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A study of the effects of some chemical and physical factors on plankton in an artificial lake

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A STUDY OF THE EFFECTS OF SOME CHEMICAL AND PHYSICAL FACTORS ON PLANKTON IN AN ARTIFICIAL LAKE

BY

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INTRODUCTION

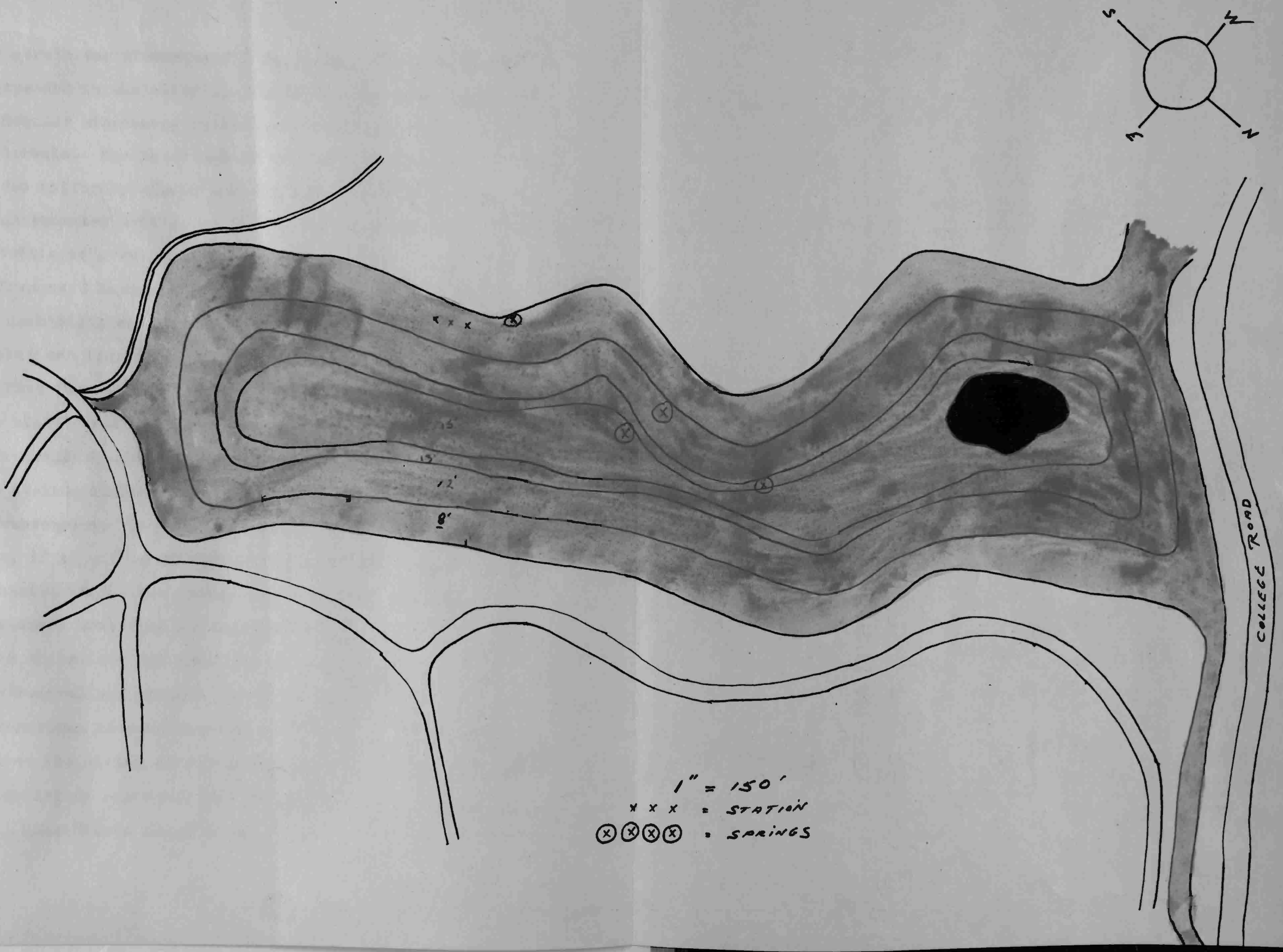
It has been well established that chemical and physical factors exert a marked effect upon the plankton population in bodies of water. However, the literature reveals the fact that the same chemical and physical factors not only produce a different effect upon plankton in different bodies of water, but are not consistent in their effects upon plankton in like bodies of water. For example, Birge and Juday (1911) made a study of 150 lakes, not widely separated in distance or varying in topographic conditions. These lakes were also of the same age, yet all were individual as to the amount of dissolved gases, organic matter, temperature, minute geology, productivity and ability to support a population of plankton.

The work herein reported on was undertaken to make a comparison of similar factors and their effects upon plankton population in a body of water located in Richmond. Accordingly, a study was made of a few of the more common factors which might be expected to play an important role in the plankton population of artificial lakes or ponds. The factors selected for this study were dissolved oxygen, free carbon dioxide, temperature, alkalinity, acidity, suspended matter and precipitation. These factors have been considered by Birge and Juday (1911), Tressler and Bere (1939), Prescott, et al. (1945), Brinley (1942a) and Pennak (1946) to be important influences on plankton population.

The results of this study are intended to serve as a report on the effects of the named factors on the plankton population in an artificial lake between October 23, 1947, and March 20, 1948.

MATERIALS AND METHODS

The artificial lake upon which this study was based is Westhampton Lake located on the University of Richmond campus. This lake was created approximately one hundred years ago by the construction of a dam across Westham Creek. The water is derived from three major sources, namely, drainage water, fresh water springs and Westham Creek. Westham Creek collects water from the territory lying northwest for a distance of approximately three miles, while a smaller stream brings in drainage water from a smaller area to the west of the lake. In addition to these two streams there are four springs within the lake itself that empty their water into the lake. Three of these are located in the central area of the lake bed, while the fourth and largest is located on the west shore. The northeast and southwest sides gradually deepen to fifteen feet. The channel runs from northwest to southeast. The bottom is of sand, completely topped at present by a layer of black muck. The lake is irregular in shape and covers less than one hectare (approximately 1-1/2 acres). It is a very small, shallow, drainage lake, according to Juday et al. (1935). It is smaller than the smallest lake described by Pennak (1945). The sloping terrain on all sides is covered with trees. The trees afford protection from the wind and prevent the waters from becoming unduly stirred. Since 1910 the lake has been drained and cleaned approximately every ten years and the sediment removed. It has not been drained and cleaned since 1940.


S
W
E
N
COLLEGE ROAD
15'
13'
12'
8'
1" = 150'
x x x = STATION
ⓧⓧⓧⓧ = SPRINGS

To sample the microscopic life of the lake, six slides were suspended in the water at depths ranging from one to six feet. Regular microscope slides were taped to a cord at one foot intervals. The lower end of the cord was weighted to keep the slides uniformly spaced while the upper end was attached to an empty corked bottle. A weighted cord was tied to one end of the bottle to prevent it from drifting. The slides were suspended from cord rather than wire to avoid rusting. In this manner, each slide was one foot below the other - the first slide being one foot below the surface and the last slide exactly five feet below the first or at a depth of six feet. Only one station was used. Three sets of slides were found to be advantageous since one or two sets often disappeared from the station without apparent reason. This method was quite advantageous. For example, the slides collected organisms, if any, from different strata simultaneously. It is likewise useful but cannot be classified with the more precise methods described by Welch (1948).

After the slides had remained in the water for two weeks they were removed and brought to the laboratory to be stained and the organisms thereon counted. [Studies were made, whenever possible, on the living material (about 25%). This method is vastly superior to any other and should be done whenever time permits]. Schaudinn's fixative was found to be quite satisfactory.

