

AN INVESTIGATION  
OF THE PHYSICAL, CHEMICAL, AND BIOLOGICAL ASPECTS OF STREAM POLLUTION  
IN THE JAMES RIVER AT BIG ISLAND, VIRGINIA

BY

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INTRODUCTION

The Semi-chemical Pulp Waste project is one of a number of research projects sponsored by the National Council for Stream Improvement, Inc. (of the Pulp, Paper and Paperboard Industries) in an effort to aid in the abatement of industrial stream pollution. Funds for the project were granted to the V.P.I. Research Foundation which entered into a contract to conduct the investigation. The project was carried out on the industrial fellowship plan under the general direction of Dean E. B. Norris. Dr. F. C. Vilbrandt, Professor of Chemical Engineering, served as project director with P. H. McGauhey, Professor of Sanitary Engineering, as co-director.

The purpose of the project was to explore the possibility of reducing the pollutional effects of semi-chemical pulp wastes, either through treatment of wastes or alteration of process.

The program included a survey of available literature; the preparation of material balances and flow diagrams; the determination of the composition of effluents; and the extent of stream pollution.

Three chemical engineers, Messrs. H. Kress, E. R. Turner and B. Jacknin, and one sanitary engineer, the author, were assigned to the project. The former were concerned with the chemical and chemical engineering aspects of the program, while the author was concerned primarily with the extent of the stream pollution.

The National Container Corporation of Virginia's plant at Big Island, Virginia was the focus of the investigation. This plant, producing 100 tons of paper daily, is located on the James River halfway between Lynchburg and Natural Bridge.

Studies made on the river in the reaches below the plant during the period from July 25 to August 28, 1947 serve as source material for this thesis.

THE PROBLEMExisting Conditions

The James River above Big Island is a stream of approximately 50 miles in length to which the Jackson River, its principal headwaters tributary, adds another 87 miles, making a total length for the two of approximately 137 miles.

Located on these streams above Big Island are the communities of Covington, Clifton Forge, Iron Gate, Eagle Rock, Buchanan, and Glasgow. The River is of primary importance to these towns and cities, and is of great concern to the entire State since a large portion of Virginia lies in the James River Basin. (See Map 1.)

Mr. B. C. Moomaw, Jr. (1) in reporting on data taken from a survey made on the James River states:

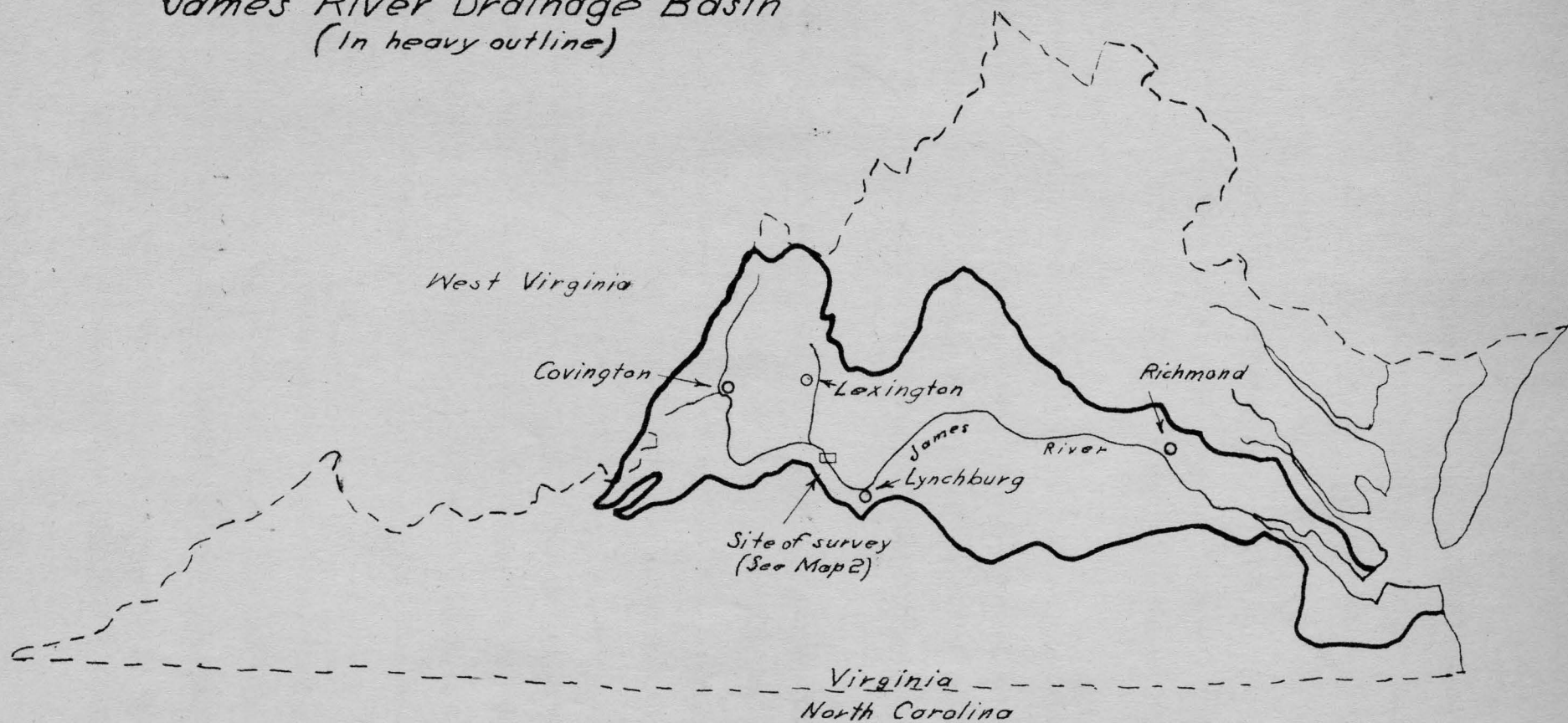
"The James and Jackson Rivers are streams which have now a number of objectionable features. These are primarily the wide fluctuations in stream flow, varying from destructive floods to severe droughts, and widespread pollution of the stream by industrial wastes and municipal sewage. This latter condition has long been the subject of Statewide concern. Almost every Legislature for the past thirty years has considered bills for the prevention of pollution. These bills were aimed primarily at the James River. The Legislature of 1946 enacted such a measure into law."

He goes on to say that this State Water Control Law is "a bill designed to (1) prevent pollution from new sources (2) prevent increase of pollution from existing sources (3) gradually reduce the pollution from existing sources.

"The operation of this law, over the years will do much to reduce the pollution of the James River. It is my information that the industries at

# MAP I

James River Drainage Basin  
(In heavy outline)



Covington, Big Island, and Lynchburg, are installing or have definite plans for installing facilities which will substantially reduce the pollution they are now discharging into the stream. But these industries (paper and pulp manufacture) use enormous quantities of water. While it is possible to treat their more concentrated wastes, the millions of gallons of water used in processing and washing the pulp cannot be treated economically. These industries will be compelled to continue to discharge large quantities of such water into the stream."

The James River is characterized by wide fluctuations in stream flow. The maximum flow at Balcony Falls, a town located a few miles above Big Island, is recorded as 100,000 cfs, and the minimum as 242 cfs. This, of course, represents a range from a condition of destructive flooding to one of severe drought.

In regards to stream conditions Mr. Moomaw (1) says further:

"More serious than the flood hazard is the other extreme of low water which occurs practically every year for periods of from three to five months and which carries with it a high concentration of industrial and municipal pollution. The pollution renders the water unfit for domestic or municipal water supply and for most industrial uses. The stream has an unattractive color, and a disagreeable odor which makes it unpleasant for those who live near it. Conditions are unfavorable for fish and wildlife, and boating, fishing, and other recreational uses of the stream are possible to a very limited extent.

"Every few years there is an unusually severe drought which aggravates these conditions. During such periods the stream gets very low, and stagnant pools are left along its edges. The pollution becomes highly concentrated and under the effects of the summer heat becomes very objectionable. The small volume of water moves so slowly that the natural forces of puri-

fication do not work effectively and the objectionable conditions are carried far downstream. While such extreme conditions are of relatively short duration and do not occur every year, they serve to emphasize the worst features of present conditions.

"Pollution both from municipal and industrial sources exists on the Jackson and James Rivers at several points. This pollution, considered in terms of sewer connected population is as follows: At Covington, the pollution is equal to a sewer connected population of 373,000; at Rayon Terrace of 24,000; at Clifton Forge 6,000; at Iron Gate 7,500.

"This renders 2½ miles of the Jackson River unfit for other uses. The pollution carries downstream through the James with diminishing intensity, as it is diluted with clear water from the tributary streams and as the natural forces of stream purification get in their beneficial work. However, the 5½ miles of the James in Botetourt County have the character and appearance of a polluted stream. The water is brown or black with frequent occurrences of white foam, and there are noticeable odors. During the hot summer months, these conditions are intensified, and have been the subject of much complaint from the communities along the stream. A little fishing is done, especially for the coarser fish. Boating and other recreational uses of the stream are practically non-existent, both by reason of low water and the unpleasant nature of the stream.

"By the time the river reaches Balcony Falls, evidences of this pollution have disappeared and the nine miles of stream from that point to Big Island are practically clear. There is considerable boating, fishing, and other recreational use of the River at Big Island above the dam.

"However, at Big Island, industrial wastes again enter the stream in an amount equivalent to a sewer connected population of 81,000. This renews the polluted conditions of the stream to Lynchburg, where combined municipal

sewage and industrial wastes are discharged into the stream in an amount equivalent to a sewer connected population of 210,000. Thus again there is a highly polluted condition of the James with the usual objectionable features, beginning at Big Island, continuing through Amherst and Bedford counties to Lynchburg where they are greatly intensified, and then extending far downstream with diminishing intensity as unpolluted tributaries and natural forces of stream purification gradually correct the character of the water."

#### Anti-pollution Legislation

Pollution is a rather ambiguous term; and being such, lends itself to controversy. Wiley (2), however, defines it in such a way as to be acceptable by any quarter. He considers pollution as an unwarranted or unreasonable amount of objectionable substances contributed to the natural waters of a stream which, because of the amount and kind, should be removed, counteracted, or prevented from entering the stream.

Likewise, a controversial issue in the subject of stream pollution is the question of whose rights shall prevail, the public's or industry's. Although it is now generally accepted that pollution abatement is necessary, industry does not agree with the public on the necessity of immediate prosecution of anti-pollutional measures. Murdock (3), defends industry's point of view by stating that industry is a vital part of our economy, and it must be given an opportunity to continue. Until satisfactory processes for waste treatment are developed, "it is advisable that an existing plant use the stream as the final disposal medium for liquid wastes from municipality as well as industry." The public's point of view is defended by Murdock (4), who cites a statement from a division of the Court of Common Pleas of Philadelphia County as being a signal for action on a matter which has been put

off too long. This statement is as follows:

"Nothing is more fundamental than the right of people to have the public streams from which they draw water supply, free from pollution."

A more rational and compromising point of view is taken by Scott (5) and Hoak (6). Scott (5) maintains that the streams must be used for the disposal of sewage and industrial wastes, but it is essential that the total load of pollution should be kept low so as not to create foul conditions. Hoak (6) points out that, "a stream's ultimate use can only be determined by an impartial survey which takes in account all pertinent engineering and economic factors and the effect of such use on the population bordering the streams."

To provide a solution for this problem various legislation has been proposed and some accepted. Scott (7) gives an excellent review of State Legislation, Interstate Compact Legislation, and Federal Legislation that deals with this problem. Although no Federal Legislation has yet developed Wisely (8) believes that Congress is eager to consider pollution control on a national scale. As evidence of this eagerness he cites the introduction of no less than six bills. At the present, regulatory authority of stream pollution resides with the states. Parran (9) believes that standards for State Legislation are needed so that there will be reasonable uniformity from state to state. There is considerable concern that any stream pollution legislation will drive away industrial payrolls, and this is especially true of those industries that produce wastes for which there is no practicable treatment method at the present. Hedgepeth (10), believes that special consideration will have to be given in such cases, but this should not be a valid reason for continued abuse of the streams. Wolman (11) points out that basically stream pollution law within the states had its origin in the police power of the state to protect public health. He also states that the state

Laws have been designed for two major purposes: (a) the protection of the public health, water supply, aquatic life, industry, recreation, and (b) the prevention or abatement of local or general nuisances.

Of Virginia's pollution legislation, Hedgepeth (12), who is the Executive Secretary of the State Water Control Board, explains the Virginia Pollution Control Act, passed in 1946, as "a 'license' to do some selling of pollution abatement to industry, and the prevention of new or increased pollution. Pollution already existing prior to the passage of the new act could be continued under permits with the expectancy that efforts are to be made to reduce pollution as rapidly as permissible. The permits to pollute are subject to modifications or revocations whenever circumstances justify such withdrawals." In another article, Hedgepeth (13), lists the general objectives of the State's stream pollution program as the following:

1. Removal of scum, sludge, and grease.
2. Destruction or diversion of objectionable concentrations of toxic agents.
3. Reduction of discoloration to imperceptibility in the stream.
4. Adjustment of acidity or alkalinity to a normal range.
5. Reduction of the B.O.D. so as not to drop the D.O. below an acceptable minimum.

#### Nature of the Pollutants

Literature is void of references to the semi-chemical pulp manufacture. Possibly this absence is due to two factors. First, the process is a recent development and, second, the term semi-chemical is rather ambiguous, referring to a number of processes operating under mild acid or alkaline conditions, such as the semi-sulfite, semi-sulfate, semi-chemical soda, etc. In all these processes the principle involved is a digestion of hard wood chips under rela-

tively mild conditions, which softens but does not fully pulp the chips, with a subsequent reduction to pulp by mechanical disintegration. It is quite obvious that the semi-chemical process varies considerably from mill to mill and that each mill has its own individual problem of waste disposal.

The Big Island Mill uses two semi-chemical pulping processes. One is a neutral sulfite cook on tannin-extracted chestnut chips, and the other is a semi-soda cook on pine and mixed hardwoods. The waste from these processes enters the river from three sources; the digester blow-down, the washers, and the machines. Crawford (14) gives the following data on these effluents:

Average Values for May 1947

	Globe Digester Blowdown	Washer Effluent	Machine Effluent
Volumes (gal./day)	24,000	2,000,000	864,000
Solids Total (ppm)	102,300	4,593	658
Solids Fixed (ppm)	35,000	1,547	166
Solids Volatile (ppm)	67,300	3,046	492
Solids Total (tons/day)	10.8	38.3	2.4
Color (Platinum - ppm - cobalt standard)	165,000	12,000	500
% of total color of effluents (%)	13.8	84.7	1.5
5-day B.O.D. (lbs./day)	1,940	16,440	230

No thorough analyses of the chemical nature of the effluents are available. However, it is known that they contain cellulose, tannins, lignins, pentosans, hexosans, sulfur in either sulfate, sulfite, or sulphide forms, and various other organic compounds of small molecular weight.

THE INVESTIGATION

A criterion for the solution of any pollution problem involves, along with a thorough knowledge of processes and materials, information as to the exact effects of the pollution. These effects are manifest in the physical, chemical, and biological conditions existing in the polluted stream.

Early in the spring of 1947 Mr. George Maniates, chemist for the National Container Corporation, began investigating as many of the physical and chemical aspects of the pollution present in the river as possible with only one assistant to aid him on the project. Dr. Vilbrandt and Professor McGauhey thought it advisable for the author to spend five weeks at Big Island so as to round out the picture by supplementing Mr. Maniates' work with mineral, bacterial and microscopic analyses of the water.

On the seven mile reach of river under investigation, eight sampling stations had been established. (See Map 2.) Station #1 was located just above the plant and served as a control. Station #2 was located 0.5 miles downstream from the plant, where the river is only a few feet deep and the current very swift. Station #3 was located one mile further downstream where the depth is greater and the velocity slackens. At Station #4, 0.8 miles downstream from Station #3, the pondage created by Coleman Dam is first evidenced by a widening of the river and still lower velocities. Station #5 is located on the quiescent pond behind Coleman Dam 1.7 miles downstream from Station #4. Here, the depth is the greatest found on the reach investigated and during periods of low flow, the current is imperceptible. Below Coleman Dam, 0.5 miles from Station #5, Station #6 is located on a shallow shoal where the current is again swift. A mile further downstream Station #7 is located where the ponding effect of Holcomb Dam is first evidenced. At Station #8, 0.8 miles from Station #7, the pondage creates a condition

# MAP 2

(From Fairchild Aerial Survey Map 3879-1133)

Distance from plant to Station #2 = 0.5 miles

#3 = 1.5

#4 = 2.3

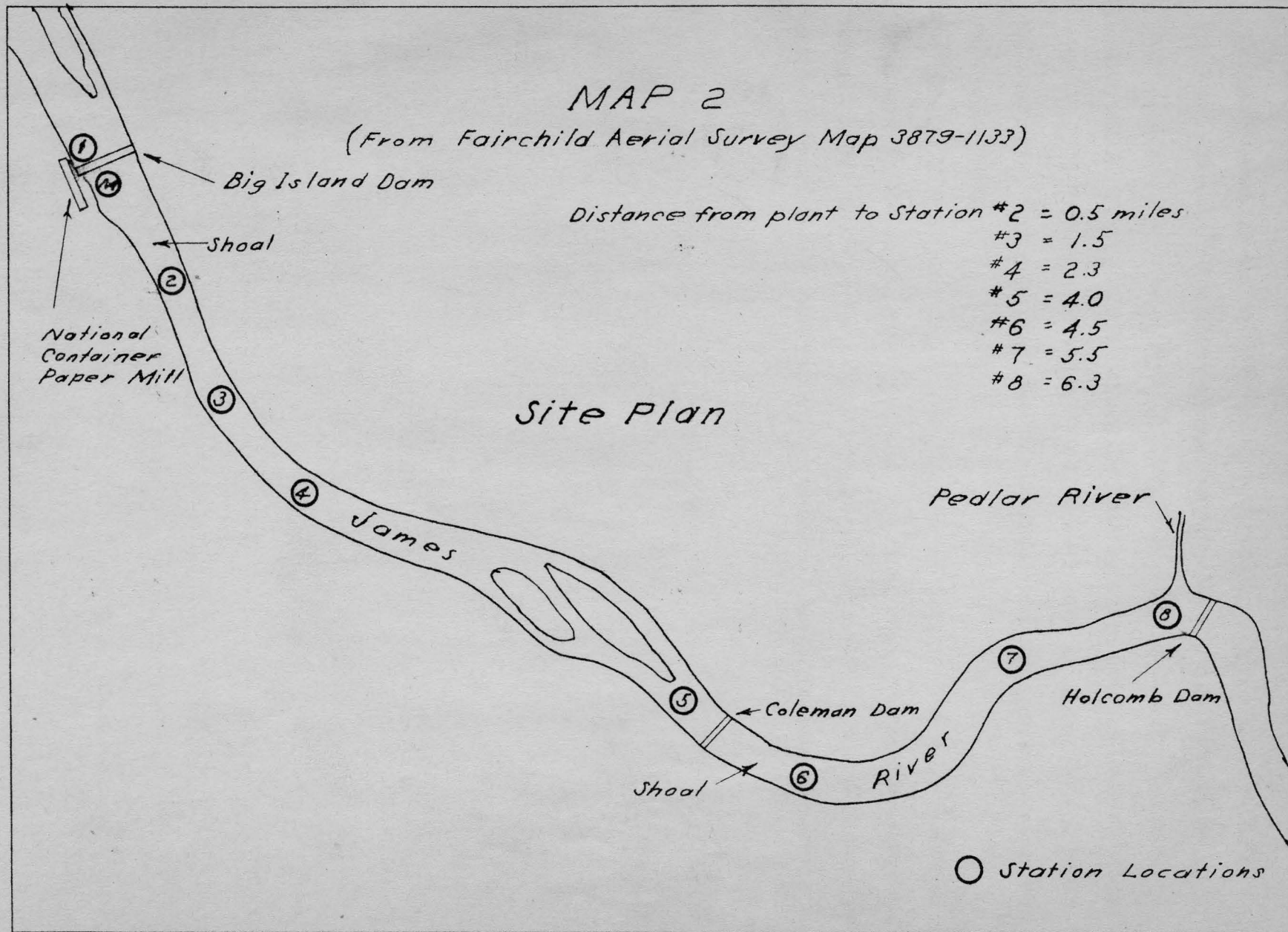
#5 = 4.0

#6 = 4.5

#7 = 5.5

#8 = 6.3

## Site Plan



similar to that at Station #5.

Mr. Maniates' investigation included pH, color, dissolved oxygen, dissolved solids--total, fixed, and volatile, and the B.O.D. The author's investigation included alkalinity, CO<sub>2</sub>, bacterial analysis - both coliform and total 37°C count, and a survey of the micro-organisms in the water, in the mud at the banks, in the deposits on the bottom, and in the sludge that was found floating on the surface.

A schedule of two sampling trips per week was maintained. The trips were made in two boats, one for use on the river above Coleman Dam and the other for use below the dam. The boats were propelled by an outboard motor and four to six hours were required for making a complete sampling trip.

BACTERIAL CONCENTRATIONSPurpose

The bacterial population in the river was investigated in order to determine whether or not the mill wastes were toxic to those organisms responsible for the biochemical oxygen demand. It seemed certain that if the wastes were toxic a condition would exist where the pollutants would undergo only a minimal attack from the bacteria, and the pollution would be carried to reaches far downstream.

