THE PRODUCTIVITY OF OKLAHOMA WATERS WITH SPECIAL REFERENCE TO RELATIONSHIPS BETWEEN TURBIDITIES FROM SOIL, LIGHT PENETRATION, AND THE POPULATIONS OF PLANKTON

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TABLE OF CONTENTS

Page

LIST OF TABLES

Table		Page
XII.	The average turbidities and the average growths made by largemouth bass in Village and Metzger Ponds during six months	41
XIII.	The average numbers of phytoplankters, zooplankters, cocci, bacilli, and spirilla per liter; the average volumes of net plankton in cubic centimeters per liter; and the ranges of turbidities for the farm ponds	43
XIV.	The ranges of turbidities and the average growths made by largemouth bass in the farm ponds during six months.	48
XV.	Rankings of the twenty farm ponds on the bases of plankton productivity and turbidity	50
XVI.	The average numbers of phytoplankters, zooplankters, cocci, bacilli, and spirilla per liter; the average volumes of net plankton in cubic centimeters per liter; and the ranges of turbidities for the lakes. .	52
XVII.	Rankings of the twenty lakes on the bases of plankton productivity and turbidity.	59

LIST OF ILLUSTRATIONS

INTRODUCTION

The data herein presented concern a study of the productivity of impounded waters in Oklahoma. The relationship between turbidities from suspended soil particles and plankton was studied. Light penetration was considered to learn if plankton populations were smaller in the waters in which light penetration was decreased by turbidities from suspended soil particles.

It is generally believed that muddy waters are less productive of fish crops than are clear waters. Some people believed that poor fish crops were present in muddy waters because the fish could not see to collect their food. Others were of the opinion that food is less abundant in muddy waters. Because plankton is believed to be the basis for aquatic food chains, certain groups of plankton were studied. A study of the existing plankton crops in clear and muddy impoundments should lead to a better understanding of fish management in ponds and lakes.

The writer was unable to find in the literature a comparative study of plankton productivity in relation to turbidities from soil particles and light penetration. The literature is scant with regard to studies made on light penetration in muddy waters. The writer was unable to find in the literature a comparative study of bacterial populations in muddy waters.

The field study of the plankton productivity in clear and muddy water impoundments was started in July, 1953 and was concluded in October, 1954. The approach used in the solution of the problem was the selection of twenty farm ponds (ten with clear and ten with muddy waters) for studies of plankton productivity. Twenty lakes were later selected (ten with clear and ten with muddy waters) in order to determine if the pattern of distribution of plankton organisms would be similar to that which was to be found in the farm ponds.

Two groups of plankton were considered, net plankton and bacteria. Net plankton organisms were classified as either phytoplankton or zooplankton. Because of the involved classification of the indigenous water bacteria and because at the present time there is not a satisfactory classification, it was decided arbitrarily to use the term cocci to include all spherical forms, the term bacilli to include all rod-shaped forms, and the term spirilla to include all spiral forms. The bacteria studied included only the unicellular forms.

A method of ranking impoundments on a basis of plankton productivity and turbidity devised by Dr. W. H. Irwin is presented in the study. Some data furnished by Dr. D. Homer Buck on the growth of largemouth bass in muddy and clear farm ponds is included.

The following terms as used in the manuscript are defined.

1. Surface water is the layer of water 0-2 feet in depth in an impoundment.
2. Bottom water is the layer of water which extends upward for two feet from just above the bottom in an impoundment.
3. Clear water is water with a turbidity due to suspended soil particles of less than 25 parts per million.
4. Turbid (muddy) water is water with a turbidity from suspended soil particles of 25 or more parts per million.

5. Clear ponds and clear lakes are impoundments with waters in which the turbidity from suspended soil particles is less than 25 parts per million.

6. Turbid (muddy) ponds and turbid (muddy) lakes are impoundments in which the turbidity of the waters from suspended soil particles is 25 or more parts per million.

7. Range of turbidity or turbidity range refers to a group of various water turbidities within convenient limits.

The turbidity readings for farm ponds were placed into three turbidity ranges, namely, less than 25 ppm., 25-50 ppm., and 51-350 ppm. The numbers of organisms were averaged and listed for the turbidity range to which they belonged.

REVIEW OF LITERATURE

It is generally believed, other things being equal, that turbid waters are less productive of fish crops than are clear waters. Moen (1947) says:

> Many species of game fish depend upon light in the selection of their food. Muddy water makes their food much harder to obtain and is often the reason few fish are caught. They just can't see the bait.

Aldrich (1949) states that clear water produces more fish than muddy water. Schneberger and Jewell (1928) found an almost perfect correlation between high turbidity of water and low fish production. Swingle (1949) states that pond waters which are turbid, due to eroded soil, are unsuitable for bluegill and bass. Doan (1941 and 1942) showed that high turbidities decreased the sauger catches in the Ohio River and Lake Erie. Moore (1937) found that turbidity due to soil decreased the food available for fish and, as a result, fish productivity was decreased. The effects of turbidity on fishes are discussed by Van Oosten (1948) and Wallen (1951).

Solar energy is necessary for life. Coker (1954) says:

> Finally the contributions of the sun are heat and light, each an essential condition of life. There is no life without heat and none without light, although light and life are not necessarily immediately associated. There are animals and some plants that live in darkness, as in caves or in the depths of the sea, or under stones at the bottom of a stream; yet these all profit from the heat and light of the sun, as they depend upon ready-made organic materials which derive originally from plants living somewhere and sometime in the sunlight.

Chlorophyll-bearing organisms require light to conduct photosynthesis. Stiles (1953) says:

> Green plants grow and maintain themselves by taking into their bodies the simple substances of the air, soil, and water in which they live, and building up these simple materials into the very numerous and often very complex substances of which their tissues are composed. This synthesis of complex compounds requires energy. It is supplied by the light of the sun; hence the name photosynthesis to denote the fundamental process on which the green plants and in fact all life depend, for the bodies of green plants ultimately provide the materials on which animals and nongreen plants live.

Stiles (1953) also says, "It is accepted without question that the chlorophylls absorb the light energy which is required for photosynthesis."

For additional information and a complete bibliography on photosynthesis reference is made to Franck and Loomis (1949) and Van Niel (1949).

There is an abundance of literature on light penetration in clear waters. Certain investigators have approached the subject of light penetration in water by working with pure (distilled) water because natural waters have various substances in them which reduce light penetration. Shelford and Gail (1922) using a photoelectric cell found blue rays had the greatest penetration while red rays had the least in pure water. Small quantities of the violet, blue, green, and yellow rays penetrated pure water about 1800 meters. Clarke (1939) using a modification of the photoelectric cell (photometer) studied light transmission in pure water and found that blue rays had the greatest penetration.

Some investigators have studied light penetration in clear waters (less than 25 ppm.). Clarke (1938) using a photometer in his work off the coast of Massachusetts was able to show that the average total solar radiation received in a day's time in summer was much greater than that of winter and that this was due not only to seasonal changes in light intensity and length of day, but also to variations in the transparency of the waters. Clarke (1939) found that in clear ocean water the red rays were absorbed rapidly while the blue rays had the greatest penetration.

Some investigators have studied light penetration in stained waters. Birge and Juday (1930) used a pyrlimnometer in their work on Wisconsin lakes and found in heavily stained waters little penetration of wavelengths less than 6000 Å below a depth of one meter. The penetration of blue rays was slight while green and yellow soon disappeared with an increased depth. Red had the greatest penetration of any rays. Clarke (1939) worked on Rudolph Lake which was stained with organic matter and found not only a rapid reduction in light with depth, but also that the greatest light penetration was by the red rays.

Some investigators have studied light penetration in turbid waters. Moore (1950) working on the Cimarron River which had a high turbidity caused by soil erosion measured light by exposing photographic film at various depths. Irwin and Stevenson (1951) used a lumetron photoelectric colorimeter to measure the relative percentage of light transmission in turbid water.

Turbidity decreases light penetration in water and causes a relatively shallow photosynthetic zone. Coker (1954) says, "Because turbidity, or cloudiness reduces the penetration of sunlight, it makes the zone of photosynthesis relatively shallow and is generally unfavorable to productivity." Other investigators who express the opinion that turbidities decrease light are Irwin (1945, 1948) and

Irwin and Stevenson (1951), Ellis (1936), Silvey and Harris (1947), and Welch (1952). Ellis (1931) was of the opinion that a turbidity caused by soil does a greater amount of damage to the total productivity in water than a turbidity caused by plankton. Ellis (1936, 1937, 1944) states that organisms such as fishes and mussels are affected directly by soil turbidity by the clogging of gill structures and that the indirect effects include the screening of light. Meyer and Heritage (1941) and Meyer et al. (1943) were able to show that turbidity affected the rate at which photosynthesis took place in vascular plants.

Some investigators believe that turbidity reduces phytoplankton populations. Chandler (1940, 1942a, 1942b, 1944) and Chandler and Weeks (1945) showed that plankton pulses occurred at relatively low turbidities and that lesser populations were present in high turbidities. Prescott (1939) found that inorganic matter suspended in water tended to reduce phytoplankton production. Leonard (1950) showed evidence that turbidity was related to the reduced phytoplankton population of Lake Carl Blackwell. Langlois (1941, 1945, 1948) found that suspended erosion silt affected phytoplankton production. Aldrich (1949) says, "All green plants require sunlight and only rooted types which emerge above the surface will grow in muddy water." Corfitzen and Vetter (1939) found that suspended silt absorbed light and decreased the growth of "moss" and algae in canals. Silvey and Harris (1947) found that turbidity caused by soil affected phytoplankton production in an East Texas Lake. Harris and Silvey (1940), in some Texas lakes, found high phytoplankton numbers in waters with high turbidities and low phytoplankton numbers with low turbidities.

Several studies have been made of the indigenous water bacteria of fresh waters.

Henrici (1933) states that at the present time there is not a classification into which the indigenous water bacteria fit.

Bere (1933) made a study of certain Wisconsin lakes. He compared the direct counting method with the plate method and obtained higher numbers of bacteria by the direct method. He believed that the direct counting method gave a more accurate estimation of the bacteria present in uncontaminated waters than the plate method. He found that bacterial counts (direct method) varied from 19,000 to 2,000,000 per cubic centimeter. The numbers of bacteria were greater in the bottom water than in the surface water in some lakes; the opposite was found for others; while in still other lakes the numbers were greater at the five meter water depth which was followed by smaller numbers to the bottom waters. Cocci composed about eight per cent of the total bacterial counts.

Fred, Wilson, and Davenport (1924) working on Lake Mendota used the plate method for counting bacteria and found that bacterial counts varied from hundreds to thousands per cubic centimeter. Snow and Fred (1926) working on the same lake used both the direct counting method and the plate method and found the bacterial counts obtained by the direct counting method were about nine times greater than those obtained by the plate method. The counts obtained by the direct method ranged from 740-32,600 per cubic centimeter. They found that about ten per cent of the plated colonies were cocci. Both sets of investigators described the bacteria of Lake Mendota on the basis of their physiological characteristics and pigmentation. They found bacteria were generally uniformly distributed between the surface and the bottom, except in the hypolimnion. They believed that variations were due to season, rainfall, temperature, the physical and chemical conditions of the water, and the flora present.

Graham and Young (1934) in their work on Flathead Lake used the plate method for counting bacteria and found that bacterial counts varied from 70-6,752 per cubic centimeter. They found the smaller numbers in the surface water, and high concentrations at the five foot level and between the thirty to sixty foot level, beyond which the numbers were never greater than those in the surface water. They described the bacteria of Flathead Lake on the basis of their physiological characteristics and pigmentation. The individual organisms were isolated and the greatest number were found to be rod-shaped, whereas, the number of spherical and spiral organisms was small.

The writer was unable to find a comparative study of the distribution of bacteria in clear and turbid waters.

LOCATION OF PONDS AND LAKES STUDIED

The situations studied were farm ponds and lakes. The twenty farm ponds selected for the study ranged in surface area from 0.4 to 2.2 acres, and the twenty lakes selected had a surface area ranging from 9.0 to 43,500 acres.

Farm Ponds

The farm ponds included in the study were located in Payne County, Oklahoma. Ten clear ponds and ten turbid ponds were selected. The farm ponds were selected by matching a clear and a turbid pond on the following basis: 1. similarity in the surface area, 2. similarity in the watershed, and, 3. similarity of locality.

During the period of study, an extended drought brought water levels in all ponds and reservoirs in the region far below normal. On November 12 and 13, 1954, a survey was made in which the surface acreage at spillway level was obtained for each of the farm ponds. In order to show the shrinkage which had taken place, the area covered by water in November was measured in six of the ponds. The shrinkage was found to be about 50 per cent of the area that was covered at spillway level. Table I contains a legal description in reference to the Indian Meridian, date of construction, maximum size, size of the six measured on November 12-13, 1954, and the water level on November 12-13, 1954, for each of the twenty farm ponds selected.

Table I. A description of each of the twenty farm ponds selected.

Name of Pond	Legal Description with Reference to the Indian Meridian	Date Constructed	Maximum Size Acres	Size on Nov. 12-13, 1954, Acres	Water Level on Nov. 12-13, 1954, Feet Below Spillway Level
		Clear Ponds			
Allred #3	SW1/4 SW1/4 SE1/4 S. 16, T. 20 N., R. 3 E.	1951	0.7	—	5.5
Andrews #1	SE1/4 SE1/4 SW1/4 S. 12, T. 19 N., R. 2 E.	1949	1.8	—	4.5
Berry #1	SW1/4 NE1/4 NE1/4 S. 4, T. 18 N., R. 3 E.	1944	0.9	0.6	2.5
Fisher #1	SW1/4 SE1/4 SE1/4 S. 25, T. 19 N., R. 3 E.	1944	1.3	0.6	4.0
Leach #1	SW1/4 SE1/4 SE1/4 S. 26, T. 19 N., R. 3 E.	1940	1.1	0.7	5.0
Nelson	NE1/4 NE1/4 NE1/4 S. 16, T. 20 N., R. 2 E.	1938	0.7	—	3.0
Newsom #1	NW1/4 NW1/4 SE1/4 S. 2, T. 20 N., R. 3 E.	1944	1.8	—	6.0
Newsom #2	SW1/4 SW1/4 NE1/4 S. 2, T. 20 N., R. 3 E.	1944	2.2	—	5.5
Preston #1	NW1/4 NW1/4 SW1/4 S. 15, T. 20 N., R. 2 E.	1944	1.1	—	3.5
Village	NW1/4 NW1/4 NE1/4 S. 15, T. 19 N., R. 2 E.	1938	1.5	0.6	4.0
		Turbid Ponds			
Allred #1	NW1/4 NW1/4 SE1/4 S. 16, T. 20 N., R. 3 E.	1951	0.6	—	6.0

Table I. (Continued)

Name of Pond	Legal Description with Reference to the Indian Meridian	Date Constructed	Maximum Size Acres	Size on Nov. 12-13, 1954, Acres	Water Level on Nov. 12-13, 1954, Feet Below Spillway Level
Allred #2	SE1/4 SE1/4 NW1/4 S. 16, T. 20 N., R. 3 E.	1936	0.5	---	5.0
Allred #4	NE1/4 NW1/4 SW1/4 S. 16, T. 20 N., R. 3 E.	1951	0.6	---	5.0
Andrews #2	SW1/4 SW1/4 SW1/4 S. 12, T. 19 N., R. 2 E.	1949	1.7	0.5	2.0
Fisher #2	SW1/4 SW1/4 NE1/4 S. 24, T. 19 N., R. 3 E.	1944	1.0	0.2	5.5
Glass	SW1/4 NE1/4 NE1/4 S. 19, T. 19 N., R. 3 E.	1921	0.7	---	5.0
Leach #2	SE1/4 SE1/4 NE1/4 S. 26, T. 19 N., R. 3 E.	1946	0.4	---	4.0
Metzger	SW1/4 SW1/4 SW1/4 S. 6, T. 19 N., R. 3 E.	1944	1.5	0.3	4.0
Preston #2	NE1/4 NE1/4 SE1/4 S. 11, T. 20 N., R. 2 E.	1944	1.1	---	4.0
Ross	SW1/4 NE1/4 NW1/4 S. 9, T. 18 N., R. 3 E.	1954	1.0	0.4	5.0

Lakes

The lakes studied, ten clear and ten turbid, are reservoirs which are located in the northern two-thirds of Oklahoma. The lakes were selected on a basis of turbidity of the water, availability to the public and availability to the investigator.

Table II contains the date of construction and the number of acres impounded at spillway level for each of the twenty lakes selected.

Table II. A description of each of the twenty lakes selected.