McClung (1937) suggests its use whenever available. The following staining schedule was used:

(a) Slides were immersed in Schaundinn's fixative for thirty minutes.

(b) Rinsed - 70% alcohol.

(c) Rinsed - 70% alcohol plus iodine for ten minutes (2 cc. iodine per 100 cc. alcohol).

(d) Rinsed - 70% alcohol.

(e) Washed - tap water.

(f) Stained with 5% Harris' Hematoxylin for fifteen minutes.

(g) Rinsed - tap water for fifteen minutes.

(h) Counterstained with 5% eosin in 95% alcohol for one minute.

(i) Rinsed in tap water and allowed to air dry.

It should be recorded that ordinarily the writer would not place the organisms directly in 70% alcohol after fixation, since it was found that severe distortion, contraction and change of color take place among the larger plankton forms. However, larger plankton forms are not being considered. For the purpose of this study, components of the plankton that are not independent of currents were chosen. Zooplankton, whenever used, shall mean protozoa not independent of currents. Phytoplankton shall mean algal components not independent of currents.

In order to determine the number of Zöoplankton and Phytoplankton on a microscope slide it was necessary to obtain first the average number per field of the 16 millimeter objective with a 10 X eyepiece. Ten representative fields were selected and counted and the average number of organisms per field was calculated.

The area of the microscope slide was computed and the area of the field was determined using a stage micrometer. The formula for obtaining the number of organisms per slide is as follows:

$$\text{Number of organisms per slide} = \frac{\text{area of slide}}{\text{area of field}} \times \text{average number of organisms per field.}$$

At the time the slides were removed from the lake, a sample of the water was obtained for use in the determination of physical and chemical characteristics. The sample of water was collected by partially filling a weighted gallon bottle with water from the surface of the lake and then gradually lowering the bottle to a depth of six feet. As the bottle was lowered slowly, a representative sample was collected. This method compares favorably with that of Pennak (1945a). He attached a gallon jug to a long pole and filled the jug with water as far from the edge as possible so that the sample would not become contaminated with detritus which is usually in suspension where the waves break on shore.

Samples used to determine dissolved oxygen, free carbon dioxide, total alkalinity, acidity, and suspended matter were capped immediately and taken to the laboratory for analysis. At no time was there an interval of more than ten minutes before the beginning of analysis after the collection was made. Duplicate determinations were made for each sample and the average was recorded. The materials and methods selected for determining these factors were as follows: (A complete description of the methods used here and an explanation of the preparation of all reagents can be found in "Standard Methods For the Examination of Water and Sewage." 1936).

I. Chemical factors

A. Dissolved oxygen

To determine the parts per million of dissolved oxygen in the lake, 200 cc. of the sample of water were placed in a sampling bottle. Care was taken so that agitation was kept to a minimum. Immediately after collection of the sample, 1 cc. of concentrated manganous sulfate and 1 cc. of alkaline iodide ($KOH + KI$) were added. The bottle was stoppered, so that air was excluded, and inverted several times. The precipitate that formed was allowed to settle.

After the precipitate had settled, 1 cc. of concentrated sulfuric acid was added. The bottle was stopped, inverted several times and the precipitate was allowed to dissolve. The result was a yellow iodine-containing solution which indicated that oxygen was present. This solution was titrated with .025 normal sodium thiosulfate until a faint lemon coloration was obtained. Two drops of starch indicator solution were added at this point and the titration continued until the green, blue green, and blue coloration just disappeared. The parts per million of dissolved oxygen in the original sample were recorded in terms of the number of cc. of sodium thiosulfate (.025N) used in the titration. This procedure, or some modification of it, has been adopted by such limnologists as: Chandler (1940), Kraatz (1941), Brinley (1942c) and numerous others, as the standard method for determining dissolved oxygen.

B. Total Alkalinity

In order to determine the total alkalinity of the lake, 100 cc. of the sample were measured into a 250 cc. Erlenmeyer flask and five drops of methyl orange indicator were added. The solution became yellow which indicated that hydroxides, normal carbonates or bicarbonates were present. The solution was titrated against a white background with (.02N) sulfuric acid until the faintest coloration appeared. The parts per million of total alkalinity were recorded in terms of the number of cc. of N/50 sulfuric acid required x 10.

C. Free Carbon Dioxide

In order to determine the free carbon dioxide in the lake, 10 drops of phenolphthalein indicator were added to 100 cc. of the water sample in a Nessler tube. Care was exercised to keep the agitation to a minimum. The sample was titrated with N/44 sodium hydroxide until a pink coloration just appeared and remained for one minute. The parts per million of free carbon dioxide were recorded in terms of the number of cc. of N/44 sodium hydroxide required x 10.

D. Hydrogen Ion Concentration

Wherever used in this paper, the hydrogen ion concentration is expressed in the pH scale. There are many methods for determining the pH of water - one of which is the electrometric method. A Coleman glass electrode was available and used throughout the period of study.

In order to determine the pH, a sample of water was capped and then taken immediately to the laboratory. A second pH was determined and the average of these two was recorded.

II. Physical Factors

On the same day that samples were analyzed, certain physical characteristics of the lake were determined. They were as follows:

A. Water temperature

The temperature of the water was obtained for each slide level. This was accomplished by the use of a Taylor maximum and minimum thermometer. This instrument is considered by such limnologists as Hutchinson and Pickford (1932), and Welch (1948) as being second best when used for subsurface work. The deep sea reversing thermometer is considered the best and should be employed for limnological work requiring greater depths and accuracy. A deep-sea reversing thermometer was not available.

The instrument was lowered into the water at intervals of one foot and allowed to remain for a full minute. It is necessary to note that water temperatures should be obtained, as near as possible, during the hour in which the water samples are analyzed.

B. Suspended matter

The per cent of suspended matter in the lake water was determined by evaporating 10 cc. of the water in a crucible and, with the use of an analytical balance, the weight of the residue was determined to four decimal places. This method was employed to depict the disturbances created by physical and chemical changes of the lake.

C. Precipitation

All precipitation data were obtained from the United States Weather Bureau at Chimborazo Park, Richmond, Virginia. The bureau is a distance of twelve miles from the lake.

The data on the above characteristics are recorded in tabular form in Table I and in graphic form on Figure I.

TABLE I

Date	Dissolved Oxygen PPM	Free Carbon Dioxide PPM	Water Temperature	Precipitation	Suspended Matter in %	pH	Bulk Alkalinity PPM	Zooplankton in millions	Phytoplankton in millions
Oct.23	47.1	27	17.7	0	--	7.42	11	1.9	.09891
Oct.29	37	39	14.4	.39	.536	7.1	10	.0480	.1251
Nov.12	12	31	9.9	1.31	.00565	6.75	9	5.2862	.0768
Nov.19	10	35.5	6.6	T	.00354	6.52	8	.2498	.0096
Nov.26	11.1	31	6.75	0	.000026	6.82	9	.1537	5.8338
Dec.10	12	29	5.2	0	0	6.84	6.75	.1249	.4001
Dec.26	13	26	2.3	.02	0	5.18	6.5	0	1.0672
Dec.27	13.6	26.6	2.2	T	0	6.27	6.8	.1349	.3075
Dec.28	13.9	27.8	2.4	0	0	6.58	2	.0672	.0864
Dec.29	13.5	20	1.8	0	0	6.49	3	.0480	.0672
Jan.13	12.6	43.5	2.4	.45	0	6.68	6.5	.0096	.6151
Jan.21	17	29.1	3	.52	0	6.58	5	.0480	2.6435
Jan.26	13.3	42	2.8	0	0	6.21	4.8	.0576	.3844
Feb. 4	13.2	34	2.2	0	0	6.5	3.7	1.7119	2.6713
Feb. 7	14.2	36	2.6	.09	0	7.72	6.1	0	0
Feb.11	12.6	43.5	2.6	.14	0	5.8	6.2	0	0
Feb.13	14.2	47.9	3	.14	0	6.38	5.4	0	0
Feb.18	13	40	4.8	.07	0	6.27	4	1.044	.3374
Feb.23	12.9	33.6	4	.48	.0015	6.35	4.8	.1687	.2301
Feb.25	17.1	36	5.1	0	.003	6.45	5.4	.0768	.0192
Mar. 3	12	58	8	.84	.0126	6.64	5.7	.0654	.0306
Mar.10	11.8	34.5	6.45	.33	.0107	6.5	5.4	.1826	.9703
Mar.13	12	35.8	7.3	T	.015	6.53	4.5	.0961	.4800
Mar.17	10.8	20.5	13.4	.73	.016	6.62	5.4	.2114	.6054
Mar.20	11.1	30.1	12.4	.01	.0036	6.49	6	.1736	.2114