From the standpoint of stream sanitation it would be most desirable if the pollutants were not toxic, thereby allowing the bacteria to attack them in the reaches nearest the mill. By doing this, the problem would become one of a more local nature.

It was thought that a study of the relative bacterial concentrations at each station would offer an indication as to whether or not the wastes were toxic.

Methods Used

Bacterial counts were made at each five sampling stations twice a week. Station #1 and M were investigated on each trip, and the other three samples were taken from the other six stations in rotation.

Two tests were included in this analysis. One was for determining the total 37°C count and the other for determining the number of *Escherichia coli* present. The total count of colonies was made on an agar culture after incubation for twenty-four hours at 37°C. The procedure is discussed in detail in the "Standard Methods for the Examination of Water and Sewage." (15) While it is recognized that such a count is not an accurate measure of the total bacteria in such an environment as the James River, it was felt that such a study would serve as an indicator of relative concentrations.

The test for *Escherichia coli* is in reality two tests—a presumptive test and a confirmative test. The presumptive test is considered positive when an inoculant has the ability to ferment lactose with gas formation in nutrient lactose broth. The confirmative test is considered positive when an inoculant from the presumptive test has the same ability in brilliant green bile lactose broth. Both cultures are incubated at 37°C for a maximum of forty-eight hours. By testing a series of dilutions, those dilutions were determined which bracketed the change from positive to negative, indicating the most probable number of *Escherichia coli* present. This test for *Escherichia coli* is a measure of the quantity of bacteria contributed by fecal pollution. Details concerning this test may also be found in "Standard Methods for the Examination of Water and Sewage." (15)

### Discussion of Results

#### 1. Maximum Concentration

The average values of the total count at each station are shown in Plate 1. This graph clearly demonstrates that the maximum concentration of bacteria was located at Station #2. This maximum was approximately six times as great as the largest concentration encountered elsewhere. Three factors, taken separately or in combination, could give rise to this condition.

The first factor may be explained in terms of a river turbulence which brings to the surface not only the bacteria that were engaged in decomposing the suspended wastes but also those which were attacking the bottom deposits. The reach of river which extends from the mill to Station #2 is shallow and rapid. The effect of the rapid flow over a shallow and boulder-strewn course is to provide a homogeneous condition from surface to bottom. This condition does not exist at Stations #3, #4, and #5. The samples taken from the surface

TABLE 1

Results of the Total Count Determinations  
Number of Organisms/100 ml.

<u>Run No.</u>	<u>Date</u>	<u>Sta. #1</u>	<u>Sta. M</u>	<u>Sta. #2</u>	<u>Sta. #3</u>	<u>Sta. #4</u>
2	7-31	1,000	—	1,000,000*	800,000*	800,000*
3	8-4	10,000*	1,200	—	20,000	—
4	8-8	15,000	25,000	2,450,000	—	1,500,000
5	8-13	35,000	22,500	—	500,000	—
6	8-15	15,500	800,000*	40,000,000	—	5,000,000
7	8-20	8,000	500,000	—	3,500,000	—
8	8-22	10,000	5,000,000	—	—	—
9	8-25	80,000	80,000	—	4,000,000	—
10	8-27	—	—	—	—	—
Average		21,750	918,386	14,483,333	1,764,000	2,433,330

<u>Run No.</u>	<u>Date</u>	<u>Sta. #5</u>	<u>Sta. #6</u>	<u>Sta. #7</u>	<u>Sta. #8</u>
2	7-31	600,000*	—	—	—
3	8-4	4,300,000	—	—	60,000
4	8-8	—	—	400,000	—
5	8-13	2,500,000	1,500,000	—	—
6	8-15	—	—	—	700,000
7	8-20	3,000,000	—	1,000,000	—
8	8-22	—	1,000,000	—	—
9	8-25	1,000,000	—	—	900,000
10	8-27	—	—	—	—
Average		2,280,000	1,250,000	700,000	553,333

\*Dilution was such that the indicated value represents only an approximation.

TABLE 2

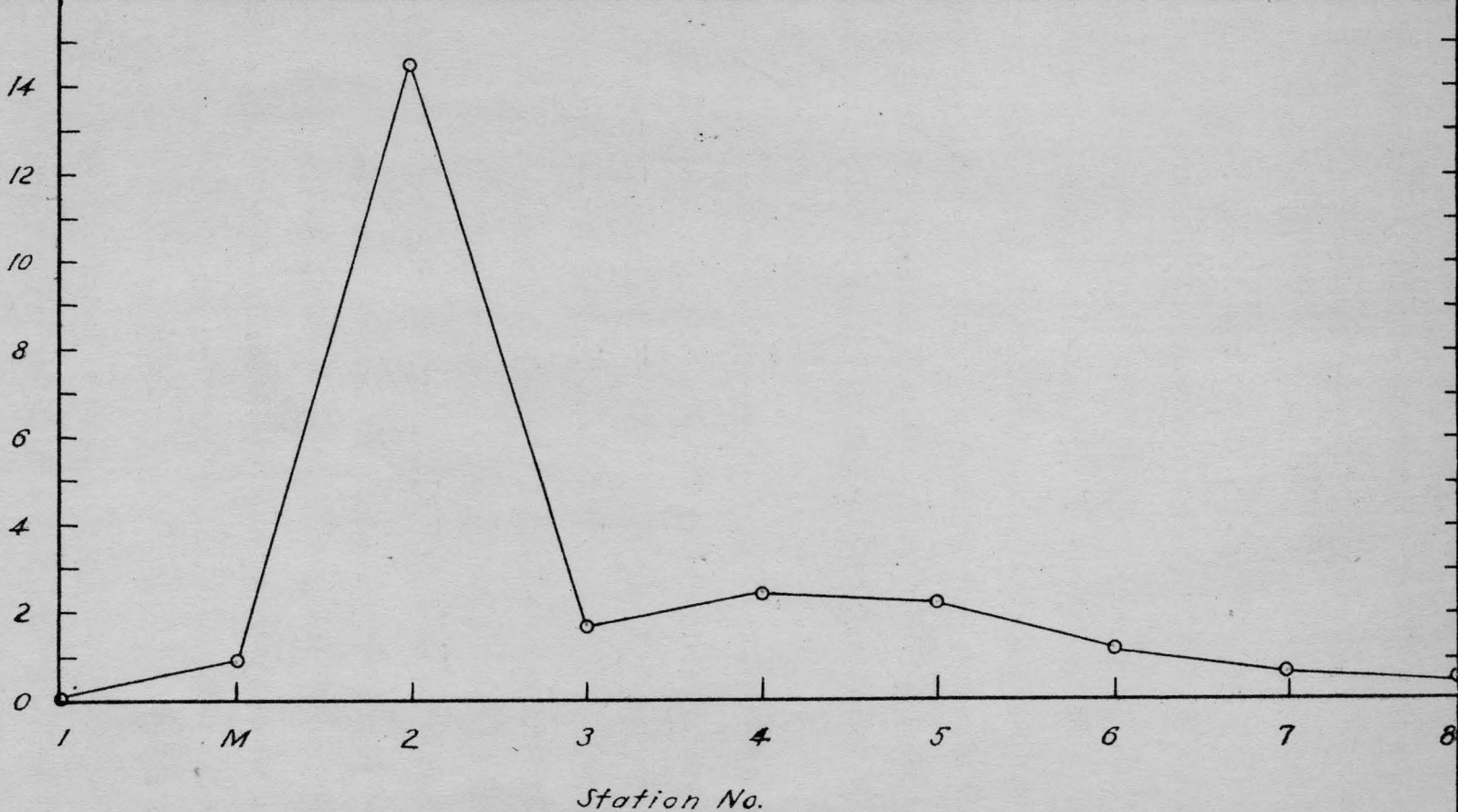
Results of the Escherichia coli Determinations  
Most Probable Number of Organisms/100 ml.

<u>Run No.</u>	<u>Date</u>	<u>Sta. #1</u>	<u>Sta. #1</u>	<u>Sta. #2</u>	<u>Sta. #3</u>	<u>Sta. #4</u>
2	7-31	240	—	> 240	> 240	> 240
→ 3	8-4	2,400	2,400	—	2,300	—
→ 4	8-8	2,400	2,400	2,300	—	24,000
5	8-13	≅ 24,000	2,400	—	2,300	—
6	8-15	≅ 24,000	≅ 24,000	2,300	—	24,000
7	8-20	≅ 230	2,400	—	24,000	—
8	8-22	2,400	≅ 24,000	24,000	—	—
9	8-25	230	2,300	—	2,300	—
10	8-27	2,400	2,300	24,000	—	≅ 230

<u>Run No.</u>	<u>Date</u>	<u>Sta. #5</u>	<u>Sta. #6</u>	<u>Sta. #7</u>	<u>Sta. #8</u>
2	7-31	> 240	—	—	—
3	8-4	2,300	—	—	2,300
4	8-8	—	—	230	—
5	8-13	≅ 230	2,400	—	—
6	8-15	—	—	—	230
7	8-20	2,400	—	2,400	—
8	8-22	—	2,400	—	—
9	8-25	≅ 230	—	—	2,300
10	8-27	—	230	—	—

*Bacteria Present in Millions/100cc*



**PLATE I**

**AN AVERAGE OF TOTAL BACTERIA COUNTS IN WATERS**

at these stations would include, because of the relative quiescence of the river flow, only the bacteria associated with the soluble and suspended waste material. That this first factor, if it is involved, does not operate alone but, instead, operates in conjunction with the other factors is readily evidenced by the bacterial concentration found at Station #6. The reach of river between Coleman Dam and Station #6 is similar to the reach above Station #2. However, the average concentration at Station #6 is only a tenth of that at #2. If this explanation of the concentration at Station #2 is correct the presence of a pollutional carpet at that point is expected. This carpet is actually present. However, it is of a transient nature. As is discussed in the section on Bottom Deposits the carpet is continually being flushed from the bottom.

A condition of extreme aeration may operate as another factor. The constant agitation present at this point furnishes the water ample contact with the air. This aeration, along with the bottom deposits being "sloughed off," can be compared with the activated sludge process of sewage treatment. In the activated sludge process domestic or industrial wastes are aerated in contact with a certain amount of recirculated sludge. A detailed explanation may be found in Metcalf and Eddy's (16) "Sewerage and Sewage Disposal," pages 636 to 678. Sufficient to say, that such a condition of extensive aeration probably contributes to an increase of the bacterial concentration.

The wastes from the mill include the polysaccharide pentosans and hexosans along with their hydrolytic products—the pentoses and the hexoses. The pentoses and hexoses are directly available to the bacteria as food. If the mill wastes contain no toxic materials, then this immediate availability of food may be recognized as an important factor in increasing the concentration of bacteria.

The picture at Station #2 was complicated by a Big Island sewer outlet

located between the mill and the station. It was considered possible that this sewer which served a population of from two to three hundred was responsible for a good portion of the bacteria found at Station #2. If so, a portion of the population found at this station was of fecal origin and must be discredited insofar as the natural bacto-oxidation of the pollutants are concerned. By a quantitative test for *Escherichia coli* it was hoped to determine the number of fecal bacteria at each station. If a greater number of *Escherichia coli* was associated with Station #2, it could reasonably be concluded that the total numbers found there would not necessarily indicate that the river at that point was engaged in an accelerated attack on the mill wastes. In order completely to isolate the effect of the sewer outlet, Station M was established between the outlet and the mill. (See Map 2.) From Table 2 it is seen that the larger concentrations of fecal bacteria occurred at other stations just as often as they occurred at Station #2. Therefore, the sewer apparently exerts no effect and the foregoing factor is not involved.

Of all the factors considered, the immediate availability of food appears to be the most important. It has been pointed out that turbulence and aeration exist elsewhere in the river without a bacterial complement of great magnitude. If these factors do operate to increase the concentration at Station #2, they probably operate in conjunction with the more dominant food supply factor. The *Escherichia coli* tests indicate that the Big Island sewer can be ignored as an influencing factor.

## 2. Concentration at Station M

From Plate 1 it is noted that a larger concentration was encountered at Station M than at Station #1. This means that at some point, or points, in the water's progress through the mill, the bacterial concentration was

increased.

Since the wood pulp is rendered sterile by the cooking process, no bacteria could be expected from this source. However, the waste paper used to make up to 30% of the final pulp is quite the opposite of sterile. A report on a microbiological analysis prepared by the National Aluminate Corporation for the mill lists a total count of the bacteria present in the waste paper beaters at 180,000,000 organisms per ml. of waste paper stock! This figure is not so astounding, however, if one stops to consider the waste paper used. This paper includes cardboard boxes that have been used to hold vegetables and meats. The rotting remains of these items are quite frequently found in the bales of waste paper used. It is readily recognized that such paper constitutes a salient source of bacteria.

The sanitary sewage from the mill, no doubt, contributes to the increase in bacteria at Station M.

### 3. Concentration at Station #3

Just why the bacterial concentration at Station #3 was less than those at Stations #4 and #5 is not known. Possibly, it was a matter of obtaining an apparent rather than an actual concentration. At Station #3 a small flow entered the river from a creek. Because the samples were taken at the surface, they could have contained, to an appreciable extent, the creek water instead of the river water. This seems to be the only justification that can be given.

### 4. Concentrations at Stations #5, #6, #7 and #8

The gradual decrease in concentration from Station #5 throughout the remainder of the river investigated was probably the result of a reduction in the available food material. Obviously, aeration and turbulence were not functions of this decrease. The reach of river concerned varies from the

extreme turbulence of water falling over Coleman Dam to the quiescent pondage behind Holcomb Dam. If we recognize the concentration at Station #2 as being there primarily because of the readily available food material, then we can accept the decrease from #5 to #8 as demonstrating a diminishing food supply.

### Conclusion

In view of the fact that the maximum concentration of bacteria is found within a half a mile of the mill, along with the fact that the magnitude of this concentration has been correlated with the ready availability of food material, and because the general decrease in concentration from Stations #5 to #8 has been ascribed to a diminishing food supply, the author has no alternative but to believe that toxicity was not present to influence the results observed. Obviously, a bacterial population could not thrive on food that is toxic, or associated with toxic elements.

PLANKTONIC POPULATIONPurpose

The planktonic population was examined in order to determine how the mill wastes affected those microscopic organisms (other than the bacteria) that are suspended in the water. Plankton, if not inhibited by toxic substances or too foul conditions, are capable of actively engaging in stream "purification." Under favorable conditions carbohydrates are split and utilized by plankton until they are finally returned to the water in their original forms: water and carbon dioxide. Also, the majority of plankton contain chlorophyll, making them capable of increasing the oxygen tension of the water. For these reasons, it was desirable to know just what effect the mill waste had upon those organisms that were so intimately concerned with the decomposition processes.

As a rule, the plankton are few in species as compared with the microorganisms found on the bottom, nevertheless, they are sometimes enormous in numbers.

Methods Used

On each trip two plankton samples were taken. A control sample was taken at Station #1, and the second sample was taken at one of the other stations. Consequently, only one or two samples were taken at most stations during the period of field study. The author recognizes the doubtful validity of any conclusions based on so few observations. For the lack of any better information on the plankton, however, he feels free to present such data as he has.

Each sample consisted of 500 ml taken at a depth varying from 2 to 5 feet below the surface. In the laboratory the sample was filtered through a half inch layer of Berkshire sand in a Sedgwick-Rafter filter funnel as

recommended by Whipple (17). The sand, along with the organisms it had removed from the water, was then placed with 5 cc of tap water in a small beaker and stirred. After stirring, the water which contained the organisms in suspension was decanted off. The organisms in the decanted water were then in a concentration 100 times their concentration in the river.

Two microscopic analyses were made on the concentrated plankton sample, one of which was a total count. The total count was determined by placing a portion of the sample in a counting cell 1 mm deep. By taking ten 1 mm<sup>2</sup> fields at random and counting the organisms included, the average content per field was determined. The concentration in the river was then obtained by dividing the total content of the 1 mm<sup>3</sup> by the dilution factor of 100.

The other microscopic analysis was a survey of the species of organisms present and their relative abundance.

#### Discussion of the Quantitative Results

From the graph on Plate 2 it is noteworthy that the maximum plankton concentrations occurred at Stations #1, #5 and #8, whereas the minima occurred at Stations #3 and #7. An explanation of why the concentrations vary as they do may in part answer the question of the pollutants' effect on the plankton.

Lackey (18) states that the nature and abundance of a stream population depends roughly upon five factors. They are: the amount of food material available, the temperature of the water, the amount of toxic substances present, the oxygen tension of the water, and the speed of the current. It must be kept in mind that although all these factors are involved, some play a more important role than others. It is the purpose of this discussion to determine the degree in which the various factors are involved.

TABLE 3

Water Plankton Survey at Station #1

Key: M for many; S for several; F for few.

Name of Organism	Date of Survey							
	7-28	8-4	8-9	8-15	8-20	8-22	8-25	8-27
Concentration/ml	226	61	166	116	108	177	128	79

Myxophyceae

Coelosphaerium	S							
Gomphosphaeria			F					
Merismopedia					F			F
Oscillatoria	F			F		F	F	F

Chlorophyceae

Ankistrodesmus	M			S	F	S	S	S
Closterium		S						
Coelastrum	S			F	F			F
Cosmarium			F					F
Horridium			F					
Merismopedia						F		
Pandorina	M	F	M		S	M	M	F
Pediastrum	S			F				
Protococcus	M							
Scenedesmus	M		F	S	S	S	S	
Selenastrum	S		F					
Spirogyra		F						
Staurastrum	F							

TABLE 3  
(continued)

Name or Organism	Date of Survey							
	7-28	8-4	8-8	8-15	8-20	8-22	8-25	8-27
<u>Bacillarieae</u>								
Amphora	F	F	S	S	F	S	F	S
Brebissonia	S	F	F		F	F	S	F
Cocconeis	F	F	F		F	F	S	
Cyclotella	F	F		S				F
Cymatopleura		F		F			F	
Cymbella		S	S			S	F	F
Diatoma		S	S	S		F	F	S
Encyonema	F					F		
Fragilaria			M	M	M	M	F	F
Gyrosigma			S	F				
Mastogloia	F							
Melosira		M	S	S	S	S	M	S
Meridion		F	F			S	S	
Navicula	S	S	S	S	F	S	S	S
Nitzschia	S	S	S				F	
Pinnularia					F			
Pleurosigma	F	F	S	S	F	F	F	F
Stephanodiscus	M		S					
Surirello	F							
Synedra	S	S	S	S	S	S	S	F
Synedra pulchella		S						
Tabellaria			F			F		F

TABLE 3  
(continued)

Name of Organism	Date of Survey							
	7-28	8-4	8-8	8-15	8-20	8-22	8-25	8-27
<u>Protozoa</u>								
Astasia				S				
Bodo caudatus						F		
Chilomonas						S		
Chlamydomonas				S				
Cryptomonas				F				
Euglena deses								F
Euglena granulata	F					S		
Euglena minima					F	S	F	
Euglena pisciformis			F					
Euglena spirogyra							F	
Euglena terricola						S		
Euglena viridis		F		F	S		S	
Glaucoma			F					
Phacus acuminata		F						
Phacus anacoelas				F				
Phacus longicaudus				F				
Phacus pleuronectus								F
Phacus pyrum					F			
Trachelomonas sp.	S							
Trachelomonas eurystoma				H				
Trachelomonas oblonga		F	F			S		
Trachelomonas similis				F				



TABLE 1.