Name of Lake		Date Constructed	Number of Acres Impounded
	Clear Water Lakes		
Canton	North Canadian River near Canton	1949	4,900
Fort Gibson	Neosho River near Fort Gibson	1951	19,000
Grand	Neosho River near Miami	1940	46,300
Hulah	Caney River near Bartlesville	1950	3,200
Pawhuska	Near Pawhuska	1937	95
Ponca	Vicinity of Ponca City	1935	805
Sanborn	Two miles north of Stillwater	1946	9
Shawnee	Near Shawnee	1935	1,336
Lower Spavinaw	Near Spavinaw	1923	1,638
Tenkiller	On Illinois River near Gore	1952	12,500
	Turbid Water Lakes		
Carl Blackwell	Stillwater Creek west of Stillwater	1937	3,380
Boomer	North of Stillwater	1925	215
Claremore City	Near Claremore	1922	470
Cushing	Near Cushing	1928	440
Liberty	Three miles east of Guthrie	1946	201
Heyburn	On Polecat Creek near Sapulpa and Bristow	1950	1,070
Perry City	Near Perry	1937	400
Pawnee City	Vicinity of Pawnee	1933	257
Tecumseh City	Near Tecumseh	1929	127
Yost	Northeast of Stillwater	1912	27

METHODS USED

Temperature

A Taylor chemical thermometer, graduated in degrees centigrade, was used to measure the temperature of the air and of the surface water. The temperature of the air was measured by holding the thermometer just above the surface of the water in the shade of the boat, and at an arm's length away from the body. The temperature of the surface water was measured by immersing the bulb of the thermometer in the water. Temperature readings were made each time data was taken on an impoundment and were later converted to degrees Fahrenheit.

Depth

The deeper waters in impoundments were located by the use of a sounding lead attached to a line which was graduated in feet. Soundings were made on each impoundment until the writer became familiar with the location of the deeper water where all the data were taken, except in the Village and Metzger Ponds where five stations on each were established.

Turbidity

Turbidities were measured in parts per million for each collection with a Jackson turbidimeter by using the method in Welch (1948).

Visibility

A Secchi disk was used to measure visibility. The disk, attached to a line, was lowered into the water until it no longer could be seen and then raised until just visible. The line was grasped at the point where it entered the water. The line and disk were withdrawn and the depth of submersion which represented depth of visibility was measured in inches along the line.

Transmission of Light

Transmission of light through turbid water was measured by the use of a Gaertner spectrophotometer in the optics laboratory of the Physics Department of Oklahoma Agricultural and Mechanical College. Turbid waters from impoundments were brought into the laboratory where they were diluted with distilled water until the desired turbidities were obtained. Each sample was read for turbidity, diluted and re-read because diluting the water with an equal volume of distilled water did not reduce the original turbidity exactly one-half.

One of the two cells of the spectrophotometer was filled with distilled water, the other with the prepared sample of turbid water and then the spectrophotometer readings were made. The spectrophotometer permitted a measurement of the transmission of each wavelength through the turbid water in comparison to the light transmitted through distilled water. The measurements were recorded in percentages. Only readings on the wavelengths within the visible spectrum were measured.

The original cells were four inches long. These four-inch cells proved to be too long to obtain readings for the higher turbidities. Therefore three more pairs of cells were made by Assistant Professor Gordon G. Smith of the Engineering Research Laboratory. The three pairs of cells were one, two, and three inches long.

A graduate student of the Physics Department was hired to read the spectrophotometer under the supervision of Associate Professor

C. Fremont Harris of the Physics Department.

The human eye is used to match colors in the spectrophotometer, thus permitting some error. The source of light is constant and the light rays pass vertically through the water sample. Any precipitation of the suspended clay will fall from the path of the rays. Thus, precipitation would result in a higher transmission reading.

Net Plankton

Net plankton samples were collected six times from each of eighteen farm ponds during a six month period starting April 16 and ending October 10, 1954. A net plankton sample generally was taken from the surface waters and at each succeeding five-foot depth. Bottom samples were not taken in ponds that were less than five feet deep. Five stations were established on both the Village and Metzger Ponds. Plankton samples were collected from each of the stations six times during the same six month period.

Net plankton samples also were taken once from each of the twenty lakes between April 10 and August 1, 1954. A sample was taken at the surface and every fifteen feet of succeeding depth.

Net plankton samples were obtained by straining 30 liters of water through a Wisconsin plankton net which was equipped with number 25 bolting silk. The concentrated samples were preserved in five per cent formalin. A Kemmerer water sampler was used to collect the water that was strained.

The examination of net plankton involved a differential count, and a volumetric measurement. Differential counts were made to determine the number of phytoplankters and the number of zooplankters per liter of water. A compound microscope (equipped with a 10X ocular and a

16 mm. objective), a Whipple ocular micrometer and a Sedgewick-Rafter counting chamber were used in counting the plankters. The numbers of phytoplankters and of zooplankters were counted in ten ocular micrometer fields which were selected at random. The numbers of each group of plankters were averaged and the number per liter was obtained by making the necessary computations.

The volumetric measurements, (Leonard, 1950), were secured by reconcentrating each sample to 3 ml. by re-straining the concentrate through a plankton bucket. The re-concentrate was placed in a centrifuge tube which was graduated in 0.004 ml. subdivisions and centrifuged at 3,000 rpm. for two minutes. The volume of plankton obtained divided by 30 (liters) gave the volume of centrifuged plankton per liter of water.

Bacteria

Water samples for bacterial counts were collected six times from each of the twenty farm ponds during a six month period starting April 16 and ending October 10, 1954. Likewise water samples for bacterial counts were taken from each of the twenty lakes between April 10 and August 1, 1954, when the net plankton samples were collected.

Water samples for bacterial counts were obtained from the 30 liters of water which had been strained through a Wisconsin plankton net in obtaining net plankton samples. Water samples were placed in glass vials and stoppered. The vials previously had been washed clean with soap and water, and rinsed in boiling water, but were not sterile. Bacterial counts were made immediately, or the water samples were packed in ice, brought into the laboratory and counted at once. Either procedure provided a bacterial count from a population which could not have changed greatly from that existing in the water in the impoundment.

Care was taken to prevent the introduction of bacteria into the water sample. Sterilization of the vials without sterilization of all other equipment would have been useless. Some of the reasons for not sterilizing the vials and the collecting equipment follow.

1. A sterilized sampler would have been necessary for each sample.
2. If the specific kinds of bacteria were to be isolated in pure cultures, greater care would have been necessary.
3. Some of the samples would have had to be packed in ice before they could be counted regardless of the sampling method used. If the iced sample would have produced a growth of bacteria, the same growth would have been possible with sterilization.
4. For surface samples, at least, the boat, oars, anchor rope, sounding lead and rope, and all other equipment would have had to be sterilized in addition to the bacteria sampler or contamination would still have been possible.
5. Any contamination from the equipment would have been proportionally low because of the large volume of water from which the sample was taken.
6. The time consumed to count a sample, including transfer of the water from the vial to the hemocytometer and counting the organisms, was not more than fifteen minutes, therefore providing a short incubation period.
7. The counting of 75 squares for averages instead of the customary 15 would reduce the effect of an occasionally introduced organism in the total count.

A hemocytometer (Stitt, Clough and Clough, 1943, p. 296) designed to count red blood cells was used to count cocci, bacilli, and spirilla.

The hemocytometer was used to count bacteria in preference to the conventional plating method because it was felt that cultural methods would not give a true picture of the bacterial population of a body of water. Since bacteria vary widely in their food, oxygen, pH, and temperature requirements, it would have been impossible to culture all of the indigenous bacteria of an impoundment on a single medium and at the same temperature. Also, the plating method would at its best be an estimate of a bacterial population since theoretically each colony in the plated medium would develop from a single bacterium. Actually, several bacteria may clump together to form a colony. The method was also of value in that a bacterial count in water could be made quickly and directly.

The water sample was well agitated in the vial and again in the pipette to insure a uniform distribution of the bacteria. Counting the bacteria was done exactly as red blood cells are counted except for two variations. 1. No dilution of the sample was made. 2. Bacteria were counted over the entire red-blood-cell field (25 squares). Three counts were made of each sample and averaged.

Since the counting field covered an area of one square mm. and a depth of one tenth of a mm. the volume of water in the counting field was 0.1 cmm. When the average number of bacteria for one field was multiplied by 10 the result was the number per cmm. Likewise 1000 times the number of bacteria per cmm. gave the number per cc., and the number per cc. multiplied by 1000 gave the number per liter.

Thus:

$N \times 10 \times 1000 \times 1000 =$ number of bacteria per liter.

Where N is the average number of bacteria in one counting field (3 counts).

PRESENTATION OF DATA

Light Penetration in Turbid Waters

The percentages of various wavelengths (4500 Å - 7000 Å) of visible light that were transmitted through waters ranging in turbidity between 25 and 350 ppm. at depths of 1 to 4 inches as measured with a spectrophotometer are shown in Table III. Readings of 0.0 percentage of light transmission means that the amount of light was reduced to the extent that it was not detectable by the human eye.

Red wavelengths (7000 Å) had the greatest penetration. Light transmission rapidly decreased as turbidity and depth were increased. Water with a turbidity of 25 ppm. permitted 24.9 per cent of the original light of 7000 Å to penetrate four inches. Water with a turbidity of 50 ppm. permitted 6.3 per cent of the original light of 7000 Å to penetrate four inches. Water with a turbidity of 150 ppm. permitted no light of any visible wavelength to pass through three inches.

Farm Pond Studies

The data obtained from each of the twenty farm ponds include Secchi disk readings; turbidity readings; numbers of phytoplankters, zooplankters, cocci, bacilli, and spirilla; and the volumes of net plankton (Appendix A).

Secchi Disk Readings

Secchi disk readings in the clear ponds ranged from a minimum reading of 14 inches to a maximum reading of 72 inches. Readings in

Table III. The penetration of visible light through various turbidities at depths of 1 to 4 inches.

	Per cent of Light Transmissity				
	1 inch cell	2 inch cell	3 inch cell	4 inch cell	turbidity
Wavelength 4500 Å	38.0	18.3	9.5	6.0	25
	16.0	5.5	2.7	1.6	50
	9.0	1.8	0.0	0.0	75
	3.5	0.0	0.0	0.0	100
	1.0	0.0	0.0	0.0	150
	1.0	0.0	0.0	0.0	200
	0.0	0.0	0.0	0.0	250
	0.0	0.0	0.0	0.0	300
	0.0	0.0	0.0	0.0	350
Wavelength 5000 Å	41.3	19.0	13.2	8.5	25
	19.0	8.4	4.1	2.0	50
	9.5	2.2	1.5	0.0	75
	6.0	0.8	0.0	0.0	100
	2.3	0.3	0.0	0.0	150
	1.7	0.0	0.0	0.0	200
	1.0	0.0	0.0	0.0	250
	0.8	0.0	0.0	0.0	300
	0.0	0.0	0.0	0.0	350
Wavelength 5500 Å	45.5	21.0	15.4	11.5	25
	21.0	11.0	5.6	2.6	50
	11.0	2.8	1.8	0.3	75
	7.0	1.3	0.5	0.0	100
	3.4	0.8	0.0	0.0	150
	2.5	0.4	0.0	0.0	200
	0.0	0.0	0.0	0.0	250
	0.0	0.0	0.0	0.0	300
	0.0	0.0	0.0	0.0	350
Wavelength 6000 Å	48.2	24.0	19.3	16.0	25
	24.3	13.0	7.4	3.5	50
	13.0	3.8	2.4	1.5	75
	9.5	1.9	1.5	0.0	100
	4.5	1.3	0.0	0.0	150
	3.3	0.9	0.0	0.0	200
	2.5	0.5	0.0	0.0	250
	1.5	0.0	0.0	0.0	300
	0.5	0.0	0.0	0.0	350

Table III. (Continued)

	Per cent of Light Transmissity				
	1 inch cell	2 inch cell	3 inch cell	4 inch cell	turbidity
Wavelength 6500 Å	53.6	26.8	22.0	20.0	25
	27.8	15.1	9.3	5.0	50
	15.5	5.5	3.2	1.9	75
	11.0	2.7	2.3	Trace	100
	5.7	1.7	0.0	0.0	150
	4.1	1.5	0.0	0.0	200
	3.3	1.3	0.0	0.0	250
	1.9	0.0	0.0	0.0	300
	0.7	0.0	0.0	0.0	350
Wavelength 7000 Å	58.0	39.2	28.0	24.9	25
	32.0	17.5	11.0	6.3	50
	19.0	7.2	4.1	2.4	75
	12.5	3.6	2.7	Trace	100
	7.0	2.3	0.0	0.0	150
	5.0	1.9	0.0	0.0	200
	3.9	1.5	0.0	0.0	250
	2.4	0.0	0.0	0.0	300
	1.0	0.0	0.0	0.0	350

the turbid ponds ranged from a minimum of 0.9 inches to a maximum of 11 inches.

Turbidity

Turbidity readings ranged from less than 25 to 350 ppm.

Plankton

Plankton data include the numbers of net plankton organisms (phytoplankton and zooplankton), the volumes of net plankton and the numbers of bacteria which include cocci, bacilli, and spirilla.

Phytoplankton. The numbers of phytoplankters per liter of water varied from pond to pond. Some of the variations found in the data included in Appendix A are listed below.

1. Clear, surface water; 5100 to 68,400.
2. Turbid, surface water; 900 to 8,700.
3. Clear, bottom water; 1100 to 54,500.
4. Turbid, bottom water; 0.0 to 3300.
5. Turbid, surface water, and clear, surface water; 900 to 68,00
6. Turbid, bottom water, and clear, bottom water; 0.0 to 54,000.

The numbers of phytoplankters in the surface waters of the clear ponds were greater than the numbers in the surface waters of turbid ones. In many instances, the numbers of phytoplankters in the bottom water of the clear ponds were greater than the numbers in the surface water of the same pond, whereas, in the turbid waters the numbers of organisms were much less in the bottom than in the surface waters.

Table IV shows the average numbers of phytoplankters per liter and the ranges of turbidities for the farm ponds. Averages of the numbers of phytoplankters are related to turbidities.

Table IV. The average numbers of phytoplankters per liter and the ranges of turbidities for the farm ponds.

		Range of Turbidity < 25 ppm.		Range of Turbidity 25 - 50 ppm.		Range of Turbidity 51 - 350 ppm.	
Collection Dates of 1954	Water Level Sampled	Phyto-plankters No./L.	No. of Ponds	Phyto-plankters No./L.	No. of Ponds	Phyto-plankters No./L.	No. of Ponds
April 16 - May 6							
	Surface	28,600	6	2,800	5	2,100	9
	Bottom	14,300	3	1,200	3	100	6
May 22 - May 27							
	Surface	23,900	9	---	0	3,700	11
	Bottom	12,700	6	---	0	300	7
June 18 - June 23							
	Surface	43,700	9	5,200	2	3,100	9
	Bottom	22,000	6	600	2	600	5
July 17 - July 31							
	Surface	16,600	8	4,500	5	2,400	7
	Bottom	9,100	5	900	1	300	5
Sept. 11 - Sept. 15							
	Surface	27,500	8	6,700	5	2,300	7
	Bottom	9,100	5	900	1	300	5
Sept. 19 - Oct. 10							
	Surface	34,200	9	9,400	6	1,900	5
	Bottom	25,300	4	1,700	3	300	5

1. The numbers of phytoplankters were greater in the waters within the range of turbidity of less than 25 ppm. and while the larger numbers were found in the surface waters, the difference in numbers between the surface and the bottom waters was small.
2. The numbers of phytoplankters were markedly smaller in the waters within the range of turbidity of 25-50 ppm. than in the waters within the range of turbidity of less than 25 ppm. Phytoplankters were fewer in the bottom waters than in the surface waters.
3. The numbers of phytoplankters were still smaller both in the surface waters and in the bottom waters within the range of turbidity of 51-350 ppm. than in waters within the turbidity range of 25-50 ppm. and phytoplankters were less abundant in the bottom waters than in the surface waters.

Zooplankton. The same pattern of distribution in the surface and bottom waters found for the phytoplankters held true for the zooplankters.

The numbers of zooplankters per liter of water varied from pond to pond. Some of the variations found in the data included in Appendix A are listed below.

1. Clear, surface water; 100 to 18,200.
2. Turbid, surface water; 0.0 to 2100.
3. Clear, bottom water; 0.0 to 15,600.
4. Turbid, bottom water; 0.0 to 1000.
5. Turbid, surface water and clear, surface water; 0.0 to 18,200.

While the maximum numbers of zooplankters in the clear ponds usually occurred in the surface water, there were several instances in which the numbers in the bottom water were greater than the numbers in the surface water.

Table V shows the average numbers of zooplankters per liter and the ranges of turbidities for the farm ponds.

Averages of the numbers of zooplankters are related to turbidities.

1. The numbers of zooplankters were greater in the waters within the turbidity range of less than 25 ppm. and were less in the bottom waters than in the surface waters.
2. The numbers of zooplankters were smaller in the waters within the turbidity range of 25-50 ppm. than in the waters within the turbidity range of less than 25 ppm. and were less in the bottom waters than in the surface waters.
3. The numbers of zooplankters were smaller in the waters within the turbidity range of 51-350 ppm. than in the waters within the turbidity range of 25-50 ppm. and were less in the bottom waters than in the surface waters.

Net plankton volume. The volume of net plankton was measured to aid in the determination of productivity.

The volume of net plankton in cubic centimeters per liter of water varied from pond to pond. Some of the variations found in the data included in Appendix A are listed below.

1. Clear, surface water; 0.0020 to 0.0421.
2. Turbid, surface water; 0.0008 to 0.0071.
3. Clear, bottom water; 0.0009 to 0.0241.
4. Turbid, bottom water; 0.0002 to 0.0033.

