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SOME OBSERVATIONS OF THE TEMPERATURE OF SURFACE WATERS; AND THE EFFECT OF TEMPERATURE ON THE GROWTH OF MICRO-ORGANISMS.

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Newton Centre - Mass.

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ON THE

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[Read Feb. 13, 1895.]

From a scientific, as well as from a practical standpoint, the study of the temperature of surface waters is interesting and important. It is interesting to the scientist because the temperature changes which occur in a body of water are sufficient to account for numerous physical phenomena, and it is important to the water works engineer for reasons that are well known and which will be recalled by merely mentioning the words "anchor ice" and "frozen water pipes." It is known also that the temperature of the water at the surface of a pond has an important effect on evaporation.

In this paper I shall endeavor to show that temperature has an influence upon the quality of the water stored in a reservoir, in that it directly or indirectly affects the growth of the micro-organisms therein.

When the biological laboratory of the Boston Water Works was established by Mr. Desmond FitzGerald in 1889 it was decided to record the temperature of every sample of water collected; and, as these samples have been taken with great regularity, we now have a series of weekly temperature observations covering a period of five years. Furthermore, numerous special sets of temperature observations have been made during portions of each year to throw light upon certain important questions.

TEMPERATURE STATIONS.

The regular weekly observations were made at the following places:

Lake Cochituate, at the surface, mid-depth, and bottom, (60 feet.)
Basin 2, at the surface, mid-depth, and bottom, (20 feet.)
Basin 3, at the surface, mid-depth, and bottom, (25 feet.)
Basin 4, at the surface, mid-depth, and bottom, (45 feet.)
Chestnut Hill Reservoir, at the surface, mid-depth, and bottom, (28 feet.)
Chestnut Hill Reservoir, in the gate-houses.
Brookline Reservoir. in the gate-house.
Service tap in Park Square, Boston.
Service tap in Mattapan.
In the brooks entering the storage basins, etc.

In Lake Cochituate and in Basin 4 observations were taken at intervals of five feet from the surface to the bottom, during the summer months. Ordinarily the observations were taken in the forenoon between the hours of eight and ten.

THERMOMETERS.

The thermometers used were nine inches long, graduated on the stem to half degrees from 0° to 120° F.

This range was longer than was necessary, but was the best obtainable without special manufacture. For protection they were mounted in wooden cases, which were weighted in order that they might be used under water.

Readings at points below the surface were obtained by lowering a thermometer in a gallon bottle enclosed in a metal frame, to which the sinking cord was attached. A cork having a separate cord was placed in the mouth of the bottle and allowed to remain during the descent. When the bottle had reached the proper depth the cork was pulled, whereupon the bottle immediately filled with water. After allowing it to remain about ten minutes in order to acquire the temperature of the surrounding water, the bottle was rapidly drawn to the surface and the reading taken.

In this method it was necessary to guard against several sources of error, among which may be mentioned the following:

1. Error from not leaving the bottle down long enough to acquire the temperature of the surrounding water. To avoid this error, in finding the temperature of the water at the bottom of Lake Cochituate, a thermometer was kept at the bottom throughout the summer, being drawn to the surface only when readings were to be taken.

2. Error from change of reading while the bottle was being drawn to the surface. In warm weather when the surface and bottom temperatures sometimes differ by more than 30° F., this becomes of some importance, though ordinarily it is less than 0.2°.

3. Error from change of temperature after the bottle has been draw up and before the reading is taken. This error is usually negligible if the bottle is not placed in the sun and if the reading is made promptly.

4. Error from not holding the thermometer at right angles to the line of sight. This is the greatest source of error, and may easily amount to half a degree.

5. Error from refraction, caused by not holding the thermometer parallel to the sides of the bottle.

THERMOPHONE.

On some of our more recent work we have used an electrical device invented by Mr. Henry E. Warren, of Newton Centre, and the writer of this paper. To this instrument we have given the name "Thermophone," because the temperature readings are obtained by listening to the sound made in a telephone.

Briefly described, the thermophone is an arrangement of resistances in the form of a Wheatstone's Bridge. Coils of resistance wires, enclosed in a brass tube, are located at the place where the temperature is desired. These coils are connected by leading wires to the indicating portion of the apparatus, where the movement of a contact along a "Slide Wire" is effected by turning a knob, which, at the same time, moves a pointer over a dial graduated in degrees of temperature. In place of the galvanometer, usually used with a Wheatstone's Bridge, a telephone with an interrupter in its circuit is used to indicate the presence of a current. The absence of sound in the telephone indicates that the bridge is balanced. Readings are taken with the thermophone by holding the telephone to the ear while the pointer is moved over the dial by means of the knob. When there is silence in the telephone the pointer will indicate the correct reading.

With this instrument we have been able to obtain readings to 0.05° F., and it sets so rapidly that not more than a minute is required to make an observation.

Results of Observations.

Some of the results of the observations from January 1, 1890, to January 1, 1895, are shown on Plates 1 and 2.

Plate 1 shows the temperatures at the surface and bottom af Lake Cochituate, Chestnut Hill Reservoir, and Basins 2, 3 and 4. The surface temperatures, being practically the same in the different reservoirs, have been plotted as one

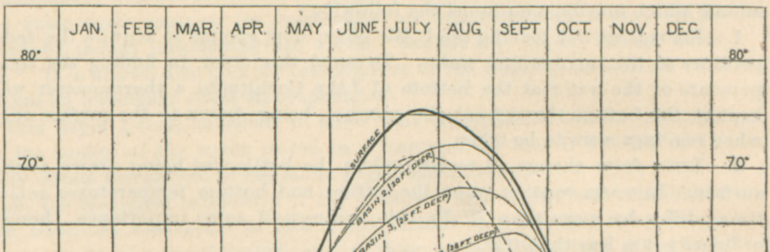


Plate 1.

line. It will be noticed that the temperature of the water at the bottom of the reservoirs depends upon the depth. In Basin 2, which is about 20 feet deep, the temperatures at the surface and bottom are almost the same. Basin 3 is 25 feet deep, and the bottom temperature during the summer is much lower than in Basin 2. During a portion of the summer the lower layers are quite stagnant, that is to say, there is no vertical circulation. In Chestnut Hill Reservoir, 28 feet deep, and in Basin 4, 45 feet deep, the summer temperatures at the bottom are still lower. The rise of the temperature at Basin 4 during September is occasioned by the drawing down of the water to supply the city. In Basins 2 and 3 the bottom temperatures are also influenced by the drawing down of the surface. In Lake Cochituate, 60 feet deep, the bottom temperature is lower than in the other reservoirs and is quite constant during the summer. In Chestnut Hill Reservoir and in Basins 3 and 4 the bottom temperatures gradually rise during the summer even though the convectional currents do not reach to the bottom. In Basin 4 the rise is quite slow ; in the reservoirs having less depth the increase is more rapid.