Water Plankton Survey at Stations #2, #3, #4, #5, #6, #7, & #8

Key: M for many; S for several; F for few

Name of Organism	Station Numbers									
	#2	#3	#4	#5	#5	#6	#7	#8	#8	
Date of Survey	8-22	8-4	8-15	7-28	8-27	8-20	8-8	7-31	8-25	
Concentration/ml	91	49	67	129	84	63	57	122	97	

Myxophyceae

Coelosphaerium				S					
Gomphosphaeria						S			
Merismopedia									
Oscillatoria	F	F				F		F	F

Chlorophyceae

Ankistrodesmus	F		S	S	S	S	F	S	S
Chlorococcum			F						
Closterium	F	F		F					
Coelastrum			F					F	
Cosmarium				F					
Crucigenia			F						
Eudorina				F					
Pandorina	F	F		M	F	S	F	S	S
Pediastrum			F	F				F	
Protococcus						S		S	
Scenedesmus	F	F	S	M		F		S	F
Selenastrum				S					
Spirogyra		F							

TABLE 4  
(continued)

Name of Organism	Station Numbers								
	#2	#3	#4	#5	#5	#6	#7	#8	#8
Date of Survey	8-22	8-14	8-15	7-28	8-27	8-20	8-8	7-31	8-25

Bacillariaceae

Amphora			F		S	F	F		S
Brebissonia	F	F		F	F			F	F
Cocconeis	F				F				
Cyclotella		S	S	F			F	S	
Cymatopleura	F	F				F			F
Cymbella	S		S		F			F	
Diatoma	F	S	S		S	F	S	S	
Fragilaria	S	S				S	S	S	F
Mastogloia							F		
Melosira	S		F		S	S	S		S
Meridion						S		F	F
Navicula	S	F	S	M	S	F	S	M	S
Nitzschia		S		S			F	F	F
Pinnularia	F								F
Pleurosigma			F		S	F	F	F	F
Stephanodiscus				M			F	S	
Synedra	S	M	S	M	S	S	S	M	S
Tabellaria	F				F				S

Protozoa

Arcella discoides		F	F						
Aetasia						F			
Bodo caudatus		S	F			F		S	

TABLE 4  
(continued)

Name of Organism	Station Numbers								
	#2	#3	#4	#5	#5	#6	#7	#8	#8
Date of Survey	8-22	8-4	8-15	7-28	8-27	8-20	8-8	7-31	8-25

Protozoa (continued)

<i>Euglena acus</i>				F					
<i>Euglena chrenbergia</i>				F					
<i>Euglena gracillis</i>	F								
<i>Euglena minima</i>					F	F			
<i>Euglena pisciformis</i>						S			
<i>Euglena spirogyra</i>			F			F	F		
<i>Euglena viridis</i>			F				M		
<i>Phacus longicaudus</i>							S		
<i>Phacus pleuronectus</i>							F		
<i>Phacus pyrum</i>						F			F
<i>Trachelomonas eurystoma</i>		F	S				M		
<i>Trachelomonas oblonga</i>		F						F	
<i>Trachelomonas urceolata</i>	F			F		M	M		S
<i>Trachelomonas volvocina</i>		F	F			S			F
<i>Trachelomonas verrucosa</i>	F								
<i>Urosoma</i>							F		
<i>Vorticella</i>			M		F	S			

Other Organisms

Nematode					F				
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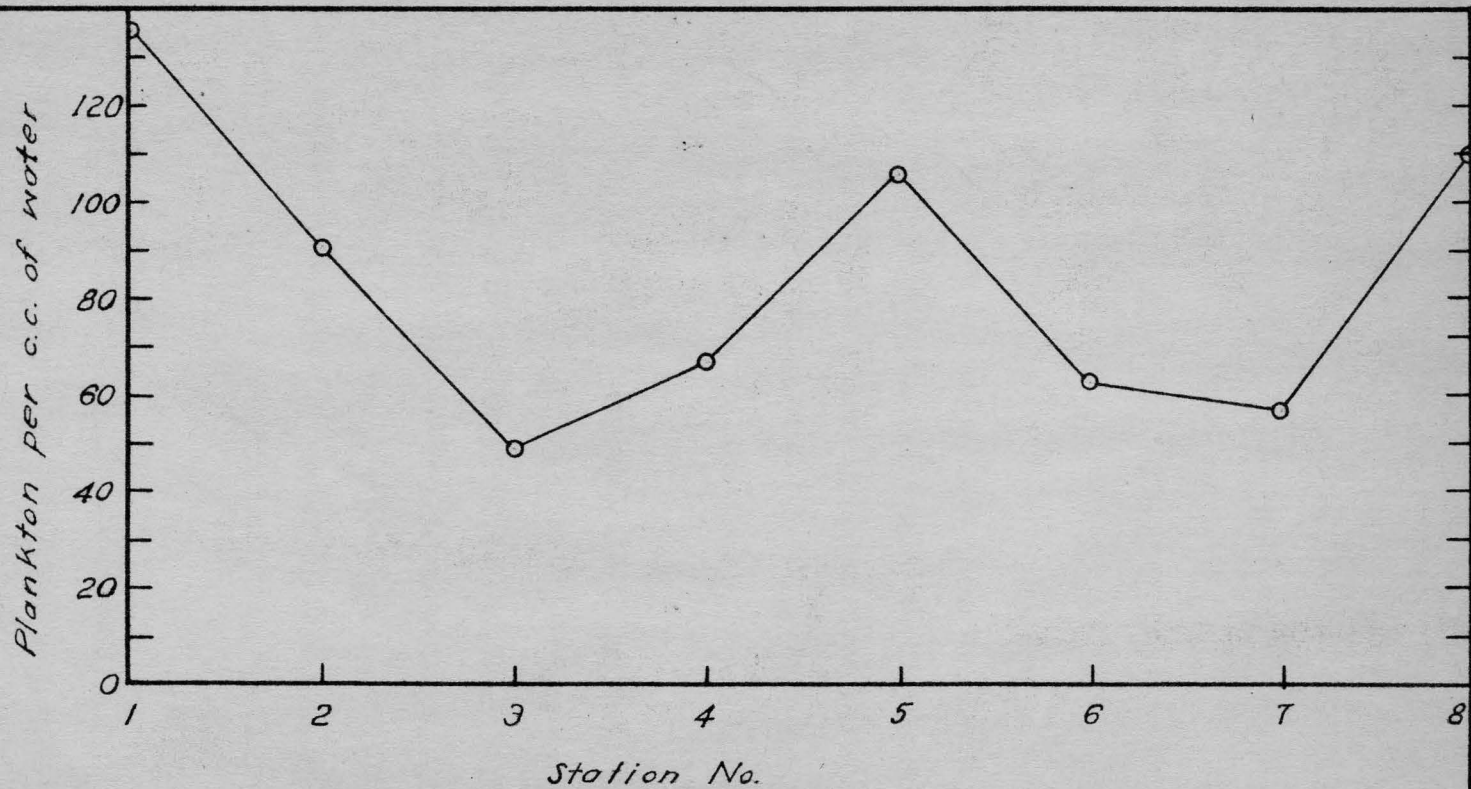


PLATE 2

AVERAGE OF THE PLANKTON COUNTS

## 1. Food Material

As far as food materials are concerned, the only variables, in the reach of river concerned, are the bacteria and the mill wastes. Everything else that the plankton can use for food can be considered to be of the same concentration at each station.

If one attempted to explain the concentrations in terms of the mill wastes, he would have to correlate the concentrations at each station with the station's proximity to the mill. This cannot be done with the results obtained. From the graph on Plate 2, it is seen that at those points closest to the mill where the food is first available, no maxima are encountered. No maximum is encountered until Station #5; and even this concentration is less than the concentration found above the mill. The general shape of the concentration graph precludes any correlation to the availability of food from the mill wastes.

Likewise, it is difficult to correlate the plankton concentrations with the bacteria concentrations. A minimum of bacteria was encountered at Station #1, a point of maximum plankton concentration. Furthermore, the maximum bacterial concentration at Station #2 does not coincide with a maximum plankton concentration. Any attempts to find a general correlation between the two concentration curves is obviously futile. Evidently, then, the food material present in the stream is not a controlling factor.

## 2. Temperature

That temperature is concerned in the differences of plankton concentrations is highly improbable. Temperature differences varied only one to two degrees Fahrenheit for the entire reach of river investigated. And even this small difference cannot be correlated to the points of maximum planktonic populations.

### 3. Toxic Substances

The trend of the concentration graph from Station #1 to #5 could be explained in terms of toxic effects. It could be pointed out that toxic substances could cause a decreasing concentration such as is shown between Station #1 and #3; and after reaching a minimum at Station #3, the stream, through the agency of self-purification, could begin to recover. The concentration at Station #5 could indicate recovery to conditions not so different from those at Station #1. However, the graph from Station #5 to #8 denies any influence from toxic substances. If toxicity were concerned to any great extent, one would expect the graph to level off at Station #5. Actually, the concentrations decrease. Consequently, the graph as a whole cannot be explained in terms of toxicity. If toxicity was concerned, it played only a minor role.

### 4. Oxygen Tension

Most plankton require oxygen. Even the autotrophs such as *Euglena* cannot live in water that contains no dissolved oxygen. However, as a rule, the oxygen requirements of plankton are not as great as those of the higher forms of aquatic life. Unless conditions are septic, water of low oxygen tension is capable of supporting large plankton communities. That a maximum concentration exists at Station #5, lends support to this statement. It is noted from the graph on Plate 11 that the average dissolved oxygen at Station #5 is the lowest encountered. Of course, it is not to be inferred that the large concentration is present because of a low oxygen content. It is mentioned in order to bring out the point that plankton can survive in a wide range of oxygen tension.

It is readily seen by comparing the curve on Plate 2 with the curve on Plate 11, that a correlation between the plankton concentrations and the

dissolved oxygen content of the water is not indicated. At Stations #1 and #8 maxima in both plankton and dissolved oxygen occur; but at Station #5 another maxima in plankton occurs where a minimum of dissolved oxygen was found.

#### 5. Speed of Current

The maximum concentrations occur at Stations #1, #5 and #8, all of which are located at points immediately above dams. These dams, the Big Island, Coleman, and the Holcomb, create local lenitic environments which are, as a rule, more conducive to large plankton concentrations than those of lotic nature. River conditions unfavorable to plankton production, such as changes in volume, contact of shore and bottom, access of heat and light, and changes in chemical constituents, are more extensive and more widely effective where currents of greater velocity are concerned.

Also, it is noted from the curve on Plate 2 that the concentrations decreased in the reaches where the current was swift. The minima, however, were located at Stations #3 and #7, rather than at Stations #2 and #6 where the swiftest currents occurred. Possibly, this "lag" in the minima was due to the river's transporting the organisms from the pondages, over the dams, and past the first station before the concentrations thinned out. In other words, the concentrations at Stations #2 and #6 were most likely transient concentrations from the pondage areas above the dams; the river at these stations being too swift to sustain a native population. The river at Stations #3 and #6 was likely to have been still too swift to support native communities and yet to have been slow enough to allow the transient plankton that had been affected by the passage over the dam and through the turbulent reaches below to settle out.

A definite correlation can be made, then, between the plankton concen-

tration and the swiftness of the current. As stated before, the current factor may not operate alone, but it must certainly be of considerable importance.

### Discussion of the Survey

Whipple (17) states that a satisfactory use of aquatic organisms as indicators of pollution and self-purification of water is dependent upon the development of an ecological system of classification that will show the normal habitat of all organisms and indicate as well their sensitivity to varying conditions of pollution. Such a system has not as yet been established. However, steps in this direction have been made by Kolkwitz and Marsson (19)(20). They have propounded an ecological classification of the microscopic aquatic organisms. Their system classifies the organisms as to the zone in which they exist. These zones are characterized chiefly by their content of organic food materials.

Polysaprobic Zone - The polysaprobic zone is characterized by its high content of decomposable organic food materials. Splitting and decomposition processes predominate causing a rapid depletion in the dissolved oxygen content of the water.

Only a few groups of organisms live in this zone. However, those that occur often occur in great numbers. Bacteria and bacterivorous protozoa (colorless flagellates and ciliates) predominate.

Mesosaprobic Zone - The mesosaprobic zone is divided into two parts. The first part, called a mesosaprobic, adjoins the polysaprobic zone; while the second, called beta mesosaprobic, extends toward the oligosaprobic zone. In the alpha portion of this zone, active decomposition of the organic molecule is still in progress, with a few organisms containing chlorophyll making their appearance. Mineralization of the organic materials is

approached in the beta portion of the zone.

In the mesosaprobic zone, those organisms that are tolerant of medium amounts of pollution reappear. They include the green and the blue-green algae, diatoms, certain protozoa, worms, and tolerant higher animals that feed on the bottoms.

Oligosaprobic Zone - In the oligosaprobic zone the organic material is low with almost complete mineralization. Bacteria are reduced in number, and algae predominates. Many chlorophyllaceous animals, crustacea, and game fish may be found in this zone.

Katarobic Zone - The katarobic zone includes that flora and fauna which is ordinarily found in springs and mountain streams.

On Table 5 are listed those organisms that were encountered many times during the survey at each station. Also listed are those that were encountered several times. The ecological character of each organism is indicated by the following letters:

- P = Polysaprobic
- M = Mesosaprobic (also alpha M and beta M)
- O = Oligosaprobic
- K = Katarobic

Appended to some of these letters are subscript numbers which indicate the authorities who are responsible for the assignments. The numbers correspond to those that list the authorities in the bibliography. For example: *Phacus longicauda*; O<sub>19, 23, 37</sub>; K<sub>23</sub> signifies that this species was listed as being oligosaprobic by Kolkwitz and Marsson, 1908; Pascher, 1913-1914; Schoenichen, 1925; and as katarobic by Pascher, 1913-1914. Those letters without subscript numbers indicate that the organism was not identified by the authorities as to specie. The author has ascribed those letters which occur most frequently in the defined species to designate the over-all genus. In other words, the letter is used by the author to designate the Genus sp.

TABLE 5

Plankton Species Distribution

Station	Average Plankton Concentration/ml	Species Encountered Many Times	Species Encountered Several Times
#1	137	Ankistrodesmus $\beta M$ ; 0	Amphora 0
		Fragilaria 0	Astasia M <sub>34</sub>
		Melosira 0	Brebissonia $\beta M$ <sub>19, 24</sub>
		Pandorina 0	Chlamydomonas P <sub>35</sub>
		Protococcus M <sub>32</sub>	Closterium $\beta M$ <sub>19, 21, 24, 37</sub>
		Scenedesmus $\beta M$	Cocconeis $\beta M$ <sub>21</sub> ; 0 <sub>21</sub>
		Stephanodiscus $\beta M$	Coelastrum 0 <sub>19, 37</sub>
		Trachelomonas eurystoma $\beta M$ <sub>33</sub>	Coelosphaerium 0
		Trachelomonas urceolata $\beta M$ <sub>33</sub>	Cyclotella 0
			Cymbella 0
			Diatom M
			Euglena granulata M <sub>23, 37</sub> ; 0 <sub>23, 37</sub>
			Euglena minima 0 <sub>19, 23</sub> ; K <sub>23</sub>
			Euglena terricola M <sub>34</sub>
			Euglena viridis P <sub>19, 21, 23, 24, 27, 33</sub> ; $\alpha M$ <sub>19, 24, 27</sub>
			Gyrosigma No classification
			Meridion 0 <sub>19, 24, 37</sub>
			Navicula M; 0
			Pediastrum $\beta M$ <sub>19, 21, 27, 37</sub> ; 0 <sub>21</sub>
			Pleurosigma 0
			Selenastrum $\beta M$

TABLE 5  
(continued)

Station	Average Plankton Concentration/ml	Species Encountered Many Times	Species Encountered Several Times
#1 (continued)			Synedra M; O Synedra pulchella No classification Trachelomonas $\beta M_{33}$ Trachelomonas oblonga $\beta M_{33}$ Trachelomonas volvocina $\beta M_{19}$ ; $M_{23}$ ; $K_{23}$ Ulothrix M; O
#2	91		Cymbella O Fragilaria O Melosira O Navicula M; O Synedra M; O
#3	49	Synedra M; O	Bodo caudatus $P_{35}$ ; $\alpha M_{20}$ ; $M_{23,37}$ Cyclotella O Diatoma M Fragilaria O Nitzschia M; O
#4	67	Vorticella $P_{35}$ ; $M_{31,34}$	Ankistrodesmus $\beta M$ ; O Cyclotella O Cymbella O Diatoma M Navicula M; O

TABLE 5  
(Continued)

Station	Average Plankton Concentration/ml	Species Encountered Many Times	Species Encountered Several Times
#4 (continued)			Scenedesmus $\beta M$ Synedra M; 0 Trachelomonas eureptoma $\beta M_{35}$
#5	107	Navicula M; 0 Pandorina 0 Scenedesmus $\beta M$ Stephanodiscus $\beta M$ Synedra M; 0	Amphora 0 Ankistrodesmus $\beta M$ ; 0 Coelosphaerium 0 Diatoma M Melosira 0 Nitzschia M; 0 Fleurosigma 0 Selenastrum $\beta M$
#6	63	Trachelomonas urceolata $\beta M_{33}$	Ankistrodesmus $\beta M$ ; 0 Euglena pisciformis $\beta M_{19}$ ; $M_{23,37}$ ; 0 $_{23,37}$ Fragilaria 0 Gomphosphaeria 0 Melosira 0 Meridion 0 Pandorina 0 Protococcus $M_{32}$ Synedra M; 0 Trachelomonas volvocina $\beta M_{19}$ ; $M_{23}$ ; $K_{23}$ Vorticella $R_{35}$ $M_{31,34}$

TABLE 5  
(continued)

Station	Average Plankton Concentration/ml	Species Encountered Many Times	Species Encountered Several Times
#7	57	<i>Euglena viridis</i> P <sub>19, 21, 23, 24, 27, 33</sub> ; $\alpha$ M <sub>19, 24, 27</sub>	Diatoms M
		<i>Trachelomonas eurystoma</i> $\beta$ M <sub>33</sub>	Fragilaria O
		<i>Trachelomonas urceolata</i> $\beta$ M <sub>33</sub>	Melosira O
			Navicula M; O
			Phacus longicaudus O <sub>19, 23, 37</sub> ; K <sub>23</sub>
			Synedra M; O
#8	110	Navicula M; O	Amphora O
		Synedra M; O	Ankistrodesmus $\beta$ M; O
			Bodo caudatus P <sub>35</sub> ; $\alpha$ M <sub>20</sub> ; M <sub>23, 37</sub>
			Cyclotella O
			Diatoms M
			Fragilaria O
			Melosira O
			Pandorina O
			Protococcus M <sub>32</sub>
			Scenedesmus $\beta$ M
			Stephanodesmus $\beta$ M
			Tabellaria O
			<i>Trachelomonas urceolata</i> $\beta$ M <sub>33</sub>

From Table 5 it is seen that the majority of organisms at each station are designated as either "M" or "O". And at two stations only, #4 and #7, were there present in abundance, plankton that could be taken as indicators of high organic content. At Station #4, Vorticella, which is ascribed to the polysaprobic and mesosaprobic zones, was found in numbers. Euglena viridis, which is likewise ascribed to the polysaprobic and mesosaprobic zones, was found in numbers at Station #7.

However, the author is prone to consider the significance of these two organisms as being overshadowed by evidence furnished by the other organisms present. At both Stations #4 and #6, the vast majority of organisms are identified as being of either the mesosaprobic or the oligosaprobic zones.

#### Conclusion

The plankton present in the reach of river investigated indicate, then, that for seven miles below the mill the river supports a homogeneous plankton population that is indicative of the mesosaprobic and oligosaprobic zones. These are zones of medium to little organic content. It is to be noted that no gross pollution is intimated from the results of the survey.

The homogeneous nature of the species found indicate the river's inability to produce plankton that is indigenous to individual reaches. This inability can be explained in terms of current. The suspended nature of plankton makes them subject to constant mixing by river current.

Therefore, it appears as though the results obtained in both the total counts and the survey can be explained in terms of the current only. If so, the waste from the mill is not an important factor, and must have little or no effect on the plankton population of the river.

LITTORAL BENTHIC POPULATIONPurpose

By qualitatively examining the benthos\* near the shore, it was hoped to throw light on the character of life found at the interfacial zone between the water and mud. This interfacial zone supports a stabler microscopic community than does the water. By virtue of this stability, the benthos reflects more completely the nature of the water where they are found than do the plankton. Whereas the plankton collected at any one station is likely to be a function of the current and represents a transient population, the benthic community is native and a function only of conditions at that station.

If the environmental zone can be determined by correlating the species found in this zone with Kolkwitz and Marsson's ecological classification, another criterion for judging the effect of the mill waste upon the river is available.

Methods Used

From two to four mud samples were secured at each station. These samples were taken at points along both banks from mud at depths of three to twelve inches below the water surface. Here the water was relatively free of currents. Only the top inch of mud was taken, as this portion contains practically all the benthos. In the laboratory, a microscopic survey was made of the sample to determine the species present and their relative abundance.

Discussion of Results

By comparing Table 6 with Table 4, it is seen that while the algal species of the benthos were more limited than that of the plankton, the

\*Those microorganisms that live at the interface between the bottom muds and the water.

TABLE 6

Benthos Survey at Stations #1, #2, and #3

Key: M for many; S for several; F for few.

Name of Organism	Station Numbers								
	#1	#1	#1	#2	#2	#3	#3	#3	
Date of Survey	8-12	8-27	8-29	7-28	8-8	7-28	8-4	8-13	
<u>Myxophyceae</u>									
Anabena									F
Gomphosphaeria									
Merismopedia							F		
Oscillatoria	F	S	F	F	F	F			F
<u>Chlorophyceae</u>									
Ankistrodesmus							F		
Closterium									
Cosmarium	F						F		
Hormidium									
Pandorina			F					F	
Pediastrum			F	F					
Protococcus									
Scenedesmus									
Spirogyra									
<u>Bacillarieae</u>									
Amphora	S	F	S	S			S	S	
Brebissonia	S	S	F	S	S	S	S	S	S
Cocconeis	S	F		F			F	F	
Cyclotella	F						F		

TABLE 6  
(continued)

Name of Organism	Station Numbers							
	#1	#1	#1	#2	#2	#3	#3	#3
Date of Survey	8-12	8-27	8-29	7-28	8-3	7-28	8-4	8-13

Bacillarieae (continued)

Cymatopleura	F	F					F	
Cymbella	S	S	S	S		S		F
Denticula				F				
Diatoma	S	S	S		F	M	S	S
Encyonema	S					F		
Epithemia								
Fragilaria			F					S
Gomphonema								
Gyrosigma								
Mastogloia	F							S
Melosira	M	M	S	S	S	M	S	S
Meridion	F	S	F		F		F	
Navicula	S	M	M	M	S	M	S	M
Nitzschia	S	F	F	S	F	S	S	F
Pinnularia			F					
Pleurosigma	S	S	S			F		S
Stauroneis				F				
Stephanodiscus			F		F	F		
Surirella							F	
Synedra	S	S	S	S	F			S
Synedra pulchella						F		
Tabellaria	S		S		S			S



TABLE 6  
(continued)

Name of Organism	Station Numbers							
	#1	#1	#1	#2	#2	#3	#3	#3
Date of Survey	8-12	8-27	8-29	7-28	8-8	7-28	8-4	8-13

Protozoa (continued)

Holophrya

Hypotrichidium

F

Lepocinclis

Lionotus

S

Metopus striatus

Nassula aurea

Notosolemus

Oxytricha

S

F

F

Oxytricha ludibunda

Paramecium

Paramecium caudatum

Peranema

F

F

F

Phacus longicaudus

F

Phacus pleuronectus

F

Platynematum

F

F

F

S

Polytoma

F

Saprophilus

F

S

Spathidium

F

Spirostomum

Spirostomum teres

Stentor igneus

F

Strombidium

TABLE 6  
(continued)

Name of Organism	Station Numbers							
	#1	#1	#1	#2	#2	#3	#3	#3
Date of Survey	8-12	8-27	8-29	7-28	8-8	7-28	8-4	8-13

Protozoa (continued)

Trachelius

Trachelomonas eurystoma

F

Trachelomonas similis

F

Trachelomonas urceolata

Trachelomonas volvocina

F

Urosoma

F

Vorticella

F

F

F

Other Organisms

Chaetontus

Cyclops

F

Daphnia

F

Nematode

S

F

Rotifer

F

TABLE 6

Benthos Survey at Stations #4, #5, and #6

Key: M for many; S for several; F for few.

