Western Michigan University
ScholarWorks at WMU

Master's Theses

Graduate College

12-1972

# The Recovery of Portage Creek in Vicksburg, Michigan

Michael Henry Herbert

Follow this and additional works at: https://scholarworks.wmich.edu/masters_theses

Part of the Ecology and Evolutionary Biology Commons

## Recommended Citation

Herbert, Michael Henry, "The Recovery of Portage Creek in Vicksburg, Michigan" (1972). *Master's Theses*. 2791.
https://scholarworks.wmich.edu/masters_theses/2791

This Masters Thesis-Open Access is brought to you for free and open access by the Graduate College at ScholarWorks at WMU. It has been accepted for inclusion in Master's Theses by an authorized administrator of ScholarWorks at WMU. For more information, please contact wmu-scholarworks@wmich.edu.

# THE RECOVERY OF PORTAGE CREEK IN VICKSBURG, MICHIGAN

by

Michael Henry Herbert

A Thesis
Submitted to the
Faculty of The Graduate College
in partial fulfillment
of the
Degree of Master of Arts

Western Michigan University
Kalamazoo, Michigan
December, 1972

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

ACKNOWLEDGEMENTS

The author wishes to express his appreciation and deepest gratitude to Dr. Clarence J. Goodnight for his guidance and encouragement during the course of this work. He also extends his appreciation to Dr. Robert E. Harmon and Dr. Richard W. Pippen for their helpful suggestions and assistance.

Finally, the author would like to thank the Simpson Lee Paper Company for their support of this research.

Michael Henry Herbert



Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

MASTERS THESIS M-4039

HERBERT, Michael Henry.
THE RECOVERY OF PORTAGE CREEK IN VICKSBURG, MICHIGAN.

Western Michigan University, M.A., 1972
Ecology

University Microfilms, A XEROX Company, Ann Arbor, Michigan

THIS DISSERTATION HAS BEEN MICROFILMED EXACTLY AS RECEIVED.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

PLEASE NOTE:

Some pages may have
indistinct print.
Filmed as received.

University Microfilms, A Xerox Education Company

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

TABLE OF CONTENTS





Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

## LISTS OF FIGURES, TABLES, AND GRAPHS

### List of Figures



### List of Tables





Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

LISTS OF GRAPHS





Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

## INTRODUCTION

Since the last decade, there has been an increased interest in all phases of environmental management. In general, society's interest in pollution has centered on its actions on living organisms, and thus, the assessment of pollution effects have become increasingly concerned with the biological parameters.

Despite the apparent relationship of organisms and environmental changes of their habitat caused by pollution, the water quality control programs have usually concentrated on chemical quality and minimized the collection of biological data. There are a number of reasons for this. First of all, biological assessments are not as amenable to numerical expressions as are chemical ones. The collection of extensive biological data is extremely time consuming as compared to the standard chemical water quality tests (Cairns and Dickson, 1971). Finally, there are no simple biological standards or agreements concerning the relationships between biological data and chemical quality.

It has been generally recognized that the destruction of aquatic organisms is one of the major consequences of water pollution. The overall effect of water pollution is to reduce the complexity of the aquatic community, and thus, instability of the ecosystem results. Due to their sensitivity, certain immature insects and other invertebrates have been used for estimating the extent of water pollution (Olsen and Ruegar, 1968). Although these benthic macrofauna have been used by various workers for the assessment of pollution, there has



Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

not yet been any precise agreements on the exact status of many of those organisms. Hynes (1966) has reported that species of the same genus have been found to react differently to the same pollutant.

Pulp and paper manufacturing is one of the major industries of the world. It is also one of the largest consumers of water for industrial purposes. The majority of previous investigations concerning effects on aquatic ecosystems have been involved with pulp mills or combination pulp and paper mills and their discharges.

During the past several years, there has been an increase in the studies on the environmental effects of paper mill discharges. Smith and Kramer (1964) investigated the toxicity of various wood pulp fibers on fish. The biochemical oxidation characteristics of cellulosic fibers in aqueous suspensions have been reported by Carpenter and Owens (1968). McKeown, Benedict, and Locke (1968) have studied the oxygen demand exerted by cellulosic benthal deposits.

The purpose of this investigation was to study the initial recovery of a stream after the removal of a paper mill's discharge. Both biological and chemical parameters were used in the study. The area of the stream under study had received only discharge from a paper mill.

A study such as this, gives at best, only a fragmentary picture of the recovery of an aquatic ecosystem. Studies on related topics will be needed before a clear understanding of the interaction between the biological and chemical factors of an aquatic ecosystem are clearly understood.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

## LITERATURE SURVEY

A major effect of discharge by paper mills is the formation of benthal deposits. In many instances, agents present in clarified discharges may react to produce a precipitate or act as a flocculent. Only when the stream velocity exceeds that velocity which allowed precipitation, does scour occur. The additional velocity is needed to overcome the force of compaction of the deposit (Gehm, 1953).

The most important phase of self-purification of benthal deposits is through bacterial action. The catobolic dissimilation of these deposits may either proceed by aerobic or anaerobic mechanisms. Under aerobic decomposition, the oxygen serves as the hydrogen acceptor, and there is complete breakdown.

Dehydration by anaerobic mechanisms may occur by three main pathways. Oxygen rich compounds such as nitrates, sulfates, and carbon dioxide may act as hydrogen acceptors. The order of these intermolecular respirations after depletion of oxygen is nitrate, sulfate, and finally carbon dioxide. The resulting products of these reactions are ammonia, hydrogen sulfide, and methane.

The second pathway is intramolecular respiration by which the hydrogen donor and acceptor are within the same molecule. The final pathway is by various types of bacterial fermentations which require no external hydrogen acceptors; an example is lactic acid fermentation.

Of the two types of mechanisms, the anaerobic mechanism is the prominent one. Because the gases of anaerobic decomposition tend to escape into the atmosphere, this mechanism may be stated to be



Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

beneficial on the oxygen economy of a stream (Heukelekian, 1953).

McKeown, Benedict, and Locke (1968) investigated the behavior of benthal deposits of paper mill origin. They reported little significant change in oxygen demand per unit area at depths greater than thirty centimeters. When an inert sediment such as sand was placed over or mixed with the cellulosic deposit, the oxygen demand was observed to decrease. Mixing or turbulance of the deposits were noted to increase the oxygen demand. The removal of the established surface layer of the deposits was observed to result in an equilibrium oxygen demand being established which was identical to the original. They concluded that the benthal oxygen demand was directly proportional to the surface area, and independent of the depth of the deposits after thirty centimeters; it was suggested that this depth dependency may be significantly less.

Lardieri (1954) studied acidic deposits collected from a stream below a paper mill. With adjustments of the deposits to a pH of 7.0, the oxygen demand nearly doubled. He further reported that samples collected one and a half meters below the surface of the deposits exhibited a rate of oxygen consumption equal to the surface deposits.

Hurwitz (1961) reported that decomposition of cellulosic benthal deposits by bacteria was influenced by retention time and temperature; the decomposition by bacteria was elevated by an increase of either factor. McDonnel and Hall (1969) concluded that oxygen consumption by benthal deposits varied with water temperature and oxygen concentration, and was essentially independent of depth of the deposits.

Cellulose fibers tend to pass through treatment plants relatively

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

unchanged. Carpenter and Owens (1968) investigated some of the oxidation characteristics of various pulp fibers. They reported a general decline in fiber oxidation rates with an increase in fiber content. They proposed that inhibitory quinone compounds were produced during periods of high oxidase activities. It was suggested that these quinone compounds were the result of reactions between hydrolytic compounds (oligo-beta-glucosidaes) and polymeric poly-phenolic compounds (orthodihydroxyphenolic substances) released upon bacterial actions on the wood pulp fibers. Fiber oxidation rates were found to be linear with time, suggesting zero-order reaction rates.

Benthal organisms have been studied for a number of years to assess the extent of water pollution and the quality of bottom sediments. Immature aquatic insects and other invertebrates have been used most often due to their characteristics such as sensitivity to changes in the environment, aquatic stages lasting from months to years, small size, and lack of mobility as compared to other fish. There does exist some disagreement over the status of many of these organisms (Hynes, 1966). Macan (1963) has stated that there are still too few fundamental factors known about the distribution of insects in a stream to justify any type of scheme of classification.

Olsen and Reugar (1968) investigated the relationship of oxygen requirements of certain immature aquatic insects to their index-organism classification. They observed that smaller members of the same species had higher oxygen consumption rates than did the larger members. Further, they reported that the respiration rates of

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

insects are not constant throughout their development; the younger insects were observed to respire more oxygen per unit body weight than did the older members of the same species. In general, the oxygen consumption rates of the immature insects studied were found to correspond with their index-organism classification.

Cairns and Dickson (1971) found that bottom fauna varied in their sensitivity to different types of pollution. Tolerant species increased in numbers due to lack of competition and predation until checked by space and food availability. Immature stages of mayflies, stoneflies, and caddisflies were observed to be quite sensitive to pollution. Tubificid worms and certain midge larvae were found to increase in large numbers under polluted conditions.

Smith, Kramer, and Cameron (1963) reported that groundwood pulps were more toxic than chemical pulps to fish; conifer groundwood pulps were stated to be the most toxic studied. At lower oxygen levels, the mortalities of walleye fingerlings and fathead minnows were increased by both chemical and groundwood pulps. A reported sublethal effect was increased levels of hematocrit counts in the blood. Analysis of other blood constituents such as blood serum suggested other changes, but the relationship to fiber content was not clear.

In continuation of their work, Smith and Kramer (1964) investigated the effects of various types of wood pulps on the survival and growth of rainbow trout, walleye fingerlings, and fathead minnows. No lethal effects were observed when trout eggs were exposed from the eye stage onward at various concentrations of conifer groundwood; lethal effects were observed at the same fiber concentrations in

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

trout alevins. Increasing the fiber concentration was reported to reduce the respiratory rate and uptake of oxygen of the fish studied.

Colby and Smith (1967) investigated the water quality of Rainy River, Minnesota, using eight stations which were located at various distances downstream from a paper mill outfall. They found low concentrations of dissolved oxygen and high concentrations of carbon dioxide. Concentrations of hydrogen sulfide which were found to be toxic to walleye eggs and fingerlings and to Gammarus pseudolimnaeus were reported to be associated with the substratum interface zone of the benthal deposits throughout the year, even at a distance of one hundred kilometers downstream from the mill outfall.

A six year biological and chemical study of a river system in Ontario was made by Beak (1964). This river system was composed of an upper lake, eighty-five kilometers of river, a lower lake, and two tributaries. Just downstream from the upper lake, a Kraft pulp mill and a town of five thousand discharged their wastes into the river. Based upon his work, he developed a biotic index system based upon the macroinvertebrate fauna present. This index ranged from zero, indicating severe pollution, to six, which represented unpolluted conditions characterized by normal numbers of predators, herbivores, and filter and detritus feeders.

The development of aquatic life in a new stream that was formed from a parent stream was investigated by Patrick in 1959. She reported that those organisms with a short life span were the first to establish natural populations. Bacteria were found to precede the algae, and the insect larvae were found to be the first group of

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

macroscopic fauna to become established.

Gaufin and Tazwell (1956) made a year round investigation of Lytle Creek near Cincinnati, Ohio. The only known source of pollution was the effluent from a primary sewage treatment plant of Wilmington, Ohio. Forty-five species of aquatic organisms were collected at the control stations upstream from the outfall. In the septic zone, the population consisted of forty percent Diptera, twenty percent Coleoptera, twenty percent Annelida, ten percent Hemiptera, and ten percent Mollusca. Further downstream, the population compositions were not as constant, but the least number of species collected was nine.

Van Horn (1961) reported that if waste cellulose fibers are discharged into a stream to such an extent as to blanket the bottom, the normal benthic fauna may be completely eliminated. With the advent of fiber recovery systems, the fiber loss from paper mills has been reduced greatly, and the resulting effluent should not have as deleterious effect upon the aquatic community.

Leclerc (1964) reported that the intensity of self-purification of a stream is dependent upon the temperature and season; in the winter the rate of recovery is greatly reduced. He also found that microbic and reducing reactions involved in recovery tend to lower the oxygen levels of a stream, but that turbulence and lower water temperatures would increase the solution of oxygen back into the stream. In streams that were undergoing self-purification, he found that the heterotropic bacteria would eventually be replaced by autotropic flora due to lack of nutritive elements. Finally, he reported

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

that each successive reach of a stream may have different self-purifying powers.

The decomposition of cellulose by fungi and bacteria was investigated by Ostertag (1952). He found that many types of fungi were able to attack cellulose, but as a rule, they first attacked the more easily decomposed chemical compounds. They were found not to be dependent on cellulose as a substrate. Cellulose-decomposing bacteria were found to be highly dependent upon cellulose as the exclusive source of energy. Thus, fungi were concluded to play an important function in self-purification of a stream.

The decomposition of cellulose in water was investigated by Klust and Mann (1954) by the loss of strength in cotton thread. They reported active decomposition at a water temperature of 1°C. The rate of decomposition was enhanced with an increase in temperature to a maximum of 36° - 40°C. The most rapid rise occurred after 20°C was reached, and the decomposition was reported to cease after 44°C. They found that the most favorable pH values were between 5.4 and 7.4. While they found that phosphates were necessary for the decomposition of cellulose, there were no relationships observed between the phosphate concentrations and decomposition rates. Ammonia, nitrates, iron, and phenols were reported not to exert any influence on the decomposition rates.

Cooke, Moore, and Kabler (1956) reported that various fungi found in paper mill white water, sewage, and polluted water have oxygen depleting capacities equal to or above bacteria. They concluded that these various types of fungi are as important in natural purification of a stream as are the bacteria, protozoans, and algae.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Several bacterial strains from lakes and polluted rivers were isolated by Berg, Hosfsten, and Goransson (1968) by using filter paper as the carbon source. All the strains were able to utilize ammonium nitrogen, except one, and all were found to be able to utilize nitrate, nitrite, urea, asparagine, histidine, and peptone as nitrogen sources. All of the strains grew well on glucose, galactose, and starch, but several appeared to have lost enzymes necessary for the utilization of several of the other sugars.

The effects of trade waters on the botton fauna of some streams in Louisiana were investigated by Biglane and LaFleur (1954). Waste waters from a Kraft pulp and paper mill were reported to be toxic to mayfly naiads and unionid clams; these organisms were found to be absent for a distance of seventy kilometers downstream from the area of discharge.

Ganczarczyk (1959) found that the decomposition rates of sulfite mill effluents occurred at different rates. He reported that the decomposition of carbohydrates occurred at a higher rate than did the lignosulfonic acids. The decomposition of the lignosulfonic acids was stated to proceed in two stages.

The relationship between the activity of cellulose-decomposing bacteria to the degree of pollution was investigated by Halme (1961). Cotton yarn was suspended in various stations around Helsinki, Finland. He found that the average cellulosic decomposing activity was directly related to the degree of pollution, being greatest in mesosaprobic waters and the least in oligosaprobic waters. He concluded that the presence of nutrients in the polluted stations stimulated the growth of the cellulose-decomposing organisms.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

## MATERIALS AND METHODS

### Water Analysis

Water samples for chemical and microbiological analysis were obtained twice each month from the midstream of each station at 8:00 A.M.

A Fisher Accumet 220 pH meter was used to measure the pH of each station. The turbidity was measured with a Hach Colorimeter.

The temperature of each station at the time of sampling was measured with an A.S.T.M. 36°C thermometer. A Gooch crucible with an asbestos mat was used for the determination of suspended matter and the resulting filtrate was used for nitrate, total dissolved matter, and total soluble phosphate determinations. The total soluble phosphates were determined by the aminonaphtholsulfonic acid method. Nitrates were determined by the brucine-sulfanilic acid method. The total dissolved matter was determined by the use of tared porcelain evaporating dishes, and the samples were dried at 105°C for eight hours. The azide modification of the idometric method was used for the oxygen determinations of both the five day biochemical oxygen demand analysis and the dissolved oxygen analysis. The chemical oxygen demand was determined by the dichromate reflux method. The bromcresol green-methyl red indicator method was used to determine total alkalinity (APHA, 1965).

With the exceptions of temperature, suspended matter, pH, and turbidity, all of the above determinations were run in duplicate.



Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

The average and standard deviation of each determination were computed.

Total count, total coliform, and total yeast and mold levels of each station were determined by the methods and materials supplied by the Millipore Corporation (1967). White, 47mm, type HA filters were used for the total count and total coliform levels of each station; black, 47mm, type HA filters were used for yeast and mold determinations.

Sterile 2ml nutrient media ampoules were used in all cases. Type M-TGE broth was used for the total count, type MF-Endo broth was used for the total coliform, and type Y and M broth was used for the total yeast and mold determinations.

The total count and total coliform plates were incubated at 37°C for twenty-four hours. The yeast and mold plates were incubated at room temperature for forty-eight hours. Counts were made under a stereoscope at 18x.

The total count and total coliform determinations were run in duplicate. The average and standard deviation were computed. Due to low numbers of yeast and mold colonies found, and the relatively large volumes passed through the filters, 250ml, only one plate was made for yeast and mold determinations of each station. All results were recorded as colonies per 100ml.

## Benthal Macrofauna

The benthal macrofauna of each station were sampled on a monthly basis at 8:00 A.M. An Ekman dredge (15x15 cm) was used to obtain

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

the samples. Three samples were collected from each station; one near the center of the creek and two at points to the left and right of the center. The samples were then concentrated by a combined washing-screening process through a No. 20 and a No. 10 sieve screen. The resulting composite of each station was placed in a shallow white dish, and the organisms were identified and counted. The organisms were reported as numbers per square meter (APHA, 1965).

## Net Plankton

Net plankton (macroplankton) samples were obtained on a monthly basis at 8:00 A.M. Fifty liters of water from each station was poured through a Wisconsin plankton net. Several drops of formalin solution were added to the resulting concentrated samples.

The enumeration and identification of the macroplankton were made by the use of a Sedwick-Rafter counting cell. The organisms were reported as numbers per hundred liters (APHA, 1965).

## Physical Parameters

The flow of water over Sunset Lake weir was recorded by a Leopold-Stevens flow meter. The total flow for the day of water collection was recorded as million liters per day.

A rod was placed in the midstream of each station. The depth of each station was recorded in meters on the day of water collection.

The velocity of the creek at each station was estimated by the use of a small cork on the day of water collection. The rate of displacement of the cork was measured over a defined distance near

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

the rod. The estimated velocity was recorded as meters per second.

## Statistical Analysis

Certain of the more important water quality parameters and benthic taxa of each station were compared by the t-test for a series of different time periods.

In the first series, station two and three were compared to station one, using station one as the control. Two time periods were used. The first time period was when the paper mill discharge was present in the creek; the other time period was after the removal of the discharge from the creek.

The second series involved the comparison of each station to itself for the time periods before and after the removal of the paper mill discharge. In certain cases such as the dissolved oxygen levels, which varied due to seasonal changes, this approach could not be used.

In all cases, the five percent level of significance was used to confirm the reliability of differences between the stations.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

## DESCRIPTION OF STUDY AREA

### Geological and Historical

Portage Creek flows west and south from Sunset Lake in Vicksburg, Michigan, to Barton Lake for a distance of three kilometers. The rate of flow of Portage Creek is controlled by a weir at the southern end of Sunset Lake.

Sunset Lake is an open lake, receiving water by way of Gourdneck Creek from the Austin Lake complex. This complex is composed of Austin, Gourdneck, Long, Sugarloaf, and West Lakes, all which are included in the St. Joseph River Basin. Gourdneck Creek meanders through several kilometers of marshes and farmlands before entering the northern end of Sunset Lake (Allen, Miller, and Wood, 1972).

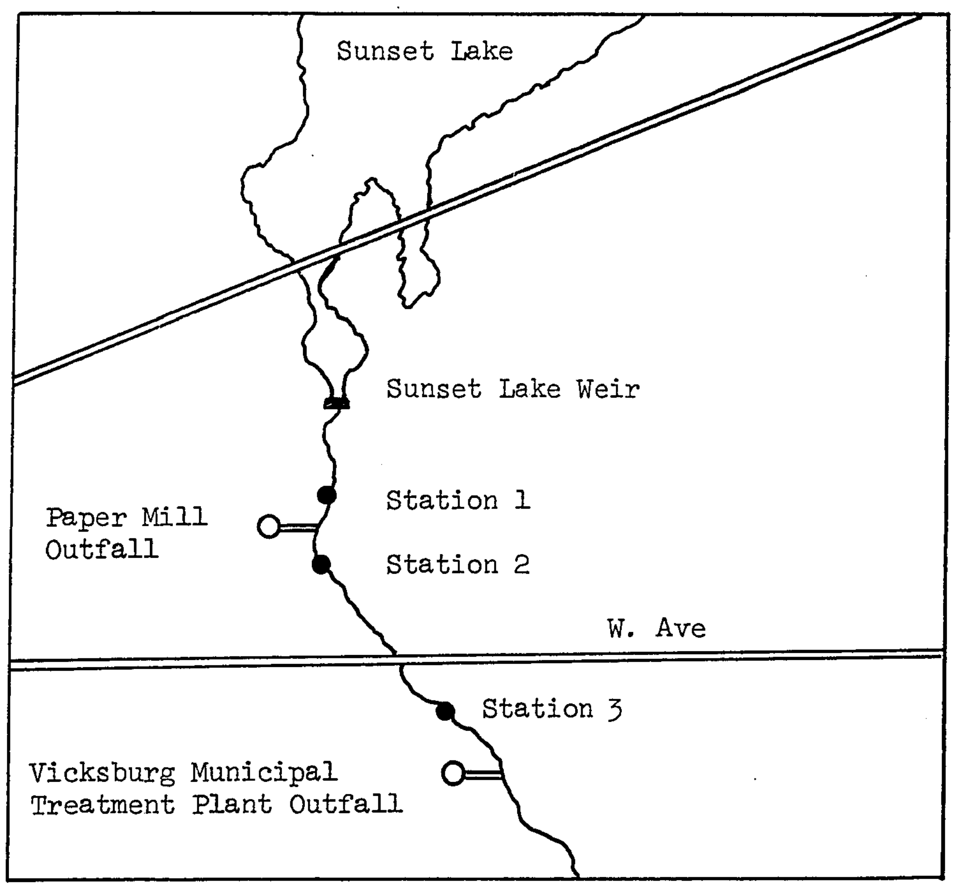
Portage Creek has been used for the disposal of paper mill effluent since 1905. In 1956, the paper mill installed a primary clarification unit to treat the effluent before discharge into the creek. The discharge was removed from the creek for several weeks during November, 1971. The mill discharge was not in the creek during the test period of 11/15/71. All discharge was permanently removed from the creek on 12/17/71.

