipod type, and Otomesostoma type (Turbellarian).

While only tentative conclusions can be drawn from the small number of Minnesota lakes already studied, it seems to be true that the bottom faunas of the lakes near St. Paul differ from each other less than might be expected in view of the findings of European workers and in view of the differences in the lakes themselves. The more outstanding differences apparent in comparison of these bottom samples seem to be related to the depth or the habitat from which the samples come, rather than the lake from which they come. Insect nymphs or larvae, except for chironomids and Corethra, were not found at greater depths than 15 feet. However, in lakes larger than those studied, they might be expected to extend to somewhat greater depths. A single amphipod was found in each of two deep-water samples, but they were not abundant except in samples from less than 15 feet. Corethra were represented in two samples between 11 and 16 feet, and were abundant in most samples from a greater depth. In the shallow-water zones of vegetation there was indication that the relatively rigid or broad-leaved plants, such as *Potamogeton crispus*, afforded a much better support for small animals than did the extremely fine-leaved varieties.

The bottom fauna of Lake Pepin differs strikingly from the fauna of the lakes just discussed. This difference cannot be explained on the basis of depth, dissolved oxygen, carbonate, or any of the other physical or chemical factors measured. In Lake Pepin, amphipods and Corethra are virtually absent, chironomid larvae are extraordinarily abundant beyond the vegetation zone, and sphaerid molluscs are almost as abundant. Presumably, the difference in fauna of Lake Pepin as compared to lakes near St. Paul is related to the pollution carried into Lake Pepin from the Twin Cities by the Mississippi River. Tables summarizing the bottom fauna data for the lakes near St. Paul, and for Lake Pepin (Tables 2 and 3), are presented. Details as to the conditions under which the samples were collected and character of the bottom, can not be presented in the tables, but are contained in the original field notes on file at the University.

IV. SUMMARY AND SUGGESTIONS FOR CONTINUATION

A survey has been made of the most significant physical and chemical conditions in groups of Minnesota lakes. Except in a few lakes for which maps showing depth were available, soundings were made to determine approximately the maximum depth and the extent of deep and shallow areas. The complete data from soundings are contained in the field notes, but could not readily be condensed in the form of a table. The maximum depth found in each lake visited, as well as the data on temperature, dissolved oxygen, carbon dioxide, and carbonates at different depths are presented in Table 1. To date 74 lakes have been included in the survey. These are considered typical of the fertile-land lakes of Minnesota. The lakes of the rock-outcrop region of northern Minnesota have not been touched in the survey, and should be made the objective of any continuation of it.

Collections of bottom organisms have been made from several lakes near St. Paul and from Lake Pepin. Depth, and in shallow water the character of the bottom and the vegetation, seem to be especially important in affecting the kind and the number of bottom organisms. The bottom fauna of Lake Pepin is strikingly different from that of lakes near St. Paul, and the difference can not be explained by any physical or chemical factor measured. It is possible that the difference may result from pollution carried into Lake Pepin by the Mississippi River. The data on bottom fauna are presented in Tables 2 and 3. Continuation of the work on bottom fauna should include samples from a larger number of lakes and samples collected at various seasons and in various years.

REFERENCES

Alm, Gunnar

1922. Bottenfaunan och fiskens biologi i Yxtasjön samt jämförande studier över bottenfauna och fiskavkastning i vara sjöar. Meddelanden fran Kungl. Lantbruksstyrelsen N:r 236.

Birge, E. A., and Juday, Chancey

1911. The inland lakes of Wisconsin. Dissolved gases. Wis. Geol. and Nat. Hist. Survey, Bull. 22.

Coates, Paul N.

1924. Special report of lake improvement. Board of County Commissioners, Ramsey County, Minn.

Dole, R. B., and Wesbrook, F. F.

1907. The quality of surface waters in Minnesota. U. S. Geological Survey, Water-supply and Irrigation Paper No. 193.

Forbes, S. A.

1887. The lake as a microcosm. Bull. Peoria Sci. Assn., pp. 1-15.

Forel, F. A.

1892, 1895, 1904. Le Leman, Monographie Limnologique. 3 vols. Lausanne: F. Bouge.

Johnson, M. S., and Munger, Francis

1930. Observations on excessive abundance of the midge, *Chironomus plumosus,* at Lake Pepin. Ecology, 11:110-126.

Kemmerer, G., Bovard, J. F., and Boorman, W. R.

1923. Northwestern lakes of the United States. U. S. Bureau of Fisheries, Bull. 39, Doc. 944.

Leverett, Frank, and Sardeson, Frederick W.

1917. Surface formations and agricultural conditions of northeastern Minnesota. Minn. Geological Survey, Bull. No. 13.

1919. Surface formations and agricultural conditions of the southern half of Minnesota. Minn. Geological Survey, Bull. No. 14.

Wiebe, A. H.

1928. Biological survey of the upper Mississippi River with special reference to pollution. U. S. Bureau of Fisheries, Bull. 43, Doc. 1028.