Name of Organism	Station Numbers							
	#4	#4	#5	#5	#5	#6	#6	#6
Date of Survey	7-28	8-8	7-28	8-4	8-13	7-31	8-8	8-15
<u>Myxophyceae</u>								
Anabena					F			
Gomphosphaeria								
Merismopedia								
Oscillatoria	F		S	S	S	F	S	F
<u>Chlorophyceae</u>								
Ankistrodesmus						F		
Closterium					F		F	F
Cosmarium					F			
Horridium						F		
Pandorina								
Pediastrum								
Protococcus						F		
Scenedesmus						F		
Spirogyra				F	M			S
<u>Bacillarieae</u>								
Amphora	S	S		S		S		S
Brebissonia	S	S	S	S	S	S		F
Cocconeis	F	S	F	F		F		
Cyclotella						S	S	

TABLE 6  
(continued)

Name of Organism	Station Numbers							
	#4	#4	#5	#5	#5	#6	#6	#6
Date of Survey	7-28	8-8	7-28	8-4	8-13	7-31	8-8	8-15

Bacillarieae (continued)

Cymatopleura	S		F	F			F	
Cymbella	S		S			S	F	S
Denticula								
Diatoma	M	S		S		S	F	
Encyonema			F					
Epithemia			F					
Fragilaria					S			S
Gomphonema						F		
Gyrosigma				F	S		F	S
Mastogloia	S	F	F	F	S			F
Melosira	M	S	M	S	S	S	S	S
Meridion	F		F	F		M	F	F
Navicula	M	S	M	S	M	M	S	M
Nitzschia	M	S	S		S	S	S	F
Pinnularia						F		
Pleurosigma	S	S	F	F	S	S		M
Stauroneis		F						
Stephanodiscus								
Suriella					F			
Synedra	S	S			S	S		S
Synedra pulchella	F		F					
Tabellaria		F			F			

TABLE 6  
(continued)

Name of Organism	Station Numbers							
	#4	#4	#5	#5	#5	#6	#6	#6
Date of Survey	7-28	8-8	7-28	8-4	8-13	7-31	8-8	8-15

Protozoa

## Actinobolus

Amoeba discoides F

Amoeba proteus S

Anisonema acinus S

## Arcella discoides

Astasia F

Bodo caudatus S S S S S M M

Bodo globosus S

## Bryophyra

## Cinetochilum

## Colpidium

## Enchelys

Euglena acus S S S

## Euglena deses

Euglena minima F

Euglena oxyuris F

Euglena spirogyra S

Euglena viridis F

## Glaucocystis

Gonium F F

Halteria S M F M S S

## Heteronema acus



TABLE 6  
(continued)

Name of Organism	Station Numbers							
	#4	#4	#5	#5	#5	#6	#6	#6
Date of Survey	7-28	8-8	7-28	8-4	8-13	7-31	8-8	8-15

Protozoa (continued)

Trachelius

Trachelomonas eurystoma

F

Trachelomonas similis

Trachelomonas urceolata

Trachelomonas volvocina

Urosoma

Vorticella

S

M

F

F

M

Other Organisms

Chaetontus

Cyclops

F

Daphnia

Nematode

F

F

F

F

F

Rotifer

F

F

F

TABLE 6

Benthos Survey at Station #7 and #8

Key: M for many; S for several; F for few

Name of Organism	Station Numbers						
	#7	#7	#7	#8	#8	#8	#8
Date of Survey	7-31	8-8	8-27	7-28	8-4	8-13	8-20

Myxophyceae

Anabena							
Gomphosphaeria							F
Merismopedia							
Oscillatoria	S	F		S			

Chlorophyceae

Ankistrodesmus							
Closterium					F		
Cosmarium							
Horridium							
Pandorina	F				F		
Pediastrum							
Protococcus							
Scenedesmus	F						
Spirogyra							

Bacillariaceae

Amphora		S				F	F
Brebissonia		F	F	S		F	F
Cocconeis	S	F		F			
Cyclotella		F					

TABLE 6  
(continued)

Name of Organism	Station Numbers						
	#7	#7	#7	#8	#8	#8	#8
Date of Survey	7-31	8-8	8-27	7-28	8-4	8-13	8-20

Bacillarieae (continued)

Cymatopleura			F				
Cymbella	S	S		S		F	
Denticula							
Diatoma			F	M	F		
Encyonema						F	
Epithemia							
Fragilaria					F		
Gomphonema							
Gyrosigma		S	S		S		
Mastogloia							
Melosira	S	S	S	S	F	F	
Meridion	S			F			
Navicula	M	S	S	M	F		F
Nitzschia	S	F		S			
Pinnularia	F			F			
Pleurosigma	F	F	F	S			F
Stauroneis		F					
Stephanodiscus							
Surirella							
Synedra	S	S	S			F	
Synedra pulchella							
Tabellaria	F	F	F	F			

TABLE 6  
(continued)

Name of Organism	Station Numbers						
	#7	#7	#7	#8	#8	#8	#8
Date of Survey	7-31	8-8	8-27	7-28	8-4	8-13	8-20

Protozoa

Actinobolus

Amoeba discoides

Amoeba proteus

Anisonema acinus

Arcella discoides

Astasia

F

Bodo caudatus

S

F

S

S

Bodo globosus

Bryophytra

F

Cinetochilum

Colpidin

F

Enchelys

Euglena acus

F

Euglena doses

Euglena minima

Euglena oxyuris

Euglena spirogyra

Euglena viridis

Glaucocma

S

Gonium

Halteria

F

S

F

S

Heteronema acus

F

TABLE 6  
(continued)

Name of Organism	Station Numbers						
	#7	#7	#7	#8	#8	#8	#8
Date of Survey	7-31	8-8	8-27	7-28	8-4	8-13	8-20

Protozoa (continued)

Holophrya							F
Hypotrichidium					F		
Lepocinclis							
Lionotus							
Metopus striatus							
Nassula aurea							
Notosolemus							
Oxytricha					F		
Oxytricha ludibunda			F				
Paramecium				F			
Paramecium caudatum							
Peranema							
Phacus longicaudus		F					
Phacus pleuronectus							
Platynematum			F				F
Polytoma							
Saprophilus							
Spathidium							
Spirostomum							
Spirostomum teres				F			
Stentor igneus							
Strombidium							

TABLE 6  
(continued)

Name of Organism	Station Numbers						
	#7	#7	#7	#8	#8	#8	#8
Date of Survey	7-31	8-8	8-27	7-28	8-4	8-13	8-20

Protozoa (continued)

Trachelius			F				
Trachelomonas eurystoma							
Trachelomonas similis							
Trachelomonas urceolata			F				
Trachelomonas volvocina							
Urosoma			F			S	
Vorticella			S				

Other Organisms

Chaetontus				F			
Cyclops							
Daphnia							
Nematode		F		F	F		
Rotifer	F		F		F	F	F

TABLE 7

Benthos Specie Distribution

Station	Species Encountered Many Times	Species Encountered Several Times
#1	Melosira M; 0 Navicula M; 0	Amphora 0 Brebissonia $\beta$ M <sup>19,24</sup> Cocconeis $\beta$ M; 0 Cymbella 0 Diatoma $\beta$ M Encyonema 0 Lionotus M <sup>31, 34</sup> Meridion 0 Nitzschia $\beta$ M; 0 Oscillatoria M <sup>32</sup> Oxytricha P <sup>35</sup> ; M <sup>31,34</sup> Pleurosigma 0 Synedra $\beta$ M; 0 Tabellaria 0
#2	Navicula M; 0	Amphora 0 Brebissonia $\beta$ M <sup>19,24</sup> Cymbella 0 Melosira M; 0 Nitzschia $\beta$ M; 0 Synedra $\beta$ M; 0 Tabellaria 0
#3	Bodo caudatus P <sup>35</sup> ; $\alpha$ M <sup>20</sup> ; M <sup>23,37</sup> Diatoma $\beta$ M	Amphora 0 Anisonema acinus $\beta$ M <sup>20</sup> ; M <sup>23</sup> ; K <sup>23</sup>

TABLE 7  
(continued)

Station	Species Encountered Many Times	Species Encountered Several Times
#3 (continued)	Halteria M <sub>31,35</sub>	Brebissonia $\beta$ M <sub>19,24</sub>
	Melosira M; 0	Cyclotella 0
	Navicula M; 0	Cymbella 0
	Synedra $\beta$ M; 0	Fragilaria 0
		Mastogloia No classification
		Nitzschia $\beta$ M; 0
		Platynematum No classification
		Pleurosigma 0
		Saprophilus M <sub>31</sub>
		Tabellaria 0
#4	Diatoma $\beta$ M	Amphora 0
	Melosira M; 0	Anisonema acinus $\beta$ M <sub>20</sub> ; M <sub>23</sub> ; K <sub>23</sub>
	Navicula M; 0	Bodo caudatus P <sub>35</sub> ; $\alpha$ M <sub>20</sub> ; M <sub>23,37</sub>
	Nitzschia $\beta$ M; 0	Brebissonia $\beta$ M <sub>19,24</sub>
		Cymbella 0
		Halteria M <sub>31,35</sub>
		Mastogloia No classification
		Pleurosigma 0
		Synedra $\beta$ M; 0
		Vorticella P <sub>35</sub> ; M <sub>31,34</sub>
#5	Halteria M <sub>31,35</sub>	Amphora 0
	Melosira M; 0	Bodo caudatus P <sub>35</sub> ; $\alpha$ M <sub>20</sub> ; M <sub>23,37</sub>

TABLE 7  
(continued)

Station	Species Encountered Many Times	Species Encountered Several Times
#5 (continued)	Navicula M; 0 Phacus pleuronectus Spirogyra $\beta$ M; 0 Vorticella P <sub>35</sub> ; M <sub>31,34</sub>	Bodo globosus M <sub>20,21,27</sub> ; M <sub>23,37</sub> Brebissonia $\beta$ M <sub>19,24</sub> Cymbella 0 Diatoma $\beta$ M Euglena acus $\beta$ M <sub>19,24</sub> ; M <sub>23,37</sub> ; O <sub>23,37</sub> Euglena spirogyra $\beta$ M <sub>19,24</sub> ; M <sub>23,37</sub> ; O <sub>23,37</sub> Fragilaria 0 Gyrosigma 0 Hypotrichidum No classification Lepocinclis M; 0 Mastogloia No classification Nitzschia $\beta$ M; 0 Oxytricha P <sub>35</sub> ; M <sub>31,34</sub> Phacus longicaudus O <sub>19,23,37</sub> ; K Fleurosigma 0 Spirostomum teres $\beta$ M <sub>20</sub> Synedra $\beta$ M; 0
#6	Bodo caudatus P <sub>35</sub> ; $\alpha$ M <sub>20</sub> ; M <sub>23,37</sub> Navicula M; 0 Fleurosigma 0 Vorticella P <sub>35</sub> ; M <sub>31,34</sub>	Amoeba proteus P <sub>35</sub> ; M <sub>31,35</sub> ; O <sub>20,27</sub> Amphora 0 Brebissonia $\beta$ M <sub>19,24</sub> Cyclotella 0

TABLE 7  
(continued)

Station	Species Encountered Many Times	Species Encountered Several Times
#6 (continued)		<p data-bbox="934 395 1115 426">Cymbella 0</p> <p data-bbox="934 457 1115 488">Diatoma <math>\beta M</math></p> <p data-bbox="934 520 1286 588">Euglena acus <math>\beta M_{19,24}^j</math> <math>M_{23,37}^j</math>; 0<sub>20,27</sub></p> <p data-bbox="934 602 1146 634">Fragilaria 0</p> <p data-bbox="934 665 1130 696">Gyrosigma 0</p> <p data-bbox="934 727 1191 758">Halteria <math>M_{31,35}</math></p> <p data-bbox="934 789 1161 820">Melosira M; 0</p> <p data-bbox="934 851 1115 882">Meridion 0</p> <p data-bbox="934 913 1221 944">Nassula aurea <math>M_{34}</math></p> <p data-bbox="934 975 1191 1006">Nitzschia <math>\beta M</math>; 0</p> <p data-bbox="934 1038 1191 1069">Notosolemus <math>M_{34}</math></p> <p data-bbox="934 1100 1381 1168">Paramecium caudatum <math>P_{21,35}^j</math>; <math>\alpha M_{20,24,27,33}^j</math>; <math>M_{21}</math></p> <p data-bbox="934 1183 1191 1214">Spirogyra <math>\beta M</math>; 0</p> <p data-bbox="934 1245 1297 1276">Spirostonum teres <math>\beta M_{20}</math></p> <p data-bbox="934 1307 1221 1338">Strombidium <math>\beta M</math>; 0</p> <p data-bbox="934 1369 1161 1400">Synedra <math>\beta M</math>; 0</p>
#7	Navicula M; 0	<p data-bbox="934 1431 1090 1462">Amphora 0</p> <p data-bbox="934 1493 1230 1562">Bodo caudatus <math>P_{35}^j</math>; <math>\alpha M_{20}^j</math>; <math>M_{23,37}</math></p> <p data-bbox="934 1576 1191 1607">Cocconeis <math>\beta M</math>; 0</p> <p data-bbox="934 1638 1105 1670">Cymbella 0</p> <p data-bbox="934 1701 1120 1732">Gyrosigma 0</p> <p data-bbox="934 1763 1191 1794">Halteria <math>M_{31,35}</math></p> <p data-bbox="934 1825 1150 1856">Melosira M; 0</p>

TABLE 7  
(continued)

Station	Species Encountered Many Times	Species Encountered Several Times
#7 (continued)		Meridion 0 Nitzschia $\beta$ M; 0 Oscillatoria M <sub>32</sub> Synedra $\beta$ M; 0 Vorticella P <sub>35</sub> ; M <sub>31, 34</sub>
#8	Diatoma $\beta$ M Navicula M; 0	Bodo caudatus P <sub>35</sub> ; $\alpha$ M <sub>20</sub> ; M <sub>23, 37</sub> Brebissonia $\beta$ M <sub>19, 24</sub> Cymbella 0 Glaucoma M <sub>31, 34</sub> Gyrosigma 0 Halteria M <sub>31, 35</sub> Melosira M; 0 Nitzschia $\beta$ M; 0 Oscillatoria M <sub>32</sub> Pleurosigma 0 Urosom No classification

protozoa species of benthos were the most extensive. This fact is not surprising. As was pointed out in the section on the planktonic population, the widest variety of species usually occurs on the bottom, whereas the greatest number of individuals occur in the suspended portion of the stream's biota.

Also to be noted is that the benthic zone supports more metazoa than does the planktonic zone. These higher forms of life because of their greater size and weight are not adapted to a pelagic existence. They are favored by an environment that offers protection from the rigors of a current borne existence. However, it is not to be inferred that these forms of life are never found in plankton. Frequently adventitious bottom forms are found in plankton. Any populations so intimately related intergrade and mix to such an extent as to defy sharp pronouncements on their individuals.

In Table 7 those organisms are listed that were found in such numbers as to warrant accepting them as representative of the population from which they were taken. Each organism is classified in terms of Kolkwitz and Marsson's ecological zones. This classification is referred to on page 31.

If all the organisms are considered of equal importance, the classification would indicate that the river, especially the reach from Station #3 to #8, supported a meso-oligosaprobic environment. The author, however, prefers to ignore this indication. The vast majority of the organisms listed in Table 7 are diatoms. If these diatoms, all of which are classified as being of either the mesosaprobic or the oligosaprobic zones, were discredited, the remaining organisms would be classified mainly as being from a poly-mesosaprobic zone. Such a depreciation, the author feels is legitimate for the following reasons.

Because of the silicon composition of diatom frustules, the carcasses of dead diatoms are of a very resistant nature. That these shells can

accumulate is witnessed in the extreme by the extensive deposits of diatomaceous earth found in this country. It is readily recognized that in a survey of this kind, where no cognizance was taken as to whether the diatoms were living or dead, an inaccurate idea could be formed as to the ratio of the diatoms to those organisms that have no shells to perpetuate their presence. For example, whereas only one generation of protozoa is surveyed, several generations of diatoms may be surveyed. Not to be forgotten, also, is the fact that after death the diatom members of the plankton population fall to the bottom to further distort the picture.

Another reason for discrediting the benthic diatoms, is their universal abundance. They are truly the "grass of the sea." Very few waters are barren of representatives of this group. Only in waters of the grossest pollution do the diatoms live in reduced numbers.

By discounting the diatoms, the emphasis is shifted to the protozoa. At Station #1, the control station, only one protozoan along with an occasional rotifer and nematode was conspicuously present. No pollution indicators at all were found at Station #2.

At the remainder of the stations the protozoa; Halteria, Vorticolla, Bodo, Oxytricha, and Paramecium identify the presence of a high organic content. Some of these organisms attack the organic material directly and others, especially the ciliates, feed upon the bacteria that are the natural complement. Rotifers and Nematodes, likewise pollution indicators, were found regularly at these stations.

### Conclusion

The results obtained from the benthic survey indicate that the organic content of the water was increased at Station #3 and remained so increased throughout the remainder of the reach investigated. Since there is no other

cause to which this increase could be attributed, the mill must suffer the indictment.

CHEMICAL AND PHYSICAL ANALYSISPurpose

In the light of present day knowledge, chemical and physical analyses form, perhaps, the best means of gaging actual stream conditions. This is not to depreciate the value of biological investigations. Rather it is only a recognizing of the far greater amount of research that has taken place in the chemical-physical aspects of stream pollution. In the past, the personnel most concerned with stream pollution have been men who for the most part had training only in chemistry. Consequently a more complete criteria for measuring pollution has been evolved from their studies than has been evolved from the investigations of the comparatively few biologists concerned.

In this investigation an analysis of the temperature, pH, color, dissolved solids, dissolved oxygen, biochemical oxygen demand, dissolved carbon dioxide and alkalinity, was made in order to determine how the chemical-physical character of the river varied from normal in those reaches where the effects of the mill waste were manifest.