During the winter, when the surface is covered with ice, the temperature at the bottom is higher than at the surface. It varies in the different reservoirs, but in all of them it tends to approach the temperature at which water is densest, *i. e.*, 39.2° F.

Especial attention has been given to the study of the temperature of Lake Cochituate because of its greater depth and because the stagnation phenomena are very marked. For four years observations have been taken at intervals of five feet from the surface to the bottom during the period of summer stagnation, *i. e.*, from about the middle of April to the middle of November. The results of these observations are shown on Plate 2. The curves represent the temperature at different points in the vertical for each month of the year. It will be observed that during the winter months, from December to March, the curves are very much alike. In April the water begins to warm up and the top of the curve bends slightly to the right. In May the water is warmer at all depths and the difference between the surface and bottom temperatures becomes more marked. From June to September the curves are practically the same below the mid-depth. Above that point they differ somewhat, though similar in character. The surface reaches its highest point in July. In October the surface temperature is about the same as for May, but the shape of the curve is different. Down to the depth of fifteen feet the water has practically the same temperature. At that point there is quite a sharp turn, and below a depth of 20 feet the curve is about the same as that of the summer months.

The stirring up occurs in November and for some time after that the temperatures are nearly the same at all depths. In November the bottom temperature reaches its highest point. It will be noticed that from May to October the curves are reversed curves, the point of inflection being found between 15 and 20 feet below the surface. This is the point where there is the greatest differ-

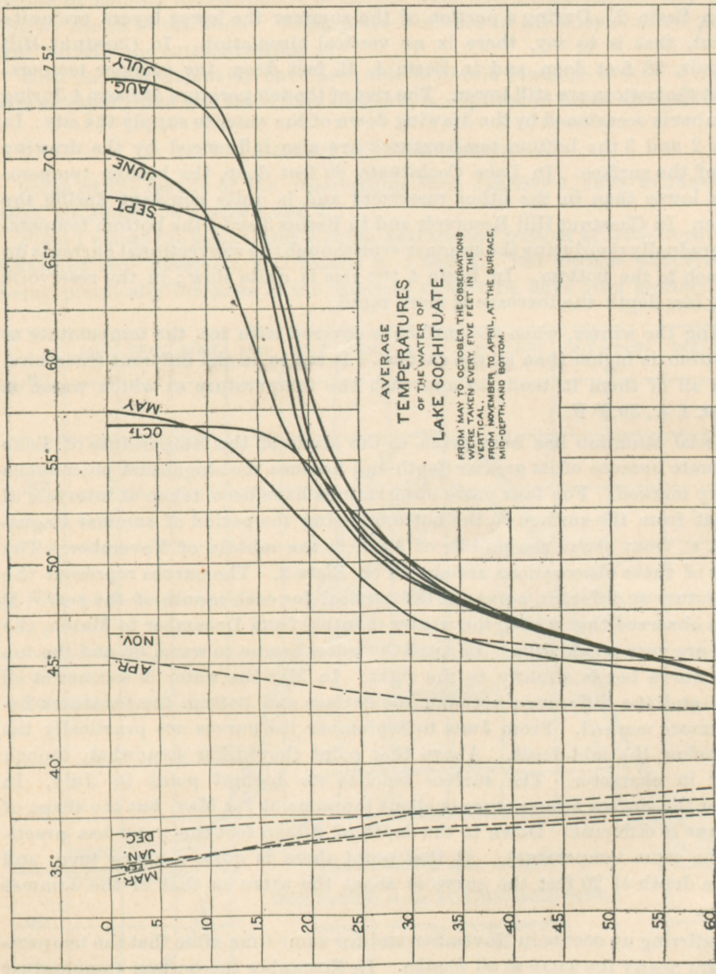

AVERAGE
TEMPERATURES
OF THE WATER OF
LAKE COCHITUATE.
FROM MAY TO OCTOBER THE OBSERVATIONS
WERE TAKEN EVERY FIVE FEET IN THE
VERTICAL.
FROM NOVEMBER TO APRIL, AT THE SURFACE,
MID-DEPTH, AND BOTTOM.
JULY
AUG.
JUNE
SEPT.
MAY
OCT.
NOV.
APR.
DEC.
JAN.
FEB.
MAR.
75°
70°
65°
60°
55°
50°
45°
40°
35°
0
5
10
15
20
25
30
35
40
45
50
55
60

PLATE 2.

ence of density of the water per foot of depth, as is shown by the following table:

AVERAGE DENSITY OF THE WATER OF LAKE COCHITUATE AT VARIOUS DEPTHS DURING THE PERIOD OF SUMMER STAGNATION.

Depth in feet.	Average Temperature during Stagnation.	Density.	Difference in Density.
Surface.	67.1°	0.998359	
			.00075
5	66.6°	0.998434	
			.00090
10	65.6°	0.998524	
			.00384
15	61.8°	0.998908	
			.00545
20	55.1°	0.999453	
			.00223
25	51.4°	0.999676	
			.00158
30	47.9°	0.999834	
			.00020
35	47.4°	0.999854	
			.00022
40	46.8°	0.999876	
			.00027
45	46.1°	0.999903	
			.00015
50	45.1°	0.999918	
			.00008
55	44.7°	0.999926	
			.00006
60	44.4°	0.999932	