DISCUSSION OF RESULTS

A. The Relation of Chemical and Physical Factors.

Reference to Table I and graphs (Figure I) reveals certain points of interest pertaining to the interrelationships of chemical and physical factors studied in the lake. These interrelationships may be treated best by selecting the results recorded for each factor and analyzing them in relation to the other factors studied. Such an analysis is incorporated in the following discussion.

1. Dissolved oxygen

It can be seen from Table I and Graph I (dissolved oxygen) that the lake was well saturated with dissolved oxygen during the period of study. ("The period of study" wherever used in this paper shall mean from October 23, 1947 to March 20, 1948.) According to Whipple and Whipple (1911) the actual mean of 13.2 parts per million represented a condition of super-saturation as compared to the theoritical mean of 12.2 parts per million for saturated fresh water lakes with corresponding temperatures.

Instances of saturation and supersaturation are found among diverse bodies of water under various conditions and seasons of the year. Kraatz (1941) found unusually high amounts of dissolved oxygen in Turkeyfoot Lake, near Akron, Ohio. For a period of thirty-two months the dissolved oxygen varied between 6.13 and 14.59 parts per million. In January, 1938, he obtained a reading of 14.59 parts per million. It can be seen from Table I that the mean of dissolved oxygen in Westhampton Lake during January 1948 was 14.63 parts per million. Utterback, et al. (1942) reported that Crater Lake in the Cascade Mountains was supersaturated during the month of July, while Birge and Juday (1911) found that most of the inland lakes of Wisconsin that were studied were supersaturated during the month of August. In a year's study of the sea water at the Puget Sound Biological Station, Thompson and Johnson (1930) found that the dissolved oxygen increased during the winter and fluctuated in the summer. Miller, et al. (1928)made a study of physical and chemical factors in San Francisco Bay. The water was found to be four-fifths saturated with dissolved oxygen at all points. Shadin (1932) stated that the waters of Oka River, Russia were well saturated with oxygen throughout the year and Scheffer (1933) made a similar statement concerning a Puget Sound Lake in the State of Washington. Whipple and Parker (1901) found ponds, lakes, reservoirs, driven well waters and systems of certain large rivers ranging from 150% to 1125% saturated with dissolved oxygen during all seasons.

From the foregoing, it might be concluded that supersaturation of dissolved oxygen in bodies of water is a common condition.

This is not the case. It is, more properly termed, a temporary phenomenon. A review of the literature indicates that supersaturation of dissolved oxygen in lake water is the exception rather than the rule. Ricker (1934) explained that the absolute standard of saturation from a physico-chemical standpoint, was the one which came closest to being an expression of the real relationship of oxygen content to prevailing conditions. This may explain the supersaturation of dissolved oxygen in Westhampton Lake when it was covered with two inches of ice from the middle of December to the middle of January. It may explain also the fact that dissolved oxygen maximum coincided with the period of temperature maximum in Buckeye Lake as reported by Tressler, et al. (1940) or a saturation deficiency of dissolved oxygen in Mountain Lake, at the bottom of the hypolimnion, determined by Hutchinson and Pickford (1932). In any event, dissolved oxygen is a variable among like and unlike bodies of water.

There is no disagreement among the authors in the literature as to the source of oxygen. Welch (1935) considers the following to be sources of dissolved oxygen: (1) the direct interchange with the atmosphere through the exposed surface. This is accomplished by a direct diffusion or through various forms of surface agitation such as wave action, waterfalls and turbulences due to obstructions. (2) From the photosynthesis of chlorophyll-bearing plants.

A comparative study of Graph I (dissolved oxygen) and Graph II (free carbon dioxide) reveals the fact that an inverse relationship existed between dissolved oxygen and free carbon dioxide throughout most of the period of study. Tressler and Bere (1937) recorded the same condition in Lake Chautauqua throughout the year. Chandler (1940) found a like relationship in Western Lake Erie during the winter months. Tressler, et al. (1940) recorded like relationships in Buckeye Lake during the summer. Tressler and Bere (1939), (1937),(1936),(1935) and 1934a) reported a similar condition among four Long Island lakes, Glenida Lake of the Lower Hudson Watershed, Lake Canadarago and Lake Otsego of the Delaware and Susquehanna Watershed, Lake Chautauqua and some lakes of the Raquette River Watershed all during the summer months. It should be noted that most of the comparisons of this nature have been reported during the summer. Due to this paucity of year round data, there are few reports in the literature that consider the dissolved oxygen - free carbon dioxide relationship during the winter months.

A study of Graph I (dissolved oxygen) and Graph III (water temperature) shows that dissolved oxygen varied inversely with the water temperature. For example, between the 29th of December and the 11th of February, the mean dissolved oxygen was at its highest (13.88 p.p.m.). During this same period, the mean water temperature was at its lowest (2.48° C). Among a study of lakes this inverse relationship was found to be typical during the winter months. There was usually a direct relationship during the summer months. For example, Chandler (1940) records an inverse relationship in some Colorado lakes durin the summer. However, there was no correlation between dissolved oxygen and water temperature during the summer, among the fish ponds studied by Wiebe (1930) (1927) or, in summer or fall in the reports by Brinley (1942a, (1942bc) of his studies of the Cumberland and White Rivers.

Theoretically, the inverse relationship between temperature and dissolved gases, in bodies of water, should be perennial. It is a known fact that, ordinarily, gases dissolve in liquids at a rate that is inversely proportional to the temperature, the pressure remaining constant. However, this study concerns biologically related water in which there is modifying aquatic life. Such conditions produce phenomena that are far from parallel to the results obtained in the laboratory.

There appeared to be an inverse relationship between dissolved oxygen and precipitation as shown by the data recorded in Graph I (dissolved oxygen) and Graph IV (precipitation). During the winter, the relationship might be expected to be direct. Raindrops lose their heat as they fall through the air. The cold rain would serve to lower the water temperature. Lowering of the water temperature would increase the capacity of the lake to dissolve more oxygen. However, this was not the case. The inflow of ground water, as the result of the precipitation, could reduce the amount of dissolved oxygen according to Welch (1935).

There was a fluctuation of dissolved oxygen a month prior to the ice cover and during the ice cover, at which time no precipitation was recorded. Inasmuch, as the amount of precipitation during the period of study was not high, the effect upon dissolved oxygen could be considered negligible.