Table V. The average numbers of zooplankters per liter and the ranges of turbidities for the farm ponds.

Collection Dates of 1954	Water Level Sampled	Range of Turbidity < 25 ppm.		Range of Turbidity 25 - 50 ppm.		Range of Turbidity 51 - 350 ppm.	
		Zoo-plankters No./L.	No. of Ponds	Zoo-plankters No./L.	No. of Ponds	Zoo-plankters No./L.	No. of Ponds
April 16 - May 6							
	Surface	11,000	6	700	5	300	9
	Bottom	6,000	3	100	3	0	6
May 22 - May 27							
	Surface	4,200	9	---	0	500	11
	Bottom	2,300	6	---	0	100	7
June 18 - June 23							
	Surface	500	9	400	2	100	9
	Bottom	300	6	0	2	0	4
July 17 - July 31							
	Surface	1,400	8	500	5	300	7
	Bottom	700	5	100	1	0	5
Sept. 11 - Sept. 15							
	Surface	2,800	8	900	5	400	7
	Bottom	1,300	4	100	2	0	3
Sept. 19 - Oct. 10							
	Surface	5,200	9	1,800	6	300	5
	Bottom	3,000	4	400	3	0	2

5. Turbid, surface water and clear, surface water; 0.0008 to 0.0421.

6. Turbid, bottom water and clear, bottom water; 0.0002 to 0.0241.

Table VI shows the volume averages of net plankton in cubic centimeters per liter and the ranges of turbidities for the farm ponds

Averages of the volumes of net plankton are related to turbidities.

1. The volumes of the net plankton were greater in the waters within the turbidity range of less than 25 ppm. and while the volumes were usually less in the bottom waters than in the surface waters, the difference was small.

2. The volumes of the net plankton were markedly smaller in the waters within the turbidity range of 25-50 ppm. than in the waters within the turbidity range of less than 25 ppm. both in the surface waters and the bottom waters and were much less in the bottom waters than in the surface waters.

3. The volumes of the net plankton were smaller in the waters wi the turbidity range of 51-350 ppm. than in the waters within the turbidity range of 25-50 ppm. both in the surface waters and the bottom waters and were much less in the bottom waters than in the surface waters.

Cocci. The cocci were a small portion of the bacterial populations in farm ponds.

The numbers of cocci per liter of water varied from pond to pond. Some of the variations found in the data included in Appendix A are listed below.

Table VI. The average volumes of net plankton in cubic centimeters per liter and the ranges of turbidities for the farm ponds.

Collection Dates of 1954	Water Level Sampled	Range of Turbidity < 25 ppm. Net Plankton Volume cc./L.	No. of Ponds	Range of Turbidity 25 - 50 ppm. Net Plankton Volume cc./L.	No. of Ponds	Range of Turbidity 51 - 350 ppm. Net Plankton Volume cc./L.	No. of Ponds
April 16 - May 6							
	Surface	0.0289	6	0.0020	5	0.0015	9
	Bottom	0.0153	3	0.0013	3	0.0003	6
May 22 - May 27							
	Surface	0.0017	9	---	0	0.0029	11
	Bottom	0.0023	6	---	0	0.0001	7
June 18 - June 23							
	Surface	0.0181	9	0.0025	2	0.0015	9
	Bottom	0.0100	6	0.0007	2	0.0005	5
July 17 - July 31							
	Surface	0.0118	8	0.0021	5	0.0014	5
	Bottom	0.0066	5	0.0006	1	0.0004	5
Sept. 11 - Sept. 15							
	Surface	0.0173	8	0.0044	5	0.0018	7
	Bottom	0.0090	4	0.0012	2	0.0005	3
Sept. 19 - Oct. 10							
	Surface	0.0208	9	0.0057	6	0.0015	5
	Bottom	0.0149	4	0.0017	3	0.0003	2

1. Clear, surface water; 3,000,000 to 50,000,000.

2. Turbid, surface water; 0.0 to 30,000,000.

3. Clear, bottom water; 3,000,000 to 70,000,000.

4. Turbid, bottom water; 0.0 to 30,000,000.

5. Turbid, surface water and clear, surface water; 0.0 to 50,000,000.

6. Turbid, bottom water and clear, bottom water; 0.0 to 70,000,000.

Table VII shows the average numbers of cocci per liter and the ranges of turbidities for the farm ponds.

Averages of the numbers of cocci are related to turbidities.

1. The greater numbers of cocci were in the waters within the turbidity range of less than 25 ppm. and the numbers were greater in the bottom waters than in the surface waters.

2. The numbers of cocci were markedly smaller in waters within the turbidity range of 25-50 ppm. than in the waters within the range of less than 25 ppm. and cocci numbers were much less in the bottom waters than in the surface waters.

3. The numbers of cocci were smaller in the waters within the turbidity range of 51-350 ppm. than in the waters within the range of 25-50 ppm. and the numbers were less in the bottom waters than in the surface waters.

Bacilli. Bacilli were the most numerous bacteria in the farm pond waters.

The numbers of bacilli per liter of water varied from pond to pond. Some of the variations found in the data included in Appendix A are listed below.

Table VII. The average numbers of cocci per liter and the ranges of turbidities for the farm ponds.

Collection Dates of 1954	Water Level Sampled	Range of Turbidity < 25 ppm. Cocci No./L.	No. of Ponds	Range of Turbidity 25 - 50 ppm. Cocci No./L.	No. of Ponds	Range of Turbidity 51 - 350 ppm. Cocci No./L.	No. of Ponds
April 16 - May 6							
	Surface	14,000,000	6	3,000,000	5	3,000,000	9
	Bottom	7,000,000	3	3,000,000	3	1,000,000	6
May 22 - May 27							
	Surface	15,000,000	9	---	0	7,000,000	11
	Bottom	20,000,000	6	---	0	3,000,000	7
June 18 - June 23							
	Surface	19,000,000	9	9,000,000	2	8,000,000	9
	Bottom	27,000,000	6	4,000,000	2	2,000,000	5
July 17 - July 31							
	Surface	14,000,000	8	11,000,000	5	3,000,000	7
	Bottom	17,000,000	5	10,000,000	1	3,000,000	5
Sept. 11 - Sept. 15							
	Surface	21,000,000	8	16,000,000	5	5,000,000	7
	Bottom	27,000,000	4	8,000,000	2	6,000,000	3
Sept. 19 - Oct. 10							
	Surface	30,000,000	9	18,000,000	6	5,000,000	5
	Bottom	58,000,000	4	22,000,000	3	7,000,000	2

1. Clear, surface water; 22,000,000 to 147,000,000.

2. Turbid, surface water; 10,000,000 to 62,000,000.

3. Clear, bottom water; 5,000,000 to 163,000,000.

4. Turbid, bottom water; 3,000,000 to 50,000,000.

5. Turbid, surface water and clear, surface water; 10,000,000 to 147,000,000.

6. Turbid, bottom water and clear, bottom water; 3,000,000 to 163,000,000.

Table VIII shows the average numbers of bacilli per liter and the ranges of turbidities for the farm ponds.

Averages of the numbers of bacilli are related to turbidities.

1. The greater numbers of bacilli were in the waters within the turbidity range of less than 25 ppm. and the numbers were greater in the bottom waters than in the surface waters.

2. The numbers of bacilli were markedly smaller in the waters within the turbidity range of 25-50 ppm. than in the waters within the range of turbidity of less than 25 ppm. and were much less in the bottom waters than in the surface waters.

3. The numbers of bacilli were smaller in the waters in the turbidity range of 51 or more ppm. than in the waters within the range of turbidity of 25-50 ppm. and were smaller in the bottom waters than in the surface waters.

<u>Spirilla</u>. Spirilla in the pond waters formed a small part of the total bacterial counts. They were always found in lesser numbers than the cocci or bacilli.

The numbers of spirilla per liter of water varied from pond to pond. Some of the variations found in the data included in Appendix A

Table VIII. The average numbers of bacilli per liter and the ranges of turbidities for the farm ponds.

Collection Dates of 1954	Water Level Sampled	Range of Turbidity < 25 ppm.		Range of Turbidity 25 - 50 ppm.		Range of Turbidity 51 - 350 ppm.	
		Bacilli No./L.	No. of Ponds	Bacilli No./L.	No. of Ponds	Bacilli No./L.	No. of Ponds
April 16 - May 6							
	Surface	41,000,000	6	20,000,000	5	15,000,000	9
	Bottom	60,000,000	3	11,000,000	3	8,000,000	6
May 22 - May 27							
	Surface	53,000,000	9	---	0	26,000,000	11
	Bottom	59,000,000	6	---	0	11,000,000	7
June 18 - June 23							
	Surface	68,000,000	9	20,000,000	2	25,000,000	9
	Bottom	73,000,000	6	10,000,000	2	9,000,000	5
July 17 - July 31							
	Surface	42,000,000	8	25,000,000	5	19,000,000	7
	Bottom	39,000,000	5	20,000,000	1	14,000,000	5
Sept. 11 - Sept. 15							
	Surface	54,000,000	8	33,000,000	5	15,000,000	7
	Bottom	63,000,000	4	29,000,000	2	16,000,000	3
Sept. 19 - Oct. 10							
	Surface	71,000,000	9	42,000,000	6	16,000,000	5
	Bottom	98,000,000	4	43,000,000	3	12,000,000	2

are listed below.

1. Clear, surface water; 0.0 to 14,000,000.

2. Turbid, surface water; 0.0 to 17,000,000.

3. Clear, bottom water; 0.0 to 26,000,000.

4. Turbid, bottom water; 3,000,000 to 20,000,000.

5. Turbid, surface water and clear, surface water; 0.0 to 14,000,000.

6. Turbid, bottom water and clear, bottom water; 0.0 to 26,000,000.

Table IX shows the average numbers of spirilla per liter and the ranges of turbidities for the farm ponds.

Averages of the spirilla numbers are related to turbidities.

1. The greater numbers of spirilla were found in the waters within the turbidity range of less than 25 ppm.

2. The numbers of spirilla were markedly smaller in the waters within the turbidity range of 25-50 ppm. than in the waters within the range of turbidity of less than 25 ppm.

3. The numbers of spirilla were smaller in the waters within the turbidity range of 51-350 ppm. than in the waters within the turbidity range of 25-50 ppm.

4. The numbers of spirilla in the waters in all three turbidity ranges were greater in the bottom waters than in the surface waters.

Special Farm Pond Studies

Village Pond, the water of which remained clear, and Metzger Pond, the water of which remained turbid, were selected for a more intensive study concerning the effects of turbidity on plankton

Table IX. The average numbers of spirilla per liter and the ranges of turbidities for the farm ponds.

Collection Dates of 1954	Water Level Sampled	Range of Turbidity < 25 ppm. Spirilla No./L.	No. of Ponds	Range of Turbidity 25 - 50 ppm. Spirilla No./L.	No. of Ponds	Range of Turbidity 51 - 350 ppm. Spirilla No./L.	No. of Ponds
April 16 - May 6							
	Surface	3,000,000	6	4,000,000	5	7,000,000	9
	Bottom	7,000,000	3	3,000,000	3	7,000,000	6
May 22 - May 27							
	Surface	3,000,000	9	—	0	7,000,000	11
	Bottom	6,000,000	6	—	0	7,000,000	7
June 18 - June 23							
	Surface	8,000,000	9	7,000,000	2	7,000,000	9
	Bottom	14,000,000	6	9,000,000	2	8,000,000	5
July 17 - July 31							
	Surface	5,000,000	8	4,000,000	5	5,000,000	7
	Bottom	8,000,000	5	10,000,000	1	7,000,000	5
Sept. 11 - Sept. 15							
	Surface	6,000,000	8	5,000,000	5	8,000,000	7
	Bottom	10,000,000	4	7,000,000	2	15,000,000	3
Sept. 19 - Oct. 10							
	Surface	8,000,000	9	6,000,000	6	4,000,000	5
	Bottom	15,000,000	4	11,000,000	3	4,000,000	2

productivity.

Five stations each in Village Pond and in Metzger Pond were located as follows: station 1, above the dam in the deeper waters; station 2, in the end of the pond opposite the dam; station 3, in shallow water on the left side when facing station 2 from the dam; station 4, on the right side of the pond in shallow water directly across from station 3; and station 5, between stations 3 and 4 in the center of the pond and approximately half way between stations 1 and 2.

The data obtained at the ten stations in Village and Metzger Ponds are shown in Appendix B.

Plankton productivity. Table X shows the average plankton production for the ten stations of Village Pond and Metzger Pond.

Table XI shows the average plankton production of the surface waters when the five stations of Village Pond and the five stations of Metzger Pond were averaged.

The numbers of phytoplankters, zooplankters, cocci, bacilli, spirilla, and the volumes of net plankton in Village Pond everywhere were greater than the numbers found in Metzger Pond.

Fish growth. The data presented in Table XII were obtained from Dr. D. Homer Buck who studied largemouth bass growth in the same twenty ponds.

Village Pond (clear) had a higher plankton productivity than Metzger Pond (turbid) and also had greater fish growth. The average gain in length of largemouth bass in Village Pond was 3.3 times greater than that made in Metzger Pond and the average gain in weight was 7.5 times greater.

Table X. The average numbers of phytoplankters, zooplankters, cocci, bacilli, and spirilla per liter; the average volumes of net plankton in cubic centimeters per liter; and the average turbidities for each of the ten stations of Village and Metzger Ponds.

	Village Pond April 16 - Oct. 10, 1954 Average Turbidity < 25 ppm.		Metzger Pond April 26 - Oct. 10, 1954 Average Turbidity 199.8 ppm.	
	Station 1		Station 1	
Plankton	Surface	Bottom	Surface	Bottom
Phytoplankton	41,500	16,900	1,400	200
Zooplankton	6,600	1,100	200	0
Net Plankton Volume	0.0299	0.0108	0.0012	0.0003
Cocci	27,000,000	39,000,000	5,000,000	2,000,000
Bacilli	59,000,000	167,000,000	16,000,000	9,000,000
Spirilla	4,000,000	15,000,000	5,000,000	9,000,000
	Station 2		Station 2	
	Surface	Bottom	Surface	Bottom
Phytoplankton	65,000	---	1,700	---
Zooplankton	12,700	---	800	---
Net Plankton Volume	0.0475	---	0.0014	---
Cocci	32,000,000	---	7,000,000	---
Bacilli	248,000,000	---	20,000,000	---
Spirilla	19,000,000	---	6,000,000	---
	Station 3		Station 3	
	Surface	Bottom	Surface	Bottom
Phytoplankton	56,400	---	2,000	---
Zooplankton	10,600	---	300	---
Net Plankton Volume	0.0386	---	0.0015	---
Cocci	57,000,000	---	3,000,000	---
Bacilli	309,000,000	---	21,000,000	---

Table X. (Continued)

Plankton	Village Pond April 16 - Oct. 10, 1954 Average Turbidity < 25 ppm.		Metzger Pond April 26 - Oct. 10, 1954 Average Turbidity 199.8 ppm.	
	Station 3		Station 3	
	Surface	Bottom	Surface	Bottom
Spirilla	22,000,000	—	7,000,000	—
	Station 4		Station 4	
	Surface	Bottom	Surface	Bottom
Phytoplankton	55,700	—	1,000	—
Zooplankton	10,300	—	300	—
Net Plankton Volume	0.0442	—	0.0016	—
Cocci	50,000,000	—	5,000,000	—
Bacilli	236,000,000	—	18,000,000	—
Spirilla	22,000,000	—	9,000,000	—
	Station 5		Station 5	
	Surface	Bottom	Surface	Bottom
Phytoplankton	40,300	16,000	2,000	—
Zooplankton	7,100	1,200	200	—
Net Plankton Volume	0.0322	0.0112	0.0014	—
Cocci	26,000,000	42,000,000	5,000,000	—
Bacilli	97,000,000	128,000,000	25,000,000	—
Spirilla	7,000,000	18,000,000	9,000,000	—

Table XI. The average numbers of phytoplankters, zooplankters, cocci, bacilli and spirilla per liter; the average volumes of net plankton in cubic centimeters per liter; and the average turbidities for Village and Metzger Ponds when the five stations on each pond are averaged.

	Village Pond April 16 - Oct. 10, 1954 Average Turbidity < 25 ppm.	Metzger Pond April 26 - Oct. 10, 1954 Average Turbidity 199.8 ppm.
Plankton	Surface	Surface
Phytoplankton	51,900	1,800
Zooplankton	9,500	300
Net Plankton Volume	0.0385	0.0014
Cocci	39,000,000	5,000,000
Bacilli	190,000,000	20,000,000
Spirilla	13,000,000	7,000,000

Table XII. The average turbidities and the average growths made by largemouth bass in Village and Metzger Ponds during six months

Name of Pond	Average Turbidity ppm.	Largemouth Bass Growth in Inches	 Weight Increase in Pounds
Village	<25	6.06	0.658
Metzger	199.8	1.82	0.087

Averages of Numbers of Phytoplankters, Zooplankters, Cocci, Bacilli, Spirilla, and Volumes of Net Plankton for the Six Collection Periods

Table XIII and Figure 1 show the averages of the numbers of phytoplankters, zooplankters, cocci, bacilli, and spirilla; the average volumes of net plankton; and the ranges of turbidities for the farm ponds.