The temperature at the bottom during the period of stagnation is not the same every year, and it has been found that the weather during the month of April determines the temperature at which the bottom will remain during the following summer. After the ice breaks up in the spring the water circulates throughout the vertical. The surface and bottom temperatures are then practically the same. As the weather grows warmer these temperatures rise. If there were no wind the bottom temperature would cease to rise as soon as the point of maximum density had been reached; but on account of the wind, and because in that part of the scale the difference in density per degree is very slight, the bottom temperature rises higher than 39.2°. It continues to rise as long as the difference between the surface and bottom temperatures does not exceed about 5° F. But with the first "warm wave" the surface temperature rapidly rises and gains 5° or more over the bottom temperature. The difference of density corresponding to this difference of temperature is usually sufficient to prevent the wind from keeping the water in circulation, consequently the water

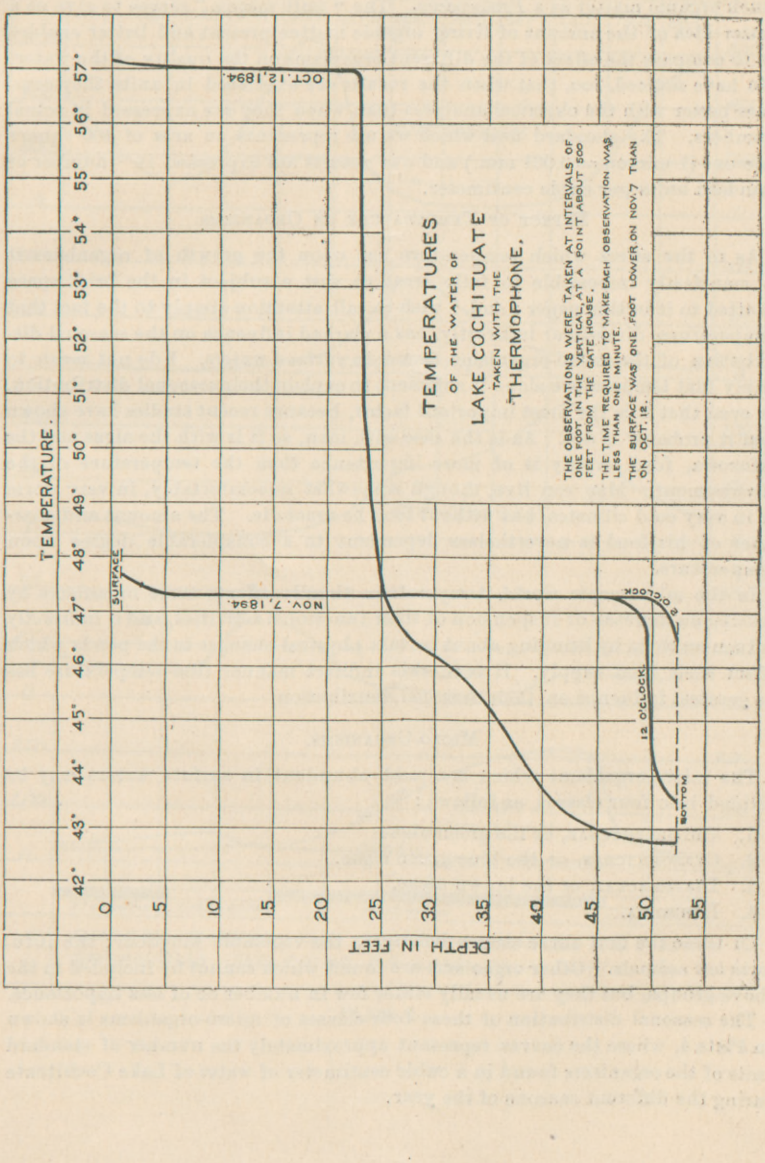

TEMPERATURES
OF THE WATER OF
LAKE COCHITUATE
TAKEN WITH THE
THERMOPHONE.
THE OBSERVATIONS WERE TAKEN AT INTERVALS OF ONE FOOT IN THE VERTICAL, AT A POINT ABOUT 500 FEET FROM THE GATE HOUSE.
THE TIME REQUIRED TO MAKE EACH OBSERVATION WAS LESS THAN ONE MINUTE.
THE SURFACE WAS ONE FOOT LOWER ON NOV. 7 THAN ON OCT. 12.
TEMPERATURE.
42° 43° 44° 45° 46° 47° 48° 49° 50° 51° 52° 53° 54° 55° 56° 57°
DEPTH IN FEET
0 5 10 15 20 25 30 35 40 45 50 55
OCT. 12, 1894.
NOV. 7, 1894.
SURFACE
BOTTOM
12 O'CLOCK.
2 O'CLOCK.

PLATE 3.

at the bottom becomes stagnant, and its temperature remains almost constant at the point where it was when circulation ceased.

In the fall stagnation does not cease until the temperature of the surface has fallen to within about 5° of the bottom temperature. After that point has been reached the first high wind generally stirs up the water to the bottom. This "turning over" usually occurs during the second week of November.

In 1894 the turning over occurred earlier than usual, on account of the cold, stormy weather during the first few days of November, and was especially interesting on account of its suddeness. Fortunately we studied it with particular care, and the thermophone enabled us to determine the temperature at all points in the vertical with great accuracy. Two of the curves obtained with the thermophone are shown on Plate 3. Observations were taken at intervals of one foot in the vertical, and in no case did the reading differ from the curve as plotted by more than 0.1° F. On October 12 the surface temperature was 57.15°. It decreased slightly to 5 feet, and from that point to a depth of 23 feet it was exactly the same. Between 23 and 23.5 feet, the temperature dropped rapidly and observations were there taken at intervals of one inch in depth. Below 23.5 feet the temperature decreased more slowly. The sharpness of the curve at 23 feet was quite remarkable. Readings at that point were several times checked to insure correct results.

On November 7, after the severe snow-storm and during a high wind, observations were again taken with the theremophone. On that day the temperature was uniform at 47.3° to a depth of 46 feet save for a slight increase at the surface, the effect of the sun. At 12 o'clock the temperature at the bottom was 43.5°. Between 48 and 51 feet the temperature was variable, sometimes changing several degrees in less than a minute. Several series of observations were made at intervals of six inches which showed that at that point the water was in a state of commotion and that the temperature at each point was gradually rising. No readings were obtained between 12 o'clock and 2 o'clock. At 2 p. m. the water had practically turned over. The temperature at 51 feet was 46.8°. At 51½ feet, with the coil partially immersed in the mud at the bottom, the reading was 46.5°.

Biological Laboratory.