Three stations were set up on Portage Creek. Station 1 was located upstream from the paper mill outfall and Station 2 and Station 3 were located at various distances downstream from the outfall. Figure one shows the locations of the three stations in relation to Sunset Lake and the outfall of the paper mill.



Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Figure 1. Map showing the location of the test stations on Portage Creek in relation to Sunset Lake and the paper mill outfall in Vicksburg, Michigan.




SE/4 Schoolcraft 15' Quadrangle

N4200 - W8530/7.5

AMS 3868 11 SE

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

## Station 1

Station 1 was located approximately fifty meters upstream from the clarifier outfall. This station was typical of the non-polluted zone of the creek. Its width was nearly four meters. Depending upon the rate of flow of Sunset Lake weir, its midstream depth and velocity ranged from 0.65 to 0.25 meters and from 0.63 to 0.21 meters per second respectively. The stream bed of this station was composed of light deposits of sand, gravel, and organic detritus.

The emergent vegetation consisted of heavy growths of arrow arum (*Peltandra virginica*) and slight growths of cattail (*Typha latifolia*), bullrush (*Scirpus acutus*) and swamp loosestrife (*Decodon virticillatus*). The submersed vegetation formed a dense mat, and was composed of two species of pondweed (*Potamogeton crispus* and *P. filiformis*), hornwort (*Ceratophyllum demersum*), and waterweed (*Elodea canadensis*). In late June of 1972, sparse growths of *Cladophora* sp. and great duckweed (*Spirodela polyrhiza*) could be observed on various sections of the shore.

This station served as the standard to compare the recovery of the other two stations. Further, its water quality parameters were used to study what effects the decomposition of the cellulosic benthal deposits had upon the other two stations' water quality.

## Station 2

Station 2 was located fifty meters downstream from the paper mill outfall. Its width was approximately ten meters. Depending

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

upon the rate of flow of Sunset Lake weir, the midstream depth and velocity ranged from 0.66 to 0.23 meters and 0.70 to 0.48 meters per second respectively.

This station represented an area of high cellulosic benthal deposits. At the initiation of this study, the mid-channel bed contained approximately thirty centimeters of loose silt, and the shores contained roughly ninety centimeters. At the conclusion of this study, gravel and sand were apparent at certain sections of the mid-channel, but the shores appeared to have lost less than thirty centimeters of material.

At the initiation of this study, the submersed vegetation consisted of a sparse growth of *Potamogeton filiformis*, and sewage fungus (*Sphaerotilus* sp.) was present in heavy growths. Hynes (1966) reported that *Sphaerotilus* sp. was common in areas of pollution due to the lack of competition by other organisms. At the conclusion of this study, there was a moderate growth of submersed vegetation, composed of the same species found at Station 1. *Cladophora* sp. was present to some extent about the shore, as was a slight growth of arrow arums and great duckweed. The growth of sewage fungus had diminished to a large extent.

## Station 3

Station 3 was located approximately six hundred meters downstream from the paper mill outfall. This station was some thirty meters upstream from the outfall of the Vicksburg Municipal Waste Treatment Plant so there could be no association of the waters of

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Station 3 and the treatment plant's discharge. Its width was nearly six meters, and depending upon the rate of flow of water over the weir, its midstream depth and velocity would range from 0.72 to 0.30 meters and 0.59 to 0.21 meters per second respectively.

The cellulosic benthal deposits were present at a lower level at this station than at station two. At the initiation of this study, the mid-channel bed contained nearly fifteen centimeters of silt and the shores contained roughly sixty centimeters. At the conclusion of this study, gravel was apparent at the mid-channel, and the shores had lost approximately twenty centimeters of material.

*Potamogeton filiformis* was the only submersed plant at the initiation of this study. Although it was slightly higher in density than at Station 2, its growth was also sparse. *Sphaerotilus* sp. was also present in heavy growths. At the conclusion of this study, all of the emergent and submersed vegetation found at Station 1 was present in moderate density at this station.

## Net Plankton

The net plankton of each station was composed of small populations of *Daphnia* sp., *Eucyclops* sp., *Volvox* sp., *Synedra* sp., and *Cladophora* sp. During the period that the paper mill discharge was in the creek, the population densities tended to be slightly lower in Station 2 and Station 3 as compared to Station 1. Generally, the population densities of *Synedra* sp., *Volvox* sp., and *Cladophora* sp. ranged from zero to ten per hundred liters and that of *Daphnia* sp. and *Eucyclops* sp. from ten to one hundred per hundred liters.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

There is general agreement that there are no true plankton communities in streams. The plankton communities that are found in streams are usually derived from the headwater lakes, and tend to be lost rather rapidly in the stream (Reid, 1961).

## Incidental Organisms

After April of 1972, schools of ten to twenty bluegills and sunfishes (Lepomis sp.) and yellow perch (Perca flavescens) could be periodically observed at all three stations. Largemouth bass (Micropterus salomoidea), redfin pickeral (Esox americanus), European carp (Cyprinus carpio), and bullheads (Ictalurus sp.) were also seen at the different stations after April of 1972.

After June of 1972, leopard frogs (Rana pipiens) were present at all three stations. Small groups of ten to twenty water scavenger beetles (Hydrophilus sp.), backswimmers (Notonecta sp.), and water striders (Gerris sp.) were also observed periodically at each station.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

# RESULTS

## Water Analysis

### Five day biochemical oxygen demand

The addition of the paper mill discharge into the creek resulted in a ten to fifteen fold increase in the creek's BOD load. After the removal of the discharge from the creek, there were no significant differences established between the control station and the two test stations (Table 1 and Graph 1). The above change was tested at the five percent level of significance.

In the recovery of the creek bed, the decomposition of the benthal deposits did not appear to result in any measurable increase in the BOD load of the creek over the area of study.

### Chemical oxygen demand

The results of these analysis paralleled that observed for the BOD test (Table 2). A three to four fold increase in the COD load of the creek was caused by the addition of the paper mill discharge into the creek. After the removal of the effluent from the creek, a small increase in COD load was found at test station three as compared to the control station; this was tested at the five percent level of significance.

Thus, the recovery of the creek bed resulted in only a slight increase in the COD of the creek over the area studied.



Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Dissolved oxygen

The discharge of the effluent into the creek resulted in a decrease of dissolved oxygen by approximately two mg/l (Table 3 and Graph 2). This decline was due in part to the increase in temperature and the dilution of the dissolved oxygen of the creek by the discharge. During the winter months after the removal of the discharge, the dissolved oxygen level of the three stations were essentially equivalent.

In May, the divergence between the control and the test stations again became more apparent; this was tested at the five percent level of significance. The recovery of the creek resulted in a small decrease of dissolved oxygen during the summer months.

Temperature

The paper mill discharge caused an increase in water temperature by several degrees centigrade (Table 4 and Graph 3). After the removal of the paper mill discharge, the water temperature was essentially constant throughout the length of the creek under study during each testing period.

Nitrate nitrogen

There were no significant variations of the nitrate levels between the three stations before or after the removal of the paper mill discharge (Table 5). This was tested at the five percent level of significance.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

During the winter months, the level of nitrates was less than 0.0 mg/l. After May, the concentration of nitrates began to increase periodically. This increase was most probably due to a combination of surface runoff caused by the spring rains, the spring turnover of the Austin Lake Complex, and increased biological activity such as bacterial nitrification.

Total soluble phosphates

There were no significant differences found between the three stations for phosphate levels either when the paper mill discharge was present, or after it was removed (Table 6 and Graph 4). This was tested at the five percent level of significance.

The increase in phosphate concentrations after May corresponded with the rise in nitrate levels of the three stations. In all likelihood, this increase was the result of similar factors which were suggested for the rise in nitrate levels.

Total suspended solids

A significant difference was observed between the control station and the two test stations when the paper mill discharge was present (Table 7). This corresponded with the higher BOD and COD levels found in the test stations during the same period.

After the removal of the discharge, no significant differences were found between the control station and test station two. Test station three did show some slight increase in suspended solids as compared to the control station; a slight increase in COD load

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

was also found at station three as compared to the control station. The above results were tested at the five percent level of significance.

Turbidity

The paper mill discharge increased the turbidity of the two test stations (Table 8). After the removal of the discharge, no difference was found between the control station and test station two, but there was a slight increase in turbidity of station three as compared to the control station; this was tested at the five percent level of significance. This increase in measurable turbidity of station three corresponded with the increase levels of COD and suspended solids found at station three as contrasted with the control station.

Dissolved matter

The dissolved matter was raised by some seventy mg/l at the two test stations by the paper mill discharge (Table 9). After the removal of the discharge, the three stations were essentially equivalent in this phase.

pH

The pH of the two test stations was lowered by several tenths from the action of the discharge (Table 10). As the discharge of the paper mill is nearly neutral, and that of the creek tends to be slightly alkaline, the lowering of the pH would be expected.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

The pH of the three stations remained essentially identical after the removal of the discharge from the paper mill.

Total alkalinity

As with the pH, the discharge of the paper mill lowered the total alkalinity of the test stations by fifteen to twenty mg/l calcium carbonate as compared to the control station (Table 11 and Graph 5).

After the removal of the discharge, the total alkalinity of all three stations remained essentially equivalent.

Total coliforms

The paper mill discharge caused an overall increase in the number of total coliforms at the two test stations (Table 12). This increase varied from twenty to one hundred fold.

There still remained a small increase in the level of total coliform colonies at the test stations as contrasted to the control station after the removal of the discharge. This was tested at the five percent level of significance.

Total count of bacteria and fungi

During the first four test periods of this study, the total count of the two test stations were found to be greater than six million colonies per one hundred milliliters, and as a result, they were recorded as too numerous to count (TNTC). There was a large increase of the total count of the two test stations caused by

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

the paper mill discharge (Table 13 and Graph 6).

After the removal of the discharge, the levels of the three stations were nearly equal through May. As the temperature of the water increased, the total count levels of the two test stations began to show a greater divergence from the control. This was tested at the five percent level of significance.

Total yeast and mold

There was only a slight noticable increase in the yeast and mold count of the two test stations as compared to the control after the removal of the discharge from the creek (Table 14). The levels of yeast and mold were quite low throughout the duration of this study. This low level of yeast and mold in the water was most probably due to the slightly alkaline pH, as yeast and mold usually flourish in an acidic environment.

Total flow of Sunset Lake Weir

There was some fluctuation of the flow during the course of this study (Table 15 and Graph 7). This variation largely reflected the water availability of the Austin Lake Complex and the amount of precipitation for the period. The lowest flow occurred during the summer months, and the highest flow occurred during the spring; this corresponded directly with the levels of precipitation during those periods of time.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

## Benthal Macrofauna

### General description of the taxa

Seventeen various taxa, representing three different phyla, were identified from the three stations (Table 16). At the initiation of this study, the taxa of the test stations were represented only by large numbers of chironomid larvae and Limnodrilus sp. in contrast to a taxa number of ten to twelve for the control station (Tables 17 - 28 and Graph 9). By February, there was an apparent migration of Eropobdella sp. from the control station downstream to the test areas.

The most significant increase in taxa numbers of the test stations occurred after May. With the exception of the two members of the Pelecypoda class, Anodonta sp. and Sphaerium sp., and members of the dragonfly family Libellulidae, all of the taxa identified at the control station were represented at one or both of the test stations at the conclusion of this study.

### Benthic population densities

During the period in which the paper mill was discharging into the creek, the control station had a two to five fold larger population density than did the test stations (Graph 8). The population densities of all three stations declined throughout the winter months.

In May, there was a general increase in the population densities

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

of all three test stations through July and then the population densities of each station began to decline again. At the conclusion of this study, the test stations still had less than one half of the population densities as compared to the control station.

Comparison of Viviparus sp. populations of the three stations

Viviparus sp. represented one of the largest populations of benthic organisms of the control station throughout the study. These organisms were totally absent from the two test stations at the initiation of this study.

By August, these organisms had successfully migrated downstream from the control area to the two test stations, but they still represented only a small percentage of the total population of these two stations. By contrast, the population of Viviparus sp. still remained one of the largest at the control station.

This difference in the populations of Viviparus sp. between the control and the test stations was tested at the five percent level of significance.

Comparison of Limnodrilus sp. populations of the three stations

No significant differences between the population densities of the three stations were found before the removal of the paper mill discharge. There was a significantly larger population found at test station three as compared to the control station after the removal of the discharge, and a significant decline was found in the population at station three after the discharge removal. This

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

was tested at the five percent level of significance.

At the initiation of this study, Limnodrilus sp. represented the second highest population at the two test stations until the benthal migration began in May.

Comparison of Hyalella sp. populations of the three stations

Hyalella sp. was absent from the two test stations at the start of this study, but they were one of the major populations at the control station.

By June, Hyalella sp. had migrated downstream to the test stations to become the greatest benthal population of these stations. Their population densities still remained significantly lower than that of the control station. This was tested at the five percent level of significance.

Comparison of chironomid larvae populations of the three stations

The chironomid larvae of the two test stations were the highest populations at the initiation of this study. In contrast, the chironomid larvae of the control station composed less than one percent of its total population.

After the removal of the paper mill discharge, the chironomid larvae declined in population at test station two, which was tested at the five percent level of significance.

The larvae were found to be absent from the stations during June due to the emergence of the adult midges. They were again found to be present in July at the three stations.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table 1. Five Day Biochemical Oxygen Demand expressed as average mg/l with standard deviation.

| Date | Station 1 | Station 2 | Station 3 |
|---|---|---|---|
| 10/8/71 | 1.0 ± 0.2 | 13.8 ± 0.3 | 11.6 ± 1.3 |
| 10/22/71 | 0.6 ± 0.3 | 15.0 ± 2.0 | 14.0 ± 1.0 |
| 11/2/71 | -- | -- | -- |
| 11/15/71 | 1.2 ± 1.1 | 1.3 ± 0.3 | 1.3 ± 0.1 |
| 12/1/71 | 0.8 ± 0.2 | 13.5 ± 1.2 | 12.9 ± 0.9 |
| 12/13/71 | 1.1 ± 0.3 | 11.7 ± 0.5 | 12.1 ± 0.6 |
| 1/3/72 | 0.9 ± 0.0 | 0.9 ± 0.0 | 0.9 ± 0.0 |
| 1/17/72 | 1.1 ± 0.4 | 1.1 ± 0.2 | 1.0 ± 0.4 |
| 2/7/72 | 1.3 ± 0.5 | 1.3 ± 0.5 | 1.2 ± 0.5 |
| 2/21/72 | 1.5 ± 0.4 | 1.4 ± 0.3 | 1.6 ± 0.5 |
| 3/7/72 | 1.5 ± 0.6 | 1.8 ± 0.2 | 1.5 ± 0.2 |
| 3/17/72 | 1.6 ± 0.4 | 1.7 ± 0.3 | 1.9 ± 0.3 |
| 4/3/72 | 1.4 ± 0.3 | 1.5 ± 0.3 | 1.0 ± 0.0 |
| 4/14/72 | 2.5 ± 0.4 | 2.0 ± 0.8 | 1.8 ± 0.1 |
| 5/2/72 | 2.3 ± 0.0 | 2.5 ± 0.0 | 2.6 ± 0.0 |
| 5/16/72 | 2.1 ± 0.0 | 2.2 ± 0.0 | 2.1 ± 0.0 |
| 6/5/72 | 0.9 ± 0.0 | 0.9 ± 0.0 | 1.2 ± 0.0 |
| 6/15/7 | 1.1 ± 0.0 | 1.0 ± 0.0 | 0.9 ± 0.0 |
| 7/10/72 | 0.8 ± 0.0 | 0.8 ± 0.0 | 0.8 ± 0.0 |
| 7/17/72 | 1.1 ± 0.0 | 1.0 ± 0.0 | 1.5 ± 0.0 |
| 8/1/72 | 0.9 ± 0.0 | 1.0 ± 0.0 | 1.0 ± 0.0 |
| 8/15/72 | 1.0 ± 0.0 | 1.3 ± 0.0 | 1.0 ± 0.0 |
| 9/5/72 | 1.4 ± 0.0 | 1.2 ± 0.0 | 1.1 ± 0.0 |
| 9/16/72 | 1.2 ± 0.0 | 1.3 ± 0.0 | 1.2 ± 0.0 |

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table 2. Chemical Oxygen Demand expressed as average mg/l with standard deviation.

| Date | Station 1 | Station 2 | Station 3 |
|---|---|---|---|
| 10/8/71 | 13.0 ± 1.8 | 43.6 ± 2.2 | 46.8 ± 3.4 |
| 10/22/71 | 9.9 ± 0.5 | 34.9 ± 0.6 | 28.3 ± 0.2 |
| 11/2/71 | 8.8 ± 0.4 | 27.2 ± 0.7 | 29.1 ± 0.2 |
| 11/15/71 | 7.7 ± 0.8 | 10.3 ± 0.2 | 11.5 ± 0.2 |
| 12/1/71 | 8.3 ± 0.5 | 38.3 ± 0.1 | 33.5 ± 0.2 |
| 12/13/71 | 9.3 ± 0.3 | 38.3 ± 0.1 | 45.7 ± 0.4 |
| 1/3/72 | 4.5 ± 0.2 | 4.9 ± 0.0 | 5.0 ± 0.2 |
| 1/17/72 | 4.3 ± 0.4 | 4.5 ± 0.2 | 4.6 ± 0.0 |
| 2/7/72 | 1.8 ± 0.3 | 3.4 ± 0.2 | 2.3 ± 0.1 |
| 2/21/72 | 2.2 ± 0.4 | 2.3 ± 0.2 | 2.5 ± 0.2 |
| 3/7/72 | 6.0 ± 0.1 | 6.1 ± 0.1 | 6.1 ± 0.2 |
| 3/17/72 | 6.9 ± 0.2 | 7.1 ± 0.2 | 7.2 ± 0.1 |
| 4/3/72 | 8.1 ± 0.1 | 8.2 ± 0.1 | 8.4 ± 0.2 |
| 4/14/72 | 6.9 ± 1.0 | 6.9 ± 1.0 | 8.7 ± 1.0 |
| 5/2/72 | 6.8 ± 0.2 | 7.0 ± 0.1 | 7.2 ± 0.1 |
| 5/16/72 | 6.1 ± 0.1 | 6.9 ± 0.1 | 7.4 ± 0.1 |
| 6/5/72 | 5.6 ± 0.1 | 5.1 ± 0.1 | 6.1 ± 0.1 |
| 6/15/72 | 8.0 ± 0.1 | 7.7 ± 0.1 | 8.2 ± 0.1 |
| 7/10/72 | 10.0 ± 0.1 | 9.5 ± 0.1 | 10.0 ± 0.1 |
| 7/17/72 | 7.6 ± 0.2 | 7.4 ± 0.1 | 8.0 ± 0.2 |
| 8/1/72 | 7.8 ± 0.3 | 8.3 ± 0.3 | 8.9 ± 0.2 |
| 8/15/72 | 5.7 ± 0.5 | 5.7 ± 0.4 | 5.5 ± 0.7 |
| 9/5/72 | 6.6 ± 0.5 | 6.6 ± 0.4 | 6.5 ± 0.7 |
| 9/16/72 | 7.3 ± 0.5 | 7.5 ± 0.9 | 7.7 ± 0.6 |

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table 3. Dissolved Oxygen expressed as average mg/l with standard deviation.

| Date | Station 1 | Station 2 | Station 3 |
|---|---|---|---|
| 10/8/71 | 8.5 ± 0.0 | 7.2 ± 0.0 | 5.8 ± 0.0 |
| 10/22/71 | 9.3 ± 0.0 | 7.8 ± 0.0 | 6.8 ± 0.0 |
| 11/2/71 | 9.1 ± 0.1 | 7.9 ± 0.0 | 7.0 ± 0.0 |
| 11/15/71 | 12.2 ± 0.0 | 12.2 ± 0.0 | 11.6 ± 0.0 |
| 12/1/71 | 12.1 ± 0.0 | 11.6 ± 0.0 | 11.4 ± 0.1 |
| 12/13/71 | 12.1 ± 0.1 | 11.8 ± 0.0 | 11.6 ± 0.0 |
| 1/3/72 | 12.9 ± 0.0 | 12.9 ± 0.0 | 12.8 ± 0.0 |
| 1/17/72 | 13.9 ± 0.0 | 13.8 ± 0.0 | 13.8 ± 0.0 |
| 2/7/72 | 11.4 ± 0.1 | 11.3 ± 0.1 | 11.4 ± 0.0 |
| 2/21/72 | 11.6 ± 0.1 | 11.5 ± 0.1 | 11.6 ± 0.1 |
| 3/7/72 | 12.6 ± 0.1 | 12.7 ± 0.1 | 12.9 ± 0.1 |
| 3/17/72 | 12.2 ± 0.1 | 12.2 ± 0.1 | 12.1 ± 0.0 |
| 4/3/72 | 12.0 ± 0.0 | 11.9 ± 0.1 | 11.7 ± 0.1 |
| 4/14/72 | 10.3 ± 0.1 | 10.2 ± 0.0 | 10.0 ± 0.1 |
| 5/2/72 | 9.9 ± 0.1 | 9.6 ± 0.1 | 9.2 ± 0.0 |
| 5/16/72 | 8.9 ± 0.1 | 8.8 ± 0.0 | 8.5 ± 0.1 |
| 6/5/72 | 8.1 ± 0.0 | 7.5 ± 0.1 | 7.0 ± 0.1 |
| 6/15/72 | 8.6 ± 0.0 | 7.8 ± 0.0 | 7.2 ± 0.0 |
| 7/10/72 | 8.2 ± 0.0 | 7.1 ± 0.0 | 6.5 ± 0.0 |
| 7/17/72 | 7.4 ± 0.1 | 6.7 ± 0.1 | 6.2 ± 0.1 |
| 8/1/72 | 8.3 ± 0.1 | 7.5 ± 0.1 | 7.3 ± 0.1 |
| 8/15/72 | 8.5 ± 0.1 | 7.8 ± 0.1 | 7.2 ± 0.1 |
| 9/5/72 | 8.1 ± 0.1 | 7.5 ± 0.1 | 7.4 ± 0.1 |
| 9/16/72 | 8.4 ± 0.1 | 8.3 ± 0.1 | 7.9 ± 0.1 |