Phytoplankton. Averages of the numbers of phytoplankters are related to turbidities.

1. The numbers of phytoplankters were greater in the waters within the turbidity range of less than 25 ppm. and were 43 per cent less in the bottom waters than in the surface waters.
2. The numbers of phytoplankters were markedly smaller in the waters within the turbidity range of 25-50 ppm. than in the waters within the range of turbidity of less than 25 ppm., both in the surface waters (81 per cent) and in the bottom waters (93 per cent), and were 79 per cent less in the bottom waters than in the surface waters within the 25-50 ppm. range of turbidity.
3. The numbers of phytoplankters were smaller in the waters within the turbidity range of 51-350 ppm. than in the waters within the range of turbidity of 25-50 ppm., both in the surface waters (49 per cent) and in the bottom waters (73 per cent), and were 89 per cent less in the bottom waters than in the surface waters within the 51-350 ppm. range of turbidity.

Zooplankton. Averages of the numbers of zooplankters are related to turbidities.

Table XIII. The average numbers of phytoplankters, zooplankters, cocci, bacilli, and spirilla per liter; the average volumes of net plankton in cubic centimeters per liter; and the ranges of turbidities for the farm ponds.

	Surface averages based on those ponds for which bottom samples were taken				Surface averages based on twenty ponds			
	Water Level	Range of Turbidity ppm.			Water Level	Range of Turbidity ppm.		
Plankton	Sampled	< 25	25-50	51-350	Sampled	< 25	25-50	51-350
Phyto-plankton	Surface	26,800	5,200	2,600	Surface	28,600	6,000	2,600
	Bottom	15,000	1.100	300				
Zoo-plankton	Surface	3,300	1,100	400	Surface	3,500	1,200	400
	Bottom	1,900	200	0				
Net Plankton Volume	Surface	0.0164	0.0029	0.0017	Surface	0.0187	0.0037	0.0019
	Bottom	0.0111	0.0012	0.0004				
Cocci	Surface	19,000,000	10,000,000	5,000,000	Surface	19,000,000	12,000,000	5,000,000
	Bottom	29,000,000	10,000,000	2,000,000				
Bacilli	Surface	47,000,000	27,000,000	20,000,000	Surface	55,000,000	29,000,000	20,000,000
	Bottom	65,000,000	24,000,000	11,000,000				
Spirilla	Surface	5,000,000	5,000,000	4,000,000	Surface	6,000,000	4,000,000	6,000,000
	Bottom	17,000,000	8,000,000	7,000,000				

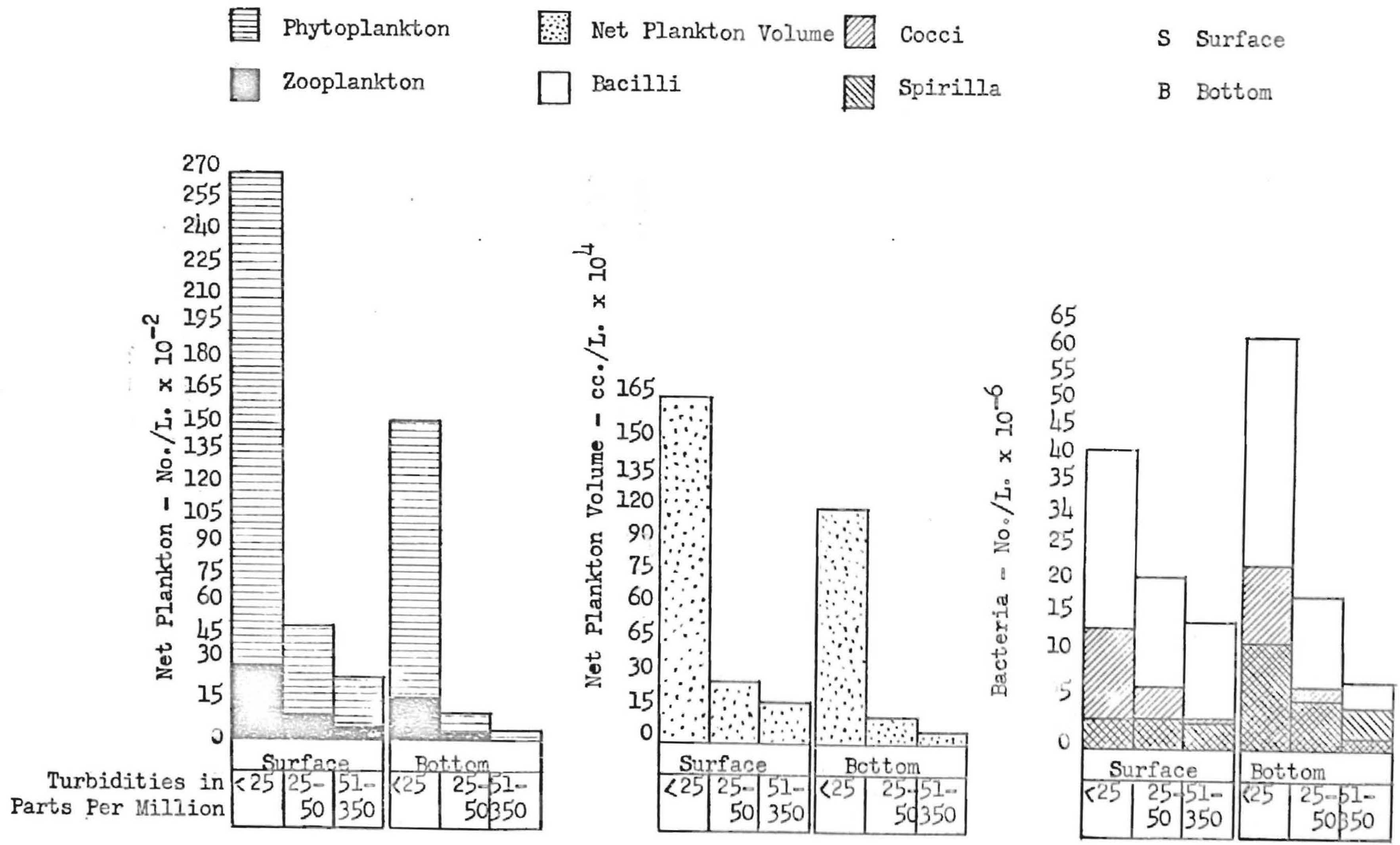

Figure 1. The average numbers of phytoplankters, zooplankters, cocci, bacilli, and spirilla per liter; the average volumes of net plankton in cubic centimeters per liter; and the ranges of turbidities for the farm ponds.

1. The numbers of zooplankters were greater in the waters within the turbidity range of less than 25 ppm. and were 32 per cent less in the bottom waters than in the surface waters.
2. The numbers of zooplankters were markedly smaller in the waters within the turbidity range of 25-50 ppm. than in the waters within the turbidity range of less than 25 ppm., both in the surface waters (67 per cent) and in the bottom waters (89 per cent), and were 82 per cent less in the bottom waters than in the surface waters.
3. The numbers of zooplankters were smaller in the waters within the turbidity range of 51-350 ppm. than in the waters within the turbidity range of 25-50 ppm., both in the surface waters (64 per cent) and in the bottom waters (100 per cent).

Net plankton volume. Averages of the volumes of net plankton are related to turbidities.

1. The volumes of net plankton were greater in the waters within the turbidity range of less than 25 ppm. and were 33 per cent less in the bottom waters than in the surface waters.
2. The volumes of net plankton were markedly smaller in the waters within the turbidity range of 25-50 ppm. than in the waters within the turbidity range of less than 25 ppm., both in the surface waters (83 per cent) and in the bottom waters (89 per cent), and were 59 per cent less in the bottom waters than in the surface waters.
3. The volumes of net plankton were smaller in the waters within the turbidity range of 51-350 ppm. than in the waters within

the turbidity range of 25-50 ppm., both in the surface waters (41 per cent) and in the bottom waters (67 per cent), and were less in the bottom waters than in the surface waters.

Cocci. Averages of the numbers of cocci are related to turbidities.

1. The numbers of cocci were greater in the waters within the turbidity range of less than 25 ppm. and were 152 per cent greater in the bottom waters than in the surface waters.
2. The numbers of cocci were markedly smaller in the waters within the turbidity range of 25-50 ppm. than in the waters within the turbidity range of less than 25 ppm., both in the surface waters (47 per cent) and in the bottom waters (66 per cent), and the numbers in the surface waters and the bottom waters were the same.
3. The numbers of cocci were smaller in the waters within the turbidity range of 51-350 ppm. than in the waters within the turbidity range of 25-50 ppm., both in the surface waters (50 per cent) and in the bottom waters (80 per cent), and were 60 per cent less in the bottom waters than in the surface waters.

Bacilli. Averages of the numbers of bacilli are related to turbidities.

1. The numbers of bacilli were greater in the waters within the turbidity range of less than 25 ppm. and were 138 per cent greater in the bottom waters than in the surface waters.

2. The numbers of bacilli were markedly smaller in the waters within the tubidity range of 25-50 ppm. than in the waters within the turbidity range of less than 25 ppm., both in the surface waters (43 per cent) and in the bottom waters (63 per cent), and were 11 per cent less in the bottom waters than in the surface waters.

3. The numbers of bacilli were smaller in the waters within the turbidity range of 51-350 ppm. than in the waters within the turbidity range of 25-50 ppm., both in the surface waters (26 per cent) and in the bottom waters (54 per cent), and were 45 per cent less in the bottom waters than in the surface waters.

Spirilla. Averages of the numbers of spirilla are related to turbidities.

1. The numbers of spirilla were greater in the bottom waters within the turbidity range of less than 25 ppm. and were 340 per cent greater in the bottom waters than in the surface waters.

2. The numbers of spirilla for the bottom waters were markedly smaller (48 per cent) within the turbidity range of 25-50 ppm. than in the waters within the turbidity range of less than 25 ppm. but were the same in the surface waters for the two turbidity ranges.

3. The numbers of spirilla were smaller in the waters within the turbidity range of 51-350 ppm. than in the waters within the turbidity range of 25-50 ppm., both in the surface waters (20 per cent) and in the bottom waters (12 per cent)

and were 175 per cent greater in the bottom waters than in the surface waters.

Largemouth bass growth. Average growths of the largemouth bass in the farm ponds are related to turbidities (Table XIV).

1. The best bass growths were made in the waters within the turbidity range of less than 25 ppm.
2. The bass growths were less in waters within the turbidity range of 25-50 ppm.
3. The bass growths were still less in waters within the turbidity range of 51-350 ppm. than in the waters within the turbidity range of 25-50 ppm.

Table XIV. The ranges of turbidities and the average growths made by largemouth bass in the farm ponds during six months.

Turbidity Range	Largemouth Bass Growth in the Twenty Farm Ponds	
	Length Increase in Inches	Weight Increase in Pounds
< 25	4.28	0.426
25-50	2.61	0.221
51-350	2.43	0.206

Rankings of Farm Ponds

The twenty farm ponds were ranked on a basis of their plankton productivity and turbidity.

1. The average numbers of phytoplankters in the surface water was computed for each of the twenty ponds. The ponds were then ranked in a descending order with the pond having the highest average number listed as number

one, and the pond with the lowest average, number 20.

2. The ponds were likewise ranked independently on the bases of the average numbers of zooplankton, cocci, bacilli, spirilla, and on the volume of net plankton.
3. The assigned number of each pond in the primary ranking was used as the numerical value of that pond. The numerical values for each pond were added for a composite ranking. (Example. Preston Pond Number 1 was ranked two for phyto-plankton, one for zooplankton, one for volume of net plankton, two for cocci, one for bacilli, and one for spirilla. The numbers were added which gave Preston Pond Number 1 a numerical value of eight.) The ponds were next listed in order of the composite rank. The pond with the lowest numerical value was then called number one and represented the highest productivity while the pond with the highest numerical value was called number twenty and represented the lowest productivity.
4. The ponds with their turbidity readings were listed in order. When turbidity readings of less than 25 ppm. occurred the Secchi disk reading was used to determine the rank.

Table XV shows the rankings for the twenty farm ponds.

Table XV. Ranking of the twenty farm ponds on the bases of plankton productivity and turbidity.

Ranking on the basis of plankton productivity. Highest productivity first.		Ranking on the basis of turbidity. Lowest turbidity first.		
Name of Pond	Rank	Name of Pond	Average Turbidity ppm.	Visibility of Secchi disk Inches*
Preston #1	1	Leach #1	< 25	42.7
Berry #1	2	Nelson	< 25	38.7
Village	3	Village	< 25	37.0
Nelson	4	Preston #1	< 25	31.1
Fisher #1	5	Newsom #1	< 25	30.5
Leach #1	6	Berry #1	< 25	27.0
Newsom #1	7	Newsom #2	< 25	25.7
Newsom #2	8	Fisher #1	25.5	15.2
Leach #2	9	Andrews #1	38.0	10.8
Allred #2	10	Fisher #2	44.5	9.1
Allred #3	11	Leach #2	50.1	10.3
Ross	12	Allred #2	65.5	6.5
Glass	13	Allred #3	68.0	7.5
Fisher #2	14	Andrews #2	74.3	5.9
Andrews #1	15	Glass	97.8	6.3
Andrews #2	16	Ross	105.1	6.0
Allred #4	17	Allred #1	115.5	3.7
Allred #1	18	Allred #4	129.5	3.6
Metzger	19	Metzger	199.8	2.5
Preston #2	20	Preston #2	213.5	2.9

*Secchi disk readings were used to determine the rank of ponds with turbidities of less than 25 ppm.

Lake Studies

The twenty lakes were studied in a manner similar to the procedure used on ponds, except that only one series of records was made for each lake. Although all data were collected during the spring and summer of 1954, a rather wide time span exists between the dates on which some of the data were collected.

The data obtained from each of the lakes include: readings for Secchi disk and turbidity; volumes of net plankton; and, numbers of phytoplankters, zooplankters, cocci, bacilli, and spirilla (Appendix C). The data from the lakes show general conditions but cannot be compared in detail because of the time span between the dates of the records.

Secchi Disk

Secchi disk readings in the clear lakes ranged from a minimum reading of 16 inches to a maximum reading of 96 inches. Readings in the turbid lakes ranged from a minimum of two inches to a maximum of nine inches.

Turbidity

Turbidity readings ranged from less than 25 to 255 ppm.

Plankton

Table XVI and Figure 2 show the average numbers of phytoplankters, zooplankters, cocci, bacilli and spirilla per liter; the average volumes of net plankton in cubic centimeters per liter; and the ranges of turbidities for the lakes.

Phytoplankton. Averages of the numbers of phytoplankters are related to turbidities.

Table XVI. The average numbers of phytoplankters, zooplankters, cocci, bacilli, and spirilla per liter; the average volumes of net plankton in cubic centimeters per liter; and the ranges of turbidities for the lakes.