Before proceeding to the second part of the subject, namely, the effect of temperature on the growth of micro-organisms, it may not be inappropriate to refer briefly to the nature and extent of the biological work which is being carried on at the laboratory at Chestnut Hill Reservoir, Since its establishment in 1889 more than 12,000 microscopical and more than 6,000 bacteriological examinations of samples of water have been made. They cover all portions of the supply, from the brooks at the head of the watershed to the service taps in the city. Samples from thirty carefully selected places are analyzed each week and other localities are visited monthly.

The methods of analysis are those ordinarily used in biological laboratories and are doubtless well known to most of the members of this association. One point of difference, however, ought to be mentioned, namely, the method of stating the results of the microscopical analysis. We have found it advisable to give the results, not in the actual number of the organisms present, but in terms of a standard unit of size. The micro-organisms vary considerably in size, a *Volvox*, for instance, sometimes containing several hundred times as much organic matter as a *Protococcus*. The "unit system" serves to give us a better idea of the amount of living organic matter present and better enables us to compare the effect of the different organisms on the quality of the water. We have noticed, too, that when the results are expressed in units they compare better with the chemical analyses than when they are expressed in actual numbers. The standard unit which we use represents an area of 400 square microns (1 micron = 0.001 mm.) and our results are expressed in "number of standard units per cubic centimeter."

Effect of Temperature on Organisms.

As to the effect which temperature has upon the growth of organisms it is manifestly impossible to fully treat so vast a subject in the brief space allotted to it in this paper; and I wish to call attention simply to the fact that temperature, directly or indirectly, has a marked influence on the seasonal distribution of the micro-organisms found in surface waters. I do not mean to imply that temperature alone is sufficient to explain their seasonal distribution, or even that it is the most important factor, because recent studies have shown that it probably is not. As is the case with man, so it is with the algae and the infusoria, food supply is of more importance than the temperature of the environment. Man can live, though somewhat uncomfortably, in very warm or in very cold climates, but without food he must die. The amount and character of his food is nevertheless dependent to a considerable degree upon temperature.

In the microscopic world, temperature directly affects some organisms by causing an increase or suspension of their functional activities, and it indirectly influences them by bringing about certain physical changes in the ponds which affect their food supply. It is in this indirect manner that temperature has its greatest influence on their seasonal distribution.

Micro-Organisms.

The micro-organisms which are most abundant in surface waters may be divided into four classes, as follows:

1. Chlorophyceae, or the green algae.
2. Cyanophyceae, or the blue-green algae.
3. Diatomaceae, or the brown algae.
4. Infusoria.

Of these the first three classes belong to the vegetable kingdom; the infusoria are animals. Other organisms are found which cannot be included in the above groups, but they are usually either few in number or of less importance.

The seasonal distribution of these four classes of micro-organisms is shown on Plate 4, where the curves represent approximately the number of standard units of the organisms found in a cubic centimeter of water of Lake Cochituate during the different seasons of the year.

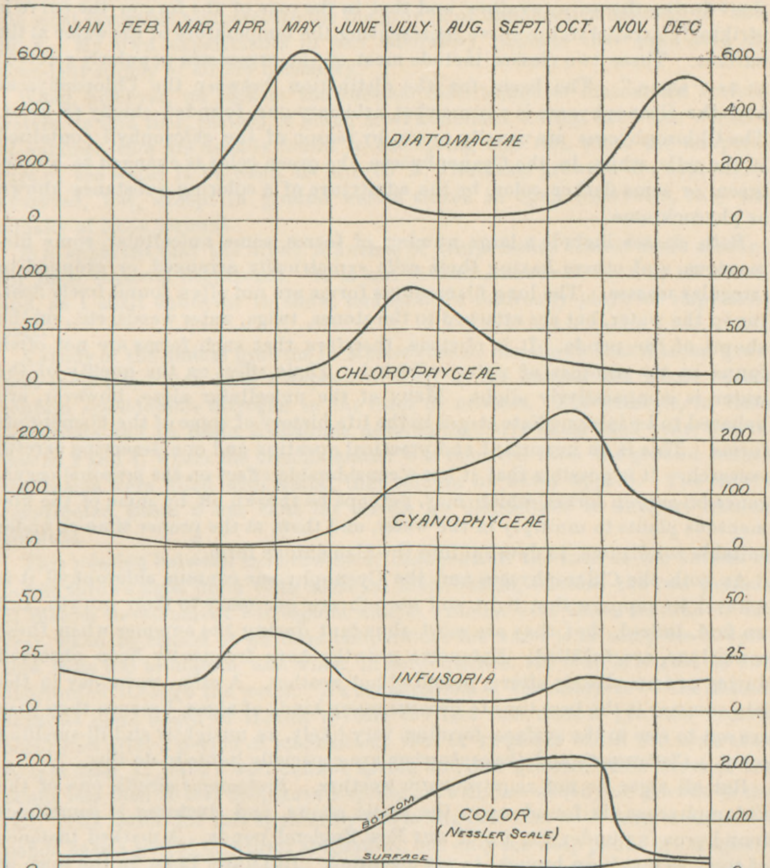

JAN
FEB.
MAR.
APR.
MAY
JUNE
JULY
AUG.
SEPT.
OCT.
NOV.
DEC.
600
400
200
0
DIATOMACEAE
100
50
0
CHLOROPHYCEAE
200
100
0
CYANOPHYCEAE
50
25
0
INFUSORIA
2.00
1.00
0
BOTTOM
COLOR
(NESSLER SCALE)
SURFACE
STAGNATION
CIRCULATION
STAGNATION
CIRCULATION
DIAGRAM SHOWING THE SEASONAL CHANGES IN THE ORGANISMS AND COLOR OF LAKE COCHITUATE.

PLATE 4.

Chlorophyceae and Cyanophyceae.

It will be noticed that the Chlorophyceae and Cyanophyceae are most abundant during the warm weather, and that in the case of the former the curve is strikingly parallel to the curve representing the temperature of the water at the surface. These two classes include most of the organisms popularly referred to as "algae." The basis for the distinction between the Chlorophyceae and the Cyanophyceae is a somewhat arbitrary one, founded chiefly on color. The Chlorophyceae are usually green, by reason of the chlorophyll contained in the cells, while, in the Cyanophyceae, the green color is changed to a blue-green, or some darker color, by the admixture of a coloring substance known as phycochrome.