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table 4. Temperature (°C) of Water at the time of collection.

| Date | Station 1 | Station 2 | Station 3 |
|---|---|---|---|
| 10/8/71 | 16.8 | 18.2 | 18.1 |
| 10/22/71 | 15.8 | 17.8 | 17.4 |
| 11/2/71 | 15.0 | 16.4 | 15.7 |
| 11/15/71 | 5.1 | 5.1 | 5.2 |
| 12/1/71 | 3.4 | 5.2 | 5.2 |
| 12/13/71 | 2.3 | 5.2 | 5.1 |
| 1/3/72 | 1.2 | 1.4 | 1.8 |
| 1/17/72 | 0.6 | 0.6 | 0.6 |
| 2/7/72 | 0.2 | 0.2 | 0.3 |
| 2/21/72 | 2.4 | 2.4 | 2.5 |
| 3/7/72 | 2.8 | 2.8 | 2.9 |
| 3/17/72 | 3.3 | 3.3 | 3.4 |
| 4/3/72 | 5.8 | 5.8 | 5.8 |
| 4/14/72 | 11.4 | 11.4 | 11.4 |
| 5/2/72 | 14.4 | 14.4 | 14.4 |
| 5/16/72 | 17.1 | 17.2 | 17.4 |
| 6/5/72 | 22.4 | 22.4 | 22.6 |
| 6/15/72 | 20.8 | 20.4 | 19.4 |
| 7/10/72 | 22.8 | 22.8 | 22.3 |
| 7/17/72 | 25.2 | 25.0 | 24.8 |
| 8/1/72 | 24.2 | 24.2 | 24.6 |
| 8/15/72 | 20.8 | 21.4 | 21.8 |
| 9/5/72 | 19.0 | 19.0 | 19.2 |
| 9/16/72 | 17.2 | 17.2 | 17.2 |

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table 5. Nitrate Nitrogen expressed as average mg/l with standard deviation.

| Date | Station 1 | Station 2 | Station 3 |
|---|---|---|---|
| 10/8/71 | 0.8 ± 0.0 | 1.0 ± 0.1 | 1.0 ± 0.1 |
| 10/22/71 | 0.8 ± 0.0 | 1.0 ± 0.0 | 1.0 ± 0.1 |
| 11/2/71 | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 |
| 11/15/71 | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 |
| 12/1/71 | 0.0 ± 0.0 | 0.5 ± 0.1 | 0.5 ± 0.0 |
| 12/13/71 | 0.0 ± 0.0 | 0.7 ± 0.0 | 0.6 ± 0.0 |
| 1/3/71 | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 |
| 1/17/72 | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 |
| 2/7/72 | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 |
| 2/21/72 | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 |
| 3/7/72 | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 |
| 3/17/72 | 0.3 ± 0.0 | 0.3 ± 0.0 | 0.3 ± 0.1 |
| 4/3/72 | 0.5 ± 0.1 | 0.5 ± 0.1 | 0.5 ± 0.0 |
| 4/14/72 | 0.6 ± 0.1 | 0.6 ± 0.0 | 0.6 ± 0.0 |
| 5/2/72 | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 |
| 5/16/72 | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 |
| 6/5/72 | 0.6 ± 0.1 | 0.6 ± 0.0 | 0.6 ± 0.1 |
| 6/15/72 | 0.5 ± 0.1 | 0.5 ± 0.0 | 0.6 ± 0.1 |
| 7/10/72 | 0.5 ± 0.0 | 0.5 ± 0.1 | 0.5 ± 0.0 |
| 7/17/72 | 0.5 ± 0.0 | 0.5 ± 0.0 | 0.5 ± 0.1 |
| 8/1/72 | 0.4 ± 0.1 | 0.4 ± 0.0 | 0.4 ± 0.1 |
| 8/15/72 | 0.5 ± 0.1 | 0.5 ± 0.1 | 0.5 ± 0.0 |
| 9/5/72 | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 |
| 9/16/72 | 0.6 ± 0.0 | 0.6 ± 0.0 | 0.6 ± 0.1 |

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table 6. Total Soluble Phosphate expressed as average mg/l phosphorus with standard deviation.

| Date | Station 1 | Station 2 | Station 3 |
|---|---|---|---|
| 10/8/71 | 0.08 ± 0.01 | 0.08 ± 0.00 | 0.08 ± 0.00 |
| 10/22/71 | 0.13 ± 0.00 | 0.13 ± 0.00 | 0.13 ± 0.00 |
| 11/2/71 | 0.13 ± 0.01 | 0.24 ± 0.03 | 0.24 ± 0.00 |
| 11/15/71 | 0.05 ± 0.01 | 0.08 ± 0.00 | 0.80 ± 0.00 |
| 12/1/71 | 0.06 ± 0.00 | 0.09 ± 0.01 | 0.09 ± 0.01 |
| 12/13/71 | 0.10 ± 0.01 | 0.10 ± 0.00 | 0.10 ± 0.01 |
| 1/3/72 | 0.06 ± 0.00 | 0.06 ± 0.00 | 0.06 ± 0.01 |
| 1/17/72 | 0.10 ± 0.01 | 0.09 ± 0.00 | 0.08 ± 0.00 |
| 2/7/72 | 0.09 ± 0.01 | 0.10 ± 0.00 | 0.09 ± 0.01 |
| 2/21/72 | 0.10 ± 0.01 | 0.10 ± 0.00 | 0.11 ± 0.01 |
| 3/7/72 | 0.07 ± 0.01 | 0.08 ± 0.01 | 0.07 ± 0.01 |
| 3/17/72 | 0.07 ± 0.00 | 0.07 ± 0.01 | 0.07 ± 0.01 |
| 4/3/72 | 0.06 ± 0.00 | 0.08 ± 0.01 | 0.08 ± 0.01 |
| 4/14/72 | 0.06 ± 0.00 | 0.06 ± 0.00 | 0.06 ± 0.01 |
| 5/2/72 | 0.08 ± 0.00 | 0.08 ± 0.00 | 0.08 ± 0.00 |
| 5/16/72 | 0.10 ± 0.00 | 0.10 ± 0.00 | 0.10 ± 0.01 |
| 6/5/72 | 0.12 ± 0.00 | 0.12 ± 0.02 | 0.12 ± 0.01 |
| 6/15/72 | 0.18 ± 0.02 | 0.20 ± 0.01 | 0.18 ± 0.01 |
| 7/10/72 | 0.14 ± 0.01 | 0.14 ± 0.00 | 0.14 ± 0.01 |
| 7/17/72 | 0.18 ± 0.01 | 0.18 ± 0.02 | 0.18 ± 0.00 |
| 8/1/72 | 0.24 ± 0.02 | 0.24 ± 0.01 | 0.23 ± 0.01 |
| 8/15/72 | 0.22 ± 0.01 | 0.23 ± 0.01 | 0.22 ± 0.01 |
| 9/5/72 | 0.22 ± 0.01 | 0.22 ± 0.01 | 0.20 ± 0.00 |
| 9/16/72 | 0.22 ± 0.00 | 0.21 ± 0.01 | 0.21 ± 0.01 |

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table 7. Total Suspended Matter expressed as mg/l.

| Date | Station 1 | Station 2 | Station 3 |
|---|---|---|---|
| 10/8/71 | 4.0 | 13.0 | 9.0 |
| 10/22/71 | 7.0 | 15.0 | 16.0 |
| 11/2/71 | 4.4 | 5.6 | 6.8 |
| 11/15/71 | 3.6 | 4.0 | 4.4 |
| 12/1/71 | 4.2 | 13.8 | 12.4 |
| 12/13/71 | 3.1 | 43.2 | 69.4 |
| 1/3/72 | 3.2 | 4.1 | 7.3 |
| 1/17/72 | 4.1 | 4.5 | 5.3 |
| 2/7/72 | 4.4 | 5.6 | 4.4 |
| 2/21/72 | 4.6 | 5.8 | 6.2 |
| 3/7/72 | 4.3 | 4.8 | 4.7 |
| 3/17/72 | 5.6 | 5.9 | 6.3 |
| 4/3/72 | 10.0 | 7.0 | 8.0 |
| 4/14/72 | 8.0 | 9.9 | 11.0 |
| 5/2/72 | 0.8 | 0.8 | 3.2 |
| 5/16/72 | 3.2 | 4.2 | 6.1 |
| 6/5/72 | 2.4 | 2.6 | 2.7 |
| 6/15/72 | 1.8 | 2.0 | 2.3 |
| 7/10/72 | 1.2 | 1.3 | 1.7 |
| 7/17/72 | 1.9 | 1.8 | 2.2 |
| 8/1/72 | 2.1 | 2.2 | 2.6 |
| 8/15/72 | 3.1 | 3.3 | 3.6 |
| 9/5/72 | 4.2 | 4.6 | 4.9 |
| 9/16/72 | 4.5 | 4.8 | 5.1 |

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table 8. Turbidity expressed as Jackson Turbidity Units.

| Date | Station 1 | Station 2 | Station 3 |
|---|---|---|---|
| 10/8/71 | 3 | 25 | 15 |
| 10/22/71 | 3 | 15 | 15 |
| 11/2/71 | 0 | 5 | 5 |
| 11/15/71 | 5 | 5 | 5 |
| 12/1/71 | 5 | 15 | 15 |
| 12/13/71 | 3 | 45 | 70 |
| 1/3/72 | 3 | 3 | 5 |
| 1/17/72 | 5 | 5 | 5 |
| 2/7/72 | 5 | 5 | 5 |
| 2/21/72 | 5 | 5 | 5 |
| 3/7/72 | 0 | 0 | 3 |
| 3/17/72 | 0 | 0 | 0 |
| 4/3/72 | 0 | 0 | 0 |
| 4/14/72 | 0 | 0 | 0 |
| 5/2/72 | 5 | 5 | 10 |
| 5/16/72 | 0 | 0 | 5 |
| 6/5/72 | 2 | 2 | 5 |
| 6/15/72 | 2 | 3 | 3 |
| 7/10/72 | 0 | 0 | 0 |
| 7/17/72 | 0 | 0 | 0 |
| 8/1/72 | 0 | 0 | 0 |
| 8/15/72 | 0 | 0 | 0 |
| 9/5/72 | 2 | 2 | 3 |
| 9/16/72 | 3 | 3 | 3 |

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table 9. Dissolved Matter expressed as average mg/l with standard deviation.

| Date | Station 1 | Station 2 | Station 3 |
|---|---|---|---|
| 10/8/71 | 187 ± 6 | 250 ± 5 | 299 ± 4 |
| 10/22/71 | 188 ± 7 | 252 ± 24 | 284 ± 2 |
| 11/2/71 | 207 ± 6 | 273 ± 7 | 293 ± 5 |
| 11/15/71 | 214 ± 5 | 216 ± 5 | 232 ± 6 |
| 12/1/71 | 216 ± 7 | 219 ± 8 | 223 ± 9 |
| 12/13/71 | 221 ± 6 | 253 ± 5 | 261 ± 11 |
| 1/3/72 | 186 ± 4 | 208 ± 7 | 216 ± 3 |
| 1/17/72 | 198 ± 6 | 201 ± 4 | 212 ± 5 |
| 2/7/72 | 222 ± 6 | 221 ± 4 | 233 ± 7 |
| 2/21/72 | 211 ± 8 | 218 ± 12 | 228 ± 8 |
| 3/7/72 | 277 ± 11 | 225 ± 14 | 242 ± 12 |
| 3/17/72 | 221 ± 21 | 208 ± 18 | 229 ± 18 |
| 4/3/72 | 162 ± 13 | 179 ± 20 | 170 ± 16 |
| 4/14/72 | 193 ± 3 | 199 ± 1 | 205 ± 2 |
| 5/2/72 | 190 ± 3 | 218 ± 9 | 202 ± 1 |
| 5/16/72 | 196 ± 5 | 209 ± 12 | 216 ± 3 |
| 6/5/72 | 230 ± 4 | 231 ± 6 | 228 ± 7 |
| 6/15/72 | 229 ± 6 | 235 ± 7 | 232 ± 6 |
| 7/10/72 | 192 ± 2 | 190 ± 3 | 192 ± 1 |
| 7/17/72 | 184 ± 3 | 188 ± 4 | 195 ± 3 |
| 8/1/72 | 179 ± 5 | 174 ± 6 | 185 ± 4 |
| 8/15/72 | 189 ± 6 | 184 ± 4 | 198 ± 6 |
| 9/5/72 | 197 ± 7 | 198 ± 7 | 198 ± 4 |
| 9/16/72 | 198 ± 6 | 203 ± 9 | 205 ± 11 |

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table 10. pH

| Date | Station 1 | Station 2 | Station 3 |
|---|---|---|---|
| 10/8/71 | 8.2 | 8.0 | 7.9 |
| 10/22/71 | 8.1 | 7.8 | 7.7 |
| 11/2/71 | 7.8 | 7.6 | 7.6 |
| 11/15/71 | 8.2 | 8.2 | 8.1 |
| 12/1/71 | 8.1 | 7.9 | 7.9 |
| 12/13/71 | 7.9 | 7.7 | 7.6 |
| 1/3/72 | 7.7 | 7.8 | 7.9 |
| 1/17/72 | 7.7 | 7.8 | 7.8 |
| 2/7/72 | 7.0 | 7.2 | 7.3 |
| 2/21/72 | 7.1 | 7.2 | 7.2 |
| 3/7/72 | 7.9 | 7.8 | 7.8 |
| 3/17/72 | 7.9 | 7.9 | 7.9 |
| 4/3/72 | 7.9 | 7.9 | 8.0 |
| 4/14/72 | 7.8 | 7.8 | 7.9 |
| 5/2/72 | 7.8 | 7.8 | 7.8 |
| 5/16/72 | 7.9 | 7.9 | 7.9 |
| 6/5/72 | 8.0 | 8.0 | 8.0 |
| 6/15/72 | 7.6 | 7.6 | 7.6 |
| 7/10/72 | 8.1 | 7.9 | 7.8 |
| 7/17/72 | 7.6 | 7.8 | 7.7 |
| 8/1/72 | 8.1 | 8.1 | 8.0 |
| 8/15/72 | 8.3 | 8.2 | 8.1 |
| 9/5/72 | 7.8 | 7.9 | 7.9 |
| 9/16/72 | 7.9 | 7.9 | 7.9 |

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table 11. Total Alkalinity expressed as average mg/l calcium carbonate with standard deviation.

| Date | Station 1 | Station 2 | Station 3 |
|---|---|---|---|
| 10/8/71 | 148 ± 1 | 139 ± 1 | 143 ± 1 |
| 10/22/71 | 164 ± 1 | 145 ± 1 | 147 ± 1 |
| 11/2/71 | 157 ± 1 | 148 ± 0 | 147 ± 1 |
| 11/15/71 | 163 ± 0 | 163 ± 0 | 160 ± 1 |
| 12/1/71 | 162 ± 1 | 148 ± 0 | 145 ± 1 |
| 12/13/71 | 142 ± 1 | 134 ± 1 | 131 ± 1 |
| 1/3/72 | 158 ± 1 | 165 ± 1 | 165 ± 1 |
| 1/17/72 | 159 ± 1 | 160 ± 1 | 161 ± 1 |
| 2/7/72 | 175 ± 1 | 179 ± 1 | 180 ± 1 |
| 2/21/72 | 179 ± 1 | 183 ± 1 | 183 ± 1 |
| 3/7/72 | 164 ± 0 | 165 ± 1 | 166 ± 0 |
| 3/17/72 | 155 ± 1 | 155 ± 1 | 156 ± 1 |
| 4/3/72 | 132 ± 0 | 133 ± 1 | 134 ± 0 |
| 4/14/72 | 154 ± 1 | 154 ± 1 | 156 ± 1 |
| 5/2/72 | 156 ± 1 | 155 ± 2 | 156 ± 1 |
| 5/16/72 | 154 ± 0 | 154 ± 0 | 154 ± 1 |
| 6/5/72 | 155 ± 1 | 156 ± 1 | 156 ± 0 |
| 6/15/72 | 144 ± 1 | 144 ± 0 | 146 ± 1 |
| 7/10/72 | 130 ± 2 | 131 ± 1 | 132 ± 1 |
| 7/17/72 | 120 ± 1 | 122 ± 2 | 120 ± 2 |
| 8/1/72 | 136 ± 3 | 134 ± 1 | 138 ± 2 |
| 8/15/72 | 145 ± 2 | 145 ± 1 | 145 ± 3 |
| 9/5/72 | 149 ± 1 | 148 ± 1 | 147 ± 1 |
| 9/16/72 | 148 ± 1 | 148 ± 1 | 149 ± 1 |

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table 12. Total Coliform expressed as average colonies per 100 ml with standard deviation.

| Date | Station 1 | Station 2 | Station 3 |
|---|---|---|---|
| 10/8/71 | 52 ± 12 | 7300 ± 500 | 3000 ± 500 |
| 10/22/71 | 150 ± 8 | 2000 ± 200 | 3000 ± 250 |
| 11/2/71 | 45 ± 7 | 1400 ± 400 | 1400 ± 200 |
| 11/15/71 | 37 ± 6 | 190 ± 21 | 280 ± 23 |
| 12/1/71 | 42 ± 7 | 1100 ± 270 | 1600 ± 230 |
| 12/13/71 | 52 ± 6 | 1300 ± 130 | 1900 ± 310 |
| 1/3/72 | 4 ± 0 | 20 ± 3 | 22 ± 4 |
| 1/17/72 | 8 ± 1 | 20 ± 1 | 26 ± 3 |
| 2/7/72 | 24 ± 3 | 22 ± 6 | 26 ± 4 |
| 2/21/72 | 10 ± 2 | 11 ± 1 | 42 ± 4 |
| 3/7/72 | 12 ± 1 | 25 ± 2 | 41 ± 3 |
| 3/17/72 | 8 ± 2 | 12 ± 3 | 18 ± 1 |
| 4/3/72 | 2 ± 1 | 3 ± 1 | 2 ± 1 |
| 4/14/72 | 7 ± 1 | 13 ± 1 | 20 ± 3 |
| 5/2/72 | 4 ± 1 | 8 ± 2 | 9 ± 1 |
| 5/16/72 | 6 ± 2 | 7 ± 2 | 11 ± 2 |
| 6/5/72 | 44 ± 2 | 49 ± 4 | 70 ± 11 |
| 6/15/72 | 56 ± 5 | 58 ± 2 | 70 ± 6 |
| 7/10/72 | 34 ± 6 | 68 ± 7 | 62 ± 4 |
| 7/17/72 | 200 ± 6 | 210 ± 14 | 230 ± 6 |
| 8/1/72 | 200 ± 7 | 190 ± 13 | 220 ± 7 |
| 8/15/72 | 180 ± 28 | 240 ± 22 | 290 ± 20 |
| 9/5/72 | 31 ± 0 | 41 ± 5 | 50 ± 5 |
| 9/16/72 | 42 ± 8 | 49 ± 6 | 53 ± 4 |

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table 13. Total Count of Bacteria and Fungi expressed as average 1000 colonies per 100 ml with standard deviation. TNTC=too numerous to count.

| Date | Station 1 | Station 2 | Station 3 |
|---|---|---|---|
| 10/8/71 | 1.7 ± 0.6 | TNTC | TNTC |
| 10/22/71 | 7.0 ± 0.2 | TNTC | TNTC |
| 11/2/71 | 8.1 ± 0.6 | TNTC | TNTC |
| 11/15/71 | 27 ± 0.3 | 72 ± 1.3 | 290 ± 29 |
| 12/1/71 | 8.3 ± 0.4 | 150 ± 1.5 | 210 ± 30 |
| 12/13/71 | 5.6 ± 0.5 | 140 ± 0.3 | 290 ± 33 |
| 1/3/72 | 2.2 ± 0.3 | 3.5 ± 0.8 | 3.6 ± 0.1 |
| 1/17/72 | 2.1 ± 0.4 | 4.0 ± 0.4 | 5.4 ± 0.3 |
| 2/7/72 | 1.3 ± 0.2 | 1.3 ± 0.3 | 1.2 ± 0.2 |
| 2/21/72 | 1.1 ± 0.1 | 2.0 ± 0.2 | 4.6 ± 0.3 |
| 3/7/72 | 2.6 ± 0.1 | 2.9 ± 0.1 | 3.1 ± 0.1 |
| 3/17/72 | 2.4 ± 0.1 | 2.6 ± 0.1 | 8.5 ± 0.2 |
| 4/3/72 | 3.7 ± 0.2 | 4.1 ± 0.1 | 5.7 ± 0.4 |
| 4/14/72 | 4.1 ± 0.2 | 4.3 ± 0.3 | 4.1 ± 0.2 |
| 5/2/72 | 1.9 ± 0.3 | 2.3 ± 0.2 | 2.4 ± 0.2 |
| 5/16/72 | 2.2 ± 0.3 | 2.4 ± 0.2 | 2.6 ± 0.3 |
| 6/5/72 | 15 ± 0.9 | 47 ± 11 | 55 ± 2 |
| 6/15/72 | 51 ± 2 | 120 ± 11 | 140 ± 5 |
| 7/10/72 | 24 ± 4 | 67 ± 6 | 86 ± 10 |
| 7/17/72 | 57 ± 6 | 98 ± 5 | 140 ± 10 |
| 8/1/72 | 44 ± 6 | 110 ± 11 | 140 ± 11 |
| 8/15/72 | 23 ± 5 | 29 ± 2 | 33 ± 4 |
| 9/5/72 | 5.2 ± 0.8 | 6.2 ± 1.0 | 9.3 ± 0.8 |
| 9/16/72 | 4.8 ± 0.7 | 5.0 ± 0.8 | 5.5 ± 1.0 |