Graph I (dissolved oxygen) and Graph V (suspended matter) indicate a direct relationship between dissolved oxygen and suspended matter from October 23 to November 19, and an inverse relationship from February 25 to March 20. Suspended matter includes plankton, both dead and alive. A reduction of oxygen concurrently with a reduction of suspended matter was expected since oxygen could be consumed in the process of the decomposition of organic matter as it settled. Rakestraw (1936) states that organic matter works downward by settling or by diffusion and mixing while it is decomposing and oxidizing. Welch (1935) supports this theory. There is no explanation for the inverse relationship from February 25 to March 20 unless suspended matter was largely colloidal clay introduced by increased precipitation during the same period. (See Graph IV and Graph V where suspended matter varies directly with precipitation).

A thorough study of Graph I (dissolved oxygen) and Graph VI (hydrogen ion concentration) reveals the fact that no apparent relationship existed between dissolved oxygen and the pH. The literature revealed one exception in salt water. Miller, et al. (1928) found in their studies of San Francisco Bay that the pH varied directly with the dissolved oxygen.

In like manner, a study of dissolved oxygen and total alkalinity, shown by Graphs I and VII, reveals the fact that no apparent relationship existed between the two.

2. Free Carbon Dioxide

An analysis of the data recorded in Graph II (free Carbon dioxide) shows that the lake was well saturated with free carbon dioxide from the last of October to the last of March (average of 34.4 p.p.m.). Since Prescott, et al. (1945a) reported that bacteria of putrefaction were found in water polluted by organic matter and that decomposition was a source of energy that led to the release of nitrates and carbon dioxide, it seemed desirable to determine the amount of nitrate nitrogen present in the water of Westhampton Lake and to ascertain the bacterial count for the water. Welch (1935) stated that ordinarily nitrogen in its final form as nitrate does not occur in great amounts in natural uncontaminated waters. Accordingly, nitrate nitrogen determinations were made at intervals of four weeks using the phenoldisulfonic acid method as outlined in Standard Methods For the Examination of Water and Sewage (1936). The results were consistently between three and five parts per million. This was not a high concentration according to Pennak (1946) who stated that nitrate nitrogen exists in most waters in quantities ranging from two to twenty parts per million. However, Rakestraw (1932) says there are uncertainties involved in determining the amounts of nitrate nitrogen. The values are relative. A bacterial count was made during the winter by the Bacteriology Class of the University of Richmond 1947-1948 and found to average 1,500,000 per cubic centimeter. This was high according to Prescott, et al. (1945a). Thus it can be seen, as explained by Prescott, et al, (1945a), the high concentration of free carbon dioxide in this lake could be due, at least in part, to decomposition.

Another source of carbon dioxide is the atmosphere. Pennak (1945a) stated that from one to two parts per million of carbon dioxide may be dissolved from the air or washed into the lake water.

Waters filtering through the soil often acquire carbon dioxide from the decomposing matters over which they pass. In a study of four lakes on the Pacific slope of Central America, Juday (1915) found that rain water contained a small amount of carbon dioxide, but springs, that emptied directly into the lakes, were high in carbon dioxide content. It will be recalled that the Westhampton Lake is supplied with four springs.

Respiration of plants and animals is a large source of carbon dioxide. Welch (1935) states that quantities so produced are much larger than is ordinarily supposed. Another source of carbon dioxide is its combination with other substances, chiefly calcium and magnesium. A thorough discussion of this subject will be gone into later when the bulk alkalinity is considered.

A wide variety of answers were found in the literature. For instance, Juday (195) attributed supersaturation of free carbon dioxide in four lakes to air, respiration, decomposition and rain-water. However, Juday, et al. (1935) stated that waters usually contained dissolved substances which increased their capacities for carbon dioxide. Utterback, et al. (1942) stated that Crater Lake was well saturated with free carbon dioxide but offered no reason for the condition. Underhill (1939) credited the high amounts of free carbon dioxide in New Hampshire fresh waters, to decay of unremoved muck and vegetation. Cowles (1923) explained that the high percentage of free carbon dioxide in a creek on Johns Hopkins campus was due to the fact that water fell slowly over decaying matter. Ganapati (1943) in an ecological study of a garden pool explained the large amounts of free carbon dioxide on the basis of high organic content.

Attention is directed to the behavior of free carbon dioxide during the ice cover as shown by Graph II. A slight rise is noted followed by a sharp decline during this period. This behavior was comparable with the behavior of mountain streams described by Powers (1929). The initial pulse under ice cover was attributed to the fact that ice held the gas in solution, while the decline was due to a slowing down of the processes of decomposition. The lake averaged 25 parts per million of free carbon dioxide while it was covered with two inches of ice. Vincent Lake, Michigan, had 23 parts per million of free carbon dioxide while under 29 centimeters of ice, as reported by Welch (1938). This condition was explained on the basis that it was the outcome of winter stagnation which had not been relieved. Rakestraw (1936) explains that decomposition proceeds during the winter because of oxidation of excretory products and death of organisms. The release from the ice cover is marked by a sharp increase in the free carbon dioxide, the answer to which could mean an acceleration of the processes of decomposition.

Free carbon dioxide varied directly with the water temperature throughout most of the period of study, as indicated by Graph II (free carbon dioxide) and Graph III (water temperature). This was to be expected - Welch (1935 says that accumulation of organic matter undergoes decomposition and gives off carbon dioxide. This process continues uninterruptedly throughout the year, though of varying rates. Other things being equal, the amount of carbon dioxide produced varies directly with the temperature. The exception to this relationship occurred between the fourth and seventeenth of March. During this time the free carbon dioxide dropped from 58 parts per million to 30 parts per million. During the same time the temperature rose from eight to thirteen degrees centigrade. Apparently, this particular lake had reached its saturation with free carbon dioxide commensurate with the temperature. When the temperature exceeded this point of tolerance the free carbon dioxide was released.

Some correlation existed between free carbon dioxide and precipitation as indicated in Graphs II (free carbon dioxide) and Graph IV (precipitation). It is of interest to observe that, with one exception, each peak on the precipitation graph corresponds to a low point on the free carbon dioxide graph. Disregard the probability of a time log and this condition could be explained on the basis that rains will cause an agitation of a lake thereby releasing free carbon dioxide. Welch (1935) states that this is a very effective way of eliminating free carbon dioxide in water. On the other hand each low point on the free carbon dioxide graph, commensurate with a peak on the precipitation graph, is followed by a sharp climb. Considering the period between rise and fall of free carbon dioxide as a time log, precipitation could be called a direct source of free carbon dioxide. This phenomenon has been explained on the basis that rain water passed over decayed vegetation as it filtered through the soil into the lake.

Suspended matter varied directly with the free carbon dioxide, except when there was no suspended matter, as indicated by Graph II (free carbon dioxide) and Graph V (suspended matter). This was expected since organic matter is a definite part of suspended matter and is decomposed along with the process of settling. Carbon dioxide is a product of decomposition. This explains the direct relationship.

Reference to Graph II (free carbon dioxide) and Graph VI (hydrogen ion concentration) shows no correlation of free carbon dioxide with the pH. However, most of the literature gives a positive correlation between these two factors. Birge and Juday (1911) reported all acidity in the inland lakes of Wisconsin, that were studied, was due to free carbon dioxide. Juday et al, (1935) studied 499 lakes in northern Wisconsin, and found the pH to be inversely proportional to the free carbon dioxide. Cowles and Schwitalla (1923) found that the free carbon dioxide was a factor in determining the pH of a creek, its waterfall and ponds. Noland (1925) made a study of fresh waters in the vicinity of Madison, Wisconsin, and found that pH depended on free carbon dioxide. Underhill (1939) attributed the high acidity of an artificial pond to free carbonddioxide. A study of rock pools by Stephenson et al. (1934) revealed that the pH of pools behaved in accordance with free carbon dioxide. As a result of limnological observations of San Francisco reservoirs, Medberry (1942) concluded that changes of pH were indicative of the production or consumption of free carbon dioxide. Brinley (1943) kept pond water from becoming acid by removing the carbon dioxide. Thus, if the preceding reports are any criteria, and they should be, there is a positive correlation between free carbon dioxide and the pH even though such is not indicated by the graphs.