Methods Used

The determinations on temperature, pH, color, dissolved solids, D. O., and B.O.D., were made by Mr. Maniates, while those on carbon dioxide and alkalinity were made by the author. Temperature and carbon dioxide determinations were made in the boat at the time of sampling while the others were made in the laboratory. All samples except those for CO<sub>2</sub> analysis were taken with a modified Whipple sampler at depths of five feet below the surface. At points of lesser river depth, the samples were taken at the bottom. The carbon dioxide samples were taken at the surface in a nessler tube. The procedures used were those set forth by "Standard Methods for the Examination of Water and Sewage." (15)

TABLE 8

Data on Temperature, pH, CO<sub>2</sub>, and (HCO<sub>3</sub>)

Date	Water Temperature F <sup>o</sup>	pH	CO <sub>2</sub> ppm as CO <sub>2</sub>	(HCO <sub>3</sub> ) ppm as CaCO <sub>3</sub>
Station 1				
July 28, 1947	76	8.2	2.6	86
July 31	79	8.1	2.1	90
August 4	79.5	8.0	1.1	99
August 8	78	7.8	1.1	102
August 13	79	7.8	4.2	86
August 15	80	7.7	2.1	92
August 20	80	8.3	3.2	100
August 22	80	-	3.2	106
August 25	-	-	2.1	92
August 27	81	7.8	2.1	80
Average	79.2	8.0	2.4	93
Station 2				
July 28, 1947	76	8.1	3.9	92
July 31	80	8.1	3.2	96
August 4	79.5	8.1	2.5	98
August 8	79	7.6	3.2	108
August 13	79	7.8	4.6	85
August 15	81	7.5	3.9	90
August 20	82	6.8	3.5	102
August 22	-	-	3.2	106
August 25	-	-	2.8	94
August 27	82	8.0	2.1	80
Average	79.8	8.0	3.3	95
Station 3				
July 28, 1947	76	8.15	4.6	88
July 31	80	8.2	3.2	94
August 4	79.5	8.0	2.5	100
August 8	79	7.9	2.8	108
August 13	80	7.7	5.3	93
August 15	82	7.7	3.9	92
August 20	82	8.0	3.2	100
August 22	-	-	-	-
August 25	-	-	2.5	93
August 27	82	7.7	3.2	78
Average	80.0	7.9	3.5	94

TABLE 8

Data on Temperature, pH, CO<sub>2</sub>, and (HCO<sub>3</sub>)

Date	Water Temperature F <sup>o</sup>	pH	CO <sub>2</sub> ppm as CO <sub>2</sub>	(HCO <sub>3</sub> ) ppm as CaCO <sub>3</sub>
Station 4				
July 28, 1947	76	8.05	3.9	84
July 31	80	7.5	4.2	91
August 4	80	8.1	3.5	100
August 8	79	7.5	4.2	110
August 13	80	7.6	4.6	93
August 15	82	7.5	4.9	92
August 20	82	7.8	3.2	100
August 22	-	-	-	-
August 25	-	-	3.2	92
August 27	82	7.7	3.5	80
Average	80.1	7.7	3.9	94
Station 5				
July 28, 1947	76	7.72	5.3	82
July 31	81	7.5	5.3	90
August 4	80	7.9	4.6	100
August 8	80	7.5	4.2	107
August 13	80	7.7	5.3	98
August 15	82	7.5	7.4	90
August 20	82	7.6	3.2	96
August 22	-	-	-	-
August 25	-	-	3.5	88
August 27	82	7.8	4.2	84
Average	80.4	7.7	4.8	93
Station 6				
July 28, 1947	76	7.79	4.2	84
July 31	82	7.8	3.5	90
August 4	80	7.8	3.5	100
August 8	80	7.8	2.8	106
August 13	81	7.6	4.9	100
August 15	82	7.6	5.6	92
August 20	81	7.8	4.2	94
August 22	82	-	4.2	106
August 25	-	-	2.1	90
August 27	81	7.7	4.2	86
Average	80.6	7.7	3.9	95

TABLE 8

Data on Temperature, pH, CO<sub>2</sub>, and (HCO<sub>3</sub>)

Date	Water Temperature F <sup>o</sup>	pH	CO <sub>2</sub> ppm as CO <sub>2</sub>	(HCO <sub>3</sub> ) ppm as CaCO <sub>3</sub>
Station 7				
July 28, 1947	77	7.84	4.9	83
July 31	82	7.9	4.6	91
August 4	80	7.8	3.8	98
August 8	80	7.7	4.2	104
August 13	81	7.9	3.9	104
August 15	82	7.6	6.7	92
August 20	81	7.6	4.2	97
August 22	82	-	4.2	107
August 25	-	-	3.2	94
August 27	81	7.8	4.2	90
Average	80.7	7.8	4.4	96
Station 8				
July 28, 1947	77	7.79	5.6	80
July 31	82	7.6	4.2	88
August 4	80	7.7	4.2	100
August 8	80	7.6	4.9	106
August 13	81	7.7	4.2	105
August 15	82	7.5	6.3	90
August 20	81	7.6	4.9	95
August 22	-	-	-	-
August 25	-	-	3.2	90
August 27	81	7.7	5.3	90
Average	80.5	7.6	4.8	94

Biochemical Oxygen Demand  
in ppm

Date	Sta. 1	Sta. 2	Sta. 3	Sta. 4	Sta. 5	Sta. 6	Sta. 7	Sta. 8
July 28, 1947	-	-	-	-	-	-	-	-
July 31	.4	9.6	9.6	10.0	7.2	6.4	6.6	6.8
August 4	.4	4.6	5.4	7.6	6.0	6.2	5.0	3.2
August 8	4.0	14.1+	12.4	10.4	7.8	8.4	8.4	7.0
	2.8	14.4+	12.0	10.8	12.6	7.2	7.4	6.4
August 13	3.4	4.2	12.8	12.0	6.4	5.4	5.6	5.6
August 15	-	-	-	-	-	-	-	-
August 20	1.1	8.5	7.1	6.4	5.0	6.3	4.9	4.2
August 22	-	-	-	-	-	-	-	-
August 27	-	-	-	-	-	-	-	-
Average	2.0	9.2	9.9	9.5	7.5	6.6	6.3	5.5

TABLE 9

Data on Dissolved Oxygen, Dissolved Solids and Color

Key: E = East side of river      T = Total  
 M = Middle of river            F = Fixed  
 W = West side of river        V = Volatile

Date	Dissolved Oxygen			Dissolved Solids			Color		
	E.	M.	W.	T.	F.	V.	E.	M.	W.
Station 1									
July 28, 1947	-	-	7.8	194	132	62	-	-	30
July 31	-	-	7.9	-	-	-	-	-	30
August 4	-	-	6.6	215	144	71	-	-	25
August 8	-	-	7.0	-	-	-	-	-	42
August 13	-	-	5.9	-	-	-	-	-	-
August 15	-	-	6.4	-	-	-	-	-	35
August 20	-	-	6.8	215	144	71	-	-	32
August 22	-	-	6.3	-	-	-	-	-	-
August 25	-	-	-	-	-	-	-	-	64
August 27	-	-	6.8	-	-	-	-	-	-
Average		6.9		208	140	68			38
Station 2									
July 28, 1947	5.2	6.3	7.5	180	124	56	130	90	50
July 31	4.2	5.9	6.8	-	-	-	170	90	32
August 4	4.1	4.9	6.5	230	146	84	130	110	-
August 8	4.6	5.7	7.0	-	-	-	140	112	50
August 13	5.6	6.0	6.3	-	-	-	-	-	-
August 15	1.7	4.0	5.4	-	-	-	220	130	70
August 20	5.6	5.5	6.8	227	146	81	50	60	35
August 22	-	6.4	-	-	-	-	-	-	-
August 25	-	-	-	-	-	-	110	110	64
August 27	6.2	5.6	6.7	-	-	-	-	-	-
Average		5.6		216	133	84	150	107	53

TABLE 9

Data on Dissolved Oxygen, Dissolved Solids and Color

Key: E = East side of river      T = Total  
 M = Middle of river          F = Fixed  
 W = West side of river        V = Volatile

Date	Dissolved Oxygen			Dissolved Solids			Color		
	E.	M.	W.	T.	F.	V.	E.	M.	W.
Station 3									
July 28, 1947	5.5	6.4	6.3	188	115	73	110	80	65
July 31	5.4	5.6	6.1	-	-	-	110	110	64
August 4	4.4	4.7	5.2	226	135	91	90	95	-
August 8	5.0	4.6	5.8	-	-	-	140	125	90
August 13	2.5	3.4	4.0	-	-	-	-	-	-
August 15	2.0	3.4	3.5	-	-	-	100	100	90
August 20	4.9	5.3	5.5	235	148	87	65	70	40
August 22	-	6.2	-	-	-	-	-	-	-
August 25	-	-	-	-	-	-	85	85	75
August 27	6.2	5.8	5.8	-	-	-	-	-	-
Average	4.9			216	133	84	106	99	77
Station 4									
July 28, 1947	5.7	5.8	5.9	181	117	64	65	70	70
July 31	3.8	4.6	4.6	-	-	-	90	75	75
August 4	3.4	3.7	4.4	227	138	89	90	95	-
August 8	4.0	3.3	4.3	-	-	-	125	100	100
August 13	2.0	2.2	2.1	-	-	-	-	-	-
August 15	2.2	2.4	3.3	-	-	-	75	75	75
August 20	3.3	4.3	4.0	229	143	86	75	70	70
August 22	-	-	-	-	-	-	-	-	-
August 25	-	-	-	-	-	-	85	-	85
August 27	4.7	4.9	4.7	-	-	-	-	-	-
Average	3.9			212	133	80	88	82	81

TABLE 9

Data on Dissolved Oxygen, Dissolved Solids and Color

Key: E = East side of river      T = Total  
 M = Middle of river            F = Fixed  
 W = West side of river        V = Volatile

Date	Dissolved Oxygen			Dissolved Solids			Color		
	E.	M.	W.	T.	F.	V.	E.	M.	W.
Station 5									
July 28, 1947	4.5	4.9	4.9	169	111	58	70	70	70
July 31	3.5	3.7	3.9	-	-	-	75	90	75
August 4	1.5	2.1	2.2	220	124	96	85	75	-
August 8	2.3	3.0	2.7	-	-	-	75	75	75
August 13	3.0	3.3	3.3	-	-	-	-	-	-
August 15	.9	1.3	1.3	-	-	-	100	100	100
August 20	2.0	2.3	2.2	216	137	79	70	70	70
August 22	-	-	-	-	-	-	-	-	-
August 25	-	-	-	-	-	-	90	90	90
August 27	4.5	3.9	3.9	-	-	-	-	-	-
Average	3.0			202	124	78	82	84	80
Station 6									
July 28, 1947	6.9	7.1	7.1	183	115	68	70	70	70
July 31	6.4	6.7	6.7	-	-	-	75	75	75
August 4	6.5	6.5	6.5	217	128	89	85	75	-
August 8	6.4	6.4	6.4	-	-	-	85	85	85
August 13	5.6	6.7	6.6	-	-	-	-	-	-
August 15	6.1	6.2	6.0	-	-	-	100	100	100
August 20	6.3	6.3	6.3	211	134	77	70	70	70
August 22	-	-	-	-	-	-	-	-	-
August 25	-	-	-	-	-	-	-	90	-
August 27	-	6.8	-	-	-	-	-	-	-
Average	6.5			204	126	78	83	83	83

TABLE 9

Data on Dissolved Oxygen, Dissolved Solids and Color

Key: E = East side of river      T = Total  
 M = Middle of river          F = Fixed  
 W = West side of river        V = Volatile

Date	Dissolved Oxygen			Dissolved Solids			Color		
	E.	M.	W.	T.	F.	V.	E.	M.	W.
Station 7									
July 28, 1947	6.9	6.7	6.7	166	106	60	70	70	70
July 31	6.3	6.1	5.8	-	-	-	75	75	75
August 4	6.3	6.1	5.8	212	137	75	70	70	-
August 8	5.9	5.7	5.7	-	-	-	75	75	75
August 13	6.3	6.3	6.0	-	-	-	-	-	-
August 15	5.6	5.6	5.4	-	-	-	100	100	100
August 20	5.9	5.8	5.6	226	134	92	70	70	70
August 22	-	-	-	-	-	-	-	-	-
August 25	-	-	-	-	-	-	-	90	-
August 27	-	6.7	-	-	-	-	-	-	-
Average		6.1		201	126	76	78	80	80
Station 8									
July 28, 1947	6.3	6.3	6.2	170	110	60	70	70	70
July 31	5.5	5.8	5.6	-	-	-	75	75	75
August 4	5.7	6.0	5.3	199	111	88	65	-	65
August 8	4.9	5.0	4.9	-	-	-	75	75	75
August 13	5.6	5.8	5.6	-	-	-	-	-	-
August 15	4.9	5.0	4.6	-	-	-	100	100	100
August 20	5.3	5.4	5.0	213	135	78	70	70	70
August 22	-	-	-	-	-	-	-	-	-
August 25	-	-	-	-	-	-	-	90	-
August 27	-	6.2	-	-	-	-	-	-	-
Average		5.5		194	119	75	77	82	77