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table 14. Total Yeast and Mold expressed as colonies per 100 ml.

| Date | Station 1 | Station 2 | Station 3 |
|---|---|---|---|
| 10/8/71 | - | - | - |
| 10/22/71 | - | - | - |
| 11/2/71 | - | - | - |
| 11/15/71 | 0.0 | 0.0 | 0.0 |
| 12/1/71 | 0.0 | 2.0 | 1.0 |
| 12/13/71 | 1.0 | 1.0 | 0.0 |
| 1/3/72 | 0.25 | 0.25 | 1.8 |
| 1/17/72 | 0.0 | 0.5 | 1.0 |
| 2/7/72 | 2.0 | 7.6 | 5.6 |
| 2/21/72 | 0.25 | 0.25 | 0.50 |
| 3/7/72 | 0.0 | 0.0 | 0.0 |
| 3/17/72 | 1.0 | 0.3 | 1.2 |
| 4/3/72 | 0.0 | 3.1 | 0.4 |
| 4/14/72 | 0.0 | 0.0 | 0.8 |
| 5/2/72 | 0.0 | 0.0 | 0.0 |
| 5/16/72 | 0.0 | 0.0 | 0.0 |
| 6/5/72 | 1.0 | 0.0 | 0.5 |
| 6/15/72 | 1.0 | 1.5 | 0.5 |
| 7/10/72 | 0.5 | 3.8 | 2.3 |
| 7/17/72 | 2.0 | 1.5 | 2.0 |
| 8/1/72 | 2.0 | 2.5 | 3.0 |
| 8/15/72 | 1.5 | 5.5 | 1.0 |
| 9/5/72 | 2.5 | 6.0 | 48.0 |
| 9/16/72 | 3.0 | 4.5 | 5.6 |

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table 15. Total Flow of Sunset Lake Weir during the day of water collection expressed as million liters per day.

| Date | Flow |
|---|---|
| 10/8/71 | 20.5 |
| 10/22/71 | 21.3 |
| 11/2/71 | 27.9 |
| 11/15/71 | 11.9 |
| 12/1/71 | 31.5 |
| 12/13/71 | 28.4 |
| 1/3/72 | 41.7 |
| 1/17/72 | 23.7 |
| 2/7/72 | 25.3 |
| 2/21/72 | 29.5 |
| 3/7/72 | 23.0 |
| 3/17/72 | 35.0 |
| 4/3/72 | 33.0 |
| 4/14/72 | 34.5 |
| 5/2/72 | 26.5 |
| 5/16/72 | 45.8 |
| 6/5/72 | 16.6 |
| 6/15/72 | 10.6 |
| 7/10/72 | 10.6 |
| 7/17/72 | 9.52 |
| 8/1/72 | 12.6 |
| 8/15/72 | 9.60 |
| 9/5/72 | 17.6 |
| 9/16/72 | 16.0 |

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table 16. Common Names and Taxanomic Phyla and Class of the Benthic Macrofauna collected from the three stations.

Mollusca

Gastropoda (Snails)

<u>Helisoma</u> sp.

<u>Physa</u> sp.

<u>Viviparus</u> sp.

Pelecypoda (Clams)

<u>Anodonta</u> sp.

<u>Sphaerium</u> sp.

Arthropoda

Crustacea

<u>Hyalella</u> sp. (Scud)

<u>Orconectes</u> sp. (Crayfish)

Insecta

Chironomidae (Midges)

Coegrionidae (Damselflies)

Ecdyuriidae (Mayflies)

Gyrinidae (Whirigig beetles)

Hydropsychidae (Caddisflies)

Libellulidae (Dragonflies)

Simuliidae (Black flies)

Tipulidae (Craneflies)

Annelida

Hirudinea

<u>Erpobdella</u> sp. (Leech)

Olgochaetae

<u>Limnodrilus</u> sp. (Tubificid worm)

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table 17. Benthic Macrofauna collected on 10/22/71 expressed as numbers per square meter ($N/m^2$) and as percentage of population (%P).

| Organism | Station 1 $N/m^2$ | Station 1 %P | Station 2 $N/m^2$ | Station 2 %P | Station 3 $N/m^2$ | Station 3 %P |
|---|---|---|---|---|---|---|
| *Viviparus* sp. | 4100 | 39% | 0 | 0% | 0 | 0% |
| *Sphaerium* sp. | 320 | 3.0% | 0 | 0% | 0 | 0% |
| *Limnodrilus* sp. | 0 | 0% | 250 | 4.7% | 58 | 2.8% |
| *Hyalella* sp. | 5300 | 51% | 0 | 0% | 0 | 0% |
| Chironomidae | 100 | 0.95% | 5100 | 95% | 2000 | 97% |
| Coenagrionidae | 300 | 2.9% | 0 | 0% | 0 | 0% |
| Gyrinidae | 29 | 0.28% | 0 | 0% | 0 | 0% |
| Hydropsychidae | 320 | 3.0% | 0 | 0% | 0 | 0% |
| Simuliidae | 70 | 0.66% | 0 | 0% | 0 | 0% |
| Total population per square meter. | 11,000 | | 5,400 | | 2,100 | |

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table 18. Benthic Macrofauna collected on 11/6/71 expressed as numbers per square meter ($N/m^2$) and as percentage of population (%P).

| Organism | Station 1 $N/m^2$ | Station 1 %P | Station 2 $N/m^2$ | Station 2 %P | Station 3 $N/m^2$ | Station 3 %P |
|---|---|---|---|---|---|---|
| *Helisoma* sp. | 15 | 0.13% | 0 | 0% | 0 | 0% |
| *Viviparus* sp. | 5300 | 45% | 0 | 0% | 0 | 0% |
| *Sphaerium* sp. | 350 | 3.0% | 0 | 0% | 0 | 0% |
| *Erpobdella* sp. | 290 | 2.5% | 0 | 0% | 0 | 0% |
| *Limnodrilus* sp. | 130 | 1.1% | 0 | 0% | 390 | 16% |
| *Hyalella* sp. | 4800 | 41% | 0 | 0% | 0 | 0% |
| *Orconectes* sp. | 15 | 0.13% | 0 | 0% | 0 | 0% |
| Chironomidae | 130 | 1.1% | 1800 | 100% | 2100 | 84% |
| Coenagrionidae | 410 | 3.5% | 0 | 0% | 0 | 0% |
| Gyrinidae | 75 | 0.64% | 0 | 0% | 0 | 0% |
| Hydropsychidae | 160 | 1.4% | 0 | 0% | 0 | 0% |
| Simuliidae | 120 | 1.0% | 0 | 0% | 0 | 0% |
| Total population per square meter. | 12,000 | | 1,800 | | 2,500 | |

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table 19. Benthic Macrofauna collected on 12/4/71 expressed as numbers per square meter ($N/m^2$) and as percentage of population (%P).

| Organism | Station 1 | | Station 2 | | Station 3 | |
|---|---|---|---|---|---|---|
| | $N/m^2$ | %P | $N/m^2$ | %P | $N/m^2$ | %P |
| *Physa* sp. | 120 | 1.1% | 0 | 0% | 0 | 0% |
| *Viviparus* sp. | 4500 | 40% | 0 | 0% | 0 | 0% |
| *Sphaerium* sp. | 290 | 2.6% | 0 | 0% | 0 | 0% |
| *Erpobdella* sp. | 60 | 0.54% | 0 | 0% | 0 | 0% |
| *Limnodrilus* sp. | 70 | 0.63% | 180 | 7.3% | 220 | 11% |
| *Hyalella* sp. | 5300 | 48% | 0 | 0% | 0 | 0% |
| Chironomidae | 140 | 1.3% | 2300 | 93% | 1700 | 89% |
| Coenagrionidae | 350 | 3.1% | 0 | 0% | 0 | 0% |
| Gyrinidae | 52 | 0.48 | 0 | 0% | 0 | 0% |
| Hydropsychidae | 200 | 1.8% | 0 | 0% | 0 | 0% |
| Simuliidae | 75 | 0.67% | 0 | 0% | 0 | 0% |
| Total population per square meter. | 11,000 | | 2,500 | | 1,900 | |

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table 20. Benthic Macrofauna collected on 1/8/72 expressed as numbers per square meter ($N/m^2$) and as percentage of population (%P).

| Organism | Station 1 | | Station 2 | | Station 3 | |
|---|---|---|---|---|---|---|
| | $N/m^2$ | %P | $N/m^2$ | %P | $N/m^2$ | %P |
| *Helisoma* sp. | 15 | 0.15% | 0 | 0% | 0 | 0% |
| *Physa* sp. | 80 | 0.81% | 0 | 0% | 0 | 0% |
| *Viviparus* sp. | 4200 | 43% | 0 | 0% | 0 | 0% |
| *Sphaerium* sp. | 630 | 6.4% | 0 | 0% | 0 | 0% |
| *Erpobdella* sp. | 180 | 1.8% | 0 | 0% | 0 | 0% |
| *Limnodrilus* sp. | 200 | 2.0% | 250 | 13% | 560 | 22% |
| *Hyalella* sp. | 3800 | 39% | 0 | 0% | 0 | 0% |
| Chironomidae | 80 | 0.81% | 1700 | 87% | 2000 | 78% |
| Coenagrionidae | 380 | 3.9% | 0 | 0% | 0 | 0% |
| Gyrinidae | 65 | 0.66% | 0 | 0% | 0 | 0% |
| Hydropsychidae | 180 | 1.8% | 0 | 0% | 0 | 0% |
| Simuliidae | 68 | 0.69% | 0 | 0% | 0 | 0% |
| Total Population per square meter. | 9,900 | | 2,000 | | 2,600 | |

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table 21. Benthic Macrofauna collected on 2/5/72 expressed as numbers per square meter ($N/m^2$) and as percentage of population (%P).

| Organism | Station 1 $N/m^2$ | Station 1 %P | Station 2 $N/m^2$ | Station 2 %P | Station 3 $N/m^2$ | Station 3 %P |
|---|---|---|---|---|---|---|
| *Helisoma* sp. | 86 | 0.79% | 0 | 0% | 0 | 0% |
| *Physa* sp. | 610 | 5.6% | 0 | 0% | 0 | 0% |
| *Viviparus* sp. | 4400 | 40% | 0 | 0% | 0 | 0% |
| *Anodonta* sp. | 15 | 0.14% | 0 | 0% | 0 | 0% |
| *Sphaerium* sp. | 1800 | 17% | 0 | 0% | 0 | 0% |
| *Erpobdella* sp. | 260 | 2.4% | 45 | 14% | 0 | 0% |
| *Limnodrilus* sp. | 650 | 6.0% | 150 | 46% | 2200 | 36% |
| *Hyalella* sp. | 2100 | 19% | 0 | 0% | 0 | 0% |
| *Orconectes* sp. | 15 | 0.14% | 0 | 0% | 0 | 0% |
| Chironomidae | 100 | 0.92% | 120 | 36% | 3800 | 63% |
| Coenagrionidae | 610 | 5.6% | 0 | 0% | 0 | 0% |
| Gyrinidae | 26 | 0.24% | 0 | 0% | 0 | 0% |
| Hydropsychidae | 180 | 1.7% | 0 | 0% | 0 | 0% |
| Simuliidae | 68 | 0.62% | 0 | 0% | 0 | 0% |
| Tipulidae | 0 | 0% | 15 | 4.6% | 0 | 0% |
| Total population per square meter. | 11,000 | | 330 | | 6,100 | |

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table 22. Benthic Macrofauna collected on 3/4/72 expressed as numbers per square meter ($N/m^2$) and as percentage of population (%P).

| Organism | Station 1 $N/m^2$ | Station 1 %P | Station 2 $N/m^2$ | Station 2 %P | Station 3 $N/m^2$ | Station 3 %P |
|---|---|---|---|---|---|---|
| *Helisoma* sp. | 15 | 0.35% | 0 | 0% | 0 | 0% |
| *Physa* sp. | 30 | 0.71% | 0 | 0% | 0 | 0% |
| *Viviparus* sp. | 1400 | 33% | 0 | 0% | 0 | 0% |
| *Sphaerium* sp. | 460 | 11% | 0 | 0% | 0 | 0% |
| *Erpobdella* sp. | 140 | 3.3% | 0 | 0% | 0 | 0% |
| *Limnodrilus* sp. | 305 | 7.2% | 68 | 23% | 2700 | 81% |
| *Hyalella* sp. | 1500 | 36% | 0 | 0% | 0 | 0% |
| Chironomidae | 100 | 2.4% | 190 | 65% | 610 | 18% |
| Coenagrionidae | 120 | 2.8% | 0 | 0% | 0 | 0% |
| Gyrinidae | 15 | 0.35% | 0 | 0% | 0 | 0% |
| Hydropsychidae | 95 | 2.3% | 0 | 0% | 0 | 0% |
| Simuliidae | 51 | 1.2% | 34 | 12% | 15 | 0.45% |
| Total population per square meter. | 4,200 | | 290 | | 3,300 | |

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table 23. Benthic Macrofauna collected on 4/8/72 expressed as numbers per square meter ($N/m^2$) and as percentage of population (%P).

| Organism | Station 1 | | Station 2 | | Station 3 | |
|---|---|---|---|---|---|---|
| | $N/m^2$ | %P | $N/m^2$ | %P | $N/m^2$ | %P |
| *Helisoma* sp. | 30 | 0.37% | 0 | 0% | 0 | 0% |
| *Viviparus* sp. | 4100 | 51% | 0 | 0% | 0 | 0% |
| *Sphaerium* sp. | 530 | 6.6% | 0 | 0% | 0 | 0% |
| *Erpobdella* sp. | 190 | 2.4% | 0 | 0% | 0 | 0% |
| *Limnodrilus* sp. | 330 | 4.1% | 210 | 14% | 2000 | 35% |
| *Hyalella* sp. | 2500 | 31% | 0 | 0% | 0 | 0% |
| Chironomidae | 30 | 0.37% | 1300 | 86% | 3700 | 65% |
| Coenagrionidae | 150 | 1.9% | 0 | 0% | 0 | 0% |
| Hydropsychidae | 120 | 1.5% | 0 | 0% | 0 | 0% |
| Simuliidae | 30 | 0.37% | 0 | 0% | 30 | 0.52% |
| Total population per square meter. | 8,000 | | 1,500 | | 5,700 | |

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table 24. Benthic Macrofauna collected on 5/6/72 expressed as numbers per square meter ($N/m^2$) and as percentage of population (%P).

| Organism | Station 1 | | Station 2 | | Station 3 | |
|---|---|---|---|---|---|---|
| | $N/m^2$ | %P | $N/m^2$ | %P | $N/m^2$ | %P |
| *Physa* sp. | 45 | 0.50% | 0 | 0% | 0 | 0% |
| *Viviparus* sp. | 4900 | 55% | 0 | 0% | 0 | 0% |
| *Anodonta* sp. | 15 | 0.17% | 0 | 0% | 0 | 0% |
| *Sphaerium* sp. | 670 | 7.5% | 0 | 0% | 0 | 0% |
| *Erpobdella* sp. | 110 | 1.2% | 0 | 0% | 0 | 0% |
| *Limnodrilus* sp. | 160 | 1.8% | 270 | 18% | 2400 | 33% |
| *Hyalella* sp. | 2800 | 31% | 0 | 0% | 0 | 0% |
| *Orconectes* sp. | 15 | 0.17% | 0 | 0% | 0 | 0% |
| Chironomidae | 60 | 0.67% | 1200 | 82% | 4800 | 67% |
| Coenagrionidae | 120 | 1.3% | 0 | 0% | 0 | 0% |
| Hydropsychidae | 60 | 0.67% | 0 | 0% | 0 | 0% |
| Total population per square meter. | 9,000 | | 1,500 | | 7,200 | |

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table 25. Benthic Macrofauna collected on 6/3/72 expressed as numbers per square meter ($N/m^2$) and as percentage of population (%P).

| Organism | Station 1 $N/m^2$ | Station 1 %P | Station 2 $N/m^2$ | Station 2 %P | Station 3 $N/m^2$ | Station 3 %P |
|---|---|---|---|---|---|---|
| *Helisoma* sp. | 15 | 0.12% | 0 | 0% | 0 | 0% |
| *Physa* sp. | 60 | 0.50% | 60 | 6.9% | 45 | 2.1% |
| *Viviparus* sp. | 5300 | 44% | 0 | 0% | 0 | 0% |
| *Sphaerium* sp. | 500 | 4.1% | 0 | 0% | 0 | 0% |
| *Erpobdella* sp. | 260 | 2.2% | 45 | 5.2% | 45 | 2.1% |
| *Limnodrilus* sp. | 300 | 2.5% | 400 | 46% | 1800 | 84% |
| *Hyalella* sp. | 5300 | 44% | 240 | 28% | 150 | 7.0% |
| *Orconectes* sp. | 30 | 0.25% | 0 | 0% | 0 | 0% |
| Coenagrionidae | 210 | 1.7% | 0 | 0% | 0 | 0% |
| Ecdyuriidae | 60 | 0.44% | 45 | 5.2% | 30 | 1.4% |
| Hydropsychidae | 45 | 0.37% | 45 | 5.2% | 60 | 2.8% |
| Simuliidae | 30 | 0.25% | 30 | 3.5% | 15 | 0.70% |
| Total population per square meter. | 12,000 | | 870 | | 2,200 | |

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table 26. Benthic Macrofauna collected on 7/8/72 expressed as numbers per square meter ($N/m^2$) and as percentage of population (%P).

| Organism | Station 1 $N/m^2$ | Station 1 %P | Station 2 $N/m^2$ | Station 2 %P | Station 3 $N/m^2$ | Station 3 %P |
|---|---|---|---|---|---|---|
| *Physa* sp. | 0 | 0% | 180 | 2.7% | 315 | 3.7% |
| *Viviparus* sp. | 6600 | 41% | 0 | 0% | 0 | 0% |
| *Sphaerium* sp. | 620 | 3.8% | 0 | 0% | 0 | 0% |
| *Erpobdella* sp. | 380 | 2.4% | 60 | 0.89% | 90 | 1.1% |
| *Limnodrilus* sp. | 230 | 1.4% | 330 | 4.9% | 670 | 7.9% |
| *Hyalella* sp. | 7400 | 46% | 3200 | 48% | 2100 | 25% |
| Chironomidae | 0 | 0% | 90 | 1.3% | 60 | 0.70% |
| Coenagrionidae | 360 | 2.2% | 180 | 2.7% | 90 | 1.1% |
| Ecdyuriidae | 45 | 0.28% | 45 | 0.67% | 15 | 0.18% |
| Hydropsychidae | 75 | 0.46% | 30 | 0.45% | 0 | 0% |
| Simuliidae | 450 | 2.8% | 2600 | 39% | 5200 | 61% |
| Total population per square meter. | 16,000 | | 6,700 | | 8,500 | |

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table 27. Benthic Macrofauna collected on 8/5/72 expressed as numbers per square meter ($N/m^2$) and as percentage of population (%P).

| Organism | Station 1 $N/m^2$ | Station 1 %P | Station 2 $N/m^2$ | Station 2 %P | Station 3 $N/m^2$ | Station 3 %P |
|---|---|---|---|---|---|---|
| *Helisoma* sp. | 30 | 0.22% | 30 | 0.87% | 0 | 0% |
| *Physa* sp. | 60 | 0.44% | 150 | 4.3% | 220 | 5.4% |
| *Viviparus* sp. | 4700 | 34% | 30 | 0.87% | 30 | 0.87% |
| *Sphaerium* sp. | 480 | 3.5% | 0 | 0% | 0 | 0% |
| *Erpobdella* sp. | 180 | 1.3% | 0 | 0% | 45 | 1.1% |
| *Limnodrilus* sp. | 230 | 1.7% | 150 | 4.3% | 380 | 9.3% |
| *Hyalella* sp. | 7200 | 52% | 2300 | 66% | 2500 | 62% |
| *Orconectes* sp. | 0 | 0% | 0 | 0% | 15 | 0.37% |
| Chironomidae | 130 | 0.95% | 120 | 3.5% | 120 | 3.0% |
| Coenagrionidae | 270 | 2.0% | 100 | 2.9% | 120 | 3.0% |
| Ecdyuriidae | 60 | 0.44% | 90 | 2.6% | 230 | 5.7% |
| Hydropsychidae | 300 | 2.2% | 120 | 3.5% | 200 | 4.9% |
| Libellulidae | 30 | 0.22% | 0 | 0% | 0 | 0% |
| Simuliidae | 90 | 0.65% | 380 | 11% | 230 | 5.7% |
| Total population per square meter. | 14,000 | | 3,500 | | 4,100 | |

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table 28. Benthic Macrofauna collected on 9/2/72 expressed as numbers per square meter ($N/m^2$) and as percentage of population (%P).