A comparison of Graph II (free carbon dioxide) with Graph VII (bulk alkalinity) shows that free carbon dioxide varies directly with the bulk alkalinity. This was quite normal according to the literature. Due to the fact that there was no alkalinity reaction with phenolphthalein, the bulk alkalinity as determined by methyl orange actually represented the bicarbonates of calcium or magnesium as illustrated by Welch (1948). Welch (1935) stated that free carbon dioxide unites with ground water to form carbonic acid. The carbonic acid in turn converts the highly insoluble monocarbonates to bicarbonates. This explanation is rather convincing. Other authors simply take this for granted. For example, Chandler (1940) stated that carbon dioxide transforms carbonates to bicarbonates. Utterback, et al. (1942) observed that carbon dioxide and carbonates were remarkably similar in distribution while Brinley (1943) found that the removal of carbon dioxide resulted in the precipitation of the monocarbonates held in solution by the carbonic acid.

3. Water Temperature

An examination of Graph III (water temperature) shows that the period of study began when the lake was undergoing a transition in temperature from warm (17.7°C.) through cold (1.8°C.) to warm (13.4°C.) again. This transition might be considered fast as compared with the lake studied by Kraatz (1940). Corresponding temperatures for Turkeyfoot Lake existed from the middle of September to the middle of May. The coldest period of Westhampton Lake existed from the last of December to the last of February with an average of 2.48°C. The coldest period for Turkeyfoot Lake existed from the first of December to the last of March with an average of 2.8°C. The coldest period for Western Lake Erie existed from the last of November to the first of April with an average of 1.36°C.

The lowest temperature of 1.8°C was reached when the lake was covered with ice. At that time the ice had increased to a thickness of two inches and was covered with a blanket of snow.

The paucity of literature on year round limnological studies was obvious particularly on the subject of lake temperatures. Comparisons could be made of the temperature of Westhampten Lake with only two other lakes.

There was some correlation between water temperature and precipitation from October through March as indicated in Graph III (Water Temperature) and Graph IV (Precipitation). It is possible that precipitation aided in the cooling of the lake between October and period of ice cover, and contributed to the warming of the lake as the ice melted and the cold weather declined. The literature contributed no information as to the relationship between water temperature and precipitation from October to March.

There was a strong correlation between water temperature and suspended matter as shown by Graph III (temperature) and Graph V (suspended matter). This was a phenomenon to be expected according to Welch (1935). The warmer heavier water permits fine particles to remain in suspension, while the colder lighter water contributes to the settling of these particles. Ice cover eliminates surface disturbance while melting ice release winter accumulations of foreign matter into a body of water.

Westhampton Lake showed no correlation between temperature and suspended matter for a month following the melting of the ice cover. This would indicate that the melting ice contained little windblown material which confirmed the original judgment that the lake is well protected from winds by the high terrain. Welch (1935) adds weight to the data, which includes a long period of no suspended matter, when he states that there is no reason for believing that all natural waters contain a certain amount of non-settling suspended matter.

There seems to be no relationship between water temperature and the hydrogen ion concentration as can be seen by Graph III (water temperature) and Graph VI (hydrogen ion concentration).

Likewise a study of Graph III (water temperature) and Graph VII (bulk alkalinity) indicates that no apparent relationship between water temperature and bulk alkalinity existed.

4. Precipitation

A study of Graph IV (precipitation) reveals the precipitation picture from October 23 to March 20. The date, indicated in Graph Iv, is recorded in inches. Wherever the symbol "T" occurs it indicates less than one hundreth (.01) of an inch of precipitation and appears on the graph as a zero.

Precipitation shows a direct correlation with suspended matter from February 23 to March 20 as can be seen by Graph IV (precipitation) and Graph V (suspended matter).

The washing of matters from the terrain into thelake is offered as an explanation, in part, of this direct correlation. Welch (1935) suggests that rain not only agitates the water and returns into suspension finely divided materials previously settled to the bottom but it erodes and transports shore materials which are fine enough to become suspended.

There appears to be no correlation between precipitation and hydrogen ion concentration or between precipitation and bulk alkalinity as shown in Graph IV (precipitation), Graph VI (hydrogen ion concentration) and Graph VII (bulk alkalinity). There was no information in the literature concerning the interrelationship of these factors.

5. Suspended matter.

Reference to Graph V (suspended matter) shows that the suspended matter reflected, in part, the fall and spring overturns. A fall overturn, reports Birge and Juday (1911) is that period between summer andwinter in which a lake gradually cools, a maximum load of oxygen is being dissolved, matters are brought into suspension and the lake finally becomes homothermous. This activity occurs between late September and December according to the area and depth of the lake. It lasts until the lake is frozen. Welch (1935) says the same and adds that the hydrogen ion concentration is uniform from top to bottom and the lake becomes turbid due to the materials in suspension being mixed from surface to bottom. The period of study began in the early stage of a fall overturn as can be seen by a review of Figure I. [Graph I (dissolved oxygen), Graph III (water temperature), Graph V (suspended matter), Graph VI (hydrogen ion concentration].

The spring overturn as described by Birge and Juday (1911) and Welch (1935) is marked by that period, following an ice cover, in which the temperature of the water reaches a uniformity of 4°C, oxygen is being released and matters are again brought into suspension. This phenomenon in Westhampton Lake began February 23, at which time an immediate reflection was noted in the data recorded in Figure I [Graph I (dissolved oxygen), Graph III (water temperature), Graph V (suspended matter), and Graph VI (hydrogen ion concentration)].

Reference to Graph V (suspended matter) and Graph VI (hydrogen ion concentration) and Graph VII (bulk alkalinity) indicate no correlation between suspended matter and hydrogen ion concentration or between suspended matter and bulk alkalinity.

6. Hydrogen ion concentration.

It must be recorded that the pH, obtained by the Coleman glass electrodes, was an average of the initial pH and the reserve pH. That is to say, the sample of lake water was taken immediately from the lake, capped, taken to the laboratory and the pH obtained, whereas the second pH was taken after the water was aerated. In every instance, the second reading was higher than the first. This indicated the possibility of gases, such as carbon dioxide, being released. Although the difference was slight, the suggestion is offered that an alkali reserve may have existed.

Graph VI (hydrogen ion concentration) shows that little change in the pH existed from October 23 to March 20. Welch (1935) shows that natural waters of various kinds may have extreme ranges. He states, however, that while special circumstances surrounding smaller lakes may impose changes of great magnitude, the surface waters of larger lakes undergo relatively small changes in pH from season to season. The literature brings out other interesting conditions. Small lakes studied by Noland (1925) had little variation in pH. A bog-lake studied by Welch (1938) had considerable variation in pH. The pH of San Francisco Bay showed little variation when studied by Miller et al. (1928). The pH of marine water in the Puget Sound Biological Station varied but little, according to Thompson and Johnson (1930), in an all year around observation. Jewell (1922) found that Big Muddy River kept a constant pH for two winter months. Cowles and Schwitalla (1923) concluded definitely that a pond may maintain a constant pH under certain conditions.