Plankton	Water Level Sampled	Range of Turbidity ppm. Less than 25	25-50	51-255
Phytoplankton No./L.	Surface	14,900	3,200	2,200
	Bottom	4,700	600	300
Zooplankton No./L.	Surface	1,500	900	200
	Bottom	300	100	100
Net Plankton Volume cc./L.	Surface	0.0084	0.0024	0.0012
	Bottom	0.0061	0.0011	0.0030
Cocci No./L.	Surface	11,000,000	6,000,000	5,000,000
	Bottom	23,000,000	5,000,000	11,000,000
Bacilli No./L.	Surface	54,000,000	25,000,000	50,000,000
	Bottom	118,000,000	15,000,000	106,000,000
Spirilla No./L.	Surface	9,000,000	3,000,000	8,000,000
	Bottom	18,000,000	5,000,000	15,000,000

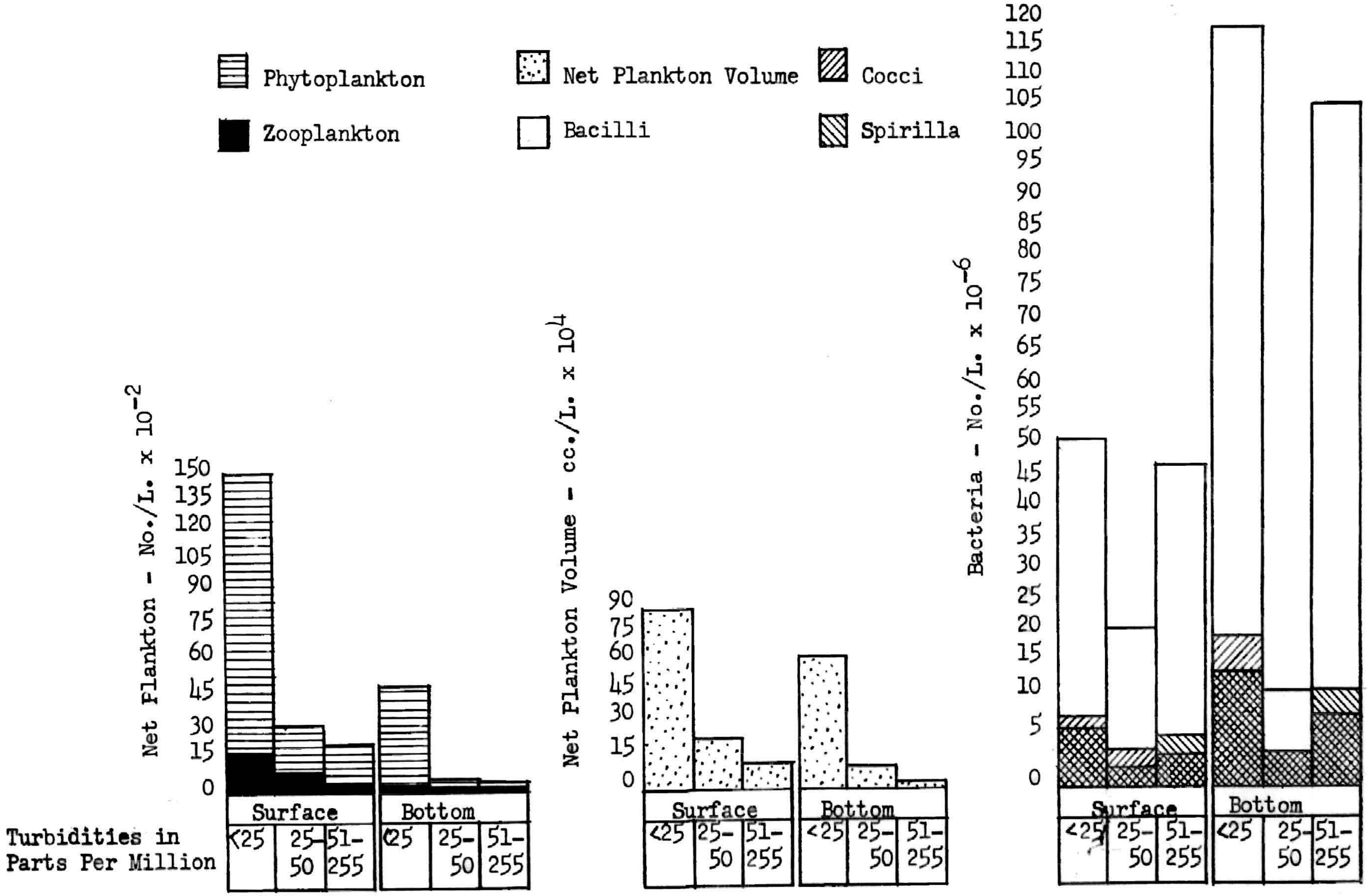

Figure 2. The average numbers of phytoplankters, zooplankters, cocci, bacilli, and spirilla per liter; the average volumes of net plankton in cubic centimeters per liter; and the ranges of turbidities for the lakes.

1. The numbers of phytoplankters were greater in waters within the turbidity range of less than 25 ppm. and declined 68 per cent between the surface waters and the bottom waters.
2. The numbers of phytoplankters were markedly smaller in the waters within the turbidity range of 25-50 ppm. than in the waters within the turbidity range of less than 25 ppm., both in the surface waters (78 per cent) and in the bottom waters (87 per cent), and were 81 per cent less in the bottom waters than in the surface waters.
3. The numbers of phytoplankters were smaller in waters within the turbidity range of 51-255 ppm. than in the waters within the turbidity range of 25-50 ppm., both in the surface waters (31 per cent) and in the bottom waters (50 per cent), and were 86 per cent less in the bottom waters than in the surface waters.

Zooplankton. Averages of the numbers of zooplankters are related to turbidities.

1. The numbers of zooplankters were greater in the waters within the turbidity range of less than 25 ppm. and 80 per cent less in the bottom waters than in the surface waters.
2. The numbers of zooplankters were markedly smaller in the waters within the turbidity range of 25-50 ppm. than in the waters within the turbidity range of less than 25 ppm., both in the surface waters (40 per cent) and in the bottom waters (66 per cent), and were 89 per cent less in the bottom waters than in the surface waters.
3. The numbers of zooplankters were smaller in the surface waters within the turbidity range of 51-255 ppm. than in the waters

within the turbidity range of 25-50 ppm. (78 per cent) but remained the same in the bottom waters. The numbers were 50 per cent less in the bottom waters than in the surface waters.

Net plankton volume. Averages of the volumes of net plankton are related to turbidities.

1. The volumes of net plankton were greater in the waters within the turbidity range of less than 25 ppm. and were 27 per cent less in the bottom waters than in the surface waters.
2. The volumes of net plankton were markedly smaller in the waters within the turbidity range of 25-50 ppm. than in the waters within the turbidity range of less than 25 ppm., both in the surface waters (71 per cent) and in the bottom waters (82 per cent), and were 54 per cent less in the surface waters than in the bottom waters.
3. The volumes of net plankton were smaller in the waters within the turbidity range of 51-255 ppm. than in the waters within the turbidity range of 25-50 ppm., both in the surface waters (50 per cent) and in the bottom waters (73 per cent), and were 75 per cent smaller in the bottom waters than in the surface waters.

Cocci. Averages of the numbers of cocci are related to turbidities.

1. The numbers of cocci were greater in the waters within the turbidity range of less than 25 ppm. and were 209 per cent greater in the bottom waters than in the surface waters.

2. The numbers of cocci were markedly smaller in the waters within the turbidity range of 25-50 ppm. than in the waters within the turbidity range of less than 25 ppm., both in the surface waters (45 per cent) and in the bottom waters (78 per cent), and were 17 per cent less in the bottom waters than in the surface waters.

3. The numbers of cocci were smaller in the surface waters within the turbidity range of 51-255 ppm. than in the waters within the turbidity range of 25-50 ppm. (17 per cent) but were greater in the bottom waters (220 per cent) and were 220 per cent greater in the bottom waters than in the surface waters.

Bacilli. Averages of the numbers of bacilli are related to turbidities.

1. The numbers of bacilli were greater in the waters within the turbidity range of less than 25 ppm. and were 218 per cent greater in the bottom waters than in the surface waters.

2. The numbers of bacilli were markedly smaller in the waters within the turbidity range of 25-50 ppm. than in the waters within the turbidity range of less than 25 ppm., both in the surface waters (46 per cent) and in the bottom waters (87 per cent), and were 40 per cent less in the bottom waters than in the surface waters.

3. The numbers of bacilli were greater in the waters within the turbidity range of 51-255 ppm. than in the range of 25-50

ppm., both in the surface waters (200 per cent) and in the bottom waters (706 per cent), and were 212 per cent greater in the bottom waters than in the surface waters.

Spirilla. Averages of the numbers of spirilla are related to turbidities.

1. The numbers of spirilla were greater in the waters within the turbidity range of less than 25 ppm. and were 200 per cent greater in the bottom waters than in the surface waters.
2. The numbers of spirilla were markedly smaller in the waters within the turbidity range of 25-50 ppm. than in the waters within the turbidity range of less than 25 ppm., both in the surface waters (66 per cent) and in the bottom waters (72 per cent), and were 166 per cent greater in the bottom waters than in the surface waters.
3. The numbers of spirilla were greater in the waters within the turbidity range of 51-255 ppm. than in the waters within the turbidity range of 25-50 ppm., both in the surface waters (266 per cent) and in the bottom waters (300 per cent) and were 186 per cent greater in the bottom waters than in the surface waters.

Rankings of Lakes

The twenty lakes were ranked from one to twenty, based upon their plankton productivity and on turbidity. The methods used for ranking the lakes were the same as for the farm ponds, except that the averages for the ponds were computed from surface samples only, whereas, the lake averages were based on samples taken at all depths.

Table XVII shows the rankings of the twenty lakes.

Table XVII. Rankings of the twenty lakes on the bases of plankton productivity and turbidity.

Ranking on the basis of plankton productivity. Highest productivity first.		Ranking on the basis of turbidity. Lowest turbidity first.		
Name of Lake	Rank	Name of Lake	Average Turbidity ppm.	Visibility of Secchi disk Inches*
Sanborn	1	Tenkiller	< 25	96.0
Fort Gibson	2	Grand	< 25	92.0
Canton	3	Fort Gibson	< 25	48.0
Lower Spavinaw	4	Lower Spavinaw	< 25	42.0
Boomer	5	Canton	< 25	36.0
Pawhuska	6	Pawhuska	< 25	30.0
Ponca	7	Sanborn	< 25	28.0
Shawnee	8	Shawnee	< 25	20.0
Carl Blackwell	9	Ponca	< 25	18.0
Grand	10	Hula	< 25	16.0
Liberty	11	Carl Blackwell	34.0	9.0
Hula	12	Liberty	40.5	9.0
Tenkiller	13	Yost	55.0	8.0
Yost	14	Claremore City	73.0	6.0
Cushing	15	Boomer	87.5	5.0
Tecumseh City	16	Tecumseh City	90.5	4.0
Claremore City	17	Cushing	136.0	3.0
Perry City	18	Pawnee City	204.0	2.0
Pawnee City	19	Perry City	224.0	2.0
Heyburn	20	Heyburn	228.0	2.0

*Secchi disk readings were used to determine the rank of lakes with turbidities of less than 25 ppm.

TURBIDITY AS A FACTOR IN THE PRODUCTIVITY OF WATERS

Plankton

An analysis of the data presented shows certain specific conditions to exist during the time the collections were made.

The numbers of phytoplankters, zooplankters, cocci, bacilli, spirilla, and the volumes of net plankton were greater in waters with turbidities of less than 25 ppm. The numbers of all organisms were markedly smaller in the waters within the turbidity range of 25-50 ppm. than in the waters within the range of turbidity of less than 25 ppm. Although the numbers of organisms were smaller in the waters within the turbidity range of 51-350 ppm. than in the waters within the range of turbidity of 25-50 ppm. the difference in numbers of organisms was slight when compared to the difference in numbers in the waters between the ranges of turbidity of less than 25 ppm. and 25-50 ppm.

Some investigators believe that turbidity caused by soil particles in suspension reduces phytoplankton populations (Chandler, 1940, 1942a, 1942b, 1944; Chandler and Weeks, 1945; Leonard, 1950; Prescott, 1939; Langlois, 1941, 1945, 1948; Aldrich, 1949; Silvey and Harris (1947). Harris and Silvey (1940), in some Texas Lakes found high phytoplankton numbers in waters with high turbidities and low phytoplankton numbers with low turbidities. The findings of Harris and Silvey (1940) are in opposition to their findings on an East Texas Lake in 1947, to the findings of others mentioned above, and to the findings of the writer.

Some investigators are of the opinion that turbidity caused by soil particles in suspension reduces zooplankton populations (Leonard, 1950; Doan, 1942).

Since the writer was unable to find a comparative study of bacteri populations between clear and turbid waters it seems unnecessary to compare the present findings with those for clear water lakes.

The numbers of organisms and the volumes of net plankton per liter of water were generally greater for the farm ponds than for the lakes in all three turbidity ranges. In all cases, except Boomer Lake, the plankton crop was smaller in the higher turbidities.

The numbers of phytoplankters, zooplankters, and volumes of net plankton were consistently smaller in the bottom waters than in the surface waters in clear and turbid lakes and ponds. The numbers of cocci and bacilli were greater in the bottom waters than in the surface waters of clear impoundments but the reverse was found in turbid impoundments. Spirilla differed from the cocci and bacilli in their distribution in the surface and bottom waters in that the numbers of spirilla were greater in the bottom waters than in the surface waters of both the clear and the turbid impoundments.

The average numbers of phytoplankters, zooplankters, cocci, bacilli, and spirilla per liter; the average volumes of net plankton in cubic centimeters per liter; and the ranges of turbidities in the surface and the bottom waters of the farm ponds and the lakes are shown in Appendix D and Figure 3.

Largemouth Bass Growth in Farm Ponds

The average growths of the largemouth bass in farm ponds are related to turbidities. The best growths were made in the waters

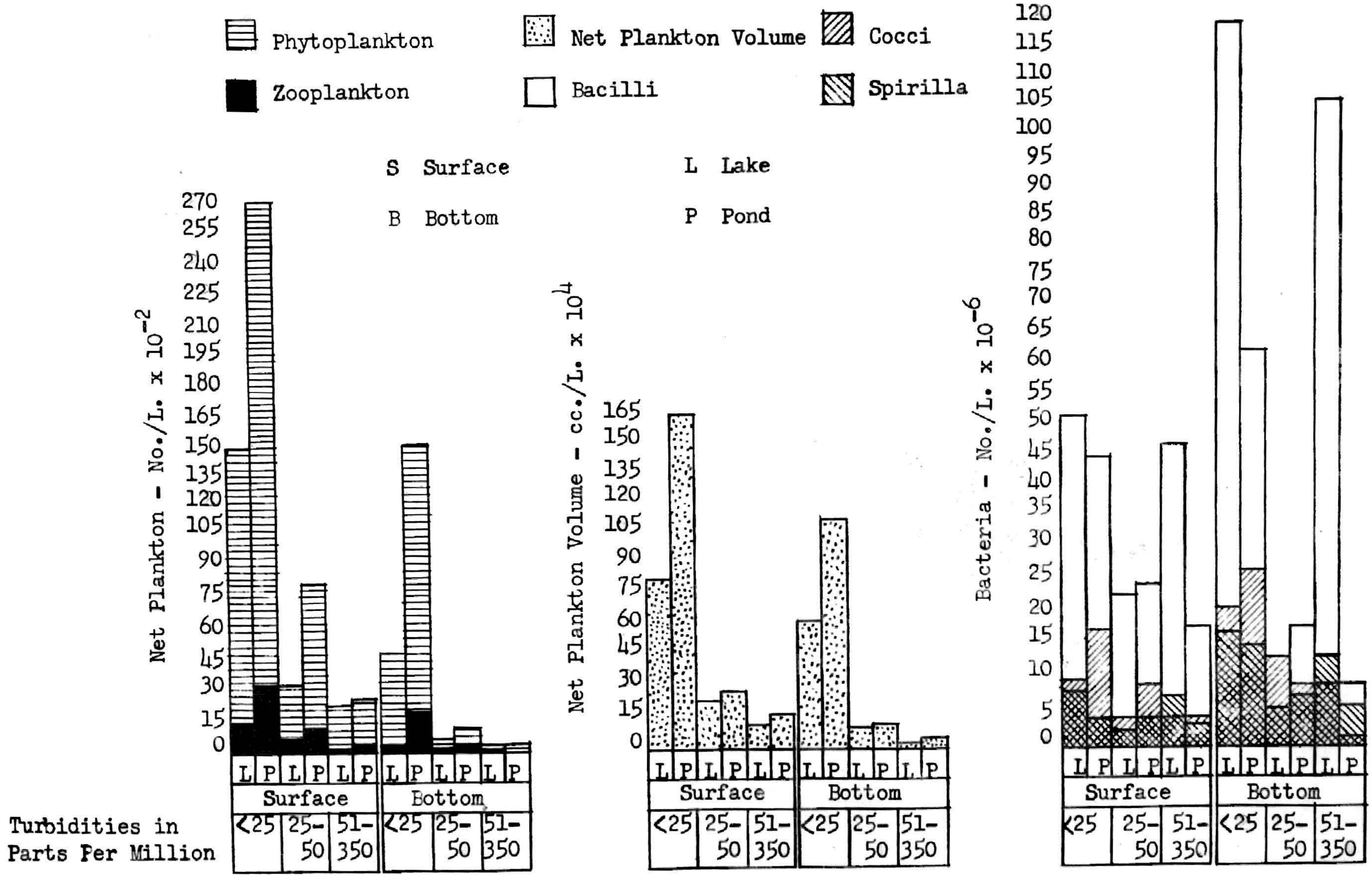

Figure 3. The average numbers of phytoplankters, zooplankters, cocci, bacilli, and spirilla per liter; the average volumes of net plankton in cubic centimeters per liter; and the ranges of turbidities for the farm ponds and lakes.

within the turbidity range of less than 25 ppm. The growths were less (39 per cent) in the waters within the turbidity range of 25-50 ppm. than in the waters within the range of turbidity of less than 25 ppm. The growths were still less (7 per cent) in the waters within the turbidity range of 51-350 ppm. than in the waters within the range of turbidity of 25-50 ppm.

Among the investigators who are of the opinion that turbidity caused by soil particles in suspension decreases fish productivity include Moen (1947), Aldrich (1949), Schneberger and Jewell (1928), Swingle (1949), Doan (1941 and 1942), and Moore (1937).

Although the net plankters and the bacteria are not eaten directly by adult largemouth bass it is thought that they form an important part of the aquatic food chain needed by bass.

Rounsefell and Everhart (1953) state that all fish are directly or indirectly dependent on plankton for food. It would seem that the small plankton crop in the turbid waters was a limiting factor to largemouth bass productivity.

Rankings of Farm Ponds and Lakes

When the rankings of farm ponds and lakes were compared, it became obvious that both the ponds and the lakes which ranked high in plankton productivity generally had clear waters. Generally, the numbers and volumes of plankton were smaller where the turbidity was higher. Both the ponds and the lakes which ranked low in plankton numbers had waters with turbidities greater than 25 ppm. and when the plankton numbers were low the turbidity was high.