| Organism | Station 1 | | Station 2 | | Station 3 | |
|---|---|---|---|---|---|---|
| | $N/m^2$ | %P | $N/m^2$ | %P | $N/m^2$ | %P |
| *Helisoma* sp. | 15 | 0.16% | 15 | 0.14% | 0 | 0% |
| *Physa* sp. | 45 | 0.47% | 130 | 3.5% | 140 | 4.1% |
| *Viviparus* sp. | 3500 | 3.7% | 45 | 1.2% | 0 | 0% |
| *Anodonata* sp. | 15 | 0.16% | 0 | 0% | 0 | 0% |
| *Sphaerium* sp. | 320 | 3.3% | 0 | 0% | 0 | 0% |
| *Erpobdella* sp. | 140 | 1.5% | 15 | 0.41% | 60 | 1.8% |
| *Limnodrilus* sp. | 240 | 2.5% | 280 | 7.6% | 390 | 12% |
| *Hyalella* sp. | 4400 | 46% | 1900 | 52% | 1700 | 50% |
| Chironomidae | 300 | 3.1% | 680 | 18% | 480 | 14% |
| Coenagrionidae | 210 | 2.2% | 110 | 3.0% | 230 | 6.8% |
| Ecdyuriidae | 45 | 0.47% | 110 | 3.0% | 230 | 6.8% |
| Hydropsychidae | 240 | 2.5% | 210 | 5.7% | 110 | 3.2% |
| Simuliidae | 130 | 1.4% | 180 | 4.9% | 210 | 6.2% |
| Total population per square meter. | 9,600 | | 3,700 | | 3,400 | |

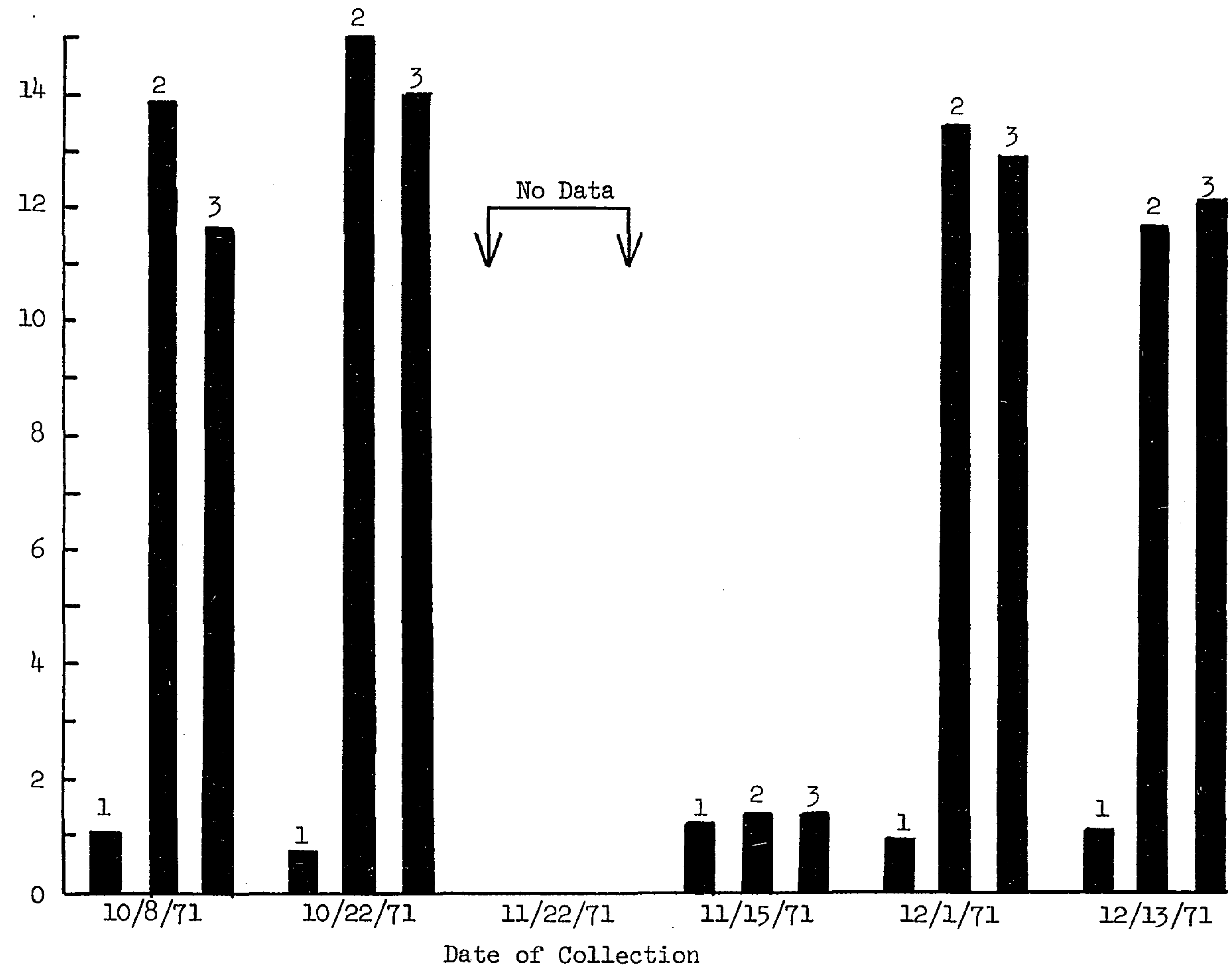
Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Graph 1. Average Five Day Biochemical Demand of Water at the Time of Collection Expressed as mg/l.

Each bar is identified by the station number at the top. The paper mill discharge was out of the creek on 11/15/71. The paper mill discharge was removed permanently on 12/17/71. There were no data available for the $BOD_5$ on 11/2/71.

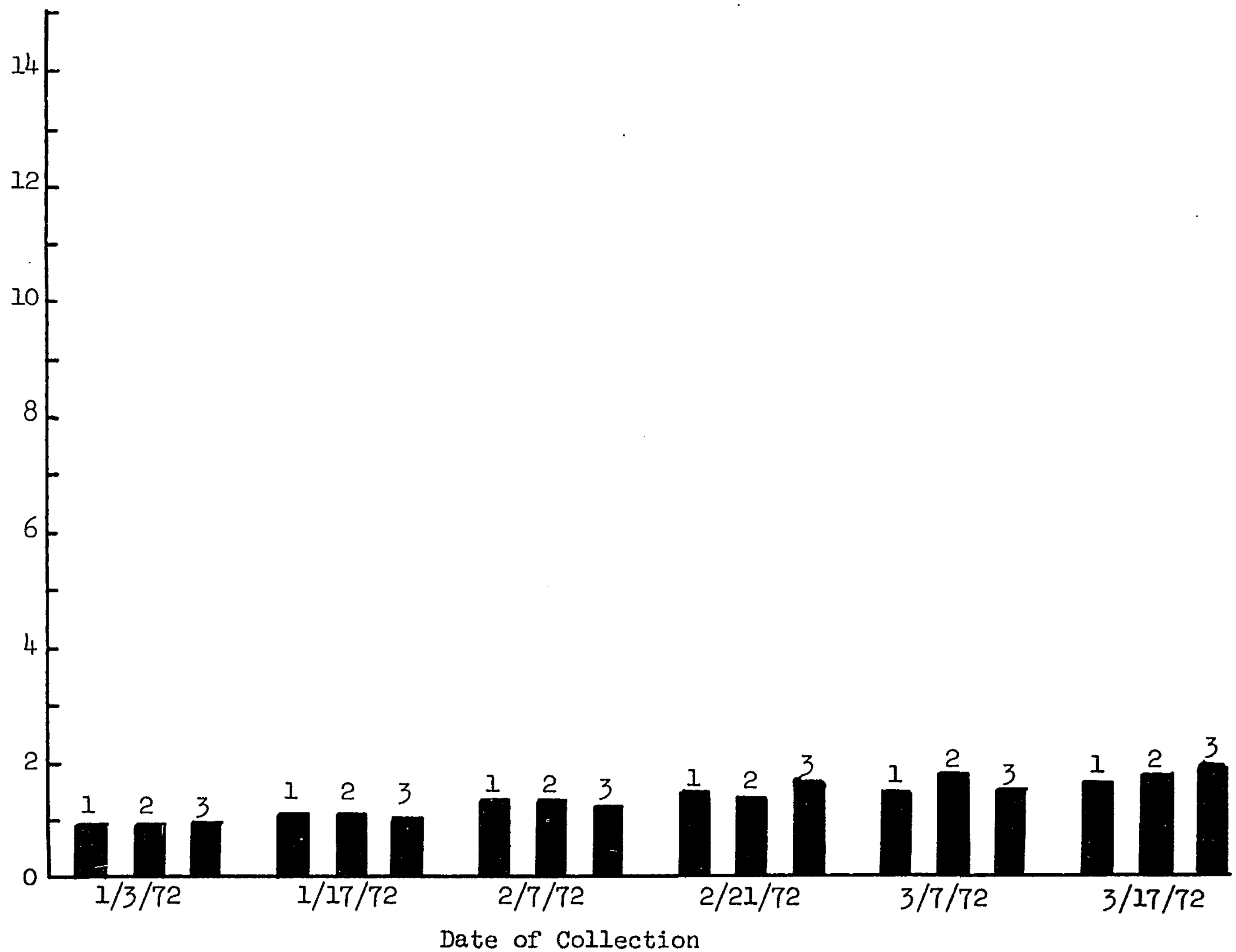
Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Graph 1. Five Day Biochemical Oxygen Demand



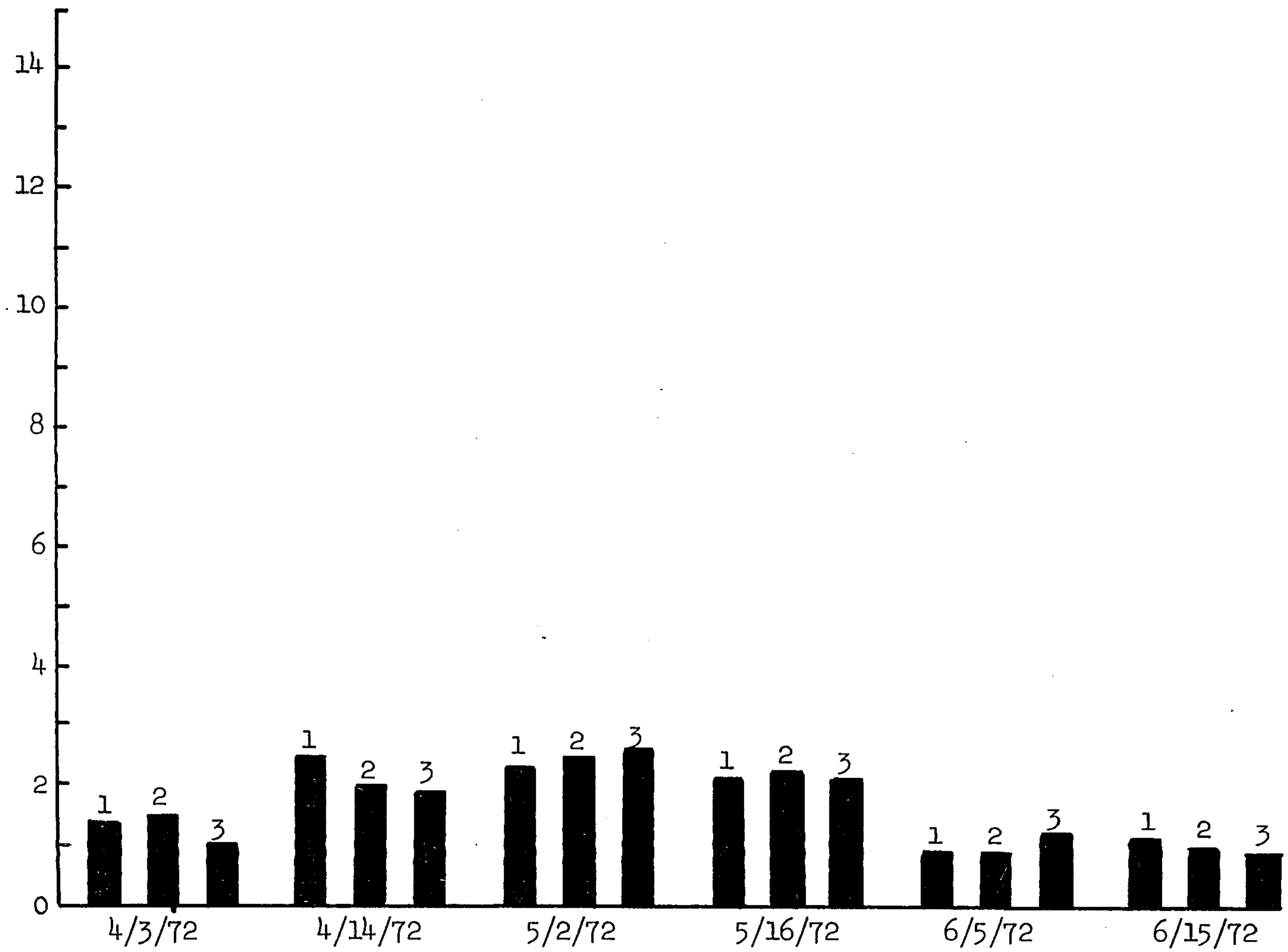

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Graph 1 (Cont.). Five Day Biochemical Oxygen Demand



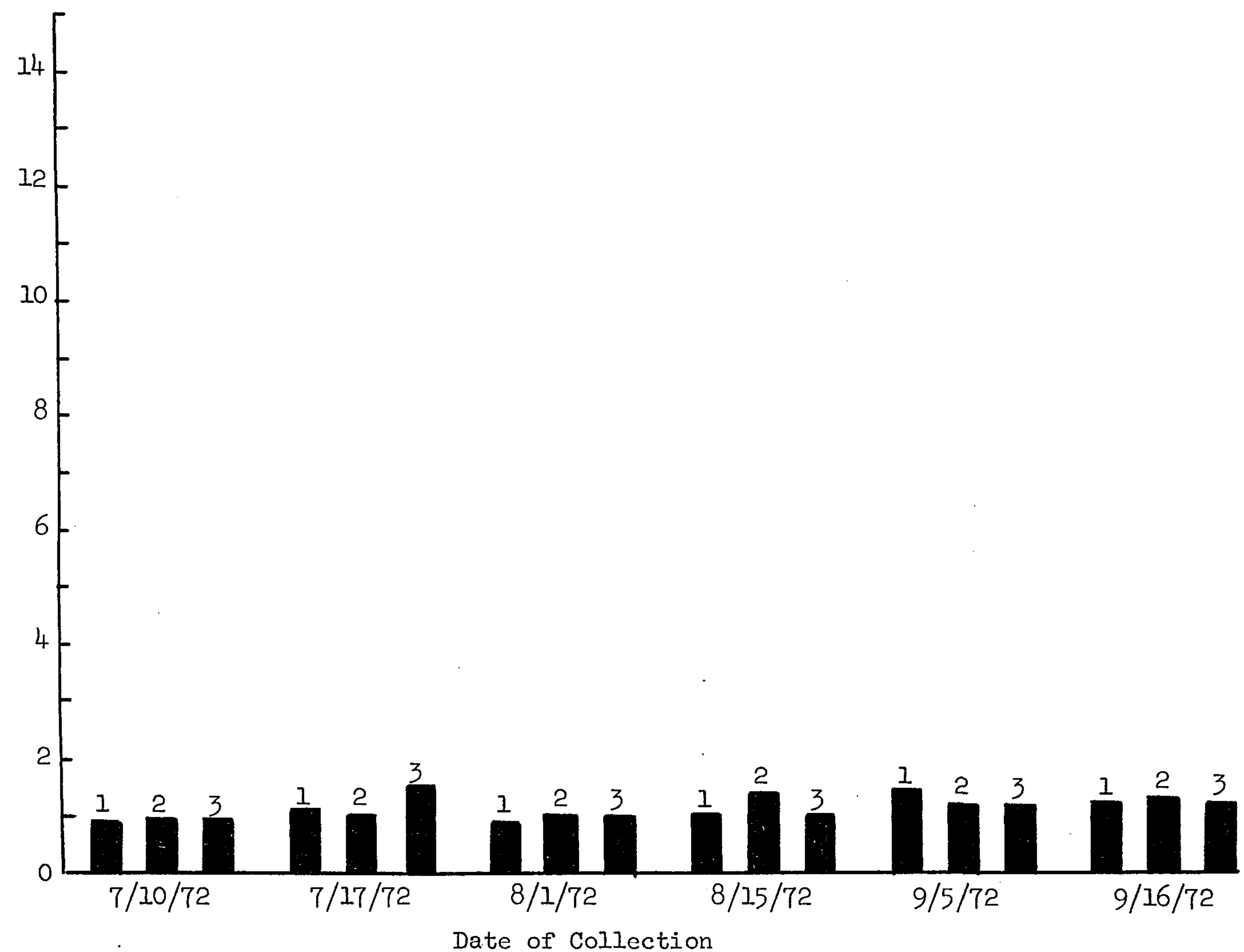

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Graph 1 (Cont.). Five Day Biochemical Oxygen Demand




Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Graph 1 (Cont.). Five Day Biochemical Oxygen Demand



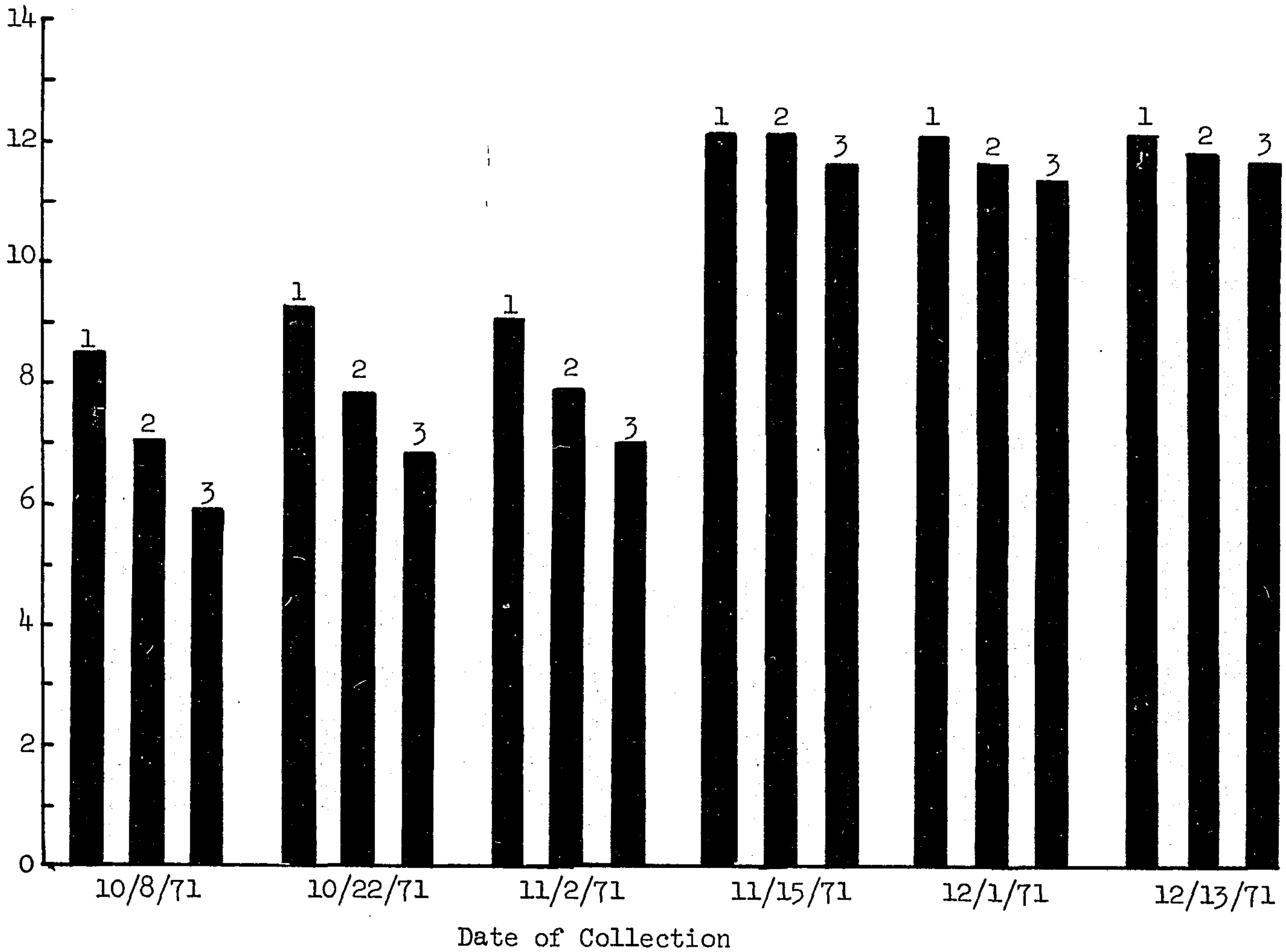

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Graph 2. Average Dissolved Oxygen of Water at the Time of Collection Expressed as mg/l.

Each bar is identified by the station number at the top. The paper mill discharge was out of the creek on 11/15/71. The paper mill discharge was removed permanently on 12/17/71.