# PLATE 3

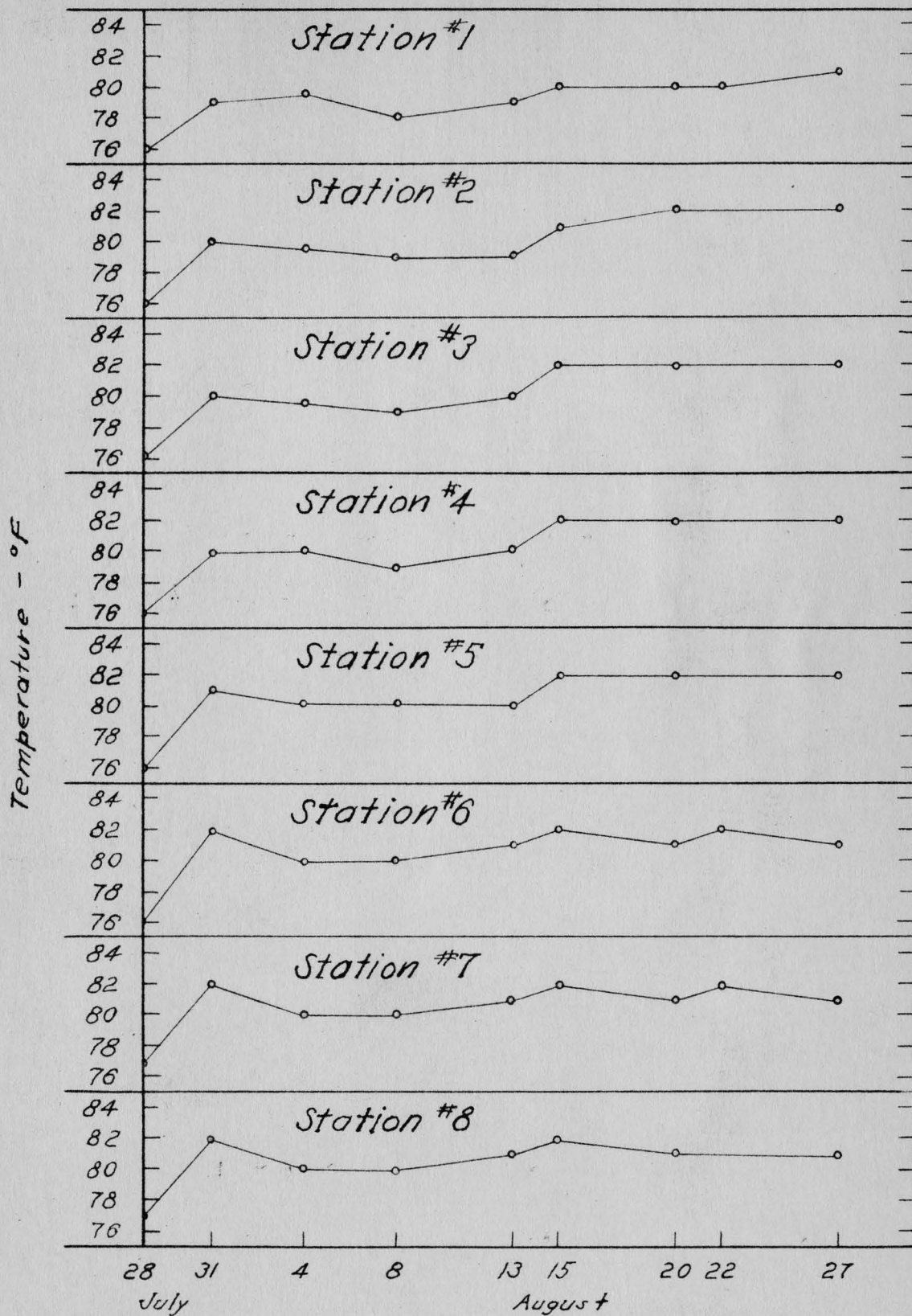


PLATE 4

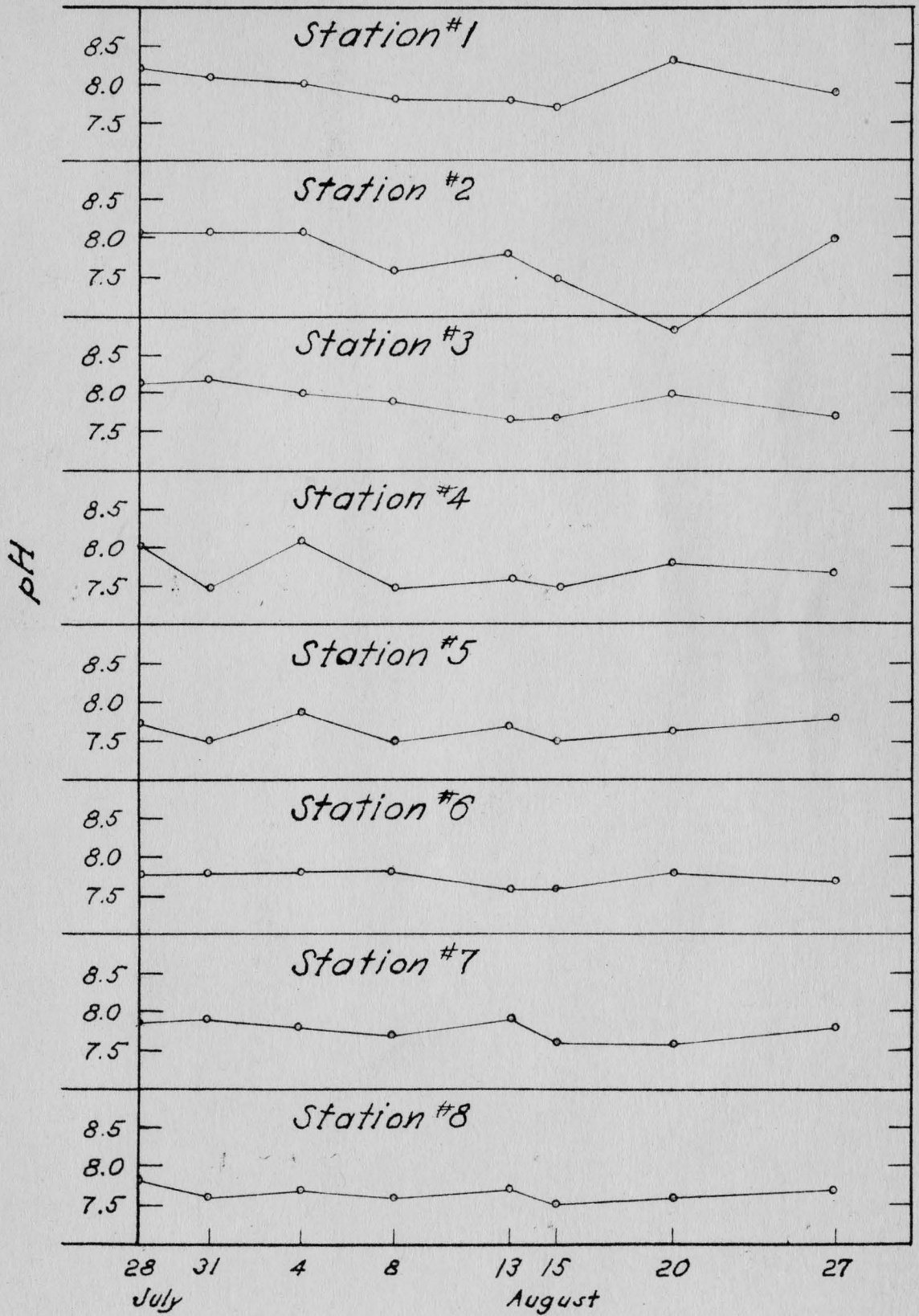


PLATE 5

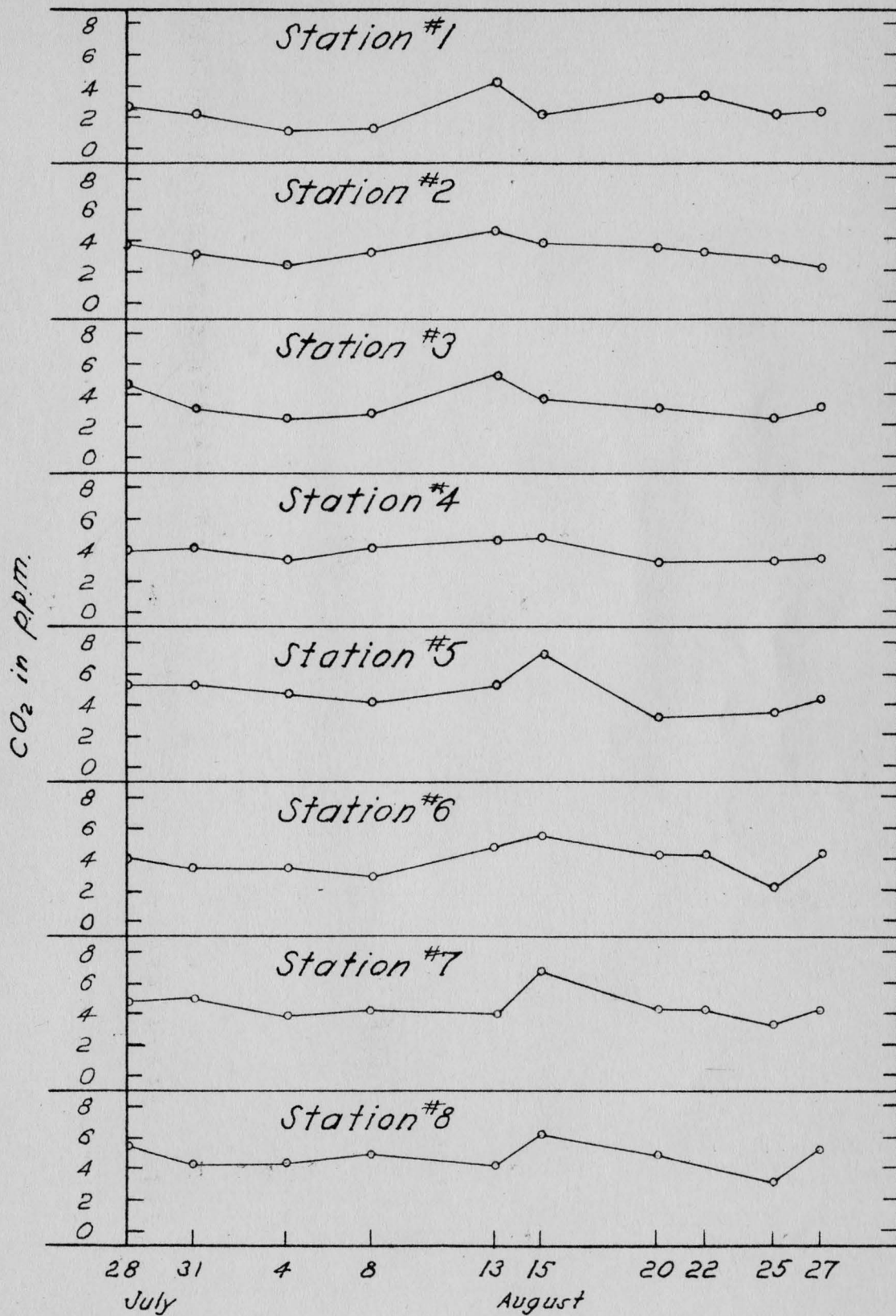


PLATE 6

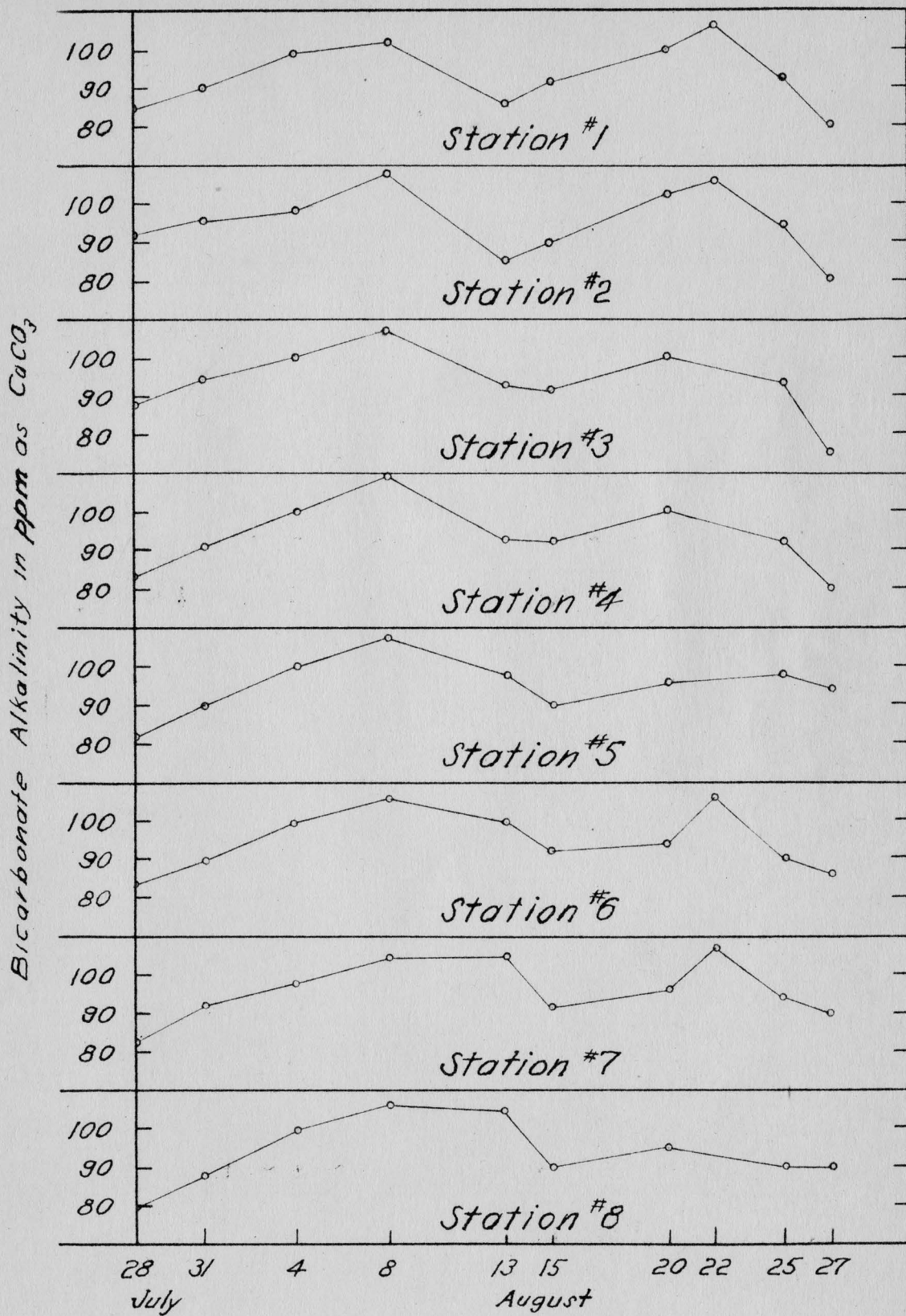
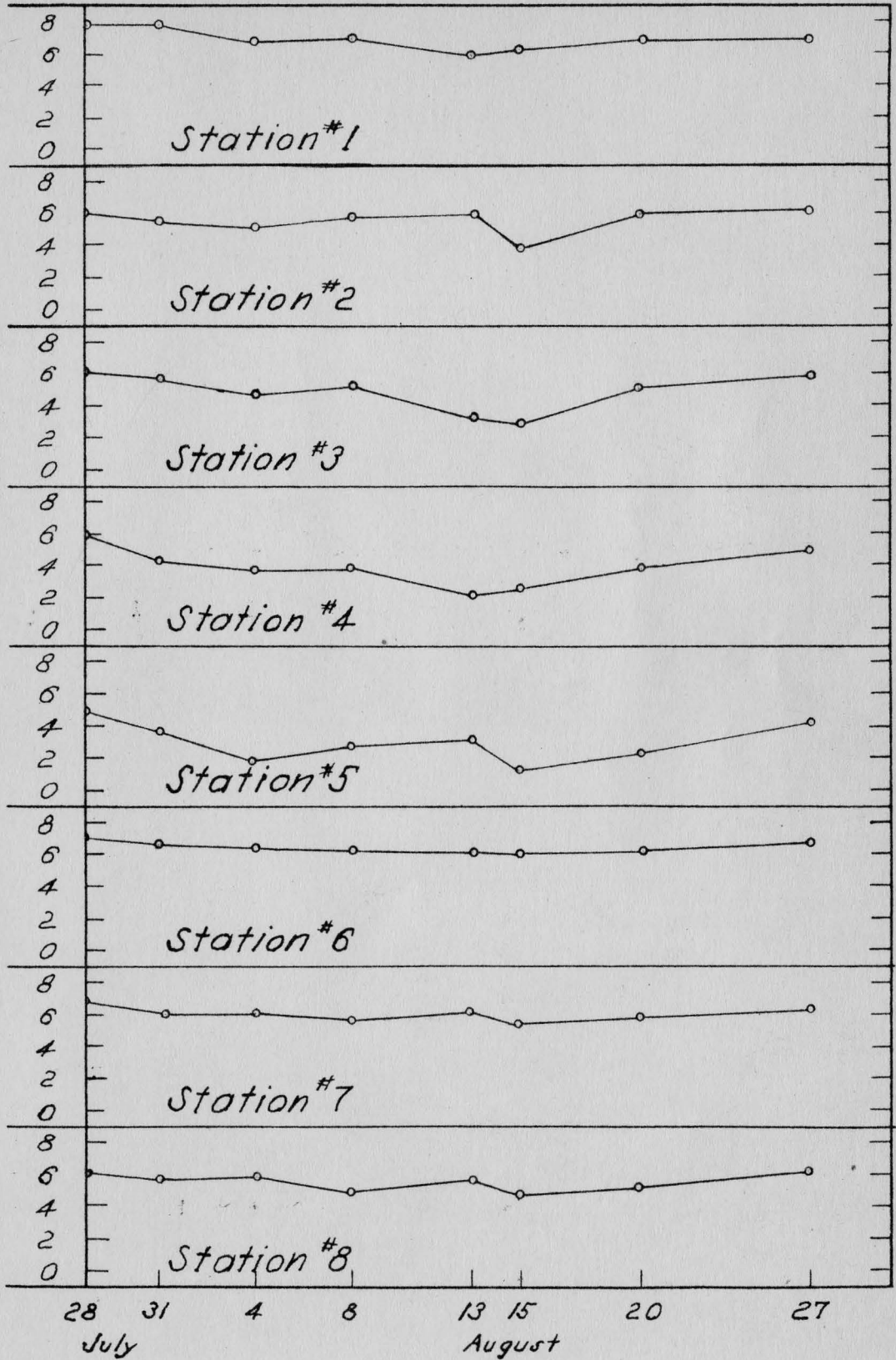


PLATE 7

Dissolved Oxygen (Avg across river) - ppm.