Table 1
Summary of Physical and Chemical Data Obtained in a Survey of Groups of Minnesota Lakes

Lake	Date	Approximate area, sq. mi.	Maximum depth found, ft.	Depth of sample, ft.	Temperature, ° F.	Dissolved oxygen, cc. per liter	Reaction to phenolphthalein	Carbon dioxide deficiency (—) or excess, cc. per liter	"Fixed" CO_2 (carbonate) cc. per liter	Comments
				ANOKA COUNTY						
Centerville Lake	8/14 1926	0.7	12½	½		5.4 5.4	acid	2.5	36.8	Shallow, sandy lake. Samples taken in forenoon in thick fog. Enormous amount of plankton algae.
				5		5.1 5.1	acid	5.1	37.2	
				10		4.8 4.7	acid	4.4	36.5	
Coon Lake, pond southwest of narrows	8/24 1926	1.7	15	½	73	7.2 7.1	alkali	—2.3	18.4	Mostly rather soft muck bottom Abundant vegetation (Elodea, etc.).
				5	73½	7.0 7.2	alkali	—1.7		
				10	73	7.1 7.2	alkali	—2.0	18.6	
Coon Lake, north part	8/24 1926	0.6	20	½	73	8.4 8.4	alkali	—2.4	21.9	
				10	74	8.4 8.4	alkali	—2.4		
				15	73	5.1 6.9	neutral		22.0	
Lake George	8/25 1926	0.4	30	½	74	7.6 7.6	alkali	—1.5	15.5	
				10	73½	7.6 7.6	alkali	—1.4		
				15	73	7.0 7.3	alkali	—1.1		
				20	70½	4.7 4.9	acid	1.6	16.0	
Ham Lake	8/24 1926	0.3	18	½	73½	9.2 9.3	alkali	—4.2	24.2	Small lake. Unusually high oxygen. Samples taken in forenoon, bright sun, abundant plankton.
				5	72½	8.9 8.5	alkali	—3.7		
				10	72½	6.4 6.4	alkali	—1.2		
				15	70½	2.4 3.5	acid	2.0	24.4	
Island Lake	8/25 1926	0.1	25	½	71½	7.7 7.7	acid	2.4	31.8	Lake located in bog, unusually acid.
				10	70	6.7 6.6	acid	3.8		
				15	69½	3.1 2.9	acid	11.1		
				20	67	0.8 1.0	acid	14.3	36.6	

Table 1—Continued

Lake	Date	Approximate area, sq. mi.	Maximum depth found, ft.	Depth of sample, ft.	Temperature, ° F.	Dissolved oxygen, cc. per liter	Reaction to phenolphthalein	Carbon dioxide deficiency (—) or excess, cc. per liter	"Fixed" CO_2 (carbonate) cc. per liter	Comments
Linwood Lake	8/24 1926	1.2	24	½	73	8.8 8.6	neutral		23.8	Mostly sand bottom.
				10	71	8.0 8.2	neutral			
				17	70	4.6 5.6	acid	2.8	24.8	
Martin Lake	8/25 1926	0.4	16	½	72½	8.5 8.5	alkali	—2.5	26.7	Sandy shore, soft muck bottom.
				6	72½	8.4 8.6	alkali	—2.0		
				12	71½	5.4 5.1	acid	1.9	27.4	
Peltier Lake	8/14 1926	0.4	12	½		4.3 4.0	acid	6.5	42.6	Small lake. Plankton algae excessively abundant. Samples taken in forenoon, dense fog.
				5		3.1	acid	8.7		
Reshenau Lake	7/7 1926	0.3	7½							Most of lake had less than foot of water at point where there was 6 to 8 inches of water. Sounding line went into mud 6 feet. Dense growth of emerging vegetation.
Round Lake	8/26 1926			½		7.2	acid	3.0	29.2	Water very shallow, 3 feet soft mud over hard sand. Emergent vegetation throughout lake. No open water.
RAMSEY COUNTY										
Bald Eagle Lake	8/20 1926		34	½	70½	6.0 6.0	acid	1.0	26.0	
				10	70	5.0 5.0	acid	2.4		
				20	69½	3.9 3.8	acid	2.8		
				30	69½	3.7 3.6	acid	3.5	26.1	
Lake Gervais	8/7 1926		38	½	73	5.5 5.6	neutral		31.1	
				5	73	5.5 5.5	alkali	—0.5		
				10	73½	5.6 5.6	alkali	—1.0		
				20	71½	3.8 3.8	acid	1.5		
				25	69	2.2 1.9	acid	2.7		
				30	66	0.4 0.5	acid	6.1	40.0	