If Sanborn Lake and Canton Reservoir had not been included, the average numbers of bacilli and spirilla in the waters in the turbidity range of less than 25 ppm. would have been higher in the ponds than in the lakes. If Boomer Lake had not been included, the average numbers of cocci and bacilli in the turbidity ranges of 25-50 ppm. and 51-350 ppm. would have been higher in the ponds than in the lakes but the average numbers of spirilla would have remained somewhat higher for the lakes.

Sanborn Lake was particularly productive. The lake was fertilized with prairie hay about four years before the study was made and while the water was clear, vascular aquatic plants had become established and the plants continuously added organic matter to the lake. The large numbers and volumes of plankters found in Sanborn Lake modified the averages for all lakes.

Canton Reservoir was partially drained, just before the study was made, to release water for Oklahoma City. The greatest depth of water found in the impoundment was 13.0 feet (about one-third of the normal conservation pool level). Lowering the water left large areas of shallow water over the bottom soil and thus increased or at least emphasized its productiveness.

Boomer Lake, which previously was drained in part as a means of re-establishing it as a fishing lake, had been fertilized with 70 tons of prairie hay and five tons of ammonium nitrate in the winter of 1953 and 1954. It is believed that the fertilizer increased the plankton crops considerable. Particularly was this true for bacteria.

The screening of light by turbidity would not be the only factor affecting the productivity of impoundments since several factors are reported as indices of productivity. One index of productivity would be the depth of a body of water. Tenkiller

Reservoir had a turbidity reading of less than 25 ppm., a Secchi disk reading of 96.0 inches, and a depth of 120 feet. It was ranked as number 1 in light penetration but number 13 in plankton productivity. Fort Gibson Reservoir had a turbidity reading of less than 25 ppm., a Secchi disk reading of 48 inches, and a depth of 60 feet. It was ranked number 3 in light penetration but number 1 in plankton productivity. Tenkiller Reservoir had deep water over a large part of its basin. Light could penetrate the clear water for a considerable depth and yet it was not as productive as Fort Gibson Reservoir which was in general a shallow lake with clear water. Light could penetrate the water of Fort Gibson Reservoir for only half the depth as in Tenkiller Reservoir. It would seem that depth would be another limiting factor in the productivity of impoundments. It is generally accepted that a shallow body of water tends to be more productive than a deep one.

Light Penetration in Turbid Waters

Birge and Juday (1930) and Clarke (1939) found that the red rays had the greatest penetration in stained waters. The writer found that turbid waters behaved like stained waters in that the red rays had the greatest penetration.

Clarke (1939) says:

It thus appears that most of the light incident on the surface of lakes or oceanic areas is absorbed by the water itself or by detritus and that only a very small part can be utilized by plants or animals. We conclude that aquatic organisms are existing under very unfavorable circumstances in regard to the utilization of solar energy. It is for this reason that the intensity, amount, and composition of light are so frequently found to be the limiting or highly significant factors in the aquatic environment.

Many investigators suggest that soil turbidities screen much of the light from natural waters (Irwin, 1945, 1948; Irwin and Stevenson, 1951; Ellis, 1936, 1937, 1944; Silvey and Harris, 1947; Welch, 1952).

Coker (1954) says:

Actual water color affects penetration of particular wave lengths, depending on the nature of the coloring substance. Turbidity from silt interferes with penetration, and therefore, with productiveness of lake, pond or stream.

Irwin and Stevenson (1951) say, "turbidity due to silt decreases the food production and affects the general economy of an impoundment." It would thus seem that light was a limiting factor for the productivity of both lakes and ponds.

Chlorophyll-bearing organisms must have light to conduct photosynthesis and nonchlorophyll-bearing organisms (Welch, 1952) are dependent to a large extent on the chlorophyll-bearing ones.

Without light the chlorophyll-bearing plankters are reduced in numbers. Light was able to penetrate the waters with turbidities of less than 25 ppm. to greater depths and could thus permit the development of a photosynthetic zone which could encompass most of the impoundment. When light was reduced by turbidities of 25-50 ppm. the photosynthetic zone was probably restricted to a thin stratum of water at the surface. The reduction of light in waters with turbidities of 50-350 ppm. was greater still than in waters with turbidities of 25-50 ppm. Coker, 1954, states that turbidity or cloudiness reduces light penetration in water causing a relatively shallow photosynthetic zone which is generally unfavorable to productivity.

The water of Village Pond, with an average turbidity of less than 25 ppm. and with an average Secchi disk reading of 37 inches, had a high productivity which was exhibited both in plankton and large-mouth bass growth. It would seem that light was able to penetrate the water to the extent that it was more nearly optimum for plankton production. A photosynthetic zone in Village Pond could have extended from the surface into the bottom waters. The water of Metzger Pond with an average turbidity of 199.8 ppm. and with an average Secchi disk reading of 2.5 inches, was low in plankton and in largemouth bass growth. Light when measured in the laboratory did not penetrate three inches of water with a turbidity of 150 ppm. (Table I). It would seem that the photosynthetic zone would be restricted to a narrow layer at the surface and that light penetration was a limiting factor to productivity in Metzger Pond.

The clear water of Fort Gibson Reservoir with a turbidity of less than 25 ppm. and a Secchi disk reading of 48 inches had a large plankton crop. Light could pass through the clear water and the photosynthetic zone most likely would extend downward for a considerable depth. Heyburn Lake with an average turbidity of 228 ppm. and a Secchi disk reading of 2.0 inches had a small plankton crop. The photosynthetic zone, in Heyburn Lake, would be restricted to a narrow layer in the surface water. The Secchi disk was visible through 48 inches of water in Fort Gibson Reservoir and only two inches in Heyburn Lake. If the illuminated waters of the two lakes were similar in productibility, inch for inch, Fort Gibson Reservoir had 24 times as much productive water for photosynthesis per unit of surface as did Heyburn Lake. The lack of light must have been one of the factors which caused low productivity in Heyburn Lake.

Irwin and Stevenson (1951) state that an impoundment receives its organic matter from two sources, namely, that carried into it from the watershed and that which is synthesized in the water. Light is necessary for the production of organic matter regardless of whether it is produced on the land or in the water. All chlorophyll-bearing plants must have light to conduct photosynthesis.

Stiles (1953) says:

This synthesis of complex compounds requires energy. It is supplied by the light of the sun; hence, the name photosynthesis to denote the fundamental process on which the green plants and in fact all life depend, for the bodies of green plants ultimately provide the materials on which animals and nongreen plants live.

In summarizing the cycle of organic matter which is produced in bodies of water, Irwin and Stevenson (1951) say:

Synthesis of organic matter in water basins is accomplished largely by chlorophyll-bearing organisms. In the presence of light these plants produce numerous organic substances from carbon dioxide and the minerals in solution. Animals feed upon plant materials or upon smaller animals. Finally, both the plant and the animal residues are decomposed by bacteria and the complex substances are again reduced to elements and simple compounds. Low turbidity to allow light penetration is thus essential for the synthesis of organic matter within a body of water.

It would seem that when light could penetrate the waters, the photosynthetic zone would extend from the surface downward for a considerable depth. Thus, chlorophyll-bearing organisms could receive the light needed for photosynthesis, resulting in a higher productivity of net plankters. When light could penetrate the pond waters rooted aquatic vegetation was generally in abundance. Organic matter was thus available in greater quantities in a form acceptable to those bacteria which were heterotrophic. Heterotrophic bacteria were able to reduce organic substances into simpler forms acceptable to the autotrophic bacteria and to other nonchlorophyll-bearing organisms. In the turbid waters, light was screened by the

the soil particles which most likely resulted in a shallow photosynthetic zone and as a result, aquatic organisms would be fewer so that substances needed by bacteria would be less available. Bere (1933) found that in about 33 per cent of the lakes he studied, the bacterial content was proportional to the organic matter. It would, therefore, be logical to assume that water with a turbidity of less than 25 ppm. would have a higher bacterial count because of the greater amount of available organic matter than in waters with turbidities of 25 ppm. or greater.

The populations of plankton and growth of largemouth bass seem to have been affected by turbidity caused by soil particles in suspension in the water. The greatest effect of turbidity seems to have been the reduction of light penetration.

The writer is convinced that the shading of light by soil turbidity was the significant factor in the productivity of the twenty farm ponds and the twenty lakes studied.

SUMMARY

1. Plankton productivity in relation to turbidity was studied for twenty farm ponds (ten with clear waters and ten with turbid waters) and for twenty lakes (ten with clear waters and ten with turbid waters).

2. The penetrations of visible wavelengths of light in the turbid waters were measured and were found to be reduced rapidly as the turbidity and the depth increased. The red rays had the greatest penetration.

3. A hemocytometer was used for counting bacteria in the water samples.

4. The photosynthetic zone in the waters with a turbidity of less than 25 ppm. could extend downward to a considerable depth, and should be confined to a narrow stratum in the surface waters within the turbidity range of 25-50 ppm. and should be confined to a narrower stratum in the surface waters within the turbidity range of 51-350 ppm.

5. The numbers of phytoplankters, zooplankters, cocci, bacilli, and spirilla, and the volumes of net plankton were largest in the waters with a turbidity of less than 25 ppm., were markedly smaller in the waters within the turbidity range of 25-50 ppm., and were still smaller in the waters within the turbidity range of 51-350 ppm.

6. The numbers of phytoplankters and zooplankters and the volumes of net plankton generally were smaller in the bottom waters

than in the surface waters.

7. Volumes of net plankton generally corresponded to the combined numerical counts of the phytoplankters and the zooplankters.

8. The numbers of cocci and bacilli were greater in the clear bottom waters than in the clear surface waters. The reverse was found in the turbid waters. The numbers of spirilla were greater in the bottom waters than in the surface waters in both the clear and the turbid impoundments.

9. Largemouth bass made their best growths in the clear ponds. The growths were less in the ponds with waters within the turbidity range of 25-50 ppm. and were still less in ponds with waters within the turbidity range of 51-350 ppm.

10. A ranking method for the classification of impoundments on the basis of productivity and turbidity is presented.

11. Productivity, as measured by plankton populations and largemouth bass growth, was greater (with some exceptions) in the waters with low turbidities than in the waters with higher turbidities.

12. The productivity of a turbid water impoundment was found to be increased by fertilization.

13. Light penetration appeared to be the way by which turbidity reduced the plankton productivity of impoundments.

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A P P E N D I C E S

Appendix A

Table I. Data obtained from each of the twenty farm ponds between April 16 - May 6, 1954.

Pond	Date 1954	Depth Feet	Secchi Disk Inches	Turbidity ppm.	Phytoplankton No./L.	Zooplankton No./L.	Net Plankton Volume cc./L.	Cocci No./L.	Bacilli No./L.	Spirilla No./L.
Allred #1	5/3	0-2	3.5	150	900	200	0.0009	3,000,000	13,000,000	10,000,000
		6			100	0	0.0003	0	10,000,000	8,000,000
Allred #2	5/3	0-2	3.0	160	3,100	400	0.0024	3,000,000	27,000,000	9,000,000
		7			100	0	0.0002	0	5,000,000	9,000,000
Allred #3	5/3	0-2	4.0	100	7,400	400	0.0026	0	22,000,000	7,000,000
		6			100	100	0.0003	3,000,000	10,000,000	8,000,000
Allred #4	5/3	0-2	2.5	200	1,000	200	0.0014	3,000,000	15,000,000	7,000,000
		6			100	0	0.0002	0	10,000,000	3,000,000
Andrews #1	5/6	0-2	8.0	40	2,600	600	0.0016	10,000,000	17,000,000	2,000,000
		10			3,300	100	0.0033	3,000,000	5,000,000	3,000,000
Andrews #2	5/6	0-2	3.5	150	1,500	400	0.0011	0	21,000,000	7,000,000
Berry #1	4/28	0-2	14.0	< 25	28,400	13,200	0.0329	20,000,000	43,000,000	3,000,000
Fisher #1	4/28	0-2	16.0	< 25	16,500	4,000	0.0103	10,000,000	37,000,000	3,000,000
Fisher #2	4/28	0-2	7.0	50	3,400	700	0.0029	0	17,000,000	10,000,000
Leach #1	4/29	0-2	14.0	< 25	29,800	1,300	0.0271	7,000,000	40,000,000	3,000,000
		8			17,000	1,100	0.0118	7,000,000	47,000,000	7,000,000
Leach #2	4/29	0-2	7.0	50	4,100	900	0.0024	3,000,000	27,000,000	3,000,000

Table I. (Continued)

Pond	Date 1954	Depth Feet	Secchi Disk Inches	Turbidity ppm.	Phytoplankton No./L.	Zooplankton No./L.	Net Plankton Volume cc./L.	Cocci No./L.	Bacilli No./L.	Spirilla No./L.
Nelson	4/28	0-2	20.0	< 25	26,500	12,300	0.0213	10,000,000	10,000,000	3,000,000
		5			21,800	15,600	0.0241	13,000,000	63,000,000	3,000,000
Newsom #1	5/3	0-2	8.0	40	2,100	700	0.0016	3,000,000	20,000,000	0
		13			100	100	0.0005	3,000,000	19,000,000	3,000,000
Newsom #2	5/3	0-2	8.0	35	2,000	500	0.0014	0	17,000,000	7,000,000
		10			200	100	0.0003	3,000,000	10,000,000	3,000,000
Glass	5/6	0-2	2.0	220	1,100	300	0.0010	3,000,000	10,000,000	3,000,000
		8			0	100	0.0003	0	3,000,000	7,000,000
Preston #1	4/28	0-2	16.0	< 25	39,000	18,200	0.0396	18,000,000	51,000,000	3,000,000
Preston #2	4/28	0-2	1.5	350	2,100	300	0.0018	3,000,000	23,000,000	3,000,000
		7			100	0	0.0002	0	7,000,000	4,000,000
Ross	5/3	0-2	0.9	330	900	100	0.0009	3,000,000	13,000,000	17,000,000
Metzger	4/26	0-2	1.5	320	1,200	300	0.0011	10,000,000	12,000,000	3,000,000
Village	4/16	0-2	30.0	< 25	31,200	17,000	0.0421	17,000,000	33,000,000	3,000,000
		11.5			4,200	1,200	0.0097	27,000,000	70,000,000	10,000,000

Table II. Data obtained from each of the twenty farm ponds for the period May 22 - May 27, 1954.

Pond	Date 1954	Depth Feet	Secchi Disk Inches	Turbidity ppm.	Phytoplankton No./L.	Zooplankton No./L.	Net Plankton Volume cc./L.	Cocci No./L.	Bacilli No./L.	Spirilla No./L.
Allred #1	5/27	0-2	2.5	140	3,100	800	0.0019	4,000,000	29,000,000	3,000,000
		6			500	100	0.0004	3,000,000	10,000,000	7,000,000
Allred #2	5/27	0-2	6.0	54	5,200	1,000	0.0033	7,000,000	30,000,000	3,000,000
		7			600	200	0.0006	3,000,000	10,000,000	3,000,000
Allred #3	5/27	0-2	5.0	80	4,100	600	0.0028	3,000,000	37,000,000	7,000,000
		6			200	100	0.0003	3.000,000	13,000,000	7,000,000
Allred #4	5/27	0-2	3.0	130	2,900	500	0.0017	7,000,000	27,000,000	3,000,000
		6			100	100	0.0004	0	10,000,000	3,000,000
Andrews #1	5/23	0-2	20.0	< 25	8,500	1,200	0.0039	10,000,000	33,000,000	7,000,000
		10			3,300	100	0.0033	3,000,000	5,000,000	3,000,000
Andrews #2	5/25	0-2	5.0	70	3,000	800	0.0021	7,000,000	20,000,000	3,000,000
Berry #1	5/25	0-2	24.0	< 25	25,500	1,000	0.0299	13,000,000	97,000,000	3,000,000
Fisher #1	5/24	0-2	18.0	< 25	10,200	2,000	0.0098	10,000,000	57,000,000	3,000,000
Fisher #2	5/24	0-2	6.0	82	3,100	600	0.0027	7,000,000	23,000,000	3,000,000
Leach #1	5/22	0-2	36.0	< 25	25,500	1,000	0.0190	20,000,000	40,000,000	0
		8			23,500	1,100	0.0198	27,000,000	63,000,000	3,000,000
Leach #2	5/22	0-2	5.0	84	2,800	500	0.0104	10,000,000	30,000,000	3,000,000

Table II. (Continued)

Pond	Date 1954	Depth Feet	Secchi Disk Inches	Turbid-ity ppm.	Phyto-plankton No./L.	Zoo-plankton No./L.	Net Plankton Volume cc./L.	Cocci No./L.	Bacilli No./L.	Spirilla No./L.
Nelson	5/26	0-2	40.0	< 25	21,300	8,200	0.0193	13,000,000	70,000,000	3,000,000
		5			22,500	10,200	0.0220	10,000,000	61,000,000	0
Newsom #1	5/26	0-2	36.0	< 25	13,200	1,400	0.0096	20,000,000	23,000,000	3,000,000
		13			8,500	900	0.0081	20,000,000	73,000,000	7,000,000
Newsom #2	5/26	0-2	26.0	< 25	9,600	1,000	0.0091	13,000,000	53,000,000	3,000,000
		10			5,400	600	0.0084	30,000,000	70,000,000	7,000,000
Glass	5/27	0-2	5.0	100	2,900	700	0.0017	10,000,000	20,000,000	3,000,000
		8			100	100	0.0005	3,000,000	17,000,000	7,000,000
Preston #1	5/27	0-2	27.0	< 25	30,800	12,300	0.0285	17,000,000	64,000,000	3,000,000
Preston #2	5/27	0-2	3.0	220	1,900	700	0.0020	7,000,000	17,000,000	3,000,000
		8.5			200	100	0.0004	3,000,000	7,000,000	7,000,000
Ross	5/27	0-2	4.0	120	4,000	200	0.0026	3,000,000	30,000,000	10,000,000
Metzger	5/24	0-2	3.0	200	1,500	200	0.0010	7,000,000	20,000,000	3,000,000
		5.5			100	0	0.0004	3,000,000	10,000,000	17,000,000
Village	5/22	0-2	36.0	< 25	32,800	10,200	0.0310	20,000,000	43,000,000	3,000,000
		12.5			13,000	900	0.0146	30,000,000	82,000,000	10,000,000

Table III. Data obtained from each of the twenty farm ponds between June 18 - June 23, 1954.