An explanation for a constant pH is the effect of bulk alkalinity. There were probably enough bicarbonates present in Westhampton Lake to reestablish equilibrium which could be upset by fluctuations in carbon dioxide. Another possible influence is that of carbonic acid which was made available by carbon dioxide. Carbonic acid is a weak acid and may have acted as a buffer in preventing rapid changes in the pH because of the fact that the initial ionization is low. Welch (1935) explains that when newly entering substances affect the pH at any instant, the remaining undissociated molecules yield ions until a new equilibrium is established which has about the same pH as before. Welch (1938) in a study of Vincent Lake, concluded that the low buffer effect made a considerable variation in pH. The high buffer effect of carbonic acid probably accounted for the pH remaining fairly constant in Westhampton Lake.

The mean of 6.51 indicates that Westhampton Lake was on the acid side. In a previous discussion it was concluded that carbon dioxide was the greatest contributor to this condition. Neland (1925) adds that the pH not only depends upon free carbon dioxide but also salts of calcium and magnesium. It is interesting to note that the

(1945a), since it contained less than 10 p.p.m. of fixed carbon dioxide. It will be recalled that the lake was well saturated with free carbon dioxide and that a positive correlation between free carbon dioxide and bulk alkalinity existed, throughout the period of study including the ice cover. Birge and Juday (1911) found 26 out of 31 soft lakes had high concentrations of free carbon dioxide and were acid. This three-way correlation was also observed by Tressler and Bere (1934a),(1935), (1936), and Chandler (1940).

B. Relation of Plankton Population to Chemical and Physical Characteristics.

The influence of chemical and physical factors in Westhampton Lake on the plankton population is made possible by a comparison of data in Graph VIII for Zooplankton and Graph IX for Phytoplankton and the graphs for the chemical and physical factors included in this report. Accordingly, a comparison is made in the following manner:

1. Zooplankton

It can be seen from Graph VIII that there was little fluctuation of Zooplankton during the period of study. Although a consideration of the populations of individual species has not been attempted, it should be borne in mind that seasonal activity is thought to be distinct for each specie. Pennak (1946) published a diagrammatic representation to illustrate the accepted concept of the annual plankton curve in typical lakes in temperate latitudes.

Briefly, the curve shows a large spring pulse, a decreased population during the summer, a less pronounced pulse in the autumn and a very small population in the winter. Table I indicates a small Zooplankton population, by comparison, prior to the ice cover. One outstanding pulse on November 12, can be seen on Graph VIII. Chandler (1940) reports the autumn Zooplankton pulse in Western Lake Erie came in November while Kraatz (1941) among his studies of Turkeyfoot Lake, found that the so-called Autumnal Pulses were irregular from year to year. Shadin (1932) found that Zooplankton remained at a minimum throughout the winter in Oka River, Russia, and Thompson (1930) made a similar observation at the Puget Sound Biological Station. Hupp (1943) said that Zooplankton pulses were common in White River during the autumnal season, and Harvey, et al. (1935) reported a rise of Zooplankton in the Plymouth Breakwater about the middle of September.

The fluctuation of Zooplankton all but vanished during the ice cover. Batchelder (1936) made an ecological study of brackish water and concluded that the formation of ice forces some Zooplankton organisms to migrate while others hibernate until more favorable conditions prevail. This was the only conclusion found in the literature that was concerned with the fluctuation of Zooplankton under ice.

While there appears to be no correlation between dissolved oxygen and Zooplankton as seen in Graph I (dissolved oxygen) and Graph VIII (Zooplankton) we know that dissolved oxygen is essential in the respiration of Zooplankton. Scheffer (1933) thinks that oxygen has the greatest biological significance, of all gases in lake water. Medberry (1942) concluded that plankton growths and bacterial action governed dissolved oxygen concentration in San Francisco reservoirs. However, Birge and Juday (1911) could find no correlation between Zooplankton and dissolved gases, while Thienemann (1927) found a positive correlation between dissolved oxygen and the course of life in a lake in the Plön region.

There appears to be no correlation between free carbon dioxide and Zooplankton as indicated by Graph II (free carbon dioxide) and Graph VIII (Zooplankton). It was noted in a previous discussion that carbon dioxide is a product of decomposition of organic matter and respiration of animals. Tressler (1948), Tressler and Bere (1935) and others found positive correlations between carbon dioxide and Zooplankton while Pennak (1946) in a study of seven artificial lakes in Colorado explained that exceptionally high concentrations of carbon dioxide would drive Zooplankters out of bottom waters. Birge and Juday (1911) considered the gaseous effects of decomposition to have no unfavorable influence on Zooplankton. An absence of cold weather correlations between these factors was noticeable in the literature.

Although water temperature and Zooplankton seem to be unrelated, as indicated by Graphs III (Water temperature) and Graph VIII (Zooplankton), the greatest contributor to the inactivity of Zooplankton is, in all probability, water temperature. Campanile (1927) presumed that temperature controlled all plankton development, while Batchelder (1926) concluded that temperature was as much responsible as any factor for the distribution of Zooplankton. All limnologists quoted herein agree that water temperature has a partial effect upon Zooplankton activity.

Precipitation and Zooplankton appear to be unrelated, as can be seen by Graph IV (precipitation) and Graph VIII (Zooplankton). Welch (1935) states that precipitation serves as a means of furnishing nutrients in the water. Pennak (1946), however, believes that the knowledge of nutrient requirements of individual Zooplankters is almost nothing. There was no other correlation among the literature between precipitation and Zooplankton.

Reference to Graph V (suspended matter) and Graph VIII (Zooplankton) indicates no relation between suspended matter and Zooplankton. Pennak (1946) found that a major part of the food of Zooplankton was detritus which in turn was a large percentage of suspended matter. Since this is true there must be a positive correlation between suspended matter and Zooplankton.

No correlations were found between hydrogen ion concentration and Zooplankton or between bulk alkalinity and Zooplankton as can be seen by graph VI (hydrogen ion concentration), Graph VII (bulk alkalinity), and Graph VIII (Zooplankton).

2. Phytoplankton

A study of Graph IX (Phytoplankton) indicates that phytoplankton fluctuated more than Zooplankton. The initial Phytoplankton pulse preceded the initial Zooplankton pulse. There was some activity under the ice cover, as contrasted with the Zooplankton, indicating that Photosynthesis proceeds under ice if conditions are favorable. This phenomenon is supported by Welch (1935) and Chandler (1940). Chandler (1940) also reported Phytoplankton pulses throughout the year while Thompson and Johnson (1930) reported the maxima in late spring and fall. Pennok (1946) made a plankton study of seven artificial lakes and found differences in algal population among all of them but no definite seasonal pulses.

There should be a correlation between dissolved oxygen and Phytoplankton even though it does not appear in Graph I (dissolved oxygen) and Graph IX (Phytoplankton). Tressler and Austin (1939) attributed oxygen to the Photosynthetic activities of Phytoplankton while Tressler and Bere (1934) accounted for an abundance of oxygen due to the relative scarcity of life. Granapati (1943) credited the low of dissolved oxygen content to a scarcity of Phytoplankton. Akehurst (1931) attributed the swarming of Phytoplankton to the quantity of accessible oxygen. Pennok (1946) stated that nitrogen and Phosphorus were limiting factors for Phytoplankton growth. However, Gaarder (1927) added nitrogen and phosphorus to algal cultures and concluded that they did not increase the algal population or the dissolved oxygen. Rudolfs and Heukelekian (1931) proved a positive correlation in the laboratory by showing that the dissolved oxygen could be cut in half by reducing the number of algae by half.

A strong correlation exists between free carbon dioxide and Phytoplankton as can be seen by Graph II (free carbon dioxide) and Graph IX (Phytoplankton). The significant peaks on the Phytoplankton graph are marked by low points on the free carbon dioxide graph. It was evident that Phytoplankton contributed to this phenomenon by consuming carbon dioxide in the normal processes of photosynthesis. Prescott, et al. (1945), Tressler and Bere (1934b), (1936), Tressler and Austin (1939) support this theory in their reports.