Table 1—Continued

Lake	Date	Approximate area, sq. mi.	Maximum depth found, ft.	Depth of sample, ft.	Temperature, ° F.	Dissolved oxygen, cc. per liter	Reaction to phenolphthalein	Carbon dioxide deficiency (—) or excess, cc. per liter	"Fixed" CO_2 (carbonate) cc. per liter	Comments
Lake Johanna	8/3 1926	0.2	39	½	76½	5.5	alkali	—2.3	20.6	
				5	76½	5.4 5.8	alkali	—2.3		
				10	75½	4.9 3.8	alkali	—0.9		
				20	69	1.1 0.7	acid	3.6		
				25	65	0.3 0.3	acid	6.6	30.7	
Lake Josephine	8/2 1926	0.2	48	½	79	5.8 5.9				Data on CO_2 not available.
				5	76	3.9 4.1				Oxygen sample from 29 feet inadvertantly aerated.
				20	71	1.1 1.0				
				29	65					
Keller Lake	8/6 1926		5	½	70	7.0 7.0	alkali	—6.3	24.9	
Long Lake, south part	8/11 1926		25	½	72	6.8 6.8	alkali	—2.4	30.0	
				5	71½	6.9 6.9	alkali	—2.6		
				10	71	6.5 6.7	alkali	—2.4		
				15	71	5.9 5.4	alkali	—1.3		
				20	70	2.3 2.3	acid	2.7	34.1	
McCarron's Lake	8/7 1926		49	½	74	5.7 5.7	alkali	—3.9	28.5	
				10	73	5.5 5.5	alkali	—3.5		
				20	72	3.0 2.8	neutral			
				30	61	0.4 0.6	acid	4.3		
				40	54	0.0 0.0	acid	11.8		
				47	52	0.0 0.0	acid	14.9	43.6	

Table 1—Continued

Lake	Date	Approximate area, sq. mi.	Maximum depth found, ft.	Depth of sample, ft.	Temperature, ° F.	Dissolved oxygen, cc. per liter	Reaction to phenolphthalein	Carbon dioxide deficiency (—) or excess, cc. per liter	"Fixed" CO_2 (carbonate) cc. per liter	Comments
Lake Owasso, east side	8/5 1926	0.1	30	½	73½	5.9 6.0	alkali	—3.5	20.0	
				5	74	5.8 5.8	alkali	—2.9		
				10	73½	5.2 5.4	neutral			
				15	72	2.2 3.4	neutral			
				20	68½	1.6 1.5	acid	2.6	20.8	
Lake Owasso, west side	8/5 1926	0.3	35	½	74	6.3 6.3	alkali	—2.5	26.9	
				5	74	6.1 6.1	alkali	—1.2		
				10	73	5.6 5.6	alkali	—1.7		
				20	71	2.3	acid	2.3		
				30	66	0.6	acid	6.3	27.8	
Phalen	8/6 1926		83	½	74	6.2 6.2	alkali	—1.5	29.6	
				10	73	6.2 6.2	neutral			
				20	72	4.1 4.4	acid	1.1		
				40	58	0.3 0.4	acid	5.0		
				60	51½	0.0 0.0	acid	8.2		
				70	52	0.0 0.0	acid	5.2	30.5	
Snail Lake, north part	8/4 1926	0.1	27	½	76	5.5 5.5	alkali	—1.5	12.7	The present lake is the center of a much larger lake shown on plat map.
				5	75	5.4 5.4	alkali	—1.1		
				10	75	2.5 4.0	acid	0.3		
				15	72½	2.1 2.1	acid	3.7	12.7	
Turtle Lake	8/4 1926	0.6	30	½	75½	6.1 6.2	alkali	—1.9	22.9	
				5	75	6.2 6.2	alkali	—1.5		
				10	75	6.2 6.3	alkali	—1.2		
				15	74	5.2 5.7	neutral			
				20	73	3.1 3.0	acid	2.9	22.9	

Table 1—Continued

Lake	Date	Approximate area, sq. mi.	Maximum depth found, ft.	Depth of sample, ft.	Temperature, ° F.	Dissolved oxygen, cc. per liter	Reaction to phenolphthalein	Carbon dioxide deficiency (—) or excess, cc. per liter	"Fixed" CO_2 (carbonate) cc. per liter	Comments
WASHINGTON AND RAMSEY COUNTIES										
White Bear Lake	8/20 1926	3.7	72	½		6.9	neutral		21.9	Deepest part of lake is in Washington County.
				10	71	6.1	acid	1.3		
				20	70½	5.8 5.8	acid	1.4		
				30	70	4.5 4.3	acid	2.1	23.2	
				40	69½	2.6 2.5	acid	3.5		
				50	67	0.7 0.7	acid	6.4		
				60	66	0.3 0.4	acid	8.0	27.1	
WASHINGTON COUNTY										
Big Marine Lake, north end	8/18 1926	0.6	21½	½	70½	6.6 6.5	alkali	—1.7	13.6	Most of lake rather shallow, mostly sandy bottom. Some clay.
				5	70½	6.5 6.6	alkali	—2.0		
				10	70½	6.5 6.6	alkali	—1.7		
				17	70½	5.2 5.3	alkali	—1.0	14.1	
Big Marine Lake, east bay	8/18 1926	0.5	29	½	70½	6.3 6.3	alkali	—1.2	14.2	
				10	70½	6.2 6.2	neutral			
				20	69	2.8 3.7	acid	1.9		
				25	66	1.4 1.4	acid	5.2	16.6	
Big Marine Lake, main lake	8/18 1926	1.2	37	½	71	6.4 6.5	neutral		15.8	
				10	70½	6.2 6.2	neutral			
				20	70½	5.6 5.6	acid	0.5		
				30	70	4.1 4.3	acid	2.2	16.2	