Pond	Date 1954	Depth Feet	Secchi Disk Inches	Turbidity ppm.	Phytoplankton No./L.	Zooplankton No./L.	Net Plankton Volume cc./L.	Cocci No./L.	Bacilli No./L.	Spirilla No./L.
Allred #1	6/23	0-2	3	128	4,000	100	0.0014	7,000,000	33,000,000	7,000,000
		6			400	0	0.0002	3,000,000	13,000,000	7,000,000
Allred #2	6/23	0-2	8	45	6,000	600	0.0025	7,000,000	20,000,000	7,000,000
		7			600	0	0.0005	0	10,000,000	10,000,000
Allred #3	6/23	0-2	18	< 25	12,700	100	0.0020	10,000,000	57,000,000	7,000,000
		6			4,200	0	0.0009	10,000,000	62,000,000	10,000,000
Allred #4	6/23	0-2	3	125	2,300	300	0.0014	30,000,000	20,000,000	7,000,000
		6			300	0	0.0012	0	7,000,000	10,000,000
Andrews #1	6/20	0-2	10	40	4,400	100	0.0024	10,000,000	20,000,000	7,000,000
		10			500	0	0.0008	7,000,000	10,000,000	7,000,000
Andrews #2	6/20	0-2	7	52	3,400	200	0.0016	3,000,000	30,000,000	7,000,000
Berry #1	6/21	0-2	36	< 25	68,400	1,000	0.00341	20,000,000	147,000,000	10,000,000
Fisher #1	6/21	0-2	36	< 25	39,400	300	0.00124	17,000,000	80,000,000	3,000,000
Fisher #2	6/21	0-2	6	60	5,700	100	0.0019	3,000,000	30,000,000	10,000,000
Leach #1	6/20	0-2	36	< 25	59,300	100	0.0263	27,000,000	50,000,000	10,000,000
		8			28,600	100	0.0180	30,000,000	76,000,000	13,000,000
Leach #2	6/20	0-2	4	82	3,800	100	0.0015	7,000,000	30,000,000	10,000,000

Table III. (Continued)

Pond	Date 1954	Depth Feet	Secchi Disk Inches	Turbid-ity ppm.	Phyto-plankton No./L.	Zoo-plankton No./L.	Net Plankton Volume cc./L.	Cocci No./L.	Bacilli No./L.	Spirilla No./L.
Nelson	6/20	0-2	60	< 25	46,600	1,000	0.0130	20,000,000	43,000,000	10,000,000
		5			54,500	1,200	0.0142	30,000,000	67,000,000	13,000,000
Newsom #1	6/22	0-2	18	< 25	32,200	100	0.0162	20,000,000	43,000,000	10,000,000
		12			6,600	0	0.0069	27,000,000	50,000,000	20,000,000
Newsom #2	6/22	0-2	24	< 25	26,300	100	0.0099	19,000,000	70,000,000	3,000,000
		9.5			29,300	0	0.0102	20,000,000	100,000,000	10,000,000
Glass	6/22	0-2	4	118	2,100	400	0.0023	7,000,000	20,000,000	10,000,000
		7			400	0	0.0006	3,000,000	10,000,000	7,000,000
Preston #1	6/20	0-2	36	< 25	62,300	600	0.0211	10,000,000	73,000,000	14,000,000
Preston #2	6/20	0-2	3	280	1,600	100	0.0014	3,000,000	20,000,000	7,000,000
		8			400	0	0.0003	3,000,000	10,000,000	7,000,000
Ross	6/20	0-2	6	56	4,000	0	0.0018	7,000,000	30,000,000	3,000,000
Metzger	6/18	0-2	3	150	1,000	0	0.0008	3,000,000	10,000,000	3,000,000
		5			200	0	0.0002	0	7,000,000	7,000,000
Village	6/19	0-2	36	< 25	46,400	800	0.0275	27,000,000	50,000,000	3,000,000
		11			8,700	200	0.0099	46,000,000	80,000,000	17,000,000

Table IV. Data obtained from each of the twenty farm ponds between July 17 - July 31, 1954.

Pond	Date 1954	Depth Feet	Secchi Disk Inches	Turbidity ppm.	Phytoplankton No./L.	Zooplankton No./L.	Net Plankton Volume cc./L.	Cocci No./L.	Bacilli No./L.	Spirilla No./L.
Allred #1	7/21	0-2	3	100	1,800	400	0.0011	3,000,000	27,000,000	3,000,000
		5			300	0	0.0004	0	20,000,000	7,000,000
Allred #2	7/21	0-2	4	63	3,000	600	0.0018	3,000,000	20,000,000	5,000,000
		6			500	100	0.0007	0	17,000,000	10,000,000
Allred #3	7/21	0-2	8	38	5,400	500	0.0021	8,000,000	33,000,000	3,000,000
		5			900	100	0.0006	10,000,000	20,000,000	10,000,000
Allred #4	7/21	0-2	3	120	1,900	200	0.0013	3,000,000	10,000,000	8,000,000
Andrews #1	7/21	0-2	14	<25	6,100	500	0.0028	3,000,000	30,000,000	7,000,000
		8.5			1,100	100	0.0009	7,000,000	19,000,000	10,000,000
Andrews #2	7/21	0-2	5	60	2,300	400	0.0014	3,000,000	17,000,000	7,000,000
Berry #1	7/26	0-2	36	<25	19,600	3,200	0.0191	17,000,000	67,000,000	7,000,000
Fisher #1	7/27	0-2	8	34	8,300	600	0.0032	20,000,000	33,000,000	3,000,000
Fisher #2	7/27	0-2	11	29	2,800	500	0.0016	7,000,000	20,000,000	3,000,000
Leach #1	7/31	0-2	36	<25	14,300	1,000	0.0089	10,000,000	37,000,000	3,000,000
		6.5			12,600	3,200	0.0108	13,000,000	40,000,000	7,000,000
Leach #2	7/31	0-2	10	45	4,100	500	0.0018	10,000,000	18,000,000	10,000,000

Table IV. (Continued)

Pond	Date 1954	Depth Feet	Secchi Disk Inches	Turbid-ity ppm.	Phyto-plankton No./L.	Zoo-plankton No./L.	Net Plankton Volume cc./L.	Cocci No./L.	Bacilli No./L.	Spirilla No./L.
Nelson	7/22	0-2	40	<25	21,300	1,600	0.0082	20,000,000	33,000,000	3,000,000
Newsom #1	7/23	0-2	20	<25	16,800	1,000	0.0100	17,000,000	30,000,000	7,000,000
		11			7,300	800	0.0046	20,000,000	47,000,000	7,000,000
Newsom #2	7/23	0-2	24	<25	10,200	600	0.0051	10,000,000	50,000,000	3,000,000
		9			14,100	1,000	0.0081	17,000,000	67,000,000	10,000,000
Glass	7/31	0-2	5	90	5,000	100	0.0020	3,000,000	20,000,000	3,000,000
		6			400	0	0.0003	0	10,000,000	13,000,000
Preston #1	7/22	0-2	36	<25	24,200	1,300	0.0199	20,000,000	57,000,000	13,000,000
Preston #2	7/22	0-2	3	140	1,200	200	0.0011	3,000,000	20,000,000	3,000,000
		7.5			100	0	0.0011	3,000,000	13,000,000	3,000,000
Ross	7/31	0-2	8	37	2,100	300	0.0019	10,000,000	20,000,000	3,000,000
Metzger	7/20	0-2	3	148	1,600	200	0.0014	3,000,000	20,000,000	3,000,000
		4.5			400	0	0.0003	3,000,000	10,000,000	4,000,000
Village	7/17	0-2	48	<25	20,000	2,000	0.0197	20,000,000	30,000,000	0
		10			10,200	300	0.0088	30,000,000	57,000,000	7,000,000

Table V. Data obtained from each of the twenty farm ponds between Sept. 11 - Sept. 15, 1954.

Pond	Date 1954	Depth Feet	Secchi Disk Inches	Turbidity ppm.	Phytoplankton No./L.	Zooplankton No./L.	Net Plankton Volume cc./L.	Cocci No./L.	Bacilli No./L.	Spirilla No./L.
Allred #1	9/14	0-2	5.0	83	2,700	500	0.0018	7,000,000	20,000,000	3,000,000
Allred #2	9/14	0-2	8.0	37	5,400	800	0.0036	10,000,000	33,000,000	7,000,000
		5.0			500	0	0.0009	9,000,000	27,000,000	10,000,000
Allred #3	9/14	0-2	6.0	82	2,000	300	0.0014	7,000,000	20,000,000	13,000,000
		5.0			200	0	0.0003	5,000,000	17,000,000	17,000,000
Allred #4	9/14	0-2	5.0	102	3,300	400	0.0019	5,000,000	10,000,000	10,000,000
Andrews #1	9/14	0-2	5.0	58	3,300	400	0.0019	5,000,000	10,000,000	10,000,000
		6.0			900	100	0.0009	3,000,000	20,000,000	17,000,000
Andrews #2	9/13	0-2	5.0	85	1,500	800	0.0026	3,000,000	17,000,000	3,000,000
Berry #1	9/12	0-2	28.0	<25	34,100	5,300	0.0234	20,000,000	77,000,000	7,000,000
Fisher #1	9/13	0-2	12.0	28	13,200	1,600	0.0096	30,000,000	47,000,000	3,000,000
Fisher #2	9/13	0-2	11.0	26	4,200	600	0.0029	20,000,000	33,000,000	7,000,000
Leach #1	9/12	0-2	72.0	<25	10,700	2,000	0.0103	23,000,000	40,000,000	3,000,000
		6.0			12,100	2,100	0.0109	27,000,000	43,000,000	7,000,000
Leach #2	9/12	0-2	20.0	<25	5,100	1,200	0.0021	17,000,000	22,000,000	5,000,000
Nelson	9/15	0-2	36.0	<25	31,300	1,000	0.0214	10,000,000	47,000,000	5,000,000

Table V. (Continued)

Pond	Date 1954	Depth Feet	Secchi Disk Inches	Turbid-ity ppm.	Phyto-plankton No./L.	Zoo-plankton No./L.	Net Plankton Volume cc./L.	Cocci No./L.	Bacilli No./L.	Spirilla No./L.
Newsom #1	9/15	0-2	53.0	<25	26,600	20	0.0130	20,000,000	50,000,000	10,000,000
		7.0			18,300	10	0.0088	23,000,000	63,000,000	13,000,000
Newsom #2	9/15	0-2	36.0	<25	21,500	30	0.0125	27,000,000	60,000,000	3,000,000
		6.0			13,100	9	0.0071	27,000,000	67,000,000	4,000,000
Glass	9/13	0-2	9.0	29	8,700	6	0.0031	10,000,000	22,000,000	3,000,000
		6.0			1,000	1	0.0015	7,000,000	30,000,000	3,000,000
Preston #1	9/14	0-2	36.0	<25	39,400	42	0.0280	19,000,000	70,000,000	10,000,000
Preston #2	9/14	0-2	4.0	138	2,300	5	0.0017	3,000,000	17,000,000	7,000,000
		5.0			400	0	0.0004	3,000,000	10,000,000	10,000,000
Ross	9/12	0-2	8.0	47	2,000	8	0.0026	10,000,000	30,000,000	7,000,000
Metzger	9/12	0-2	2.5	180	1,000	0	0.0010	3,000,000	10,000,000	13,000,000
Village	9/11	0-2	36.0	<25	51,000	38	0.0280	30,000,000	67,000,000	3,000,000
		9.0			18,700	10	0.0090	30,000,000	80,000,000	17,000,000

Table VI. Data obtained from each of the twenty farm ponds between Sept. 19 - Oct. 10, 1954.

Pond	Date 1954	Depth Feet	Secchi Disk Inches	Turbidity ppm.	Phytoplankton No./L.	Zooplankton No./L.	Net Plankton Volume cc./L.	Cocci No./L.	Bacilli No./L.	Spirilla No./L.
Allred #1	10/9	0-2	5	92	2,000	300	0.0016	3,000,000	17,000,000	3,000,000
Allred #2	10/9	0-2	10	34	8,000	1,000	0.0038	20,000,000	47,000,000	10,000,000
		5			1,800	100	0.0014	23,000,000	50,000,000	20,000,000
Allred #3	10/9	0-2	4	90	2,700	200	0.0013	10,000,000	13,000,000	3,000,000
		5			300	0	0.0004	10,000,000	10,000,000	3,000,000
Allred #4	10/9	0-2	5	100	2,100	300	0.0016	3,000,000	10,000,000	7,000,000
Andrews #1	9/26	0-2	8	50	2,200	500	0.0023	10,000,000	20,000,000	3,000,000
		6			600	100	0.0010	13,000,000	30,000,000	7,000,000
Andrews #2	9/26	0-2	10	29	1,700	1,000	0.0025	10,000,000	27,000,000	5,000,000
Berry #1	9/19	0-2	24	25	40,000	8,200	0.0285	30,000,000	83,000,000	10,000,000
Fisher #1	9/25	0-2	11	31	18,200	2,000	0.0120	20,000,000	62,000,000	10,000,000
Fisher #2	9/25	0-2	14	<25	6,300	1,800	0.0031	33,000,000	40,000,000	3,000,000
Leach #1	9/19	0-2	72	<25	16,400	3,000	0.0189	30,000,000	50,000,000	10,000,000
		6			18,100	3,600	0.0192	43,000,000	60,000,000	13,000,000
Leach #2	9/19	0-2	16	<25	8,700	2,000	0.0028	20,000,000	33,000,000	7,000,000
Nelson	9/30	0-2	36	<25	52,300	5,200	0.0301	30,000,000	57,000,000	10,000,000

Table VI. (Continued)

Pond	Date 1954	Depth Feet	Secchi Disk Inches	Turbidity ppm.	Phytoplankton No./L.	Zooplankton No./L.	Net Plankton Volume cc./L.	Cocci No./L.	Bacilli No./L.	Spirilla No./L.
Newsom #1	10/2	0-2	48	<25	31,500	6,000	0.0211	27,000,000	70,000,000	3,000,000
Newsom #2	10/2	0-2	36	<25	28,200	5,000	0.0187	23,000,000	80,000,000	5,000,000
		6			16,900	2,000	0.0083	30,000,000	70,000,000	10,000,000
Glass	9/28	0-2	13	28	10,000	3,000	0.0071	20,000,000	43,000,000	3,000,000
		6			2,800	1,000	0.0027	30,000,000	50,000,000	7,000,000
Preston #1	9/30	0-2	36	<25	57,000	9,200	0.0326	27,000,000	90,000,000	10,000,000
Preston #2	9/30	0-2	3	153	2,000	300	0.0015	5,000,000	20,000,000	3,000,000
		5			200	0	0.0002	3,000,000	12,000,000	5,000,000
Ross	9/28	0-2	9	41	16,400	2,300	0.0066	30,000,000	50,000,000	3,000,000
Metzger	10/10	0-2	2	200	1,800	200	0.0016	3,000,000	22,000,000	3,000,000
Village	10/9	0-2	36	<25	67,400	6,000	0.0310	50,000,000	133,000,000	10,000,000
		8			46,000	3,100	0.0125	70,000,000	163,000,000	26,000,000

Appendix B

Table I. Data obtained from each of the five stations of Village and Metzger Ponds between April 16- Oct. 10, 1954.