Although Graph III (water temperature) and Graph IX (Phytoplankton) indicate no correlation between water temperature and Phytoplankton, water temperature is partly responsible for the little fluctuation of Phytoplankton.

It has been stated that precipitation brings in nutrient materials to plankton. However, Graph IV (precipitation) and Graph IX (Phytoplankton) show no correlation between precipitation and Phytoplankton. The literature offered little data for comparison of these two factors. Fish (1925) recorded the greatest swarms of diatoms where the greatest outwash from the land occurred. Harvey, et al. (1935) concluded that algal maxima outburst depend upon weather conditions.

No relationships could be established between suspended matter and Phytoplankton, hydrogen ion concentration and Phytoplankton, or bulk alkalinity and Phytoplankton as indicated by

Graph V (suspended matter), Graph VI (hydrogen ion concentration), Graph VII (bulk alkalinity) and Graph IX (Phytoplankton). However, some information is available as to the correlation between bulk alkalinity and Phytoplankton. Birge and Juday (1911) state that plants depend upon bicarbonates, as well as free carbon dioxide for the manufacture of organic substances in the process of photosynthetic activities. Pennok (1945a) believes that free carbon dioxide and half-bound or bicarbonates of carbon dioxide are readily available to Phytoplankton in photosynthesis. It is notable that these are general statements and do not necessarily imply a positive correlation during the months of cold weather.

3. Biotic Interrelationships

According to the literature, some of the most fundamental difficulties in the study of plankton dynamics center around ignorance of the biotic interrelationships. For example, Pennok (1946) says that very little information is available concerning the relative importance of living algae in the diet of Zooplankters under natural conditions. Graph VIII (Zooplankton) and Graph IX (Phytoplankton) indicate no correlation between Zooplankton and Phytoplankton. Chandler (1940) explains that often there are as many as ten weeks between Zooplankton and Phytoplankton pulses. Clarke (1939) says that Phytoplankton produces in ten days while Zooplankton take a month or more. This relationship serves to distort a plankton graph interpretation since currents may separate one from the other before the production may appear. While a Zooplankton pulse may equal a Phytoplankton pulse, or vice versa, the effect may appear elsewhere. Pennok (1946) states that from unpublished data in his possession, the whole picture emphasizes the fact that each body of water is distinctive and should be meticulously studied as an individual case.

A scarcity of literature concerning the food requirements, reproductive rates and competition for dissolved nutrients of Zooplankton and Phytoplankton complicate the problem of graph interpretation. At best, the graphs indicate that both Zooplankton and Phytoplankton have a common factor, cold weather, inhibiting their fluctuations.

4. Plankton

Many limnologists in their quantitative studies, do not separate Phytoplankton from Zooplankton. Therefore a part of this discussion may be devoted to a consideration of plankton production as discussed in the literature. Tressler and Bere (1938) say that soft lakes are not as productive as hard lakes. Pennok (1946) says that large lakes with regular shape, great depth, high elevation, and high latitude tend to discourage the development of large plankton populations. Also one of the greatest detriments to the development of a large plankton populations is a strong current. Juday (1942) found that the addition of organic fertilizers to Weber Lake greatly increased the plankton crop. Birge and Juday (1922) considered total seston (organic and inorganic suspended matter) as a reliable index of plankton production. Chandler (1942) states that turbidity will influence composition, time, size and occurence of plankton pulses. Riley (1941) believes that the chief limiting factors of plankton are light and turbulence and that depth is important when it limits turbulence. Brinley and Katzin (1942) find that the streams that receive the largest amount of organic pollution contain the largest number of species and individuals, which is probably associated with the amount of food available in the streams. Brandt (1929) states that the regional and seasonal fluctuations in number of species and abundance of individuals of plankton are due chiefly to fluctuations in the quantity of plankton algae, since these serve as a primary food of the other forms. Brinley (1943a) states that the decomposition of organic matter will increase plankton growth.

In accordance with Van Hoff's law, plankton populations are determined by the temperature characteristics of the lake, which in turn, are dependent upon wind, depth and insolations.

The best summation for this period is given by Allen (1922) who believes that a limnological survey will show a decrease in production of all factors as cold weather approaches.

Summary and Conclusions

Between October 23, 1947, and March 20, 1948, a study was made of certain chemical and physical factors and their possible effects upon plankton population in Westhampton Lake. A summary of the factors studied and the conclusions drawn therefrom are as follows:

A. Chemical and Physical Factors.

A review of the relationship of dissolved oxygen, free carbon dioxide, water temperature, precipitation, suspended matter, hydrogen ion concentration and bulk alkalinity indicates the following:

1. Dissolved oxygen

   a. The lake was slightly more than 100% saturated with dissolved oxygen due to photosynthetic activity of chlorophyllaceous organisms and absorption from the air.

   b. The relationship of dissolved oxygen to free carbon dioxide was inverse.

   c. Dissolved oxygen was inversely related to the temperature. The cold water increased the lake's capacity to hold oxygen and the warm water contributed to its release.

   d. The effect of precipitation upon dissolved oxygen was negligible.

   e. The fact that suspended matter was largely organic matter that decomposed as it settled and consumed oxygen in the process, accounted for the inverse relationship between suspended matter and oxygen.

f. There was no apparent relationship between the pH and dissolved oxygen or between bulk alkalinity and dissolved oxygen.

2. Free Carbon Dioxide.

a. The lake was well saturated with free carbon dioxide due mostly to decomposition. Other contributors were the atmosphere, inflowing ground water, and respiration of plants and animals.

b. Free carbon dioxide varied directly with the temperature probably because the normal rate of organic decomposition is directly influenced by temperature.

c. There was a direct relationship between free carbon dioxide and precipitation. Disregarding a time log, precipitation contributed to the release of free carbon dioxide.

d. Whenever there was suspended matter, it varied directly with carbon dioxide because it contained organic matter and decomposed as it settled.

e. Since the pH did not vary to any extent, it was not possible to establish any correlation between hydrogen ion concentration and free carbon dioxide.

f. Free carbon dioxide varied directly with the bulk alkalinity.

3. Water Temperature.

a. The transition in water temperature from warm through cold to warm again was rapid.

b. A direct correlation was established between water temperature and suspended matter.

c. There was no apparent relationship between water temperature and hydrogen ion concentration nor between water temperature andbulk alkalinity.

4. Precipitation.

a. A direct relationship existed between precipitation and suspended matter due, partly, to shore erosion and agitation of the water caused by precipitation.

b. No apparent relationship existed between precipitation and hydrogen ion concentration or between precipitation and bulk alkalinity.

5. Suspended Matter.

a. Suspended matter was not related to the hydrogen ion concentration or bulk alkalinity.

6. Hydrogen Ion Concentration.

a. The lake water was slightly acid and contained an alkali reserve.

b. The lake maintained a fairly constant pH due in part to reestablishment of equilibrium by the bulk alkalinity and to the buffer effect of carbonic acid.

c. There was no indication of a relation between the hydrogen ion concentration and bulk alkalinity.

B. Biological Factors.

A review of the relationship of dissolved oxygen, free carbon dioxide, water temperature, precipitation, suspended matter, hydrogen ion concentration and bulk alkalinity to Zooplankton and Phytoplankton indicates the following:

1. Zooplankton

a. The data indicate no relationship of Zooplankton to dissolved oxygen or water temperature.

b. The data show no correlation between Zooplankton and precipitation.