Both classes include a large number of forms, some unicellular, some filamentous, and others having their cells symetrically arranged, or grouped in irregular masses. The long filamentous forms are not often found freely floating in the water, but are attached to the stones, twigs, water weeds, etc., on the shores of the ponds. It is obvious, therefore, that such forms are not often found in the samples of water collected. Their effect on the quality of the water is comparatively slight. Many of the unicellular algae, however, are believed to be intermediate stages in the life history of some of the filamentous forms. This is an important and practical question and one deserving careful research. It is possible that it has a considerable effect on the seasonal occurrence of certain forms, which may, perhaps be thrown off by some of the filamentous plants to multiply in the water, and then, at the proper time or under suitable conditions, to develop into the filamentous form.

As both the Chlorophyceae and the Cyanophyceae contain chlorophyll it is natural to suppose that light and warmth are necessary to their growth, and we find, indeed, that they are most abundant during the summer when these conditions are fulfilled. Extensive growths have frequently been observed during or immediately after a period of hot weather. A calm, warm day in the late summer is the best time to observe many kinds of algae, because then they are apt to rise to the surface, forming, very likely, an unsightly and ill-smelling scum. *Clathrocystis* and *Coelosphaerium* are especially liable to do this.

But all algae do not require warm weather. *Protococcus nivalis*, one of the Chlorophyceae, is found upon the arctic snows, and *Anabaena* is sometimes found growing under the ice of our New England ponds. A marked instance of this has just been brought to my attention. In Laurel Lake, in the town of Fitzwilliam, N. H., *Anabaena* is at the present time growing vigorously. It has become frozen into the ice to such an extent that much of the ice on the lake has a brilliant green color. Fragments of this ice when thrown upon the snow look like little emeralds. Besides being objectional from its appearance, the green ice has a decidedly unpleasant taste.

Diatomaceae.

The diatoms are the most interesting of the micro-organisms found in water. They are single cells whose walls are so impregnated with silica that they have been described as "little glass boxes filled with brown plant matter."

Since they contain chlorophyll we should naturally expect that, as in the case of the other algae, light and warmth would favor their growth. Laboratory experiments tend to show that such is the case. Miquel has stated that the most favorable temperature for the growth of diatoms lies between 68° and 86° F. My own experiments in the laboratory indicate that light and an abundant supply of air are necessary.

When, however, we look at the seasonal distribution of diatoms in surface waters we find that, instead of being most abundant during the warm weather of summer, they are usually found in the spring and fall, when the temperature of the water is between 40° and 60° F. Summer growths are sometimes observed, but, except in ground waters stored in open reservoirs, they are usually of little account.

It is apparent that the direct influence of temperature cannot alone account for their seasonal occurrence. It is not difficult, however, to find its cause, and, as I shall endeavor to show, temperature indirectly plays an important part.

A study of the diatom growths in Massachusetts has shown that diatoms grow best in ponds which have a deposit of mud at the bottom and whose waters contain considerable nitrogen in the form of nitrates. For example, in Lake Cochituate and in Basin 3, diatoms develop regularly twice each year, but in Basins 2 and 4, where the organic matter was removed from the ground before the basins were filled with water, they seldom or never appear. The newly constructed Basin 6 has thus far shown no disposition to support diatom growths.

This relation between the growths of diatoms and the mud at the bottom of ponds throws light upon their seasonal distribution, because the two periods of diatom development correspond almost exactly with those seasons of the year, when by reason of uniform temperature the water is in complete circulation from top to bottom, and when, in consequence, the mud is stirred up and distributed through the water. An examination of the analyses of the Massachusetts State Board of Health reveals the fact that diatom growths usually occur just after a period of stagnation. Out of 12 ponds which are more than 30 feet deep, 11 have a well defined spring and fall growth, while most of the ponds less than 30 feet deep have a spring growth, but usually no growth in the fall. The reason for this apparently lies in the fact that both deep and shallow ponds have a period of winter stagnation, but only the deep ponds are stagnant during the summer, On Plate 5 will be found curves showing the seasonal distribution of one of the diatoms, the Asterionella, in deep and shallow ponds.

The growths that are occasionally found in shallow ponds during the summer and fall are usually quite irregular in their occurrence. I have known instances where diatoms have developed immediately after a high wind, the growth apparently being caused by the stirring up of the bottom. In the very deep ponds the growths usually appear a little earlier in the spring and considerably later in the fall than in the shallower ponds, for reasons that will be apparent when one remembers that in the deep ponds the temperature is quite low during the summer and stagnatian often does not cease until the middle of November.