Sta.	Date 1954	Depth Feet	Secchi Disk Inches	Turbidity ppm.	Phytoplankton No./L.	Zooplankton No./L.	Net Plankton Volume cc./L.	Cocci No./L.	Bacilli No./L.	Spirilla No./L.
					Village Pond					
1	4/16	0-2	30.0	<25	312	17,000	0.0421	17,000,000	33,000,000	3,000,000
		5			340	21,000	0.0498	13,000,000	37,000,000	7,000,000
		11.5			42	1,200	0.0097	27,000,000	70,000,000	10,000,000
	5/22	0-2	36.0	<25	328	10,200	0.0310	20,000,000	43,000,000	3,000,000
		5			301	14,200	0.0352	16,000,000	42,000,000	7,000,000
		12			130	900	0.0146	30,000,000	82,000,000	10,000,000
	6/19	0-2	36.0	<25	464	8,200	0.0275	27,000,000	50,000,000	3,000,000
		5			514	1,300	0.0291	30,000,000	67,000,000	3,000,000
		11.5			87	200	0.0099	46,000,000	90,000,000	17,000,000
	9/11	0-2	48.0	<25	200	2,000	0.0197	20,000,000	30,000,000	0
		5			263	2,800	0.0208	26,000,000	43,000,000	3,000,000
		10			103	300	0.0088	30,000,000	57,000,000	7,000,000
	10/9	0-2	36.0	<25	510	3,800	0.0280	30,000,000	67,000,000	3,000,000
		5			524	4,400	0.0297	27,000,000	60,000,000	10,000,000
		9			187	1,000	0.0090	30,000,000	80,000,000	17,000,000
		0-2	36.0	<25	674	31,000	0.0060	50,000,000	133,000,000	10,000,000
		5			716	33,900	0.0088	67,000,000	150,000,000	20,000,000
		8			460	12,500	0.0031	70,000,000	163,000,000	27,000,000
2	4/17	0-2	30.0	<25	631	36,200	0.0872	40,000,000	263,000,000	26,000,000
	5/22	0-2	36.0	<25	671	19,500	0.0601	50,000,000	327,000,000	20,000,000
	6/19	0-2	36.0	<25	703	1,800	0.0386	33,000,000	400,000,000	19,000,000
	7/17	0-2	48.0	<25	333	3,100	0.0210	10,000,000	125,000,000	10,000,000
	9/11	0-2	36.0	<25	600	5,000	0.0312	20,000,000	170,000,000	7,000,000
	10/10	0-2	36.0	<25	1,000	10,300	0.0471	40,000,000	200,000,000	30,000,000

Table I. (Continued)

Sta.	Date 1954	Depth Feet	Secchi Disk Inches	Turbid-ity ppm.	Phyto-plankton No./L.	Zoo-plankton No./L.	Net Plankton Volume cc./L.	Cocci No./L.	Bacilli No./L.	Spirilla No./L.
3	4/17	0-2	30.0	<25	58,500	373	0.0701	37,000,000	271,000,000	17,000,000
	5/22	0-2	36.0	<25	62,000	140	0.0532	100,000,000	433,000,000	37,000,000
	6/19	0-2	36.0	<25	53,100	10	0.0294	78,000,000	567,000,000	27,000,000
	7/17	0-2	48.0	<25	24,100	19	0.0165	20,000,000	160,000,000	3,000,000
	9/11	0-2	36.0	<25	54,400	32	0.0261	53,000,000	200,000,000	3,000,000
	10/10	0-2	36.0	<25	86,400	60	0.0361	53,000,000	220,000,000	47,000,000
4	4/17	0-2	30.0	<25	61,300	330	0.0820	43,000,000	233,000,000	7,000,000
	5/23	0-2	36.0	<25	66,400	119	0.0590	67,000,000	300,000,000	27,000,000
	6/19	0-2	36.0	<25	73,500	14	0.0409	57,000,000	343,000,000	30,000,000
	7/17	0-2	48.0	<25	27,500	20	0.0213	30,000,000	123,000,000	7,000,000
	9/11	0-2	36.0	<25	43,300	54	0.0325	50,000,000	253,000,000	30,000,000
	10/10	0-2	36.0	<25	62,100	80	0.0296	50,000,000	167,000,000	30,000,000
5	4/17	0-2	30.0	<25	39,000	193	0.0566	27,000,000	63,000,000	0
		5			36,500	212	0.0597	20,000,000	67,000,000	7,000,000
		9			3,700	8	0.0088	33,000,000	140,000,000	10,000,000
	5/23	0-2	36.0	<25	46,300	118	0.0452	33,000,000	70,000,000	0
		5			44,700	139	0.0490	30,000,000	66,000,000	3,000,000
		9			21,300	22	0.0136	53,000,000	160,000,000	10,000,000
	6/19	0-2	36.0	<25	50,000	10	0.0310	27,000,000	67,000,000	20,000,000
		5			48,600	11	0.0329	33,000,000	73,000,000	20,000,000
		8			18,500	4	0.0103	47,000,000	100,000,000	33,000,000
	7/17	0-2	48.0	<25	13,100	16	0.0133	17,000,000	30,000,000	3,000,000
		5			18,300	21	0.0186	20,000,000	33,000,000	7,000,000
		7			10,200	6	0.0078	30,000,000	47,000,000	10,000,000

Table I. (Continued)

Sta.	Date 1954	Depth Feet	Secchi Disk Inches	Turbidity ppm.	Phyto-plankton No./L.	Zoo-plankton No./L.	Net Plankton Volume cc./L.	Cocci No./L.	Bacilli No./L.	Spirilla No./L.
5	9/12	0-2	36.0	<25	33,400	3,000	0.0220	20,000,000	100,000,000	10,000,000
		5			39,300	3,600	0.0270	33,000,000	120,000,000	20,000,000
		7			14,200	1,000	0.0093	36,000,000	126,000,000	23,000,000
	10/10	0-2	36.0	<25	60,000	6,000	0.0248	30,000,000	150,000,000	10,000,000
		5			61,300	8,000	0.0256	33,000,000	167,000,000	17,000,000
		6			28,000	2,000	0.0172	50,000,000	197,000,000	20,000,000
					Metzger Pond					
1	4/26	0-2	1.5	320	1,200	300	0.0011	10,000,000	12,000,000	3,000,000
	5/24	0-2	3.0	200	1,500	200	0.0010	7,000,000	20,000,000	3,000,000
		5.5			100	0	0.0004	3,000,000	10,000,000	17,000,000
	6/18	0-2	3.0	150	1,000	0	0.0008	3,000,000	10,000,000	3,000,000
		5.0			200	0	0.0002	0	7,000,000	7,000,000
	7/20	0-2	3.0	148	1,600	200	0.0014	3,000,000	20,000,000	3,000,000
		4.5			400	0	0.0003	3,000,000	10,000,000	4,000,000
	9/12	0-2	2.5	180	1,000	0	0.0010	3,000,000	10,000,000	13,000,000
	10/10	0-2	2.0	200	1,800	200	0.0016	3,000,000	22,000,000	3,000,000
2	4/26	0-2	1.0	320	2,300	500	0.0017	10,000,000	20,000,000	7,000,000
	5/24	0-2	3.0	200	2,600	300	0.0015	3,000,000	33,000,000	3,000,000
	6/18	0-2	2.5	150	1,400	100	0.0013	10,000,000	17,000,000	7,000,000
	7/20	0-2	3.0	148	1,000	500	0.0013	3,000,000	10,000,000	7,000,000
	9/12	0-2	2.5	180	1,000	0	0.0010	3,000,000	10,000,000	13,000,000
	10/10	0-2	2.0	200	1,300	200	0.0014	10,000,000	20,000,000	3,000,000

Table I. (Continued)

Sta.	Date 1954	Depth Feet	Secchi Disk Inches	Turbidity ppm.	Phytoplankton No./L.	Zooplankton No./L.	Net Plankton Volume cc./L.	Cocci No./L.	Bacilli No./L.	Spirilla No./L.
3	4/26	0-2	1.2	320	2,500	700	0.0023	7,000,000	17,000,000	10,000,000
	5/24	0-2	3.0	200	2,300	400	0.0016	3,000,000	30,000,000	3,000,000
	6/18	0-2	3.0	150	2,600	100	0.0016	3,000,000	10,000,000	10,000,000
	7/20	0-2	3.0	148	1,100	100	0.0009	3,000,000	17,000,000	7,000,000
	9/12	0-2	2.5	180	1,400	0	0.0012	0	20,000,000	9,000,000
	10/10	0-2	2.0	200	2,000	100	0.0011	3,000,000	30,000,000	7,000,000
4	4/26	0-2	1.5	320	2,100	700	0.0021	10,000,000	23,000,000	7,000,000
	5/24	0-2	3.0	200	3,000	400	0.0018	10,000,000	20,000,000	13,000,000
	6/18	0-2	3.0	150	1,400	100	0.0014	3,000,000	7,000,000	20,000,000
	7/20	0-2	3.0	148	1,000	100	0.0010	3,000,000	13,000,000	7,000,000
	9/12	0-2	2.5	180	1,600	100	0.0015	3,000,000	20,000,000	3,000,000
	10/10	0-2	2.0	200	2,100	100	0.0013	3,000,000	27,000,000	5,000,000
5	4/26	0-2	1.4	320	2,300	500	0.0018	7,000,000	17,000,000	13,000,000
	5/24	0-2	3.0	200	3,000	200	0.0015	3,000,000	33,000,000	10,000,000
	6/18	0-2	3.0	150	2,400	100	0.0017	3,000,000	10,000,000	17,000,000
	7/20	0-2	3.0	148	1,300	200	0.0012	3,000,000	10,000,000	9,000,000
	9/12	0-2	2.5	180	1,500	100	0.0011	3,000,000	30,000,000	3,000,000
	10/10	0-2	2.5	200	2,500	200	0.0012	10,000,000	20,000,000	3,000,000

Appendix C

Table I. Data obtained from each of the twenty lakes between April 10 - Aug. 1, 1954.

Lake	Date 1954	Depth Feet	Secchi Disk Inches	Turbid-ity ppm.	Phyto-plankton No./L.	Zoo-plankton No./L.	Net Plankton Volume cc./L.	Cocci No./L.	Bacilli No./L.	Spirilla No./L.
Carl Blackwell	4/12	0-2	9.0	28	3,000	1,500	0.0034	7,000,000	30,000,000	3,000,000
		15		32	700	200	0.0020	0	60,000,000	7,000,000
		26		43	400	100	0.0016	3,000,000	13,000,000	7,000,000
Boomer	7/4	0-2	5.0	80	7,000	300	0.0019	50,000,000	300,000,000	30,000,000
		16		95	2,300	100	0.0005	70,000,000	777,000,000	47,000,000
Canton	7/18	0-2	36.0	<25	38,000	600	0.0102	10,000,000	67,000,000	3,000,000
		13			21,400	200	0.0130	33,000,000	197,000,000	17,000,000
Claremore City	8/1	0-2	6.0	70	2,400	300	0.0016	0	10,000,000	3,000,000
		14		76	300	100	0.0009	3,000,000	3,000,000	3,000,000
Cushing	7/6	0-2	3.0	130	2,100	100	0.0011	0	30,000,000	17,000,000
		14		142	600	0	0.0003	3,000,000	7,000,000	17,000,000
Fort Gibson	7/9	0-2	48.0	< 25	21,400	1,000	0.0082	20,000,000	57,000,000	0
		15			23,000	1,400	0.0085	22,000,000	73,000,000	7,000,000
		30			16,000	500	0.0068	27,000,000	133,000,000	7,000,000
		45			2,200	200	0.0033	23,000,000	150,000,000	17,000,000
		60			1,800	100	0.0026	30,000,000	77,000,000	23,000,000
Grand	5/9	0-2	72.0	< 25	2,200	700	0.0024	7,000,000	23,000,000	3,000,000
		16			1,700	400	0.0022	7,000,000	33,000,000	7,000,000
		32			700	300	0.0018	13,000,000	30,000,000	13,000,000
		49			400	200	0.0013	10,000,000	32,000,000	3,000,000
		65			100	100	0.0009	13,000,000	40,000,000	0
		82			0	100	0.0004	17,000,000	30,000,000	7,000,000
		98			0	100	0.0003	13,000,000	30,000,000	20,000,000

Table I. (Continued)

Lake	Date 1954	Depth Feet	Secchi Disk Inches	Turbidity ppm.	Phytoplankton No./L.	Zooplankton No./L.	Net Plankton Volume cc./L.	Cocci No./L.	Bacilli No./L.	Spirilla No./L.
Heyburn	4/18	0-2	2.0	200	600	100	0.0009	3,000,000	10,000,000	3,000,000
		15		230	200	100	0.0004	0	3,000,000	7,000,000
		23		255	100	0	0.0001	0	0	7,000,000
Hula	7/23	0-2	16.0	<25	4,700	100	0.0016	3,000,000	30,000,000	7,000,000
		15			2,100	100	0.0014	10,000,000	43,000,000	3,000,000
		30			800	0	0.0008	3,000,000	37,000,000	7,000,000
		45			200	0	0.0005	0	25,000,000	7,000,000
Liberty	7/18	0-2	9.0	38	3,300	200	0.0014	3,000,000	20,000,000	7,000,000
		17		43	800	100	0.0005	0	17,000,000	20,000,000
Perry City	4/19	0-2	2.0	210	1,000	300	0.0014	3,000,000	13,000,000	0
		17		238	300	100	0.0006	0	10,000,000	3,000,000
Pawhuska	7/24	0-2	30.0	<25	17,700	200	0.0038	20,000,000	43,000,000	17,000,000
		15			12,500	100	0.0044	33,000,000	40,000,000	17,000,000
		30			900	100	0.0021	33,000,000	67,000,000	30,000,000
Pawnee City	7/21	0-2	2.0	200	1,000	100	0.0007	0	8,000,000	3,000,000
		14		208	200	0	0.0002	3,000,000	17,000,000	7,000,000
Ponca	7/6	0-2	18.0	< 25	19,300	200	0.0031	7,000,000	30,000,000	17,000,000
		18			2,300	100	0.0020	33,000,000	17,000,000	20,000,000
Sanborn	4/10	0-2	28.0	< 25	20,700	9,300	0.0297	17,000,000	100,000,000	3,000,000
		9			16,500	2,100	0.0348	30,000,000	473,000,000	17,000,000

Table I. (Continued)

Lake	Date 1954	Depth Feet	Secchi Disk Inches	Turbid-ity ppm.	Phyto-plankton No./L.	Zoo-plankton No./L.	Net Plankton Volume cc./L.	Cocci No./L.	Bacilli No./L.	Spirilla No./L.
Shawnee	7/25	0-2	20.0	<25	5,800	300	0.0031	20,000,000	17,000,000	3,000,000
		15			1,700	100	0.0022	33,000,000	27,000,000	17,000,000
Lower Spavinaw	5/8	0-2	42.0	<25	14,400	2,200	0.0190	7,000,000	63,000,000	3,000,000
		15			6,800	900	0.0164	17,000,000	126,000,000	10,000,000
		24			2,200	400	0.0036	20,000,000	107,000,000	30,000,000
Tecumseh City	7/25	0-2	4.0	90	800	100	0.0012	10,000,000	33,000,000	0
		12		91	100	500	0.0005	3,000,000	20,000,000	7,000,000
Tenkiller	7/9	0-2	96.0	<25	4,500	400	0.0029	3,000,000	23,000,000	30,000,000
		15			3,200	300	0.0026	7,000,000	27,000,000	3,000,000
		30			1,000	200	0.0018	10,000,000	20,000,000	7,000,000
		45			600	100	0.0008	13,000,000	30,000,000	3,000,000
	7/10	60			100	100	0.0007	3,000,000	33,000,000	7,000,000
		75			100	0	0.0005	7,000,000	30,000,000	10,000,000
		90			0	0	0.0001*	10,000,000	33,000,000	3,000,000
		105			0	0	0.0001*	3,000,000	30,000,000	7,000,000
		120			0	0	0.0001*	3,000,000	17,000,000	3,000,000
Yost	7/2	0-2	8.0	52	2,600	200	0.0008	10,000,000	30,000,000	7,000,000
		14		58	800	100	0.0003	3,000,000	17,000,000	13,000,000

*Detritus only - no living organisms.

Appendix D

Table I. The average numbers of phytoplankters, zooplankters, cocci, bacilli, and spirilla per liter; the average volumes of net plankton in cubic centimeters per liter; and the ranges of turbidities for the farm ponds and the lakes.

Plankton	Water Level Sampled	Range of Turbidity in ppm.					
		Less than 25		25-50		51-350	
		Ponds	Lakes	Ponds	Lakes	Ponds	Lakes
Phyto-plankton	Surface	26,800	14,900	5,200	3,200	2,600	2,200
	Bottom	15,000	4,700	1,100	600	300	300
Zoo-plankton	Surface	3,300	1,500	1,100	900	400	200
	Bottom	1,900	300	200	100	0	100
Net Plankton Volume	Surface	0.0164	0.0084	0.0029	0.0024	0.0017	0.0012
	Bottom	0.0111	0.0061	0.0012	0.0011	0.0004	0.0003
Cocci	Surface	19,000,000	11,000,000	10,000,000	6,000,000	5,000,000	5,000,000
	Bottom	29,000,000	23,000,000	10,000,000	5,000,000	2,000,000	11,000,000
Bacilli	Surface	47,000,000	54,000,000	27,000,000	25,000,000	20,000,000	50,000,000
	Bottom	65,000,000	118,000,000	24,000,000	15,000,000	11,000,000	106,000,000
Spirilla	Surface	5,000,000	9,000,000	5,000,000	3,000,000	4,000,000	8,000,000
	Bottom	17,000,000	18,000,000	8,000,000	5,000,000	7,000,000	15,000,000

VITA

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candidate for the degree of
Doctor of Philosophy

Thesis: THE PRODUCTIVITY OF OKLAHOMA WATERS WITH SPECIAL REFERENCE TO RELATIONSHIPS BETWEEN TURBIDITIES FROM SOIL, LIGHT PENETRATION, AND THE POPULATIONS OF PLANKTON

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