However, there was a possible relation between the two since precipitation serves to bring in nutrient materials.

c. The literature reveals that suspended matter is a source of food for Zooplankton, but no correlation was found between suspended matter and Zooplankton in the data presented.

2. Phytoplankton

a. Phytoplankton was related to dissolved oxygen because of photosynthesis and respiration.

b. Significant peaks in the Phytoplankton population correspond with minimal concentrations of free carbon dioxide which indicate probably a consumption of free carbon dioxide during photosynthesis.

c. Although the data do not indicate a relation between Phytoplankton and water temperature, other workers concede some definite correlation between the two.

d. Phytoplankton was not related to suspended matter, hydrogen ion concentration or bulk alkalinity as indicated by the data in Table I.

C. Conclusions.

A general review of the data and discussions in this paper indicates that:

1. Dissolved oxygen, water, temperature, suspended matter, and pH reflect the usual conditions that exist during a fall or spring overturn.

2. The period of ice cover marked the divisions between the fall and spring overturn.

3. The ice cover represented the period of low quantities of all factors, EXCEPT DISSOLVED OXYGEN.

4. The factors most affected during the period were dissolved oxygen, free carbon dioxide, and temperature.

5. Since overturns, activities and gases dissolved were a direct reflection of the water temperature it can be stated that the water temperature was the most significant factor during the period of study.

6. There was little fluctuation of Zooplankton during the period of study.

7. Phytoplankton fluctuated more than Zooplankton.

8. The data revealed no correlation between Zooplankton and Phytoplankton.

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Autobiography

I was born in Richmond, Virginia, on November 8, 1910. My secondary education was completed at Suffolk High School, Suffolk, Virginia, from which I was graduated in June, 1928.

In September, 1928 I matriculated at the College of William and Mary, During the ensuing four years I was elected to the Presidency of the Inter-fraternity Council, Presidency of the Philomathean Literary Society, Captaincy of the Track Team, Theta Delta Chi national social fraternity and Omicron Delta Kappa national honorary fraternity. I was graduated in June, 1932.

From 1932 to 1935 I was employed by West and Withers General Insurance Agency, Suffolk, Virginia, as a solicitor.

From 1935 to 1943 I was employed by the Travelers Insurance Company as a Field Assistant.

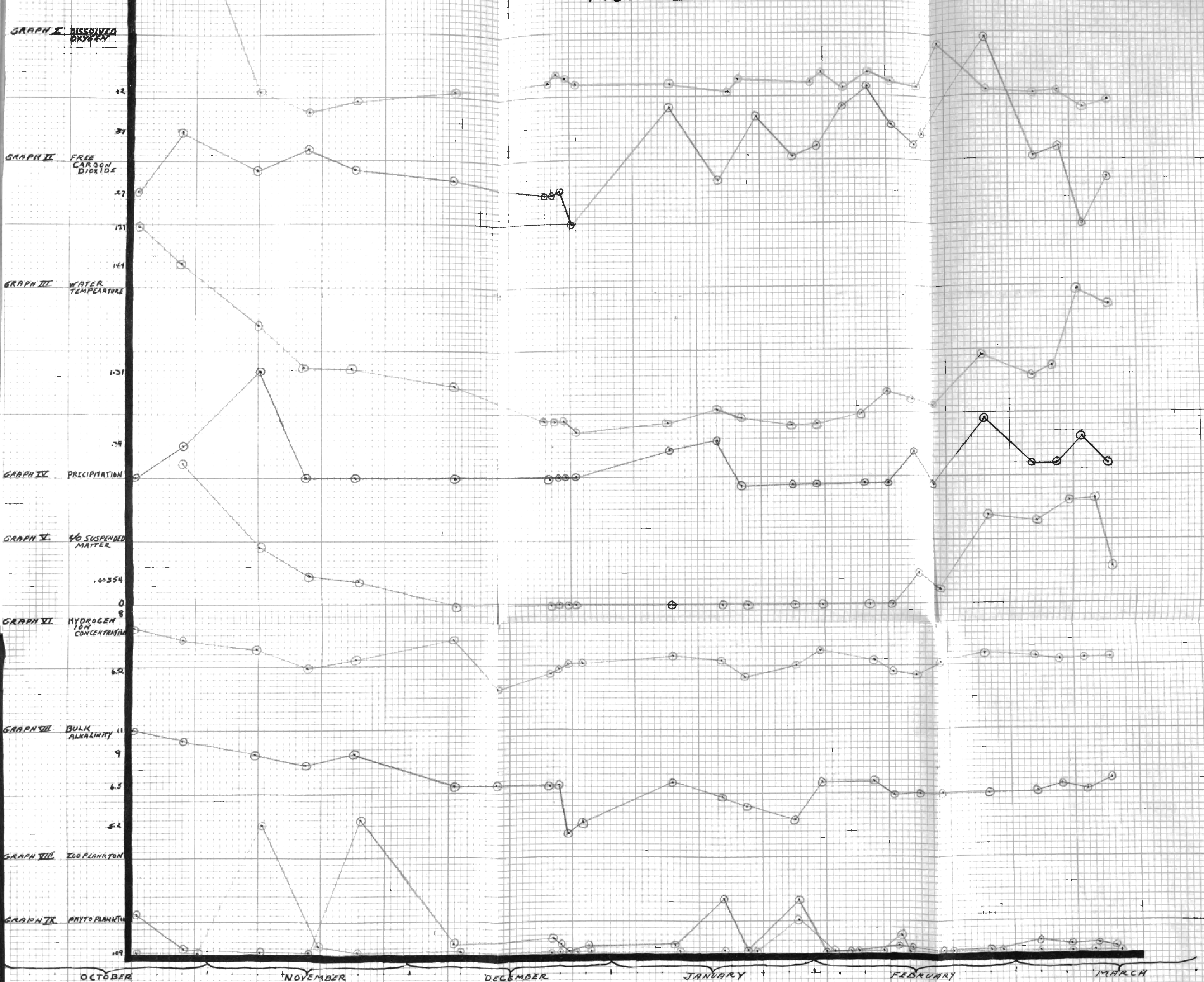
In January, 1943 I was commissioned Lieutenant junior grade in the United States Naval Reserve, served for forty-four months and was returned to inactive duty with the rank of Lieutenant Commander.

In the fall of 1946 I matriculated at the University of Richmond as a graduate student. In 1947, I reentered the University of Richmond as a candidate for the Master of Arts degree in Biology. During the fall and spring terms of 1947-1948 I was a laboratory instructor in Comparative Anatomy and was elected to Beta Beta Beta national honorary Biological fraternity.

Having satisfied all requirements for the Master of Arts degree by June, 1948, except the successful completion of a thesis, I continued my literature research and writing throughout the summer of 1948.

THE WRITER WISHES TO EXPRESS GRATITUDE FOR THE ASSISTANCE OF DR. ROBERT F. SMART AND DR. J. C. STRICKLAND, OF THE BIOLOGY STAFF OF THE UNIVERSITY OF RICHMOND, IN THE WORK DESCRIBED BY THIS PAPER.

FIGURE I


GRAPH I DISSOLVED OXYGEN
GRAPH II FREE CARBON DIOXIDE
GRAPH III WATER TEMPERATURE
GRAPH IV PRECIPITATION
GRAPH V % SUSPENDED MATTER
GRAPH VI HYDROGEN ION CONCENTRATION
GRAPH VII BULK ALKALINITY
GRAPH VIII ZOO PLANKTON
GRAPH IX PHYTO PLANKTON
12
39
27
17.7
14.4
1.31
.39
.00354
0
8
6.52
11
9
6.5
5.2
.109
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH

MATERIALS AND METHODS