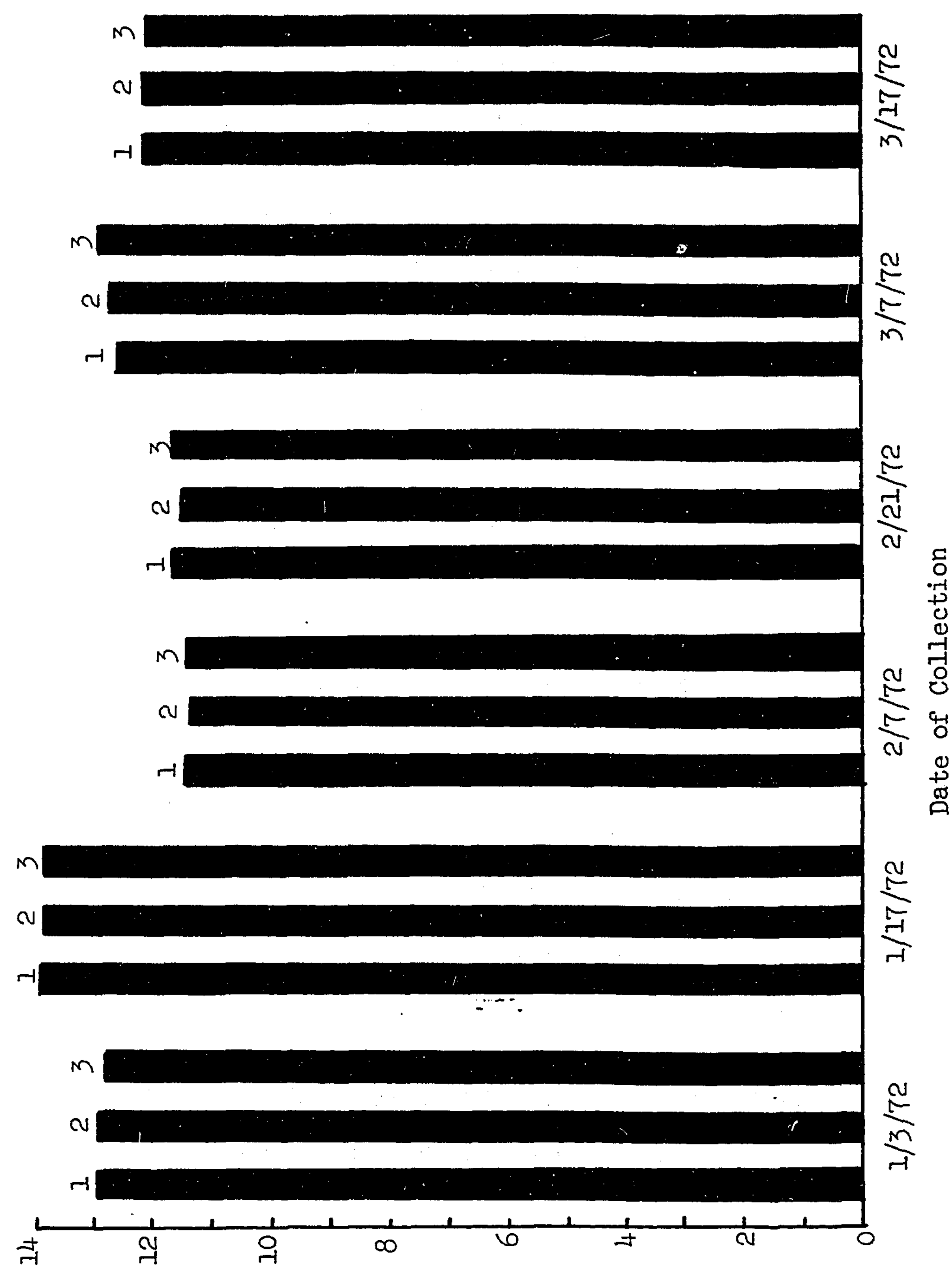
Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Graph 2. Dissolved Oxygen



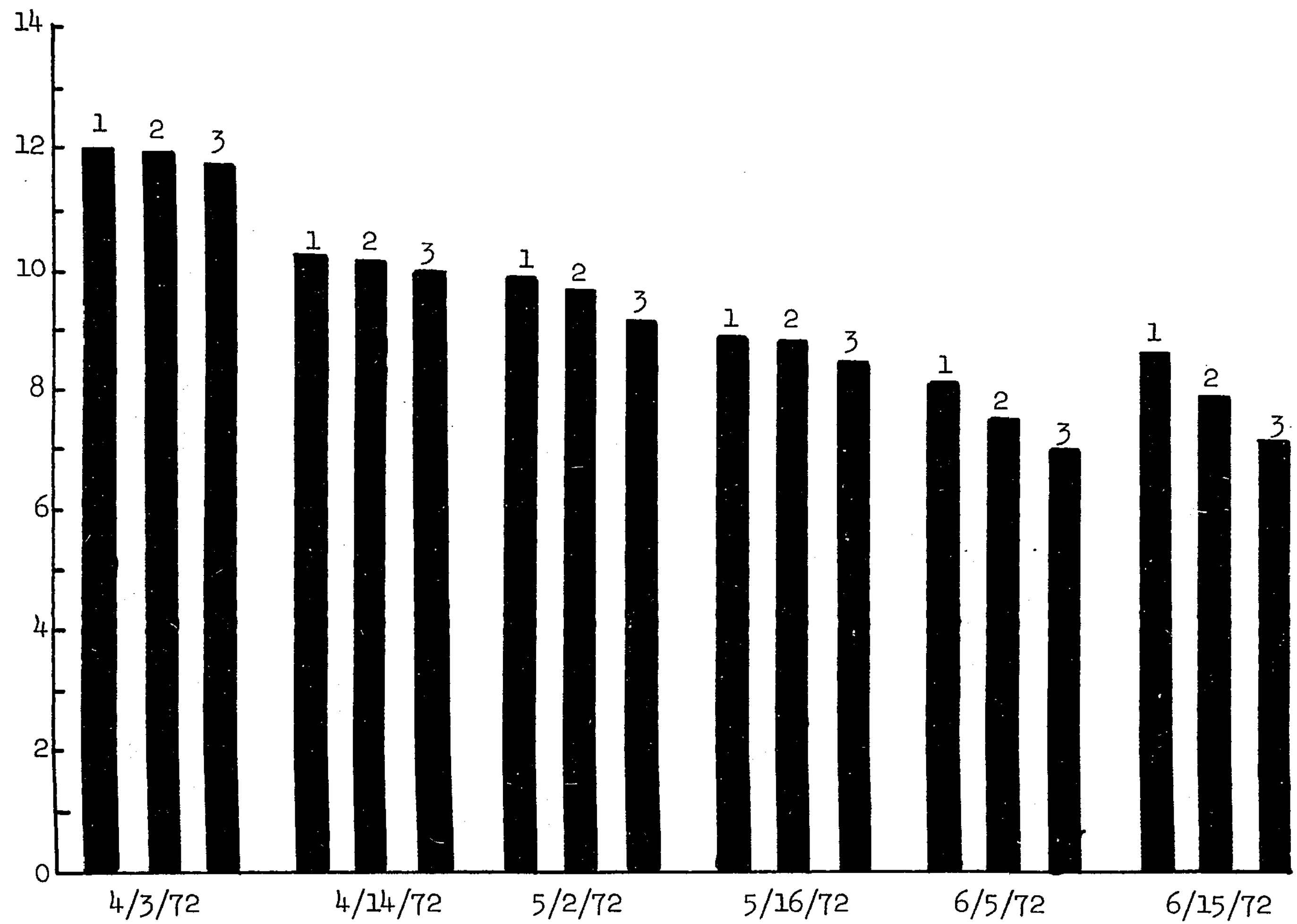

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Graph 2 (Cont.). Dissolved Oxygen



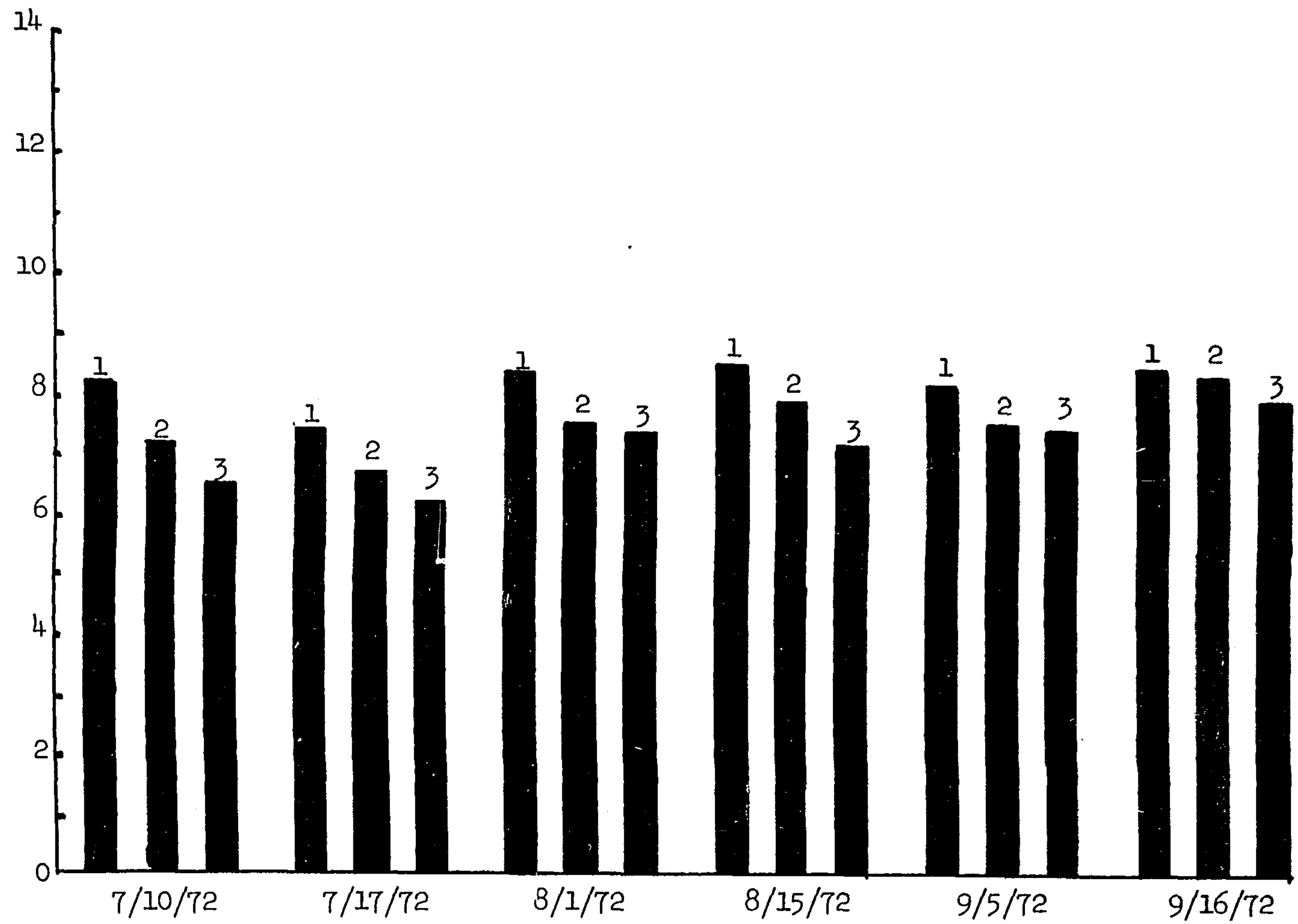

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Graph 2 (Cont.). Dissolved Oxygen




Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Graph 2 (Cont.). Dissolved Oxygen





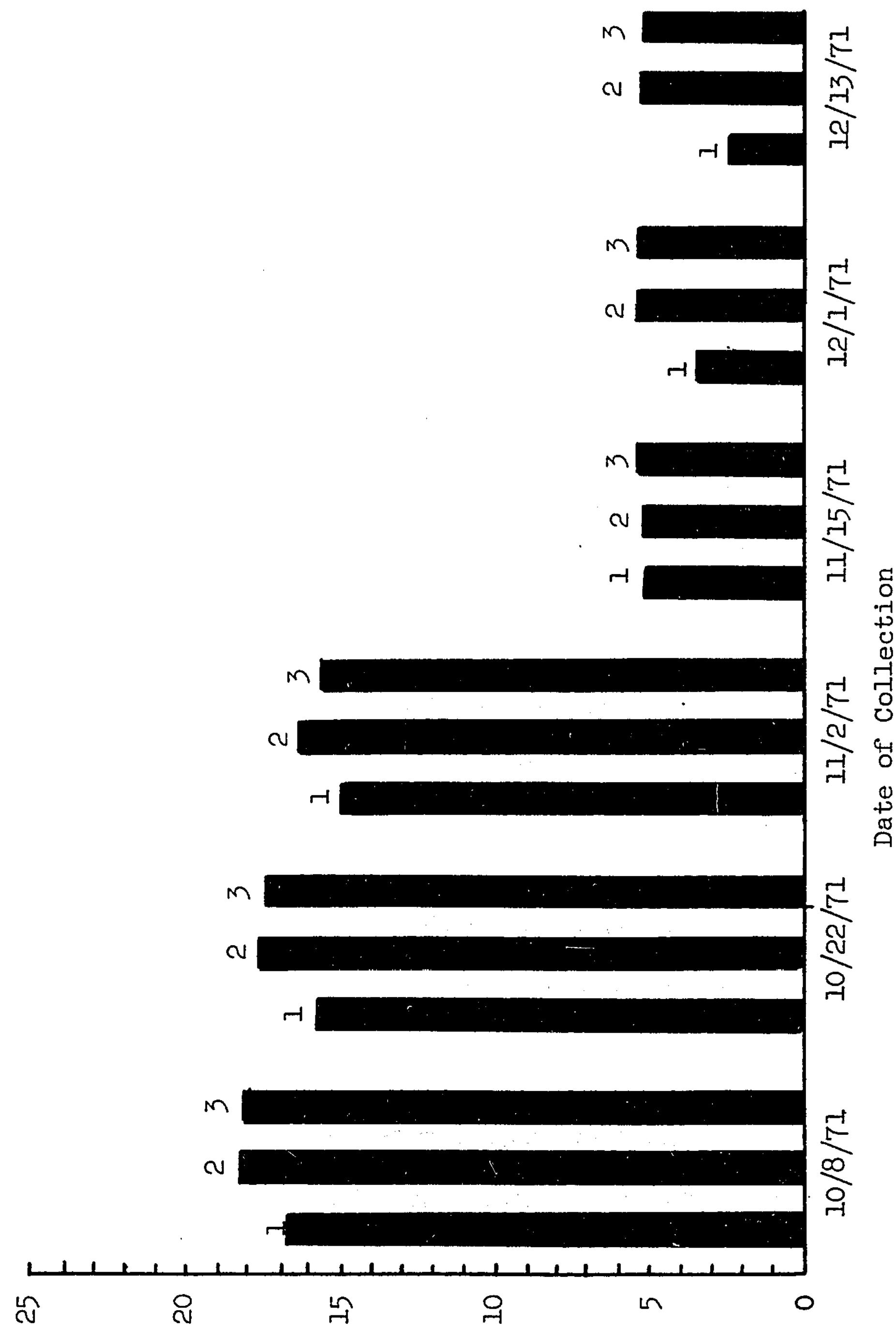

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Graph 3. Temperature of Water at the Time of Collection Expressed as Degrees Centigrade.

Each bar is identified by the station number at the top. The paper mill discharge was out of the creek on 11/15/71. The paper mill discharge was removed permanently on 12/17/71.

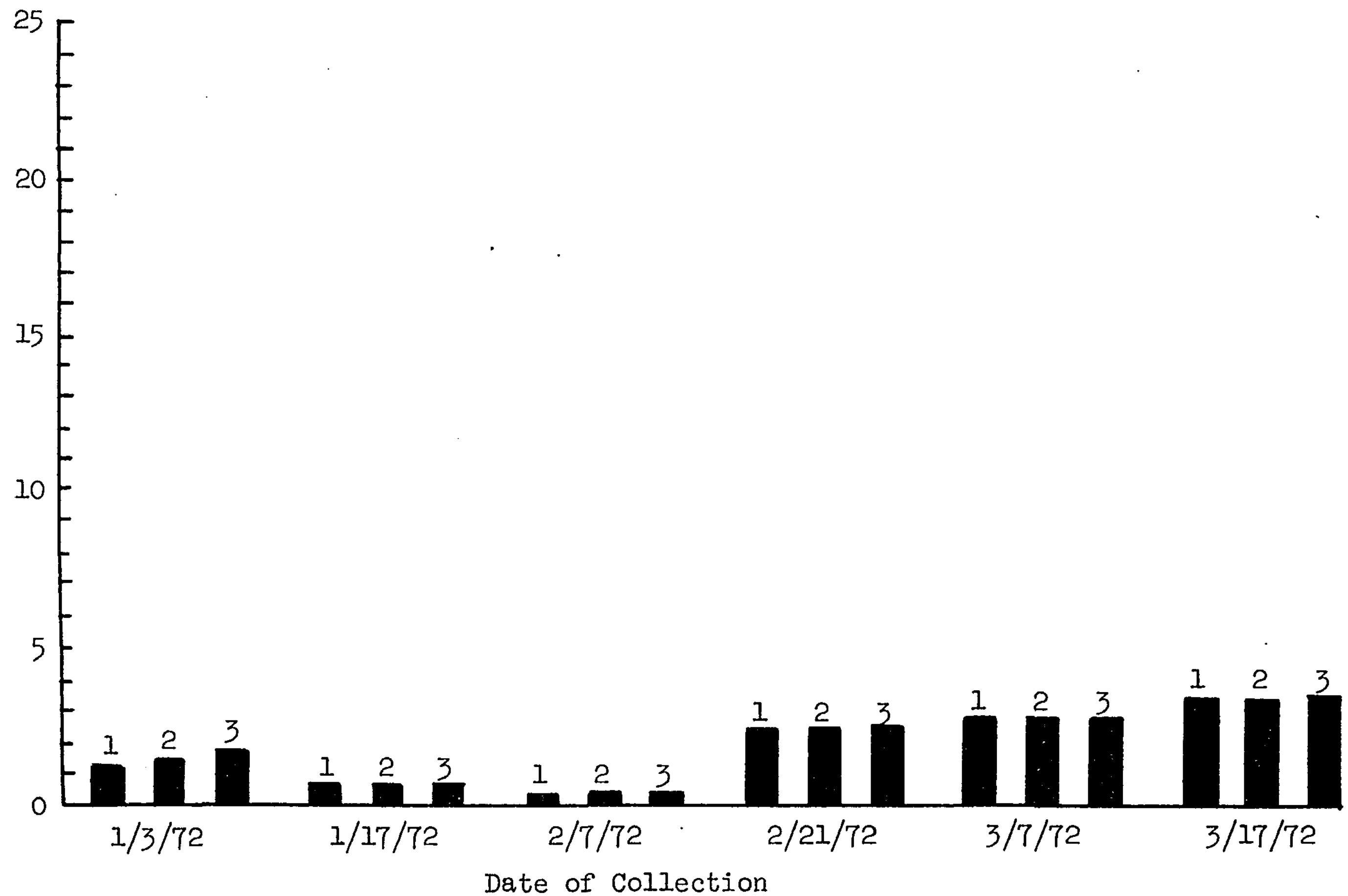
Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Graph 3. Temperature of Water



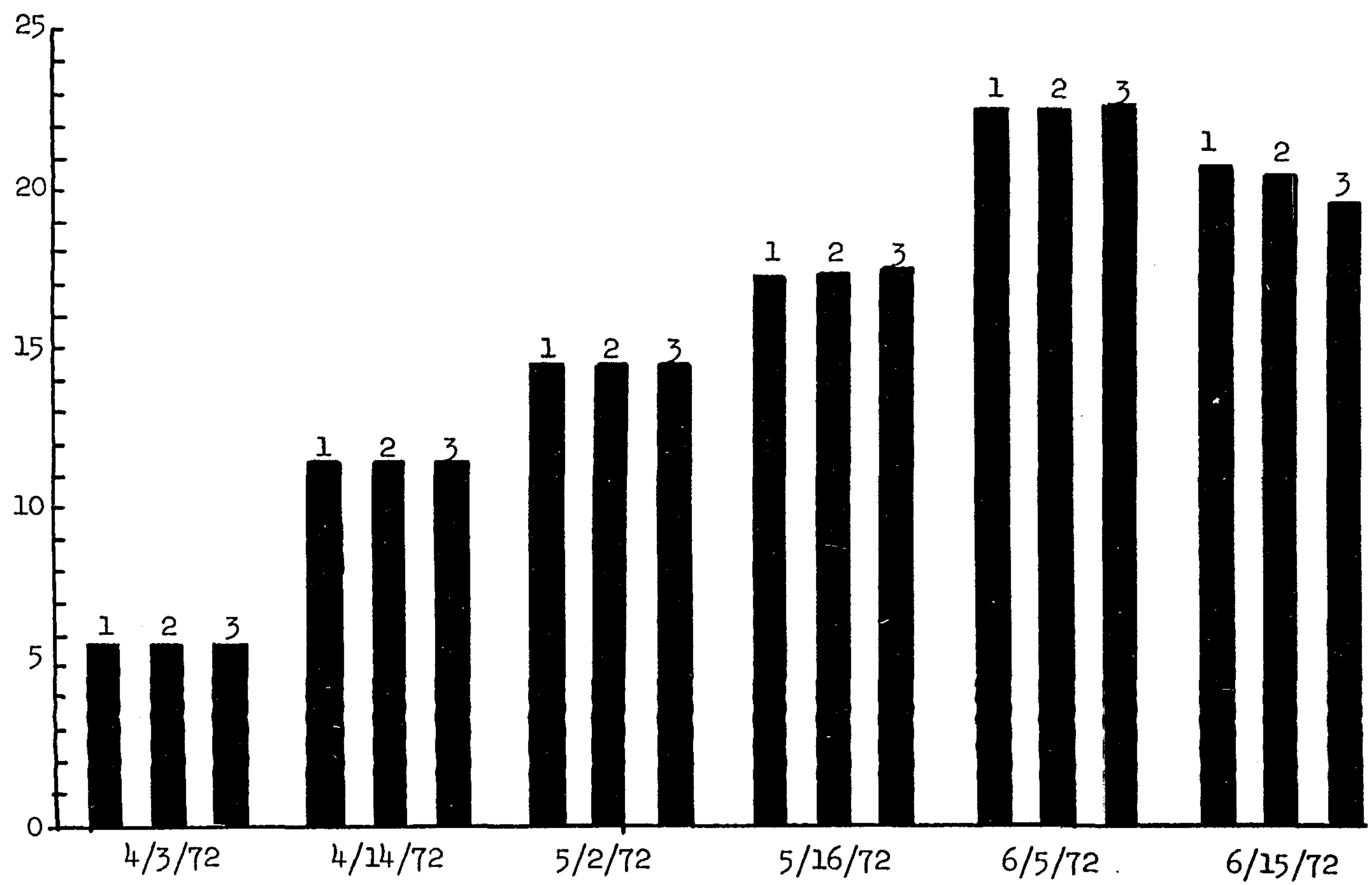

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Graph 3 (Cont.). Temperature of Water