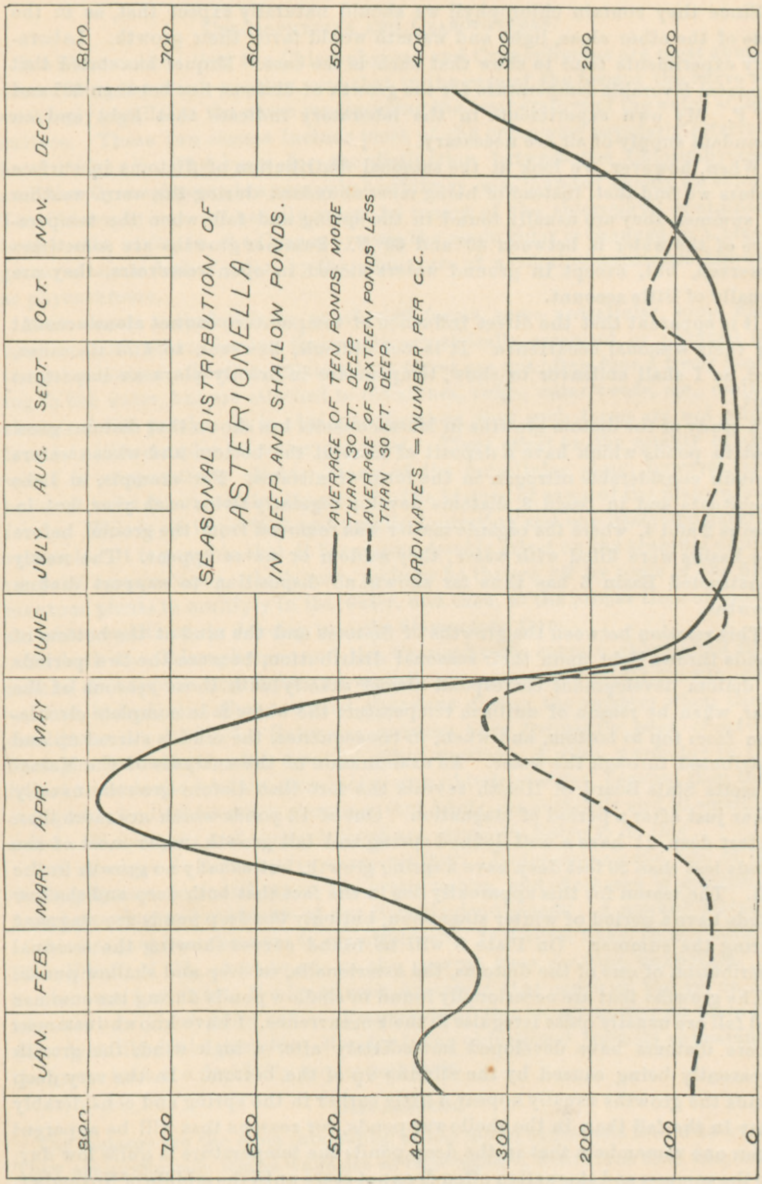

SEASONAL DISTRIBUTION OF
ASTERIONELLA
IN DEEP AND SHALLOW PONDS.
AVERAGE OF TEN PONDS MORE THAN 30 FT. DEEP.
AVERAGE OF SIXTEEN PONDS LESS THAN 30 FT. DEEP.
ORDINATES = NUMBER PER C.C.
JAN.
FEB.
MAR.
APR.
MAY
JUNE
JULY
AUG.
SEPT.
OCT.
NOV.
DEC.
800
700
600
500
400
300
200
100
0

PLATE 5.

In order to understand why it is that diatom growths occur after the stagnation periods it is necessary to study the character of the stagnant water at the bottom of a pond and the change that takes place when this water is carried into circulation. If we consider Lake Cochituate, for instance, where the bottom is covered with a deposit of organic matter, we find that during the summer some of this organic matter begins to decompose. The process is carried on at the expense of the dissolved oxygen in the lower layers of water, and of oxygen derived from some of the iron compounds. This supply of oxygen, however, is not sufficient and the decomposition is arrested at the "free ammonia" stage. The iron being left in a ferrous condition becomes dissolved in the water and the result is a deepening of the color, which increases on exposure to the air on account of the iron becoming changed to the ferric condition. The increase of color during stagnation is shown on Plate 4. Besides having a high color the stagnant water is usually turbid and often has an offensive odor.

When circulation begins, this water, with its partially decomposed organic matter, becomes thoroughly mixed with the water above it. The bacteria, supplied with plenty of oxygen, change the "free ammonia" to "nitrates," a form in which the nitrogen can be readily assimilated by plants. The color of the water at the surface also rises, as shown by Plate 4.

It is natural to suppose that, at the time when the water turns over, the diatoms, or their spores, are carried up from the bottom, where they have been lying dormant, and that, finding an abundance of food, they begin to develop. Another reason why diatoms grow best during circulation may be that since their cells are somewhat heavy the ascending currents of the water assist in keeping them near the surface, where they have an abundance of light and air. It is known that in absolutely still water diatoms sink to the bottom.

The foregoing facts point out to us the advantage of removing the organic matter from the bottom of a storage reservoir, *i. e.* of "stripping the soil." Because if there is no organic matter at the bottom of a pond, there will be no decomposition during the stagnation periods, and consequently no diatom growths, unless, as is sometimes the case, the water entering the reservoir has a sufficient amount of food material to support their growth.

Infusoria.

The seasonal distribution of the infusoria is much more variable than that of the three classes of organisms above mentioned. In some ponds, as in Mystic Lake, we find them regularly in the summer; in others their occurrence is quite irregular. I think, however, that in the majority of cases, the curve which would best represent their seasonal distribution would be one having a major maximum in the spring, a minor maximum in the fall, and which is much lower during the summer than during the winter.

As in the case of the diatoms, stagnation probably has a considerable effect on the growth of infusoria. They are animals and are therefore supposed to have the capacity to injest solid particles of food and to depend upon such for their growth. They are also obliged to live on proteaceous, or "ready manufactured" organic matter, not being able, as plants are, to manufacture their food out of the crude materials of the inorganic world.

From this it is a natural inference that, other conditions being the same, the largest number of infusoria will be found at those seasons of the year when the water contains the greatest amount of organic matter in a finely divided state. In some ponds this condition may be found at one season, in other ponds at some other season. We know by the amount of amorphous matter shown in our analyses, that in many of the deep ponds this fine organic material is most abundant during the periods of circulation, and it is doubtless for this reason that the infusoria develop at such times.

Without continuing the subject further, I think that perhaps I have said enough to bring out the point that I wished to make, namely, that while it is undoubtedly true that the temperature of the water directly affects the life of the micro-organisms, it acts chiefly in an indirect manner by bringing about physical changes in the ponds which influence their food supply.

And, in conclusion, I would suggest that if the water works superintendents who are members of this association and who have under their charge a pond or reservoir more than 25 feet deep, would establish a regular series of temperature observations at different depths, they would be adding a great deal to the data which must be collected before we arrive at a full understanding of the growth of the micro-organisms, which are so troublesome in water supplies. In connection with the analyses of the State Board of Health these observations would have great value.

DISCUSSION.

Mr. Forbes. Mr. President, I don't know that I can add much to what Mr. Whipple has said, except that the food supply is the most important element in the growth of algae. I know that in water stored in reservoirs you will find a growth of asterionella and cyanophyceae at any time of the year if the food supply is abundant. You will find in our reservoirs a growth of certain kinds of infusoria in midwinter as well as in summer. The food supply seems to be the most important thing.