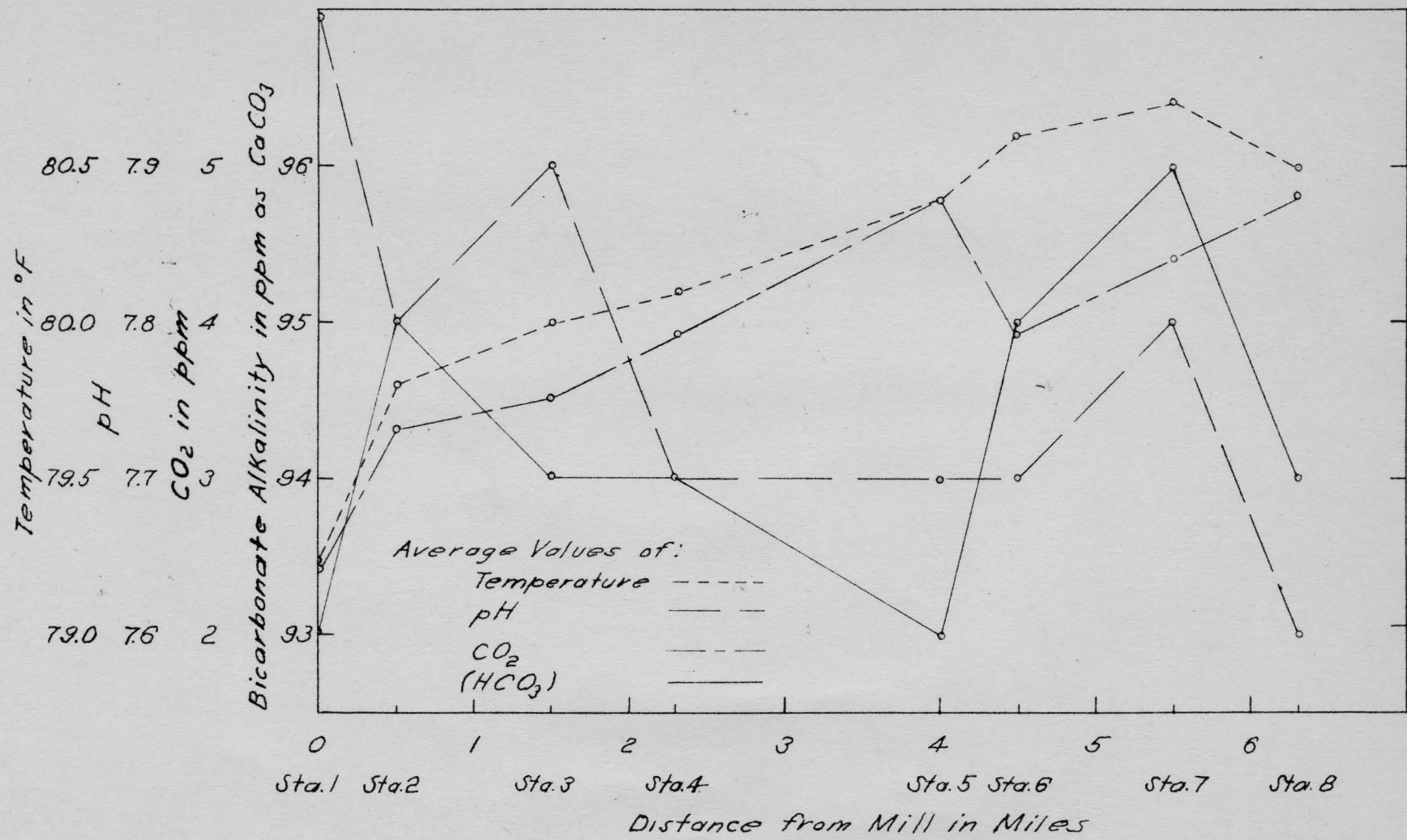


PLATE 8

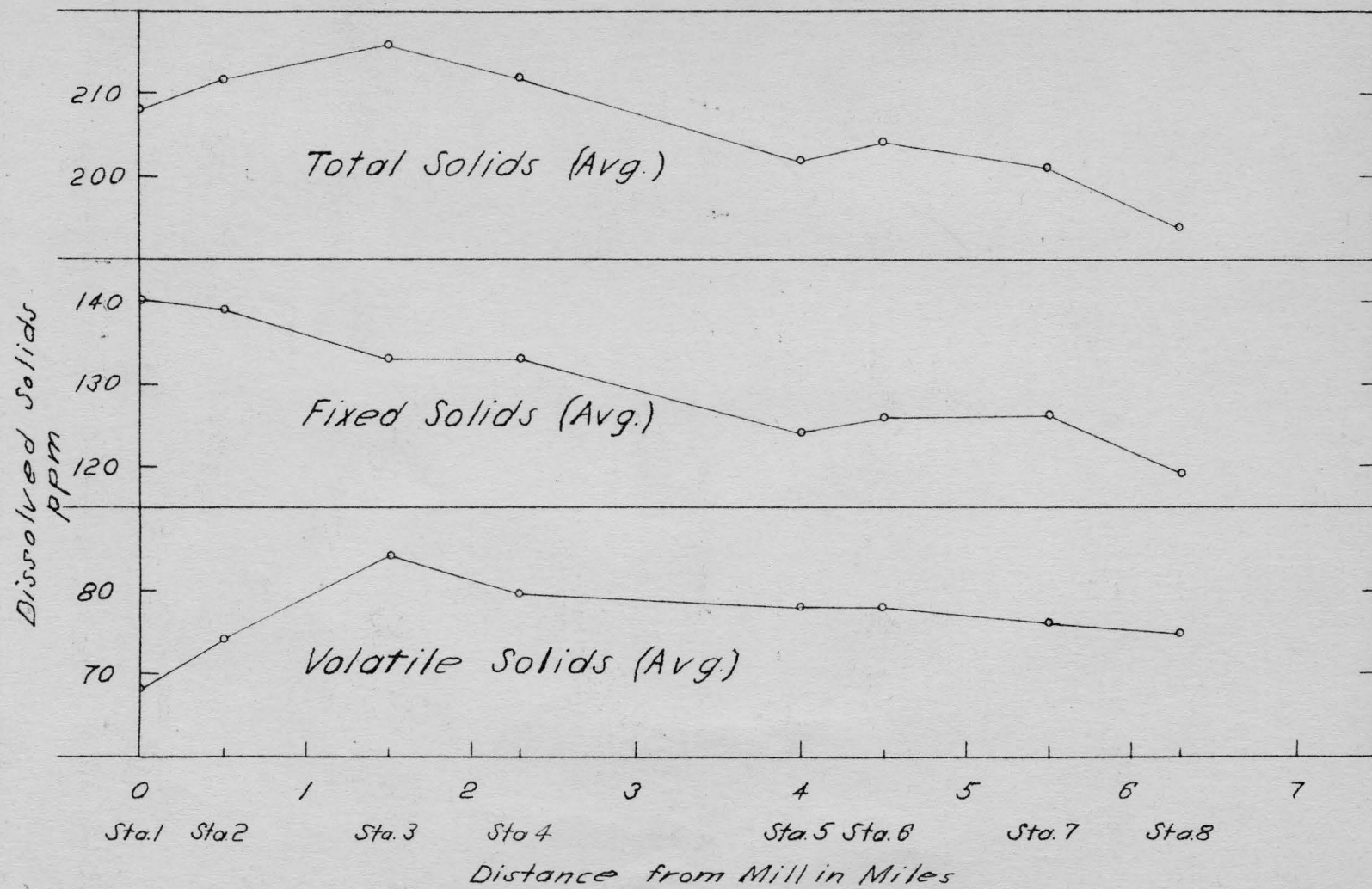


PLATE 9

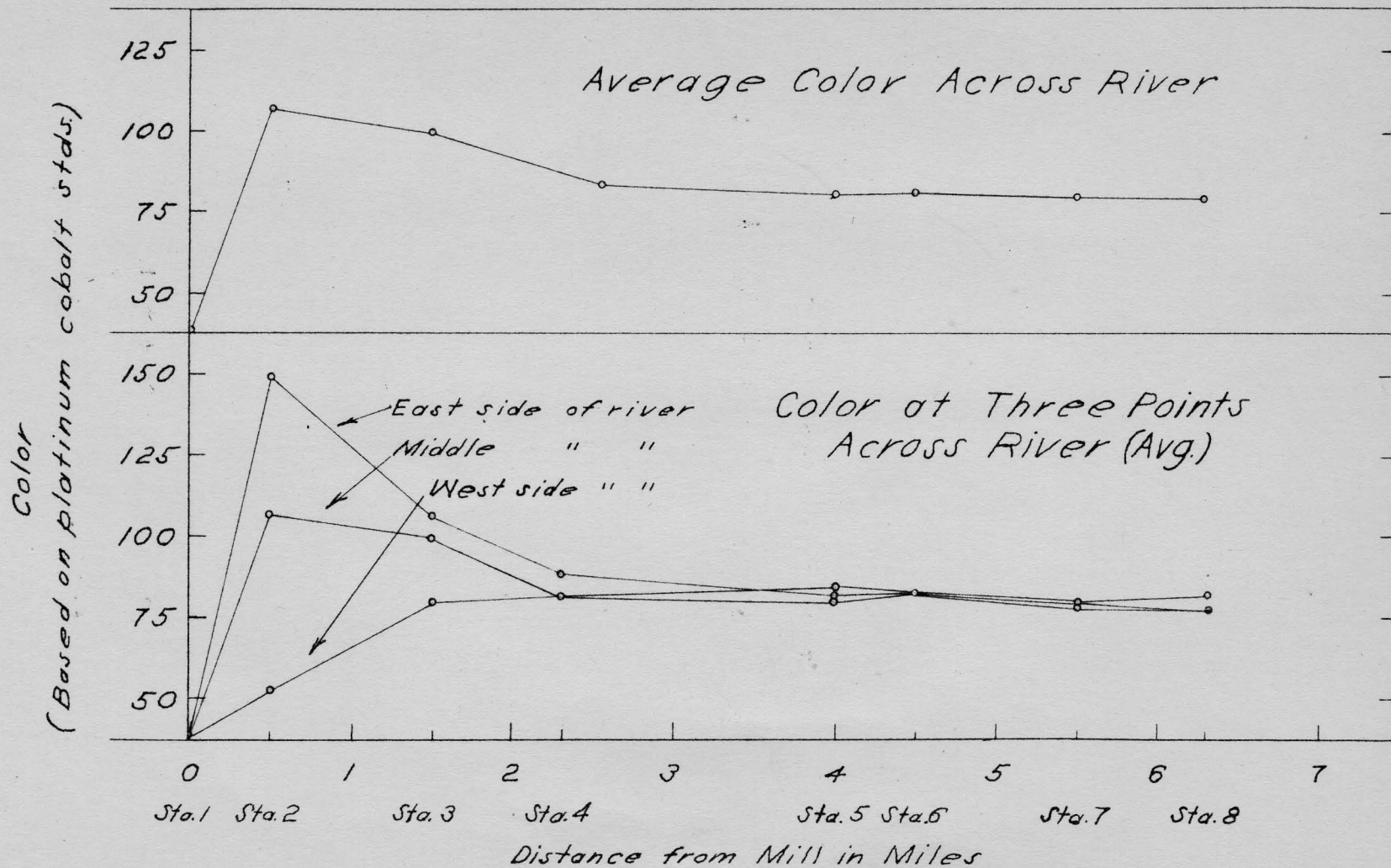


PLATE 10

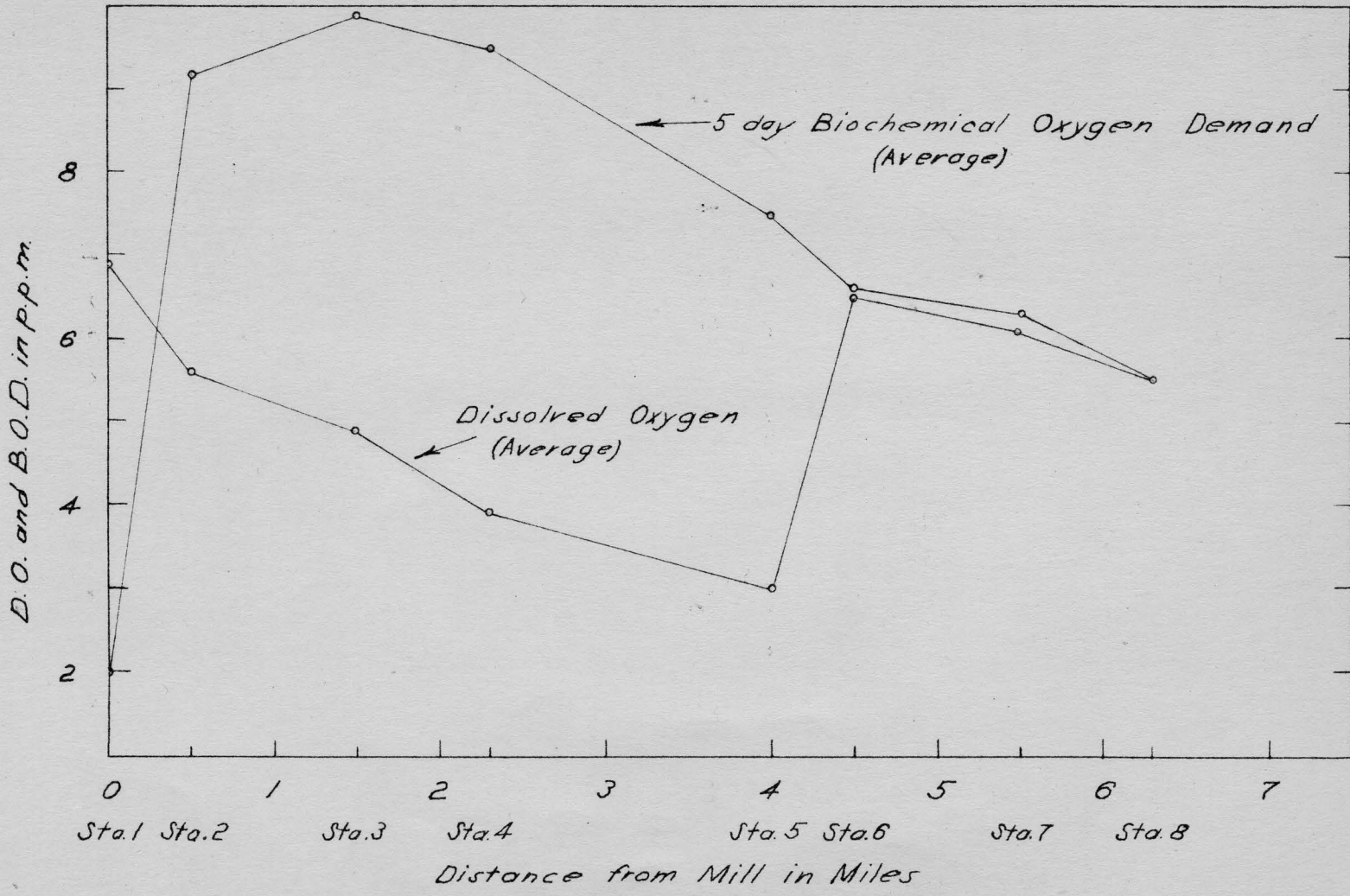
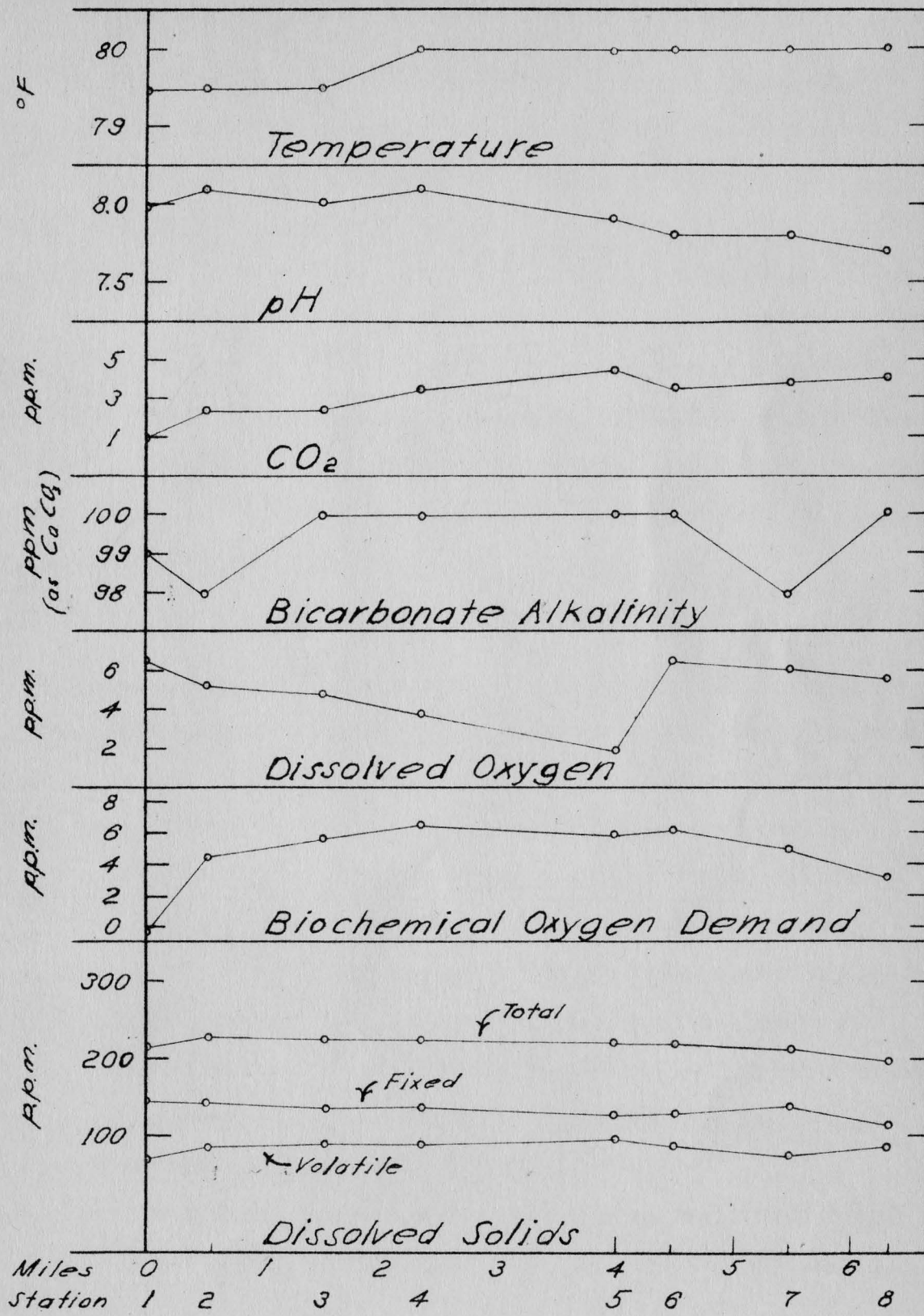


PLATE II

PLATE 12  
DATA OBTAINED AUGUST 4, 1947



## Discussion of Results

### 1. Temperature

Plate 3 shows how the temperature varied at each station during the period of the author's investigation. It is apparent that the patterns of the curves are similar. This illustrates the constancy of temperature differences between the various stations.

The temperature curve on Plate 8 represents the average temperatures at each station during the period of investigation. It is noted that the average temperatures vary only from  $79.2^{\circ}\text{F}$  to  $80.7^{\circ}\text{F}$ . This variance of a degree and a half can probably be attributed to a normal daily temperature fluctuation. The temperature at Station #1 was always taken the first thing in the morning, and that at Station #8 the last thing in the afternoon. Therefore, the temperature data has no direct significance.

### 2. pH

If the stream had not been influenced by an interplay of chemical reactions resulting from the mill wastes, the pH differences between any two stations should not have varied from trip to trip. A constancy of differences should have been encountered on each trip. However, since the curves on Plate 4 give little indication of a consistent pattern, some factor other than that associated with the stream's normal condition must be involved.

From the curve on Plate 8 representing the average pH at each station, it is seen that there is a general decrease from Station #1 to Station #8. If Station #1 is a control representing normal stream conditions, the decrease in pH is to be considered alien to these normal conditions and the result of a newly introduced factor.

Both plates, then, give evidence of some influencing factor that cannot be explained as being natural or normal to the river. Such a factor can only

be the chemical changes instigated by the mill waste.

The mill waste, however, suffers no indictment from this quarter as far as the biota is concerned. A pH fluctuation of between 7.9 to 8.1 will not radically affect aquatic life.

### 3. Carbon Dioxide

As might be expected, the decreasing pH from Station #1 to Station #8 is accompanied by a general increase in carbon dioxide. This is demonstrated on Plate 8. The explanation is simple. Carbon dioxide is produced in the decomposition of organic material. Since the dissolved  $\text{CO}_2$  is in the form of carbonic acid, a shift to a more acidic pH may be expected to accompany the production of  $\text{CO}_2$ . Although it is recognized that the mill probably contributes the majority of the organic material responsible for the  $\text{CO}_2$ , here again, an indictment is not in order. An increase of from 2.5 to 4.5 ppm of  $\text{CO}_2$  only demonstrates the presence of a state of decomposition and not a lethal variance.

### 4. Bicarbonate Alkalinity

The only alkalinity found in the river was of a bicarbonate nature. Although the curves on Plate 6 exhibit a pattern of constant differences between stations, the curve on Plate 8 appears to be unrelated to the  $\text{CO}_2$  and pH curves. Moreover, the curve on Plate 8 cannot be demonstrated as representing direct effects of the mill's waste on the river.

### 5. Color

On Plate 10 the data on the river's color is presented in two ways. One demonstrates the channeling effect and the other demonstrates the relationship of the average color at each point along the river with those of the rest of the reach.

From the bottom set of curves it is noted that at Station #2 the color varies quite widely across the river. The east side of the river, where the greatest color is found, is the side opposite the mill. The effluent as it leaves the mill flows out across the river and along the east shore. This channeling effect is in evidence downstream until Station #4 is reached.

The top curve (Plate 10) indicates two things. First; it is obvious that the mill does contribute color to the stream. Additional evidence of this is found in the channeling effect. And second; color is lost as the river flows downstream until Station #4 is reached. From this point on throughout the remainder of the reach investigated the color remains the same. From this evidence it might be concluded that the color lost between the mill and Station #4 represents the colored portion of the waste that is held in suspension, while that color which remains in the river from Station #4 to Station #8 represents the colored portion of the waste that is in solution or in a colloidal state.

Color, then, furnishes indictment of the mill as a source of stream pollution.

## 6. Dissolved Solids

From the curves on Plate 9 it is quite evident that organic material enters the river from the mill. The maximum in volatile solids is found at Station #2. The only explanation for this is that the channeling effect at that station distorted the picture and representative data was not obtained. A steady decrease of the volatile solids is noted from Station #4 to Station #8.

Quite unusual is the fact that more fixed solids (inorganic material) are in solution upstream from the mill than are downstream. Because of the steady decrease shown by the curve, it might be suggested that the mill waste exerts a "salting-out" effect on the organic material. So few deter-

minations were made on the dissolved solids, however, the picture is at best inadequate.

#### 7. Biochemical Oxygen Demand

From the B.O.D. curve on Plate 11 it is seen that the maximum B.O.D. was found at Station #3. Again, the channeling effect at Station #2 undoubtedly distorts the picture. Sufficient evidence is provided, however, to show that the mill does increase the river's B.O.D. by about 8 ppm. The B.O.D. at Station #8 is still greater by 3.5 ppm than that above the mill. The oxygen consuming properties of the waste, then, are still functioning far downstream.

#### 8. Dissolved Oxygen

By virtue of the B.O.D. given to the river by the mill, the dissolved oxygen is decreased from about 7 ppm above the mill to 3 ppm at Station #5. This is evident in the D.O. curve on Plate 11. Also evident is the fact that the waste is in such an available state that the demand for oxygen is immediate. Quite conspicuous is the increase in D.O. between Station #5 and #6. This increase is caused by the reoxygenation of the water flowing over the Coleman Dam. The dam, therefore, is beneficial in at least two ways. First; it forms a pondage which aids in keeping the B.O.D. in the reaches nearer to the mill, and second; it serves to replenish the reduced oxygen supply.

It must be remembered that this D.O. curve was plotted from the averages of data obtained during the most critical times of the year. In other words, the conditions described by this curve represent those most common during one of the months of least flow and warmest weather. Therefore, aquatic life in order to survive this period must be acclimated to the said conditions.

Also, it is to be remembered that the dissolved oxygen samples were taken at 5 ft. depths. This represents only one quarter of the depth at

Station #5. If the bottom deposits exert an appreciable demand on the D.O., conditions will be more critical at this point than are indicated.

Most forms of aquatic life need oxygen. Fish have a normal requirement of 4 to 4.5 ppm, but some fish can suffer as little as 2.5 to 3 ppm over short periods of time. If no bottom demand is present, and the values of D.O. taken at a 5 ft. depth represent conditions from surface to bottom, then certain fish might survive the critical summer months in all reaches of the stream. However, if a bottom demand is present at Station #5, it is very doubtful that fish could survive in the pondage at that station.

### Conclusion

The most evident of the mill's effects on the physical and chemical nature of the river are the increased coloration and the depression of the D.O. These effects are cited as serious in that they are the most obvious. The other physical and chemical characteristics, however, are not to be considered insignificant. For the most part, they offer proof of abnormal conditions. It is only the difficulty of singling them out from their interplay that prohibits their being presented as important evidence. Coloration and dissolved oxygen content are of a nature that can be used as salient indictments.

BOTTOM DEPOSITS

A fairly good idea of the extent of carpet formation was obtained by dropping a weight connected to the end of a sash cord into the river and noting the sonics. Whether the weight struck bare stone, stone covered with a light carpet, or a heavy carpet was easily determined by the sound of the impact. Soundings of this sort were made at three points across the river at each station and mid-station.

At most points along the river, the bottom is extremely rocky. Only behind the dams have the deposits been great enough completely to carpet the bottom. Elsewhere, the deposits appear to lie in between the boulders or to hang precariously on the boulders' surfaces. These latter deposits "slough off" and become sludge floats.

For lack of a more scientific name the term "sludge floats" is used to describe the putrescent organic masses that were found floating on the surface of the river. These floats were round, ranging from 10 to 18 inches in diameter, and consisted of a putrescent slimy mass. The greatest number originated between Station #2 and Station #3, although some appeared to originate prior to Station #5. In coming to the surface they would be accompanied by a myriad of gas bubbles. Large river flows instigated by rainfall acted as a flushing agent, and during these periods, the greatest number of floats appeared. The currents carried the floats downstream where they would either be intercepted by the river's banks or by the dam at Station #5. Once at Station #5, they would decompose on the still pond or disintegrate while going over the dam. Very few floats were encountered below Station #5.

Under the microscope, a sludge float appeared to consist of *Sphaerotilus natans*, wood fibers, amorphous material, a few sand grains, and microscopic organisms. The organisms consisted of diatom carcasses, *Paramecium caudatum*,

Oxytricha, Metopus striatus, and Blepharisma steini. These, for the most part, are predator organisms, and along with the unmistakable  $H_2S$  odors, identify the mass as being in active anaerobic decomposition.

Samples of the sludge carpet at Station #5 were examined and found to contain much amorphous material, sand, a few fibers, and several diatom carcasses. These samples were taken in 20 feet of water at a point where the water five feet from the surface often contained less than 2 ppm of D.O. When the samples were obtained, the calm of the pondage was disturbed by many gas bubbles. The fact that no predatory protozoa were found indicates a limited benthos. Very little, if any, Sphaerotilus was present.

Although the greatest part of the river bottom at Station #2 was stream with large boulders, a small portion close to the shore was covered with material which billowed in black clouds when disturbed. The water at this spot was from one to two feet deep. A microscopic analysis of this black material revealed a composition of much sand, amorphous matter, fiber, and many organisms.

The organisms present included diatoms, Rotifers, Closterium, Oscillatoria, Spirostomum teres, and some organism that resembled human hair (microscopic appearance). The filaments of this latter organism waved back and forth and appeared to be made up of strings of blue cells. Very little Sphaerotilus was noted.

The type of organisms present and the fact that no odors were detected in bringing up the samples, preclude designating the condition here as near-septic or septic.

Downstream from the dam at Station #5 no evidence of a carpet was found until Station #8. Here, in the pondage behind another dam, on one side of the river and adjacent to the point where the Pedlar River flows into the James, a slight carpet was found. No microscopic analysis was made of this

carpet, but its extent was known to be limited. Occasionally bubbles were seen to rise, but at no time was this pondage found to be offensive to the eye or nose.

From the results obtained the following conclusions are made.

There is a definite deposition of wood fibers on the river bottom. Although the deposition begins at the mill, the river's currents along with the uneven river bed prohibit the formation of a thick benthic carpet until the pondage at Station #5 is reached. Here in the deep and relatively quiescent water, a carpet has formed to such an extent as completely to cover the bottom. This carpet is decomposing anaerobically.

However, the carpet produces no visible offensive condition. Outside of the bubbles occasionally rising to the surface and the retention of what sludge floats arrive from upstream, the water is not offensive to the eye or nose.

Incriminating evidence is to be found from Station #2 to #4. Here, although partial decomposition is evidenced by gas bubbles rising to the surface, the river currents "slough off" the deposits before a complete carpet can be formed. The sludge floats thus formed, along with the bubbles that accompany their ascension, give the river a sordid appearance. The decomposition of the floats as they float downstream or collect along the bank evolves foul odors.

Some deposition, possibly some of it contributed by the Pedlar River, is present at Station #8, but like that of the more extensive carpet at Station #5 no offensive conditions are present.

SPHAEROTILUS NATANS

Quite conspicuous in the water at Station #2 was the constant flux of particles resembling tufts of wool. This condition, although limited to a relatively short reach, was observed on every trip. Samples of this floating material were taken to the laboratory and examined under the microscope. With little difficulty the substance was identified as being the so-called sewage fungus, *Sphaerotilus natans*. This fungus is vividly described by Suter (39) as follows:

"It forms in dense masses, covering the stones of the bottom and clinging to submerged sticks and plants. In still water it may be bulbous in form, like summer clouds; where there is more current the masses are more shaggy or fleecy with jagged edges and points swaying in the current. Fragments are frequently detached by the current and carried downstream into the lower zones. While submerged, these plants have somewhat the appearance of cotton wool, although made up of gelatinous threads. The newly developed forms are frequently white, but the older parts tend towards an olive green or "putty" gray color, turning to a rusty brown in the oldest portions. This fungus feeds on and disintegrates waste material and absorbs oxygen. It persists until the oxygen saturation is pulled down to about 45 per cent, 4 ppm at summer temperatures, when it dies and in turn supports the lower forms of fungo-bacteria."

As is pointed out in the section on Bottom Deposits, this fungus is flushed off the bottom where it is formed. Some of it "sloughs off" in small tufts whereas the remainder comes to the surface in chunks to form the sludge floats.

It is to be noted that this fungus occurs at the point of maximum bacterial concentration. It undoubtedly cooperates with the lower bacteria in reducing the organic content of the river.

THE RIVER'S APPEARANCE

Although the reach of river just above Big Island probably contains less pollution than any other reach of the James, the water is far from being in the clear pristine state. Instead, it is muddish and, at times, somewhat brackish along the shore. During periods of low flow, the Big Island Dam catches the scum which accumulates back up the river. However, this scum is never more than a surface film, and, other than being unsightly, creates no nuisance.

The water as it leaves the mill varies in appearance. When only the washer and the machine effluents are flowing into the river, no more than a small additional coloration and foaming results. However, when the digester effluent is added to the river, very dark coloration and increased foaming occurs. This near-black liquid flows from the mill, crosses the river, and flows downstream on the side opposite the mill. Such a channeling effect persists visibly until Station #2 is reached and can even be traced as far as Station #4 by colorimetric tests. The islands between Stations #4 and #5 effectively break up the "channeling" and a homogeneous color across the river is obtained. The foam has usually disappeared before it reaches Station #2.

In the shallow and turbulent reach at Station #2, the flux of *Sphaerotilus natans* is encountered. Between here and Station #3 the sludge floats begin ascending to the surface. These make their way down the river where a large portion collects along the shore between Stations #3 and #4. This accumulation, together with the gas bubbles that are constantly rising to the surface serves to give this reach a very sordid appearance. During hot weather the reach is further degraded by the foul odors emanating from these decomposing floats.

Those sludge floats that are not intercepted by the shore float downstream to the two islands located above Station #5. Here, in the two shallowest channels where the stronger currents do not invade, many of the floats accumulate and again, decomposition produces a foul appearance.

The floats that successfully reach the pondage at Station #5 collect there until finally they are thrown over Coleman Dam. However, their retention at this point, because of the larger area involved, does not give rise to as disagreeable a condition as is encountered in the shallow channels between the islands and shore. At Station #5 the still of the pondage is from time to time disturbed by gas bubbles.

Those floats that go over the dam disintegrate and very few are found downstream. However, a condition of frothing occurs from the dam to Station #6. This white froth, produced by the water flowing over the dam, is not as thick as foam. It appears to be made up of tiny bubbles one layer thick. The condition disappears a short distance downstream from #6.

From there to Station #8 the water is of a nature similar to that above the mill. All visible traces of the conditions caused by the mill have disappeared.