Table 1—Continued

Lake	Date	Approximate area, sq. mi.	Maximum depth found, ft.	Depth of sample, ft.	Temperature, ° F.	Dissolved oxygen, cc. per liter	Reaction to phenolphthalein	Carbon dioxide deficiency (—) or excess, cc. per liter	"Fixed" CO_2 (carbonate) cc. per liter	Comments
Bonny Lake	8/18 1926	0.3	30	½	70½	6.4 6.7	neutral		18.4	Sandy bottom, vegetation, rushes and some lilies.
				10	70½	6.3 6.7	neutral			
				17	70	4.4 4.2	acid	2.4		
				20	69	3.0	acid	5.0	20.2	
Lower Carnelian Lake	8/17 1926	0.2	35	½	73	7.2 7.2	alkali	—4.4	14.9	
				10	72	7.0 6.9	alkali	—4.1		
				15	71	5.5 5.1	alkali	—2.5		
				20	69½	2.6 2.6	acid	3.7		
				25	65	1.3 1.2	acid	5.3		
				30	62½	0.6 0.8	acid	8.6	20.1	
Big Carnelian Lake	8/16 1926	0.6	53	½	72	6.0 6.0	alkali	—1.1	22.8	
				10	72	5.9 5.9	alkali	—1.5		
				20	72	6.0 6.0	alkali	—1.2		
				30	69	2.1 2.3	acid	3.8		
				40	65	0.5 0.5	acid	6.8	28.5	
Clear Lake	8/19 1926	0.5	29	½		4.5	acid	2.6	31.1	
				10		4.2 4.3	acid	3.0		
				15		4.2 4.2	acid	2.5		
				20		4.0 4.0	acid	2.3		
				25		2.6 3.0	acid	3.8	32.4	

Table 1—Continued

Lake	Date	Approximate area, sq. mi.	Maximum depth found, ft.	Depth of sample, ft.	Temperature, ° F.	Dissolved oxygen, cc. per liter	Reaction to phenolphthalein	Carbon dioxide deficiency (—) or excess, cc. per liter	"Fixed" CO_2 (carbonate) cc. per liter	Comments
Lake Elmo	8/13 1926	0.5	121	½	71	5.0 5.2	alkali	—2.7	21.4	Deepest lake in this vicinity. Very soft shore, so lake is almost unapproachable.
				10	71	4.9 4.9	alkali	—2.1		
				20	70½	2.8 4.1	neutral			
				30	65	1.5 0.7	acid	5.6		
				40	56½	0.3 0.2	acid	6.0	31.6	
				50	54	0.1 0.1	acid	7.2		
				60	52	0.0 0.0	acid	8.3		
				70	52	0.0 0.0	acid	9.2		
				80	52	0.0 0.0	acid	9.3	33.1	
				90	51½	0.0 0.0	acid	10.2		
				100	51	0.0 0.0	acid	10.4	32.5	
Forest Lake, east pond	8/19 1926	1.2	35	½	69	6.0 6.0	neutral		27.0	Raining. Mostly sandy around shore. Most of shore has border (often wide border) of rushes.
				10	69	6.0 6.1	acid	1.3		
				20	69	5.6 5.8	acid	1.9		
				30	69	3.3 3.1	acid	5.8	28.2	
Forest Lake, middle pond	8/19 1926	0.6	26	½	69½	6.3 6.4	neutral		26.0	
				10	69	6.3 6.3	neutral			
				20	69	6.0 6.0	neutral		26.7	
Forest Lake, main pond	8/19 1926	1.5	17	½	69½	6.3 6.2	neutral		25.8	
				10	69	6.2 6.2	neutral			
				15	69	6.2 6.2	neutral		25.0	
Goose Lake	8/18 1926	0.1	14	½	70½	7.0 7.0	alkali	—2.6	5.4	Shore sand and gravel. Very soft water.
				5	70	6.9 6.8	alkali	—2.5		
				10	70	6.2 6.1	alkali	—1.4	5.7	