Mr. Fitzgerald. Mr. President, it is perhaps natural that I should be interested in these investigations which form a part of the work that we have been carrying on at the sources of supply of the Boston Water Works for a number of years. It is not very difficult to look back ten or twelve years and consider the state of our information on most of these subjects at that time. We then realize the progress that has been made ; and yet, however much we may study these matters, there is still always more ahead to be found out. That is one of the beauties of all scientific work. There are are many men who are accustomed to turn up their noses at the idea of there being any practical benefit resulting from the study of organisms in the water, the way in which they develop, and the quality of the water itself as affected by them. It is not difficult for me to call to mind the many times I have heard men say: "Oh, it doesn't make much difference. Water is water. It is a little thick, to be sure at times, but you drink it and it is all right." The fact is that as we progress and find that we can control the quality of water by our own acts we realize that it is a wicked thing to turn water containing a large amount of organic matter into a city or town for people to drink—children, invalids and people whose constitutions are too weak to overcome the effects of bad water. I think we should realize the responsibility that rests upon us as superintendents and engineers to do all that we can to raise the standard; to insist that a city or town should have good water and that they should judiciously spend enough to make it good.

In connection with this paper of Mr. Whipple's, I think one of the most interesting things to a perfect greenhorn is to take him out into the middle of a deep lake, in the summer, when the temperature of the water at the surface is perhaps up to 80°, anchor over one of these deep holes, ask him to put his hand into the water at the surface—where sometimes I have seen the water so warm that it is almost uncomfortable—then take a bottle and drop it from the same boat at the same place down 60 feet and bring up water so cold and so much like ice water that he can hardly bear to put his hand into it. That enforces on the mind the fact that Mr. Whipple has been setting forth—the great difference in temperature in this stagnation period between the surface and the bottom. Now, of course all the impurities are collecting in the bottom layers during this long period of seven months. The oxygen in the water after a while is all used up but the organic matter keeps on collecting and as soon as all this foul water comes up to the surface in November there is, of course, a vigorous growth, both animal and vegetable, as shown by the rapid rise in the lines on the diagram before you. In the case of a large deep pond, if you have a high dam and gate at the bottom, just before it turns over, you can waste that water at the bottom, and it will have a great effect in keeping the water at the surface pure a little later when the great overturning comes.

I simply mention this as being one of the practical results, and we get them every day in our studies of water supply. The fact is that any knowledge we obtain in this world is a benefit to mankind and it does not do to throw ridicule upon investigations made under scientific conditions.

One thing that we have certainly learned is that you cannot take water from swamps and other places which contain a large amount of organic matter, and turn it into a basin with mud, loam, stumps and other organic matter in it and expect that water to improve. For years and years it will give trouble. I remember very well going back to the period previous to the time when we began a systematic study of our water in Boston, that we had as high an amount of albuminoid ammonia in our basins as .05 parts in 100,000. Today this decimal has been reduced to .018.

I only wish that gentleman from New York was here who made the statement before the Association a short time since that Boston water was not fit for a dog to drink, and that it was getting worse. I did not happen to be here when he made the statement, but if I had been I am afraid I should have lost my temper, especially when he ridiculed the studies we are making. He simply did not know what he was talking about. Such an attitude is not in harmony with deep scientific knowledge. A man should have found out whether the water is getting worse before he gets up before an association of this kind and states it, or else we can no longer depend upon his statements.

However, that is a little digression. Basins 4 and 6 have furnished some of the best lessons we have learned in connection with Boston's Water Works, because these basins were built in valleys containing a large amount of loam, and we removed it entirely down to the gravel, leaving perfectly clean bottoms. The result is that we have had, even in this period of stagnation, a considerable amount of oxygen present at the bottom, and we have, as a rule, no algae growths to speak of. The line of our organisms is almost a level line on the profile and very low in the scale.

Any one caring to study more in detail the temperatures at various depths during this stagnation period will find in my report in the seventeenth annual report of the Boston Water Works a diagram giving the temperatures for every five feet in the vertical. It will be there seen how little the winds affect the condition and temperature of the water below the 15 foot level, and also what a bad conductor of heat water really is.

In drawing inferences from water temperatures it is necessary to remember that they are largely influenced by local conditions, the extent of the surface exposed to the wind, the depth of the water, its quality and climatic conditions. I have found that the temperatures in Lake Winnipiseogee, for instance, differ very much from those in Lake Cochituate, and even in different portions of the same lake we do not get the same results. In the Swiss lakes, the temperature of the water at a depth of 150 feet is about 10° warmer in the summer than it is in Lake Cochituate at a depth of 50 feet.

Mr. Coggeshall. I think that many of those present would like to hear a description of the Thermophone which Mr. Whipple has used in making his observations.

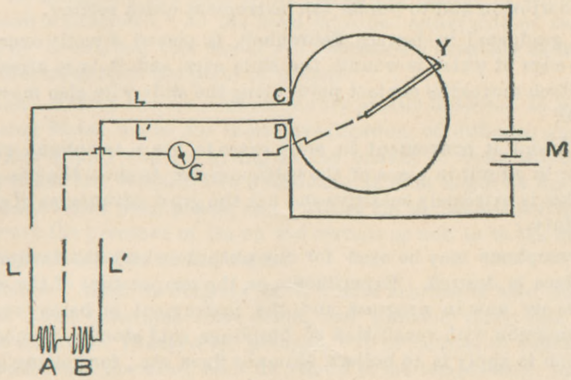
Mr. Whipple. The Thermophone is based on the principle that the resistance which a conductor offers to the passage of the electric current depends upon the temperature of the conductor; for instance, if the resistance of a copper conductor at 0°C. is represented by unity its resistance at t°C. will be represented by the equation

$$R_t = 1 + 0.003824t + 0.00000126t^2 + \ldots\ldots$$

It is a singular fact that most pure metals have electrical temperature co-efficients very much like that of copper, but that the alloys have quite different co-efficients; thus for German Silver the co-efficient is

$$R_t = 1 + 0.0004433t + 0.000000t^2 + \ldots\ldots$$

In the Thermophone we have taken advantage of this fact, that different metals have different electrical temperature co-efficients. The accompanying diagram represents the general arrangement of the electrical parts.