REAERATION

When polluted water is exposed to the air, it tends to absorb oxygen. In this manner, the water tends to offset the oxygen liabilities incurred by the B.O.D. of the pollutants. These two, reaeration and deoxygenation, are, therefore, in a simultaneous operation in polluted streams. The amount of dissolved oxygen present at any instant can be determined if their rates are known. The two have been formulated in an expression known as an oxygen sag curve. This curve is in the form of\*

$$D_t = \frac{K_1 L (10^{-K_1 t} - 10^{-K_2 t})}{K_2 - K_1} + D \times 10^{-K_2 t},$$

where

- $D_t$  = oxygen saturation deficit of the water in ppm at any time  $t$ .
- $D$  = initial oxygen saturation deficit at point of pollution, in ppm.
- $L$  = initial biochemical oxygen demand of the diluted pollution.
- $K_1$  = the deoxygenation constant.
- $K_2$  = the reaeration constant

The deoxygenation constant  $K_1$ , has been determined as being 0.1 at 20°C. This holds for all streams. However, as one might expect in dealing with biologically-activated processes, the constant changes with a change in temperature. From considerations in physical chemistry and actual test the deoxygenation constant  $K_1$  at any temperature  $T$ ,  $K_1(T) = K_1(20) [1.047^{T-20}]$ . Furthermore, temperature affects the magnitude of the first stage B.O.D., and the first stage demand  $L$  at any temperature  $T$  has been found to bear the following relation to the first stage demand at 20°C:

$$L_T = L_{20} [1 + 0.02 (T-20)]$$

\*For derivation of this formula see Appendix A, Public Health Bulletin 146, U. S. Public Health Service.

According to Babbitt (40) the reaeration constant depends largely on temperature, time, turbulence, depth, sunlight, and the rate of deoxygenation of the liquid. Consequently, the constant varies with the stream and even the reach considered. It is with the reaeration constant that this section deals.

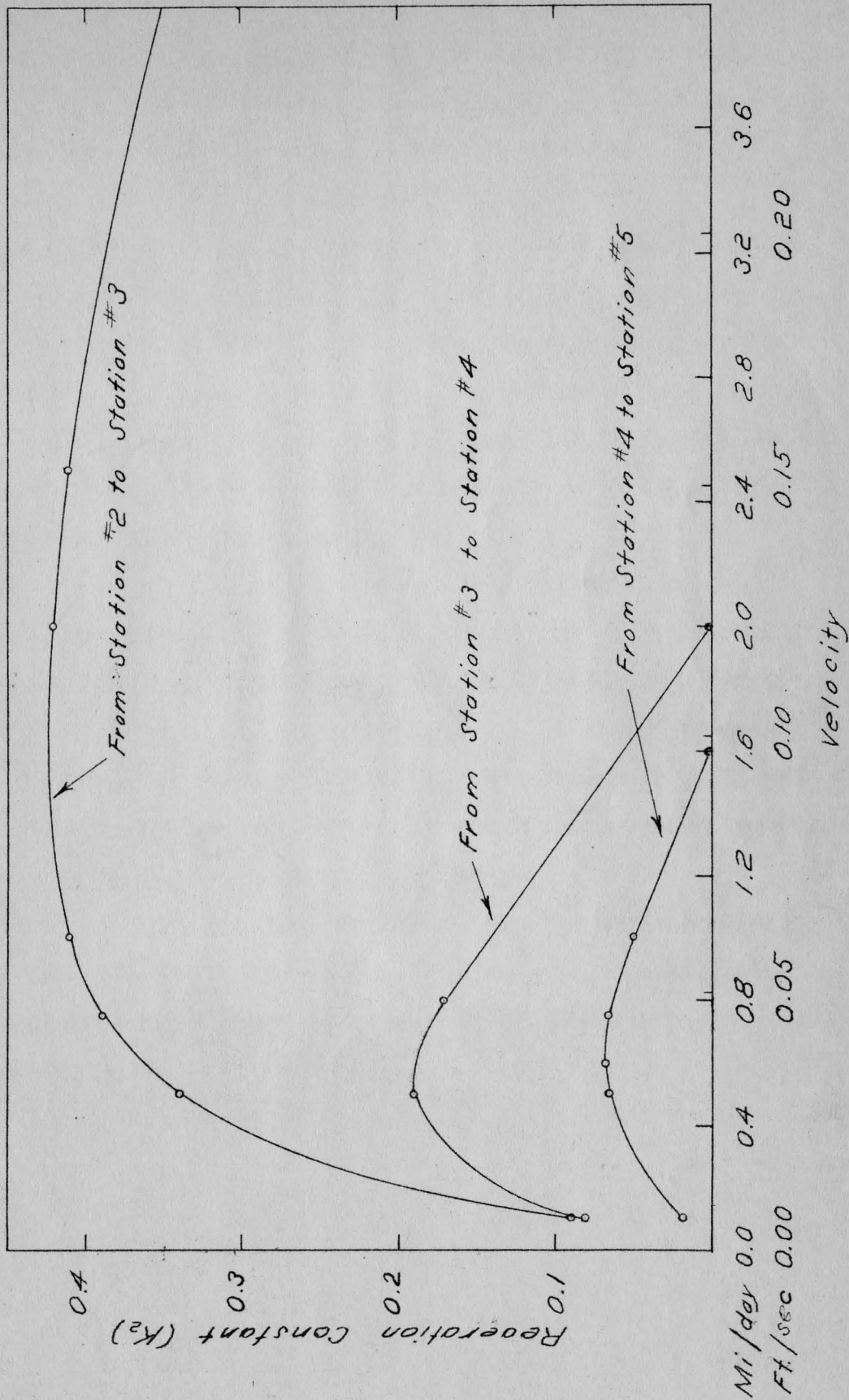
By not knowing the river velocities, it was necessary to deal with two unknowns, the reaeration constant and time. The reaeration constant for various velocities was determined by trial and error, using direct observations of dissolved oxygen and B.O.D. In this manner, three curves were obtained (Plate 13) describing the reaeration constant at different velocities for the individual reaches between Stations #2 and #3, #3 and #4, and #4 and #5.

The curve for the reach between Stations #2 and #3 appears quite reasonable. In this reach the river is quite swift, the average velocity probably being 0.1 ft./sec. According to Babbitt (40) streams of this nature have reaeration constants varying from 0.30 to 0.50. From the curve on Plate 13 it is seen that for a velocity of 0.1 fps a constant of 0.42 is obtained.

Likewise, the curve for the reach between Station #3 and #4 appears reasonable. Here the current is reduced considerably, say from 0.035 to 0.050 fps. Babbitt (40) gives the value of 0.15 to 0.20 for large streams of low velocity. The curve on Plate 13 gives a constant of .16 for a velocity of 0.050 fps.

The author does not attempt to evaluate the velocity for the reach between Stations #4 and #5. Here, due to the pondage behind Coleman Dam, the velocity is extremely slow. Babbitt (40) gives  $K_2$  a value of 0.10 to 0.15 for sluggish streams and large lakes. If the velocity of flow of the reach concerned is comparable to this classification, then it would seem that the

# PLATE 13



curve on Plate 13 is in disagreement. If this disagreement is actual, then either the observed data is incorrect or some other factor, not taken into account in the sag curve, enters the picture. Assuming the data to be correct, one may speculate on the unaccounted-for factor.

It is seen on Plate 13 that the curve for the reach between Stations #4 and #5 gives smaller values for  $K_2$  than Babbitt (40). This, of course, is based on the assumption that the velocities concerned are those that could be classified as being present in sluggish streams or large lakes. Something else, therefore, other than the B.O.D. of the water, must account for the low constant. In other words, something else is consuming the oxygen other than the pollutants in the water.

This "something else" might be in the form of bottom deposits. If there were deposits carpeting the bottom of this reach, it is quite probable that they exert an additional demand on the oxygen. Such a demand would not be evident in our B.O.D. determinations. It is quite possible that this demand does exist, because the presence of a carpet in the lower portions of this reach has been verified. (See section on Bottom Deposits.) But the extent of the demand is not known at the present.

It must not be forgotten that the above discussion is not based on known velocities. No definite conclusion can be drawn until velocities of the various reaches are taken. Further investigations along this line should prove very valuable.

Calculation of Reaeration Constants for Various Velocities  
(Data taken from run made on August 20, 1947)

1. For the reach extending from Station #2 to #3, a distance of 1 mile.

$$\begin{aligned}
 D_2 & - \text{saturation deficit at Station \#2} \\
 & \text{sat. at } 82^\circ & = 7.95 \text{ ppm} \\
 & \text{D.O. at Station \#2} & = \underline{5.50 \text{ ppm}} \\
 & \text{-----} & 2.45 \text{ ppm}
 \end{aligned}$$

$$\begin{aligned}
 L_2 & - 5 \text{ day, } 27.78^\circ\text{C B.O.D. at Station \#2} \\
 & = L_{20} [1 + .02 (T-20)] \\
 & = 8.3 [1 + .02 (27.78 - 20)] \\
 & = 8.3 \times 1.1556 = \text{-----} 9.6 \text{ ppm}
 \end{aligned}$$

$$\begin{aligned}
 K_1 & - \text{deoxygenation constant at } 27.78^\circ\text{C} \\
 & = K_{20} (1.047^{T-20}) \\
 & = .1 (1.047^{7.78}) = \text{-----} .143
 \end{aligned}$$

$$\begin{aligned}
 D_3 & - \text{saturation deficit at Station \#3} \\
 & \text{sat. at } 82^\circ & = 7.95 \text{ ppm} \\
 & \text{D.O. at Station \#3} & = \underline{5.30 \text{ ppm}} \\
 & \text{-----} & 2.65 \text{ ppm}
 \end{aligned}$$

Using the oxygen sag formula:

$$D_3 = \frac{K_1 L_2 (10^{-K_1 t} - 10^{-K_2 t})}{K_2 - K_1} + D_2 10^{-K_2 t}$$

$$2.65 = \frac{1.37 (10^{-.143 t} - 10^{-K_2 t})}{K_2 - .143} + 2.45 \times 10^{-K_2 t}$$

By trial and error the following values of  $K_2$  were found for corresponding values of time.

$t$ (in days)	$V$ (in mi./day)	$K_2$
10.00	0.10	.09
2.00	0.50	.34
1.33	0.75	.39
1.00	1.00	.41
0.50	2.00	.42
0.40	2.50	.41
0.10	10.00	.31
0.05	20.00	.18

2. For the reach extending from Station #3 to #4, a distance of .8 mile.

$D_3$  - saturation deficit at Station #3 - - - - - 2.65 ppm

$L_3$  - 5 day, 27.78°C B.O.D. at Station #3  
 =  $7 [1 + .02 (27.78 - 20)]$   
 =  $7 \times 1.1556 =$  - - - - - 8.1 ppm

$K_1$  - deoxygenation constant at 27.78°C - - - - - .143

$D_4$  - saturation deficit at Station #4  
 sat. at 82° = 7.95 ppm  
 D.O. at Station #4 = 4.30 ppm  
 - - - - - 3.65 ppm

Using the oxygen sag formula:

$$3.65 = \frac{1.16 (10^{-.143t} - 10^{-K_2t})}{K_2 - .143} + 2.65 \times 10^{-K_2t}$$

By trial and error

t (in days)	V (in mi./day)	K <sub>2</sub>
8.0	0.1	.08
1.6	0.5	.19
1.0	0.8	.17
0.4	2.0	.00

3. For the reach extending from Station #4 to #5, a distance of 1.7 miles.

D<sub>4</sub> - saturation deficit at Station #4 - - - - - 3.65 ppm

L<sub>4</sub> - 5 day, 27.78°C B.O.D. at Station #4  
 = 6.1 × 1.1556 = - - - - - 7.1 ppm

K<sub>1</sub> - deoxygenation constant at 27.78°C - - - - - .143

D<sub>5</sub> - saturation deficit at Station #5  
 sat. at 82° = 7.95 ppm  
 D.O. at Station #5 = 2.20 ppm  
 - - - - - 5.75 ppm

Using the oxygen sag formula:

$$5.75 = \frac{1.015}{K_2 - .143} (10^{-.143t} - 10^{-K_2t}) + 3.65 \times 10^{-K_2t}$$

By trial and error

t (in days)	V (in mi./day)	K <sub>2</sub>
17.00	0.10	.018
3.40	0.50	.065
2.83	0.60	.068
2.27	0.75	.065
1.70	1.00	.050
1.06	1.60	.000

The B.O.D. data used was calculated by the author from the D.O. data obtained from the middle of the river and using 7.5 ppm and 7.4 ppm respectively as the immediate and 5 day D.O. of the diluting water. A 2:1 dilution was made. These values of B.O.D. varied somewhat from those calculated by Mr. Maniates.

CONCLUSIONS

- I The reach immediately below the mill is polluted to a serious extent; especially during the late summer months. This is evidenced by:
1. Increased color
  2. Increased B.O.D.
  3. Depletion of dissolved oxygen
  4. Large bacterial populations
  5. Indicator organisms in the littoral benthic zone
  6. Profuse Sphaerotilus growth
  7. Sludge floats
  8. Gas bubbles
  9. Tendency for carpet formation.
- II In that portion of the river extending from Coleman Dam to the end of the reach investigated, the pollution is not so obvious. However, there is evidence that the stream has not effected complete recovery at the end of this reach; a point seven miles downstream from the mill. The evidence is:
1. Greater coloration than that at Station #1 - the control station
  2. Greater B.O.D. than that at Station #1
  3. Indicator organisms in the benthos.
- III The pollutants are not toxic to the microorganisms responsible for the B.O.D. In fact, the large populations of bacteria and Sphaerotilus natans located immediately downstream from the mill indicate that the pollutants are readily available as food to these fungi.
- IV The two dams below the mill, Coleman and Holcomb, decrease the seriousness of pollution in three ways:

1. By forming pondages in which the suspended material may settle out.
2. By the same pondages, retains the B.O.D. in reaches nearer the mill, and makes the problem of a more local nature.
3. By aerating the water flowing over and thereby replenishing the depleted oxygen supply.

V A considerable carpet is present in the pondage behind Coleman Dam. There is a good possibility that the carpet is exerting an oxygen demand on the water above it. However, additional studies on river velocities are necessary before this point can be clarified.

VI The greatest majority of the pollution is caused by the mill; very little of it being caused by the Big Island domestic sewage.

VII The reach investigated is sufficiently polluted to render it unfit for recreational purposes.

VIII Results obtained from this survey suggest the following for future investigations:

1. River velocities accompanied by D.O. and B.O.D. observations in order to determine the correct values for the re-aeration constants. This would allow a more accurate evaluation of the oxygen demand exerted by the bottom deposits.
2. Toxicity studies on fish. Studies of this nature would offer an insight on a matter vital to the estimation of the recreational potential of the reaches below the mill.
3. A comprehensive study of the abundant bacterial flora located at Station #2. The identification of the bacteria involved, along with a knowledge of the exact composition

of the material the flora uses for food, might suggest its use in a waste treatment process.

Although the author has confidence in his data, he recognizes the degree of validity of conclusions drawn from limited observation and should like to see his work supplemented by additional investigations.

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## BIBLIOGRAPHY

- (1) Moonaw, B. C., Jr. "Brief Outline of a Project for Improvement of the James River" (Data from The Survey Report on the James River of the U. S. Army Engineers.)
- (2) Wiley, R. B. and Howland, W. E. "Stream Pollution Abatement Standards Require Economic Justification" Civil Engineering, 179 (September 1947)
- (3) Murdock, Harold R. "Current Developments in Waste Utilization" Ind. Eng. Chem., 37, 105-6 (advertising section, October 1945)
- (4) Murdock, Harold R. "Current Developments in Waste Utilization" Ind. Eng. Chem., 38, 2, 83-4 (advertising section, February 1946)
- (5) Scott, G. R. "Stream Sanitation" Sewage Works Journal 18, 285 (1946)
- (6) Hoak, Richard D. "A Rational Examination of Stream Pollution Abatement" Science, 101, 523 (May 25, 1945)
- (7) Scott, Warren J. "Federal and State Legislation for Stream Pollution Control" Sewage Works Journal, 19, 5, 883 (September 1947)
- (8) Wisely, W. H. "National Stream Pollution Control Activities" Sewage Gas, 8, 3, 3-12 (September 1945)
- (9) Farran, Thomas, M.D. "The Public Health Service and Industrial Pollution" Ind. Eng. Chem., 39, 560-61 (May 1947)
- (10) Hedgepeth, L. L. "Industrial Use of Streams" Journal of the American Water Works Association, 39, 532-538 (June 1947)
- (11) Wolman, Abel "State Responsibility in Stream Pollution Abatement" Ind. Eng. Chem., 39, 561-65 (May 1947)
- (12) Hedgepeth, L. L. "The Virginia Industrial Wastes and Sewage Works Association" Water and Sewage Works (April 1947)
- (13) Hedgepeth, L. L. "Industrial Usage of Streams" Water and Sewage Works (June 1947)
- (14) Crawford, Stuart "May Report to the National Container Corporation" 1947
- (15) American Public Health Association Standard Methods for the Examination of Water and Sewage, Ninth Edition, Am. Pub. Health Assoc., New York, N. Y. (1946)
- (16) Metcalf, Leonard and Eddy, H. P. Sewerage and Sewage Disposal Second Edition, McGraw-Hill Book Company, New York, N. Y. (1930) Pages 636-678

- (17) Whipple, G. C. Microscopy of Drinking Water, Fourth Edition, John Wiley & Sons, New York, N. Y. (1947) Pages 90-101
- (18) Lackey, J. B. and Phelps, E. B. Stream Sanitation, John Wiley & Sons, New York, N. Y. (1944) Pages 235-250
- (19) Kolkwitz, R. and Marsson, M. 1908. "Ekologie der pflanzlichen Saprobien." Ber. d. Deut. Bot. Gesell. XXVla. Pages 505-519.
- (20) Kolkwitz, R. and Marsson, M. 1909. "Ekologie der tierischen Saprobien." Int. Rev. de. ges. Hydrobiologie u. Hydrographie II, Pages 126-152
- (21) Kolkwitz, R. 1911. "Biologie des Trinkwassers, Abwassers und der Vorfluter." Rubner, Gruber and Ficker's Handbuch der Hygiene. III, 2. Leipzig: S. Hirzel
- (22) Forbes, S. A. and Richardson, R. E. 1913. "Studies on the Biology of the Upper Illinois River." Ill. Nat. Hist. Survey IX, Art. X
- (23) Pascher, A. 1913 to 1914. "Die Süßwasserflora Deutschlands, Oesterreichs, u. d. Schweiz." Heft 1, u. 2. Flagellatae.
- (24) Johnson, J. W. Haigh. 1914. "A Contribution to the Biology of Sewage Disposal" Jour. of Economic Biology IX, Pages 117-121
- (25) Forbes, S. A., and Richardson, R. E. 1919. "Some Recent Changes in Illinois River Biology" Ill. Nat. Hist. Survey XIII, Art. VI
- (26) Richardson, Robert E. 1921. "Changes in the Bottom and Shor Fauna of the Middle Illinois River and its Connecting Lakes since 1913 to 1915 as a Result of the Increase, Southward, of Sewage Pollution" Ill. Nat. Hist. Survey XIV, Art. IV
- (27) Ohlmüller, W., and Spitta, O. 1921. "Die Untersuchung und Beurteilung des Wassers und Abwassers" Berlin: Julius Springer
- (28) Suter, R., and Moore E. 1922. "Stream Pollution Studies" New York State Conservation Commission
- (29) Purdy, W. C. 1922. "A Study of the Pollution and Natural Purification of the Ohio River" Part I. Plankton and Related Organisms. U. S. Pub. Health Bulletin No. 131
- (30) Crozier, W. J., and Harris, E. S. 1922. "Studies in the Biology of Sewage Disposal" 1st Ann. Rep. Sewage Substation N. J. Agr. Exp. Stations and N. J. S. D. of Health.
- (31) Hausman, L. A. 1923. "Studies in the Biology of Sewage Disposal" 2nd Ann. Rep. Sewage Substations N. J. Agr. Exp. Stations and N. J. S. D. of Health.

- (32) Haenseler, C. M., Moore, W. D., and Gaines, J. G. 1923. "Studies in the Biology of Sewage Disposal" 2nd Ann. Rep. Sewage Substation. N. J. Agr. Exp. Stations and N. J. S. D. of Health.
- (33) Hentschel, E. 1923 Abwasserbiologie, Handbuch der biologischen Arbeitsmethoden by Emil Abderhalden, Section IX, Part 2. First half, Book I, Page 240. Berlin-Vienna: Urban and Schwarzenberg
- (34) Lackey, J. B. 1924 "Studies in the Biology of Sewage Disposal" 3rd Ann. Rep. Sewage Substation. N. J. Agr. Exp. Stations and N. J. S. D. of Health.
- (35) Lackey, J. B. 1925 "Studies on the Biology of Sewage Disposal" N. J. Agr. Exp. Station. Bull. 147
- (36) Richardson, Robert E. 1925 "Changes in the Small Bottom Fauna of Peoria Lake," 1920-1922 Ill. Nat. Hist. Survey XV, Art. V
- (37) Schoenichen, W. 1925 Eyfert's Einfachste Lebensformen des Tier-und Pflanzenreiches Vol. I, Berlin: Hugo Bernhahler
- (38) Lackey, J. B. 1926 "Studies on the Biology of Sewage Disposal" 4th Ann. Rep. Sewage Substation. N. J. Agr. Exp. Stations and N. J. S. D. of Health.
- (39) Suter, R. and Moore, E. "Stream Pollution Studies" New York State Conservation Commission (1922)
- (40) Babbitt, H. E. Sewerage and Sewage Treatment, Fifth Edition, John Wiley & Sons, Pages 321-342