Table 1—Continued

Lake	Date	Approximate area, sq. mi.	Maximum depth found, ft.	Depth of sample, ft.	Temperature, ° F.	Dissolved oxygen, cc. per liter	Reaction to phenolphthalein	Carbon dioxide deficiency (—) or excess, cc. per liter	"Fixed" CO_2 (carbonate) cc. per liter	Comments
Lake Jane	8/10 1926	0.2	30	½	72	6.5 6.5	alkali	—1.9	10.7	Fairly firm bottom at east end, rest of bottom and shore soft mud.
				10	72	6.6 6.8	alkali	—1.6		
				15	71	4.4 4.8	alkali	—0.5		
				20	70	2.4 1.5	acid	3.8		
				25	65½	1.3 1.1	acid	5.6	12.4	
Root Lake	8/17 1926	0.03	34	½	73½	6.0 5.9	acid	1.0	9.9	Bottom altogether of soft mud, not any sandy shore.
				5	73	5.9 5.9	acid	1.1		
				10	72½	5.9 6.0	acid	1.1		
				15	72	6.0 6.0	acid	0.9		
				23	65½	2.8 3.0	acid	3.6		
				30	57	0.3 0.5	acid	12.1	13.6	
Square Lake	8/16 1926	0.4	61	½	73	6.4 6.5	alkali	—1.6	22.6	Collections in afternoon, cloudy, intermittent breeze. Mostly sandy shore and firm bottom.
				10	73	6.5 6.5	alkali	—2.8		
				20	73	6.3 6.3	alkali	—2.4		
				30	66	2.2 2.8	acid	2.6		
				40	59	1.2 1.4	acid	4.7		
				55	54½	0.5 0.7	acid	6.6	30.4	
Tanner's Lake	8/10 1926	0.1	44	½	72	6.0 6.0	alkali	—1.8	27.4	
				10	71½	5.9 5.9	alkali	—1.4		
				20	68	1.7 3.0	acid	2.1		
				30	60½	0.0 0.0	acid	9.4		
				40	56	0.0 0.0	acid	17.2	40.6	

Table 1—Continued

Lake	Date	Approximate area, sq. mi.	Maximum depth found, ft.	Depth of sample, ft.	Temperature, ° F.	Dissolved oxygen, cc. per liter	Reaction to phenolphthalein	Carbon dioxide deficiency (—) or excess, cc. per liter	"Fixed" CO_2 (carbonate) cc. per liter	Comments
				HENNEPIN COUNTY						
Bass Lake	8/11 1927	0.2	29	0	76	6.9 7.0	alkali	—2.9	15.9	
				15	70	2.9 2.0	acid	2.7		
				25	62	0.0 0.0	acid	7.2 6.3	23.1	
Brownie Lake	8/29 1927	0.03	44	0	76½	6.2 6.0	alkali	—2.3	28.9	
				10	76	6.2 5.8	alkali	—1.3		
				20	64	3.7 1.5	acid	4.7		
				35	57	0.5 0.8	acid	8.4	37.6	
Lake Calhoun	7/28 1927	0.6	74	0	76	6.5 6.5	neutral		32.4	
				25	70½	4.9 5.5	acid	0.9		
				50	58½	0.7 0.4	acid	5.4		
				65	58½	0.4 0.2	acid	6.0	37.4	
Cedar Lake	7/29 1927	0.3	48	0	75½	6.3 6.2	alkali	—1.1	31.3	
				20	73	3.5 5.1	neutral			
				40	57	0.0 0.0	acid	7.5	40.4	
Diamond Lake	8/18 1927	0.8	7	0	69½	6.7 6.5	alkali	—7.4	15.3	Very soft bottom into which weight sinks 2 feet or more.
				6	68	6.7 6.7	alkali	—6.4	15.1	
Eagle Lake	8/12 1927	0.5	32	0	73½	6.2 6.3	alkali	—5.9	42.3	
				15	72	4.2 4.2	neutral			
				25	69	0.6 0.1	acid	4.0	45.5	
Fish Lake	8/12 1927	0.3	51	0	74	6.2 6.3	alkali	—4.9	30.2	
				20	70½	2.4 2.7	acid	1.1		
				40	55½	0.0	acid	12.5	41.1	
Half Moon Lake	8/19 1927	0.1	26	0	69	3.9 4.1	acid	4.7	27.5	Samples taken at 7:00 a.m. Lake unusually acid at surface.
				12	67	2.0 1.7	acid	4.8		
				25	54	0.0 0.0	acid	11.1	32.8	

Table 1—Continued

Lake	Date	Approximate area, sq. mi.	Maximum depth found, ft.	Depth of sample, ft.	Temperature, ° F.	Dissolved oxygen, cc. per liter	Reaction to phenolphthalein	Carbon dioxide deficiency (—) or excess, cc. per liter	"Fixed" CO_2 (carbonate) cc. per liter	Comments
Lake Harriet	8/1 1927	0.5	64	0	74½	6.3 6.4	alkali	—3.1	33.3	
				20	72½	5.7 5.8	alkali	—1.9		
				40	54	0.2 0.6	acid	5.5		
				60	54	0.0 0 0	acid	6.3	38.4	
Lake Independence	8/5 1927	1.4	49	0	74½	6.1 6.2	alkali	—2.2	21.9	
				20	72½	5.2 4.9	alkali	—1.3		
				40	64	0.0	acid	5.6	25.8	
Lake of the Isles	7/29 1927	0.2	37	0	76	6.5 6.7	alkali	—2.9	25.4	
				15	73	4.3 4.5	acid	0.4		
				30	60	0.8 0.7	acid	6.3	37.9	
Long Lake	8/4 1927	0.5	28	0	72	3.6	acid	0.9	21.8	Surprisingly low oxygen.
				15	70	0.0 0.0	acid	4.3		
				25	62	0.0 0.0	acid	10.2	39.5	
Lake Minnetonka: Maxwell Bay	9/1 1926	0.4	41	½		5.9 5.9	alkali	—1.7	25.6	
				10		5.8 5.8	alkali	—1.6		
				20		2.0 2.0	acid	3.8		
				25		0.8	acid	5.9	31.7	
Lake Minnetonka: Crystal Bay	9/1 1926	1.3	101	½		5.4 5.4	alkali	—1.2	24.3	
				10		5.4 5.5	alkali	—0.9		
				20		4.6 4.7	neutral			
				30		1.2 1.5	acid	3.0		
				40		0.4 0.4	acid	5.9	28.9	
				50		0.3 0.2	acid	6.5		
				60		0.2	acid	6.5		
				70		0.2	acid	6.5		
				80		0.3	acid	7.2	29.0	