A and B are coils of copper and German silver resistance wires placed in proximity. CYD is a slide wire, the two ends of which are connected in circuit with a battery, M. Leading wires from A and B are also carried to the points C and D. Another leading wire is carried from the junction of A and B to a movable contact, Y, on the slide wire, and in this circuit is placed a galvanometer, G. Any one familiar with electrical instruments will recognize this as a modification of the Wheatstone's Bridge, and will see that the galvanometer will indicate zero current when the ratio of the resistances A to B is the same as that of the ratio of CY to YD. A and B having different temperature co-efficients will vary in resistance at different rates with changes in temperature. Consequently there will be a different value of the ratio of A to B for every temperature. This ratio of A to B, which with zero deflection of the galvanometer, is the same as the ratio of CY to YD, may be directly read from a scale placed under the sliding contact Y, or the temperature corresponding to the given ratio of A to B may be marked upon the scale.

It is easily seen that the temperature of the slide wire, CYD, has absolutely no effect upon the reading of the instrument, for being made of one piece of metal which has the same temperature throughout its length, it will rise or fall in resistance at the same rate on both sides of Y as its temperature changes, and consequently the ratio of CY to YD will not vary. The effect of temperature changes on the leading wires will not sensibly affect the readings, because the two wires L and L′ are on opposite sides of the bridge, and consequently balance each other. Compared with the resistances A and B these leading wires are of large size, and in order that they may have the same average temperature they may either be twisted together or laid side by side and covered with braided cotton.

In that form of the instrument used for obtaining the temperature of water we have found it best to inclose the copper and German silver coils, A and B, in a long brass tube of small diameter coiled in a helix and hermetically sealed. The space between the wires and the inner walls of the tube is filled with oil to prevent corrosion and to render the instrument quick setting.

The dial, graduated in degrees Fahrenheit, is placed directly over the disk around the edge of which is wound the slide wire, and it is so arranged that the knob which moves the contact point along the slide wire also moves a hand over the dial.

We have found it convenient in most cases to use a telephone with a current breaker in circuit in place of the galvanometer to show the presence of a current. This is extremely sensitive and has the great advantages of cheapness and portability.

The Thermophone may be used for any purpose where the temperature of a distant place is desired. Experiments on the temperature of the soil at various depths are now in progress, and the instrument is being successfully used in connection with ventilation of buildings, cold storage, incubators, etc. We hope soon to apply it to boilers, chimney flues, etc., for getting high temperatures.

Mr. Winslow. For my own information, and perhaps the information of others, I would like to ask a question. As I understand it, the resistance of the wire, increasing and decreasing, is shown by the pointer on the instrument. If the resistance coil is at any great distance from the instrument, will the size of the line wires affect the operation of the indicator?

Mr. Whipple. No, sir. We have allowed for that. We have made these line wires so large that they have no effect on the reading. That is, we can allow for a range of temperature as high as 100°.

Mr. Winslow. On the line wire?

Mr. Whipple. Yes, sir ; and still have no greater effect on the reading, probably, than one-tenth of a degree Fahrenheit.

Mr. Porter. I would like to ask also if the inventors of this instrument propose that it shall be used for very high temperatures?

Mr. Whipple. I would say, in answer to that, that we have thought of it, but have not had the time to do much in that line. We probably may do so later on, and I shall be pleased to inform you of the results.

Mr. Porter. Does there appear to be any reason why it cannot be used in such cases?

Mr. Whipple. No, sir ; it is only a question of minor detail in the arrangement of the apparatus. The principle ought to hold for any range of temperature, but there are certain details in connection with the way the instrument is constructed that would limit it to certain ranges. Probably it can be used quite easily up to a temperature of 350°, and by taking certain precautions to 1,500° or 2,000°. But we have not experimented along that line and cannot tell exactly.

Mr. Tidd. Do I understand you that the change of temperature is indicated by the difference in tone you have through the sound of the instrument?

Mr. Whipple. No, sir. At one point on the dial there is absolutely no sound in the telephone and that point shows the degree of temperature to which the coil is subjected. As the hand is turned either side of that point a sound will be heard, and this sound will increase in intensity as the hand is moved farther away from the point of silence.

Mr. Chace. I think the Association is very greatly indebted to the officials of the Boston Water Works for their investigation of different questions relating to water supply and for giving us the benefit of their information. I would like to ask Mr. Whipple two questions ; at what depth he draws the line between shallow and deep ponds, and whether his investigations show any relation between the presence of ice on the surface or not, as to the effect on organisms or the condition of the water?

Mr. Whipple. Well, in diagram No. 5, I have arbitrarily used the depth of thirty feet. I had to assume some depth, and probably thirty feet is as good as any. It might be twenty-five, perhaps, but, of course, it depends on the locality, the force of the wind, etc. In regard to the temperature, immediately under the ice, the water is naturally slightly higher than freezing ; but as you go down the temperature rises, so that you will find it warmest at the bottom. Ordinarily at the bottom of ponds of forty or fifty feet in depth the temperature is approximately 39.2°. It varies more or less for certain reasons, but ordinarily is at about that point.

Mr. Porter. I would like to ask about this matter of circulation of water —whether Mr. Whipple has found at any time that there seems to be a well-defined current in ponds that do not receive any large stream into them? I remember several years ago in making some inquiries about lakes in the central part of New York, Cayuga, Seneca, etc., that the belief was frequently expressed by men familiar with the lakes, that there was a decided current at certain points. Those lakes are very long, compared with their width, and at the time I supposed that these currents, if there were any, must be due to the action of wind, perhaps long continued in one direction. But I have wondered if anything of that kind had been observed in lakes around here.

Mr. Whipple. I do not think we have the data to answer your question. Most of our reservoirs have large streams entering them at one end. As far as the temperature observations go, we have been in the habit of taking them at only one locality in each reservoir. The constant readings which we get at certain depths during the summer would indicate that during the periods of stagnation there is very little circulation in the lower layers.

The President. I will say that to my mind this illustrates or explains some things that were brought before this Association some time ago in regard to the difference in the quality of water at different depths in reservoirs. I never heard an explanation or any reason given for it before, and I would like to inquire if this is not an explanation or a reason for finding good water and very bad water at different depths? I think that Mr. Ball of Worcester cited a case here of the Worcester reservoir, where they had to change the location of the gatehouse. The water was very bad at the point taken, and after changing and taking it from a different depth, or locating where the good water was, the trouble was obviated. I would like to ask if this is not a reasonable explanation of that phenomena in reservoirs.

Mr. Whipple. There is no doubt but that there is sometimes a great difference in the quality of water at the surface and at a point some distance below. My paper no doubt partially explains what you refer to.