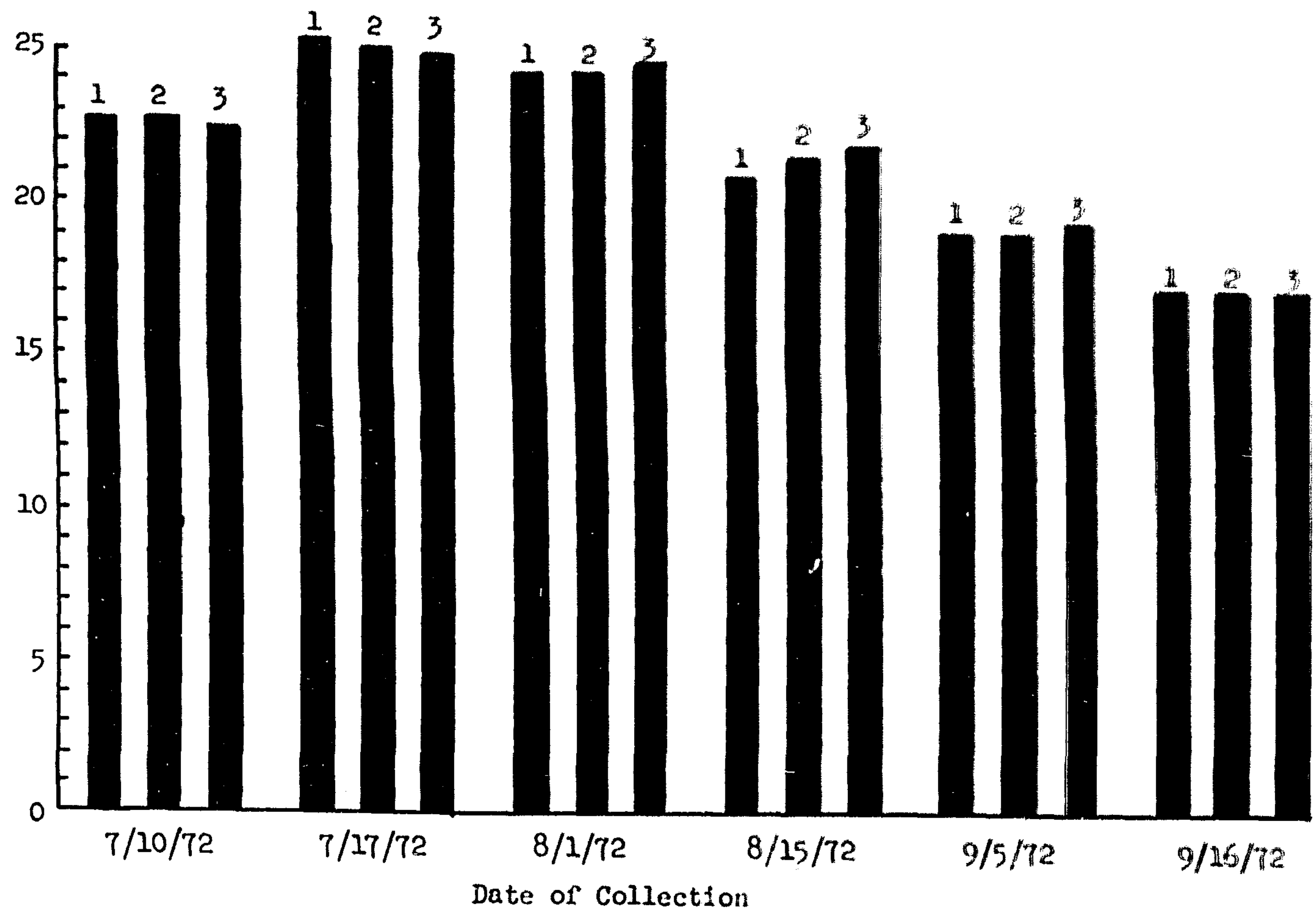

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Graph 3 (Cont.). Temperature of Water




Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Graph 3 (Cont.). Temperature of Water



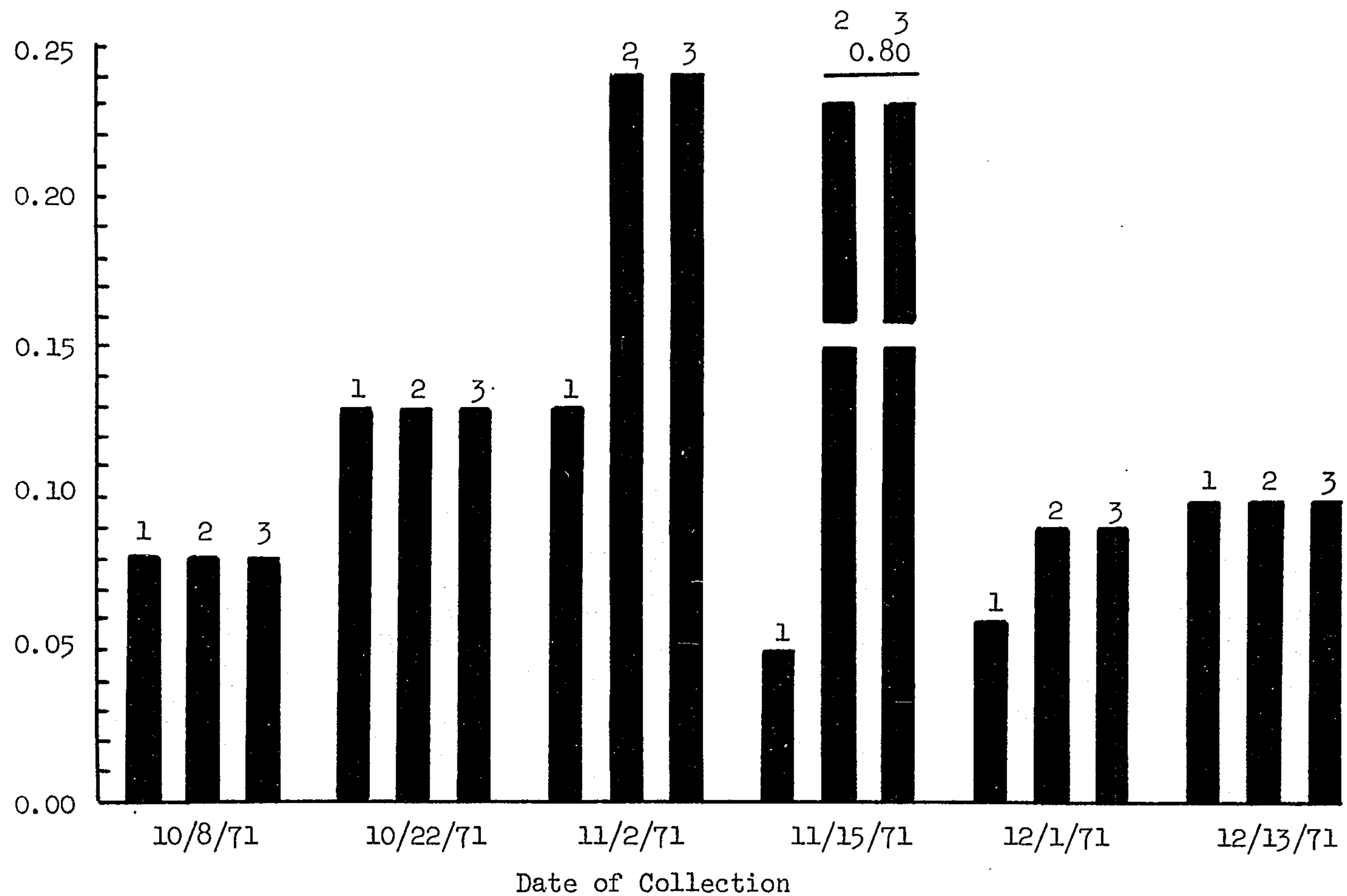

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Graph 4. Average Total Soluble Phosphates at the Time of Collection Expressed as mg/l Phosphorus.

Each bar is identified by the station number at the top. The paper mill discharge was out of the creek on 11/15/71. The paper mill discharge was removed permanently on 12/17/71.

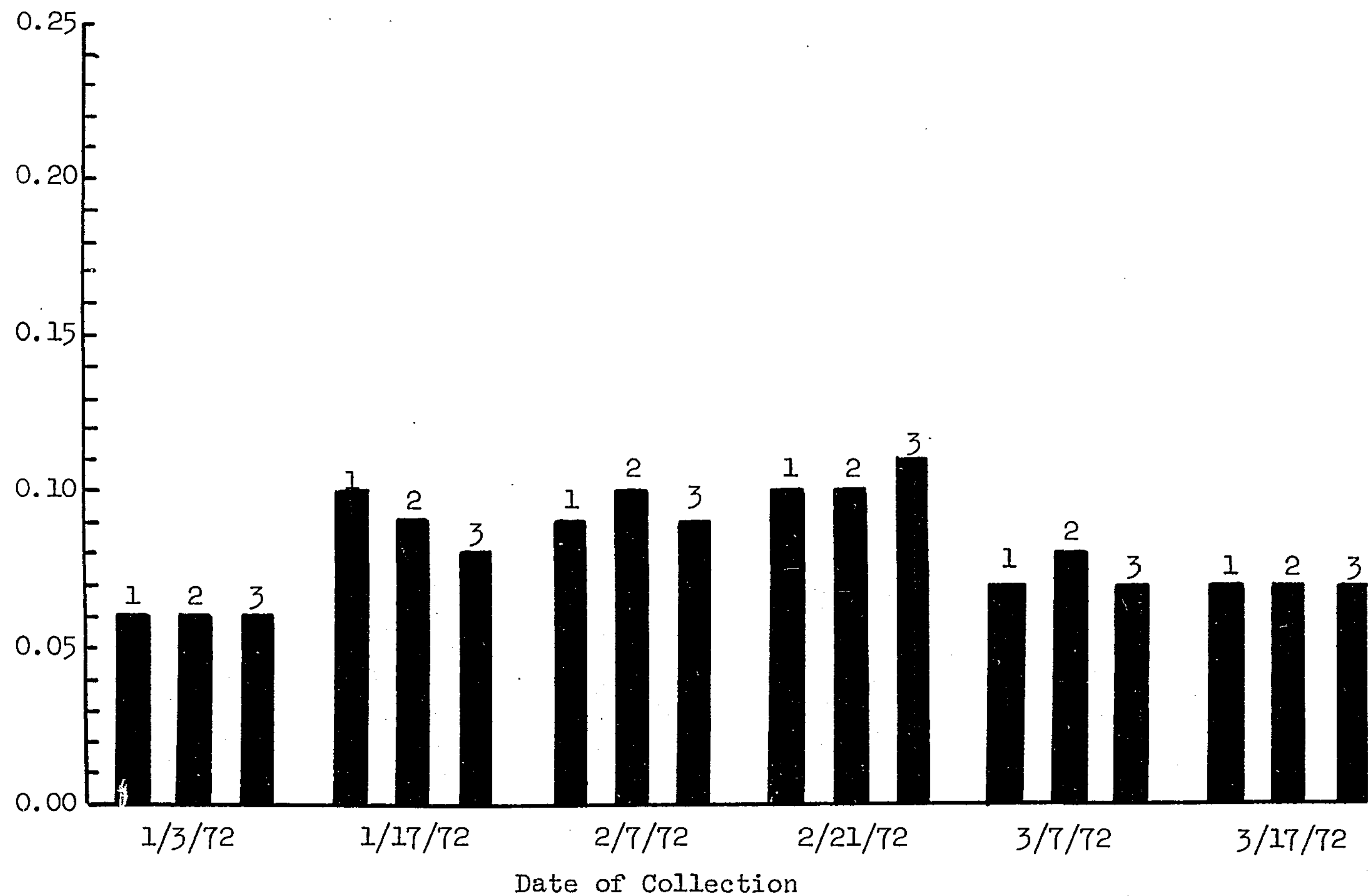
Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Graph 4. Total Soluble Phosphates



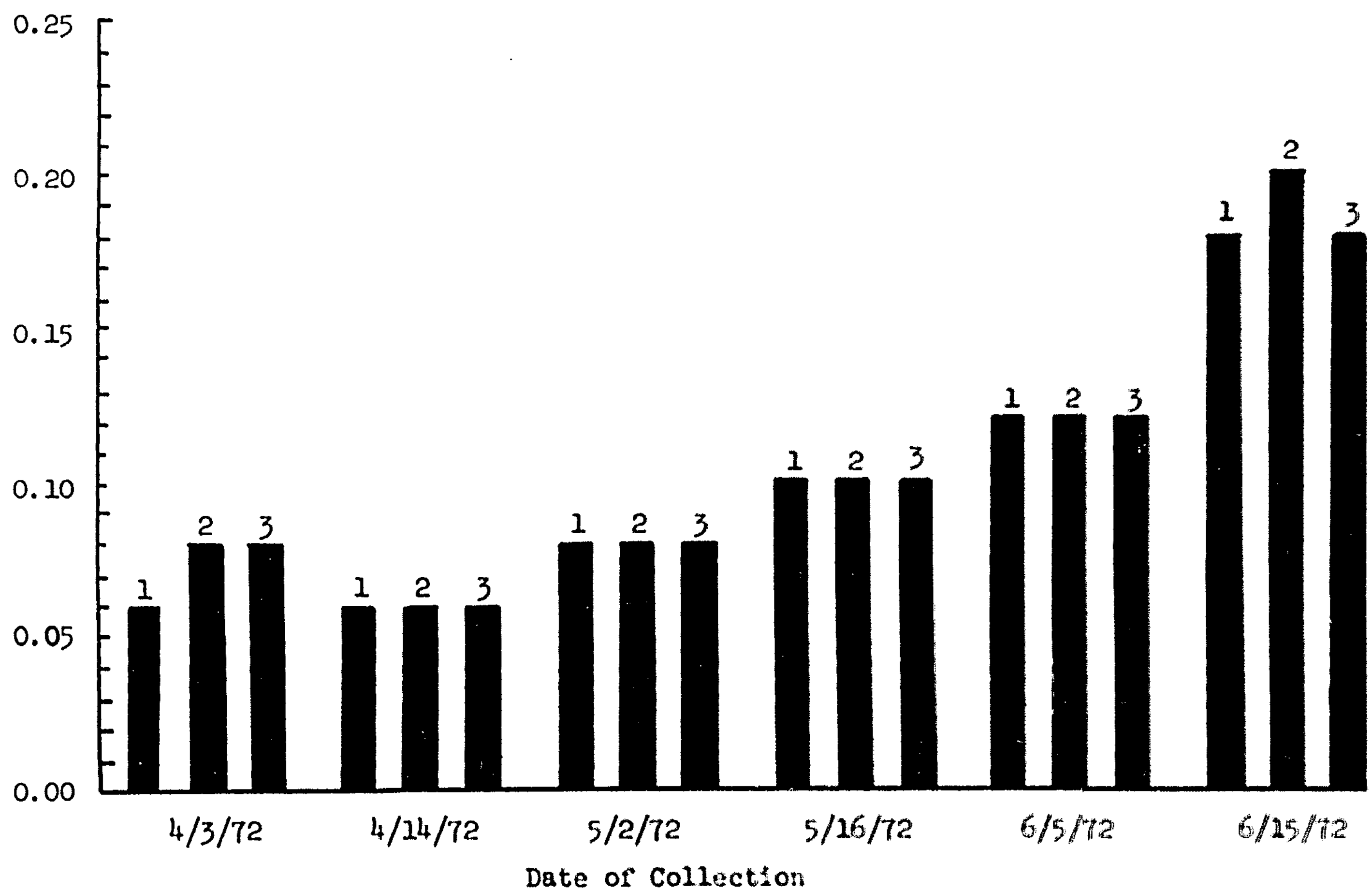

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Graph 4 (Cont.). Total Soluble Phosphates




Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

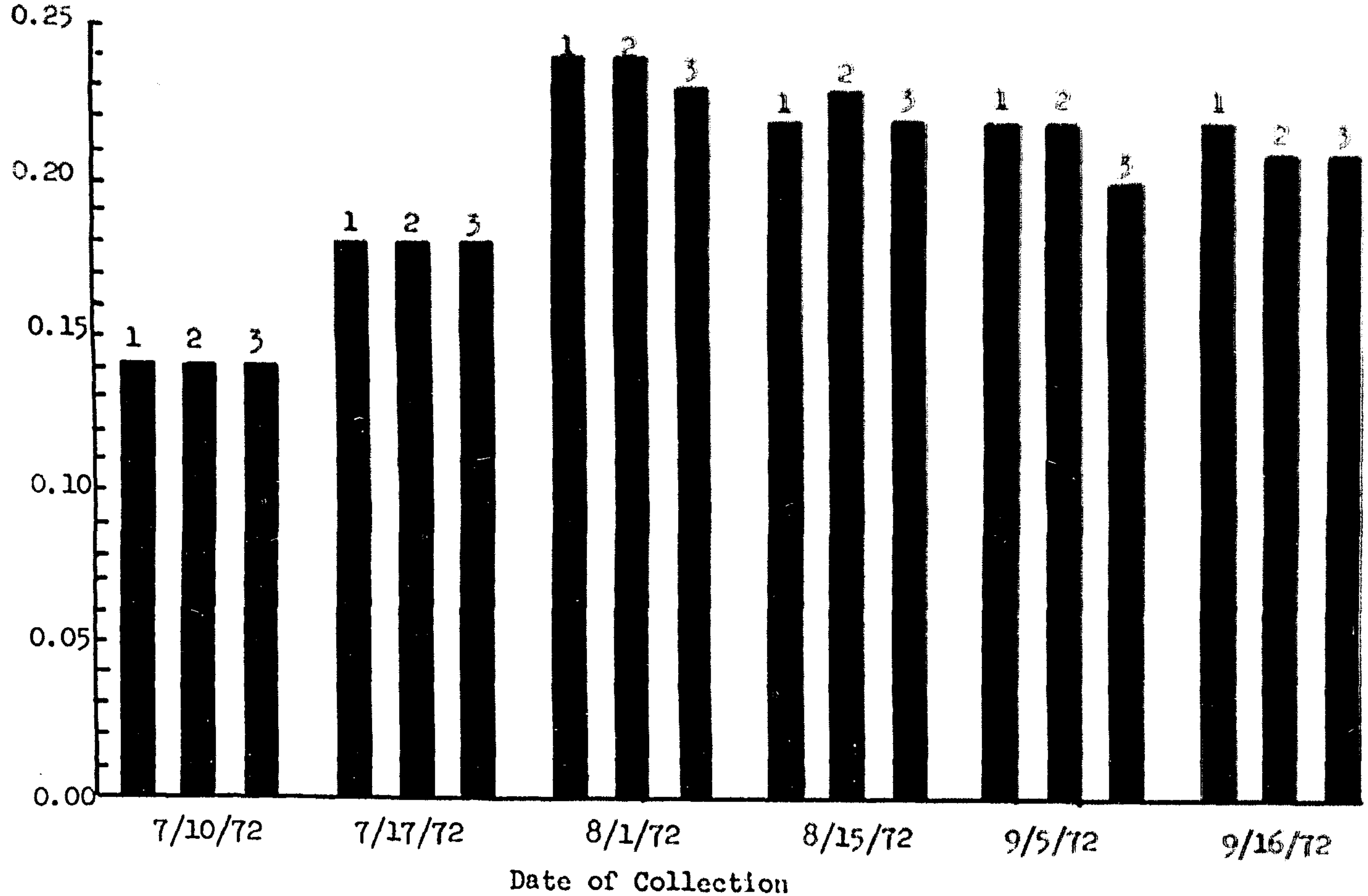
Graph 4 (Cont.). Total Soluble Phosphates






Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Graph 4 (Cont.). Total Soluble Phosphates



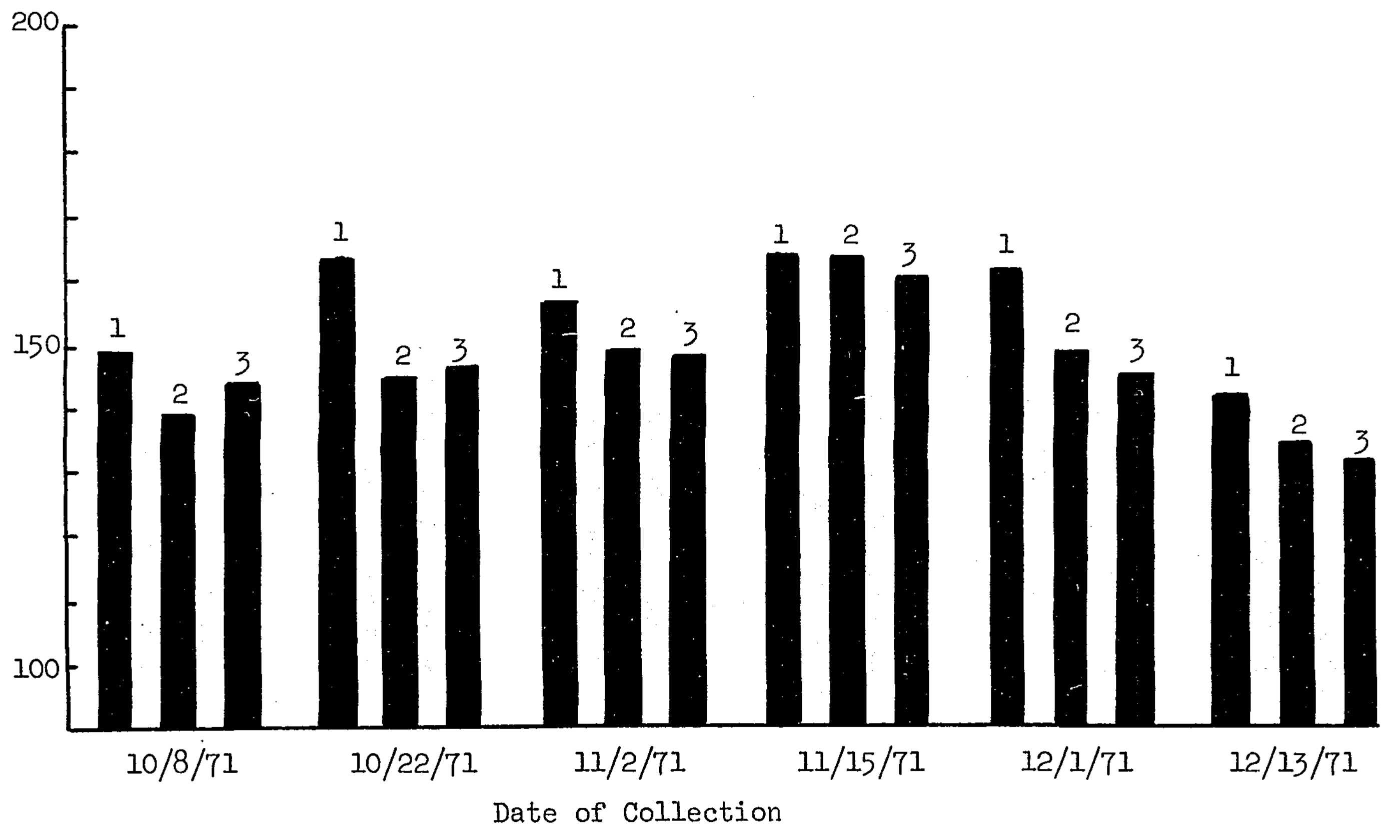

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Graph 5. Average Total Alkalinity of Water at the Time of Collection Expressed as mg/l Calcium Carbonate.