Table 1—Continued

Lake	Date	Approximate area, sq. mi.	Maximum depth found, ft.	Depth of sample, ft.	Temperature, ° F.	Dissolved oxygen, cc. per liter	Reaction to phenolphthalein	Carbon dioxide deficiency (—) or excess, cc. per liter	"Fixed" CO_2 (carbonate) cc. per liter	Comments
Lake Minnetonka: main body of lake	9/2 1926	4.5	90	½		6.0 6.0	alkali	—1.4	24.6	
				20		5.7	neutral			
				40		0.6	acid	4.8		
				60		0.2 0.3	acid	6.2		
				80		0.1	acid	10.0	29.5	
Medicine Lake	8/3 1927	1.2	38	0	72½	6.0 6.0	alkali	—2.5	31.0	
				15	72	5.9 6.0	alkali	—1.2		
				25	70½	1.8 2.2	acid	3.9	32.5	
Lake Rebecca	8/6 1927	0.5	26	0	72½	6.9 6.9	alkali	—3.1	22.9	
				10	72	5.8 5.1	neutral			
				20	67	0.3 0.2	acid	1.5	32.6	
Lake Sarah	8/6 1927	0.8	59	0	75	7.0 6.8	alkali	—3.9	23.9	
				15	71	3.4 3.9	acid	1.3		
				35	60½	0.0 0.0	acid	5.3		
				55	58	0.0 0.0	acid	8.7	34.4	
Sylvan Lake	8/18 1927	0.3	10	0	69½	6.6 6.2	alkali	—5.1	13.9	Small shallow lak mud bottom. Alga and duckweed.
				8	68	5.4 4.9	alkali	—3.1	14.4	
Twin Lakes, south	8/17 1927	0.2	42	0	72	5.6 5.7	alkali	—2.3	29.7	No sandy shores.
				20	67	0.9 0.4	acid	6.4		
				40	57½	0.0 0.0	acid	10.6	46.9	
Twin Lakes, north	8/17 1927	0.2	18	0	71	4.7 4.8	alkali	—2.9	24.9	
				10	69½	3.4 3.4	neutral		25.3	
Wolsfield Lake	8/4 1927	0.1	27	0	73½	6.2 6.2	alkali	—10.0	23.3	Unusually grea change in CO_2 fro top to bottom.
				15	63	0.7 1.0	acid	8.8		
				25	56	0.0 0.0	acid	15.2	38.8	

Table 1—Continued

Lake	Date	Approximate area, sq. mi.	Maximum depth found, ft.	Depth of sample, ft.	Temperature, ° F.	Dissolved oxygen, cc. per liter	Reaction to phenolphthalein	Carbon dioxide deficiency (—) or excess, cc. per liter	"Fixed" CO_2 (carbonate) cc. per liter	Comments
				WRIGHT COUNTY						
eebe Lake	8/22 1927	0.5	24	0	69	4.5 4.3	alkali	—3.3	16.1	
				10	68½	4.2 4.0	alkali	—4.0		
				20	68	1.6 1.4	alkali	—1.1	18.1	
uffalo Lake	8/25 1927	2.3	25	0	71	7.0 7.1	alkali	—5.1	36.4	Bottom soft mud. Unusual amount of algae.
				10	70	6.9 6.7	alkali	—3.2		
				20	69	3.3 4.0	acid	0.4	36.7	
ake Charlotte	8/22 1927	0.5	43	0	71½	6.4 6.3	alkali	—4.2	20.9	
				20	71	6.4 6.4	alkali	—4.2		
				40	58	0.0	acid	9.1	24.8	
ilchrist Lake	8/23 1927	0.3	12	0	72	6.3 6.5	alkali	—7.7	29.8	
				9	69	6.4 6.3	alkali	—5.3	31.5	
Iaple Lake	8/26 1927	0.9	76	0	70½	6.0 6.2	alkali	—0.5	25.8	
				25	68	0.8	acid	2.6		
				50	56	0.1	acid	6.9		
				70	54	0.0	acid	7.9	31.8	
ake Pulaski	8/24 1927	1.1	79	0	70½	6.0 5.8	alkali	—4.1	25.3	
				25	70	5.7 5.9	alkali	—4.6		
				50	58	0.3	acid	4.3		
				75	56	0.0	acid	7.1	28.3	
				DOUGLAS COUNTY						
ake Carlos	7/12 1927	3.7	153	0	70	6.4 5.7	alkali	—0.8	40.0	Deep lake with hard bottom.
				25	67	6.1 6.2	neutral			Shows little oxygen depletion or carbon dioxide excess at bottom.
				50	64	5.0 4.8	acid	1.5		Probably fish could live below the thermocline all summer.
				75	56	4.0 4.0	acid	3.3		
				100	56	4.0 3.8	acid	3.6		
				125	56	3.5 3.4	acid	1.5	40.6	

Table 1—Continued

Lake	Date	Approximate area, sq. mi.	Maximum depth found, ft.	Depth of sample, ft.	Temperature, ° F.	Dissolved oxygen, cc. per liter	Reaction to phenolphthalein	Carbon dioxide deficiency (—) or excess, cc. per liter	"Fixed" CO_2 (carbonate) cc. per liter	Comments
Chippewa Lake, southwest portion	7/23 1927	0.1	20	0	71	6.8 6.8	alkali	—1.3	44.4	
				5	71	6.8 6.8	alkali	—1.1		
				15	69	6.4 6.5	neutral		44.9	
Chippewa Lake, main lake	7/23 1927	1.6	80	0	72½	6.7 6.8	alkali	—2.1	45.4	
				25	70	6.3 6.3	neutral			
				50	60	1.5 1.7	acid	6.0		
				75	57	2.3 1.9	acid	6.0	49.6	
Lake Cowdry	7/7 1927	0.3	48	0	69	5.6	alkali	—1.9	43.8	
				10		5.8 5.9				
				20		5.5 5.6				
Lake Darling	7/8 1927	1.4	52	0		5.5 5.7			42.2	
				40		2.9 3.7			43.2	
Lake Geneva	7/13 1927	0.9	55	0	71	6.1 6.0	neutral		38.2	
				25		4.7 4.9				
				50	61	1.6 1.0	acid	6.1	40.8	
Lake L'Homme Dieu	7/12 1927	2.3	61	0	72	6.3 6.5	alkali	—0.9	38.7	
				25	68	5.0 4.7	acid	1.4		
				55	59	0.5 0.5	acid	7.3	41.5	
Lake Ida	7/15 1927	7.2	94	0	71½	6.0 6.0	alkali	—2.1	42.6	
				10	71½	6.2 6.2	alkali	—2.1		
				30	69	5.4 5.7	alkali	—1.4		
				50	67	4.5 4.7	acid	1.2		
				70	61½	2.3 2.5	acid	2.5	43.4	
Lake Mary	7/14 1927	4.6	26	0		5.7 5.6	neutral		43.2	Water sampler ou of order.

Table 1—Continued

Lake	Date	Approximate area, sq. mi.	Maximum depth found, ft.	Depth of sample, ft.	Temperature, ° F.	Dissolved oxygen, cc. per liter	Reaction to phenolphthalein	Carbon dioxide deficiency (—) or excess, cc. per liter	"Fixed" CO_2 (carbonate) cc. per liter	Comments
ake Miltona	7/19 1927	9.9	95	0	70½	6.0 6.0	alkali	—0.9	41.8	
				10	70½	6.1 6.1	alkali	—0.6		
				30	69	3.4 5.5	alkali	—0.3		
				50	67	2.4 3.3	acid	2.1		
				70	60	0.8 0.7	acid	5.8	43.3	
towe's Lake	7/22 1927	0.7	16	0	73	7.2 7.3	alkali	—1.9	41.9	Almost entire bottom covered with about a foot of soft mud.
				5	73	7.2 7.1	alkali	—2.1		
				15	71½	6.6 7.0	alkali	—2.6	42.2	
ake Victoria	7/9 1927	0.7	56	0	72	6.3 6.3	alkali	—2.2	39.7	
				35		0.8 2.3	acid	3.2	43.0	
MILLE LACS COUNTY										
ille Lacs Lake	8/30 1926	200	43	½		6.1 6.1	neutral		19.5	
				10		6.1 6.1	neutral			
				15		5.9 5.9	neutral			
				20		5.7 5.7	neutral			
				25		5.0 4.9	acid	1.4	20.3	
CROW WING COUNTY										
hitefish Lake. main body	8/31 1926		48	½		6.1 6.1	alkali	—0.9	26.9	
				10		6.0 6.0	neutral			
				20		3.9 3.7	acid	1.9		
				25		2.3 2.4	acid	4.5		
				35		0.3 0.5	acid	5.9		
				45		0.3 0.3	acid	7.1	32.8	

Table 1—Continued

Lake	Date	Approximate area, sq. mi.	Maximum depth found, ft.	Depth of sample, ft.	Temperature, ° F.	Dissolved oxygen, cc. per liter	Reaction to phenolphthalein	Carbon dioxide deficiency (—) or excess, cc. per liter	"Fixed" CO_2 (carbonate) cc. per liter	Comments
Whitefish Lake, southeast bay	8/31 1926		39	½		6.2 6.2	neutral		28.4	
				10		6.2 6.3	acid	0.4		
				20		3.5 3.7	acid	3.4		
				25		1.9 1.3	acid	6.2		
				35		0.4	acid	10.0	36.6	
OTTERTAIL COUNTY										
Ottertail Lake	7/21 1927	23	72	0	68	6.3 6.4	neutral		38.4	Large area. Uppe layer of complet mixing is relativel thick.
				25	68	6.1 6.3	neutral			
				55	64	2.8 2.1	acid	4.0	39.5	
GOODHUE AND WABASHA COUNTIES										
Lake Pepin	8/11 1928	38	35	0	78	7.7 7.6	acid	0.5	29.2	Surface water c lake is supersatu rated with oxyge altho data of th Metropolitan Drai age Commissio show that at th outlet of the lak (where the surfac water is mixed wit water from lowe levels) the oxyge content is conside ably below satur tion.
				25	76	4.5 4.1	acid	3.5	29.7	

Table 2

Bottom Fauna of Eight Small Lakes Near St. Paul

amples were collected in July 1929. Each sample represents 36 square inches (1/36 square yard) of lake bottom.

	Depth, ft.	Organisms—Bottom Fauna															
		Sponge	Planaria	Nematode	Annelid	Leech	Bivalve mollusc	Snail	Cladoceran	Amphipod	Crayfish	Chironomid	Corethra	Other Diptera	Mayfly	Damselfly	Caddisfly
urtle Lake*	3–5					11	32	1		40		6					
					1	3	14			7		3					
	6–10																
	11–15					1				1							
	16–25						5					3	1				
												2	1				1
	26–40																
	41–60																
	60—																
oose Lake*	3–5																
	6–10																
	11–15											7					
		1										11		4			
	16–25				1							46					
					7					2		61					
	26–40																
	40–60																
	60—																
ake Gervais†	3–5							6		121		66			5		
								3		32		10					2
								9		2							
	6–10				1			2		303		35		2	6		1
										36		20			4		
	11–15																
	16–25				25							29	28				
					38							21	85				
	26–40																
	41–60																
	60—																

* Small shallow lakes. Oxygen present at bottom.
† Small lakes. Oxygen deficient at bottom.

Table 2—Continued

	Depth, ft.	Organisms—Bottom Fauna															
		Sponge	Planaria	Nematode	Annelid	Leech	Bivalve mollusc	Snail	Cladoceran	Amphipod	Crayfish	Chironomid	Corethra	Other Diptera	Mayfly	Damselfly	Caddisfly
Lake Jane†	3–5					1				41		2					
	6–10																
	11–15					1				4		4	4	1			
					2					7	1	10					
	16–25																
	26–40				2							5					
					2		1					13	9				
	41–60																
	60——																
Tanner's Lake‡	3–5																
	6–10			1						4	1				2		
			2							11	1	175					
	11–15																
	16–25				34							15	31				
	26–40																
	41–60											2	36				
										1		2	42				
	60——																
McCarron's Lake‡	3–5			1	38	3				3		13					1
				1	15	8				5	1	102					8
	6–10											17					
	11–15				8	6						8		1			
	16–25																
	26–40																
	41–60											1	22				
												3	13				
Lake Phalen§	3–5																
	6–10																
	11–15					1				21		71			4	3	1
										50		51	1		6	3	
	16–25																
	26–40				1				1					1			
	41–60				112							57	33				
	60——											1	4				
										1		2	7				

† Small lakes. Oxygen deficient at bottom.
‡ Small lakes. Oxygen absent from bottom.
§ Fairly deep lakes. Oxygen absent from bottom.

Table 2—Continued

	Depth, ft.	Sponge	Planaria	Nematode	Annelid	Leech	Bivalve mollusc	Snail	Cladoceran	Amphipod	Crayfish	Chironomid	Corethra	Other Diptera	Mayfly	Damselfly	Caddisfly
		Organisms—Bottom Fauna															
Lake Elmo§	3-5					6	2			9		181			6	2	
					15	2	3			19		35			4	3	
	6–10																
	11–15																
	16–25						43					2		1			
	26–40																
	41–60																
	60—				7							1					
					8			1									

§ Fairly deep lakes. Oxygen absent from bottom.

Table 3

Bottom Fauna of Lake Pepin

Organisms obtained in collections from two stations. Collections were made from more than thirty such stations, but the two given here may be regarded as representative of the whole.

Each sample represents 36 square inches (1/36 square yard).

Lake Pepin					
		Bottom fauna—Organisms			
Date	Depth, ft.	Annelid	Bivalve Mollusc	Snail	Chironomid
Near Lake City					
August 8, 1928	30	2	8	4	53
August 17, 1928	32		6	1	38
August 22, 1928	..	2	22		67
August 24, 1928	33	13	29		50
August 28, 1928	34		31		47
September 20, 1928	35		45	2	33
November 12, 1928	34		64	1	44
Middle of lake opposite Lake City					
August 10, 1928	27		17		22
August 17, 1928	25		2		86
August 24, 1928	29	7	64		46
August 28, 1928	28½	4	15		13
September 20, 1928	31½	9	44		69
November 12, 1928	28	3	49		49