Each bar is identified by the station number at the top. The paper mill discharge was out of the creek on 11/15/71. The paper mill discharge was removed permanently on 12/17/71.

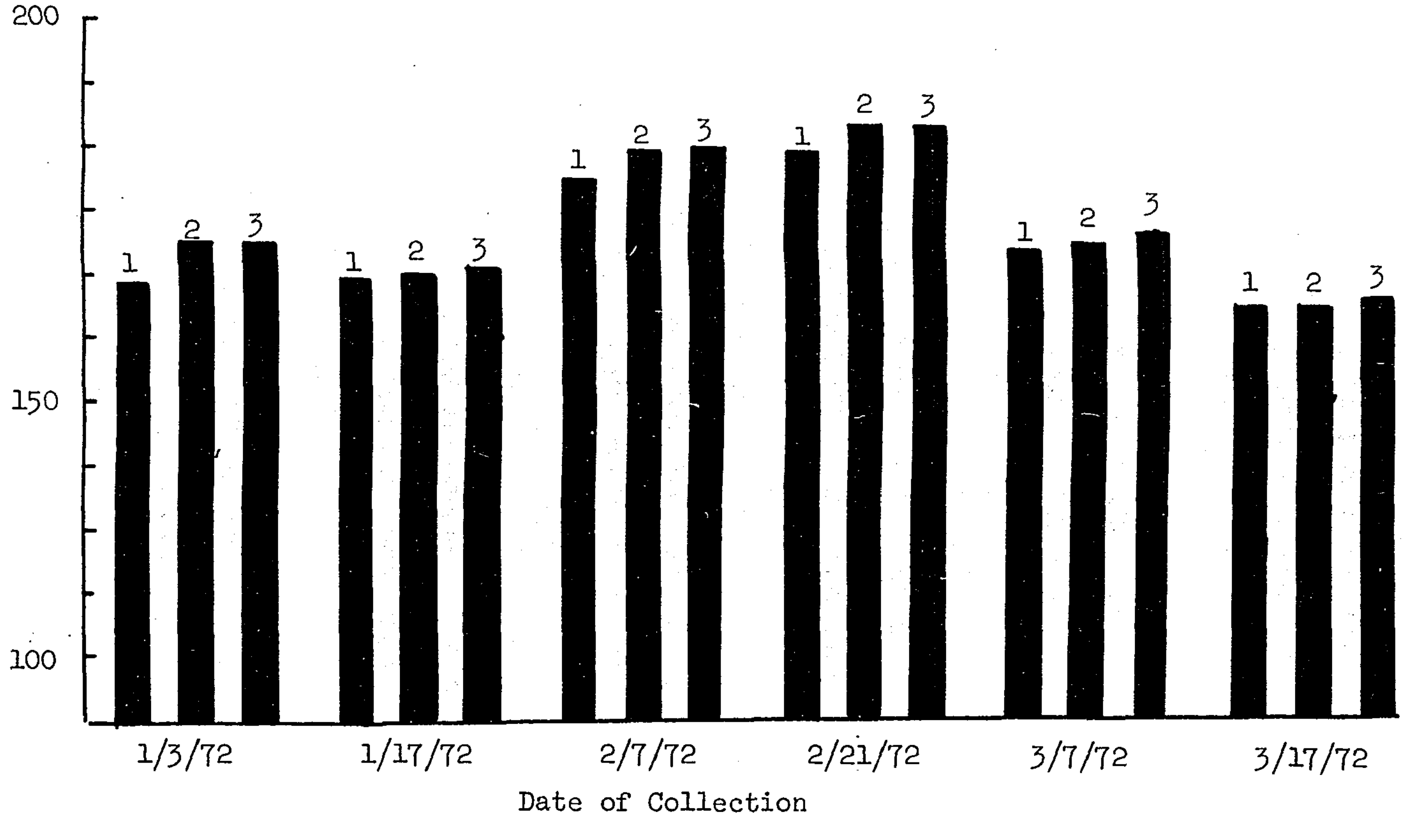
Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Graph 5. Total Alkalinity



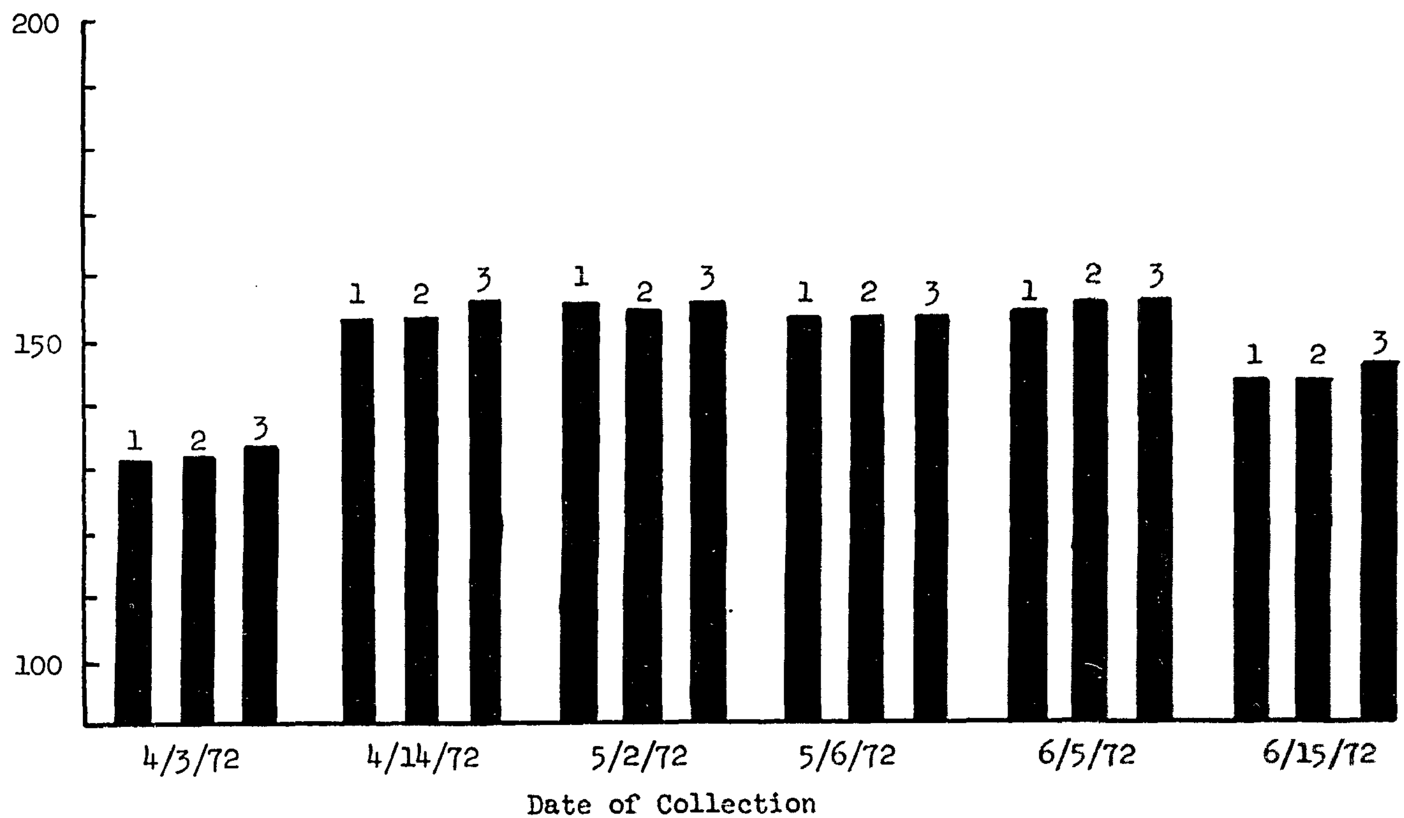

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Graph 5 (Cont.). Total Alkalinity



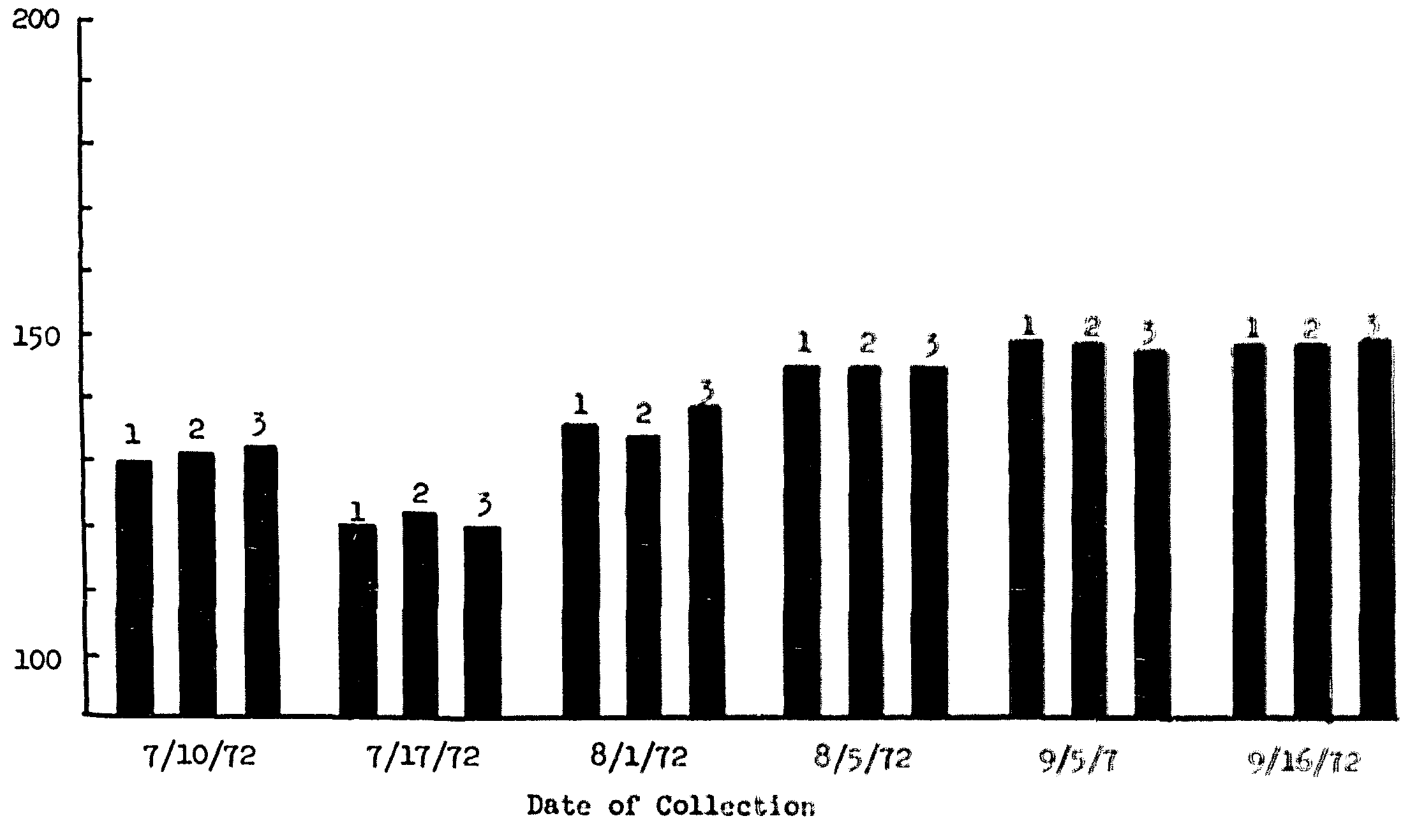

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Graph 5 (Cont.). Total Alkalinity




Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Graph 5 (Cont.). Total Alkalinity



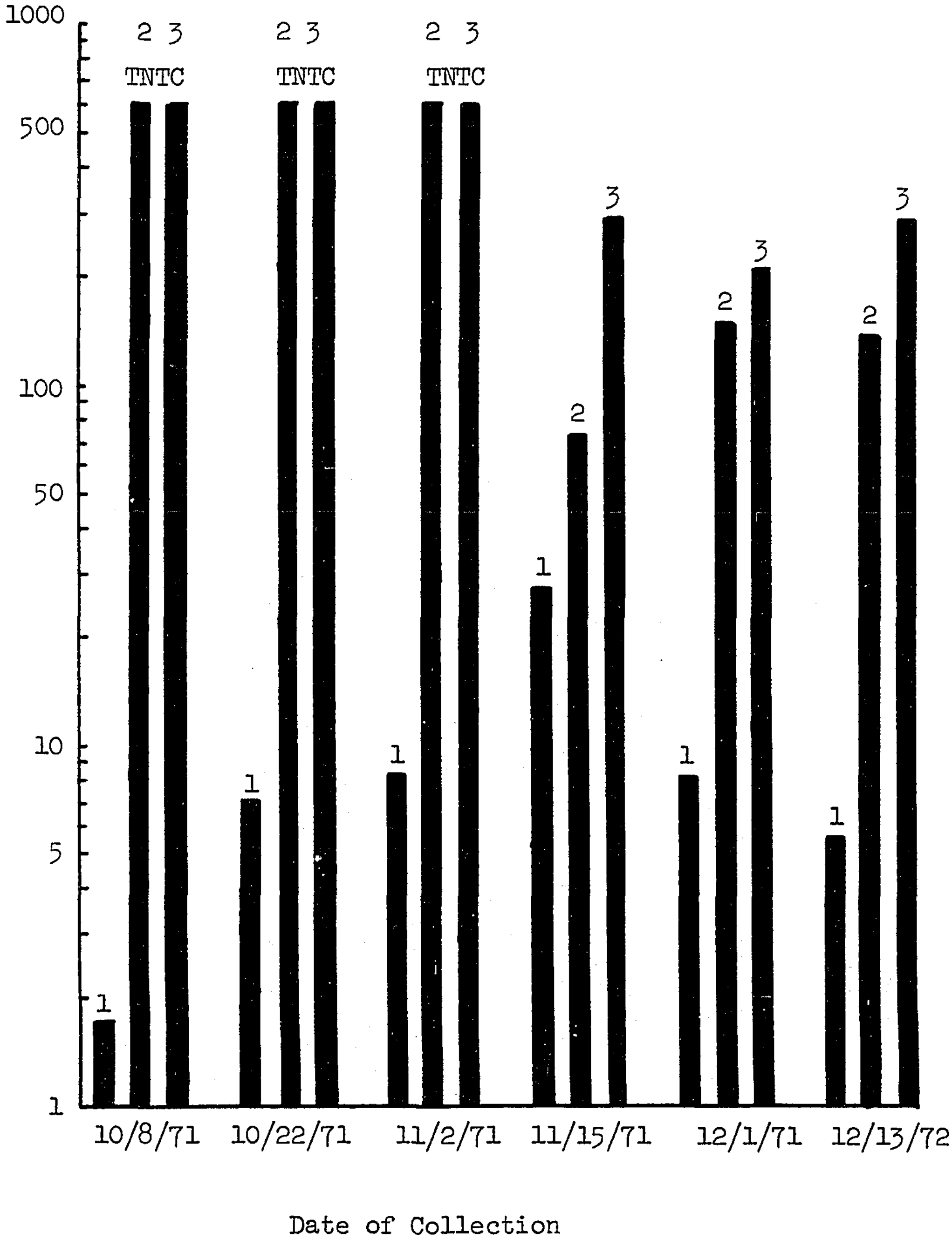

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Graph 6. Average Total Count of Bacteria and Fungi at the Time of Collection Expressed as 1000 Colonies per 100 ml on Logarithmic Scale.

Each bar is identified by the station number at the top. The paper mill discharge was out of the creek on 11/15/71. The paper mill discharge was removed permanently on 12/15/71. TNTC = Too numerous to count.

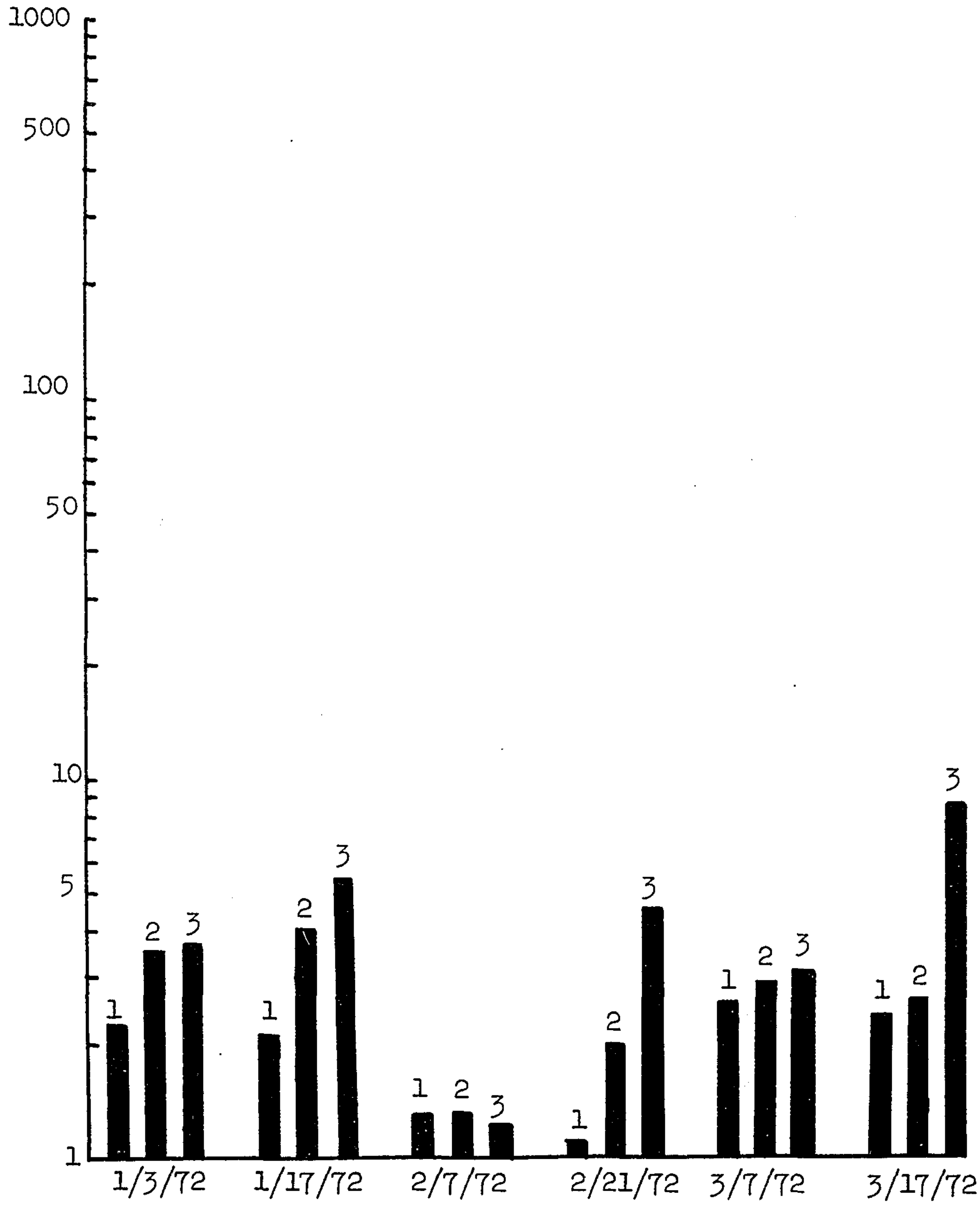
Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Graph 6. Total Count of Bacteria and Fungi




Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

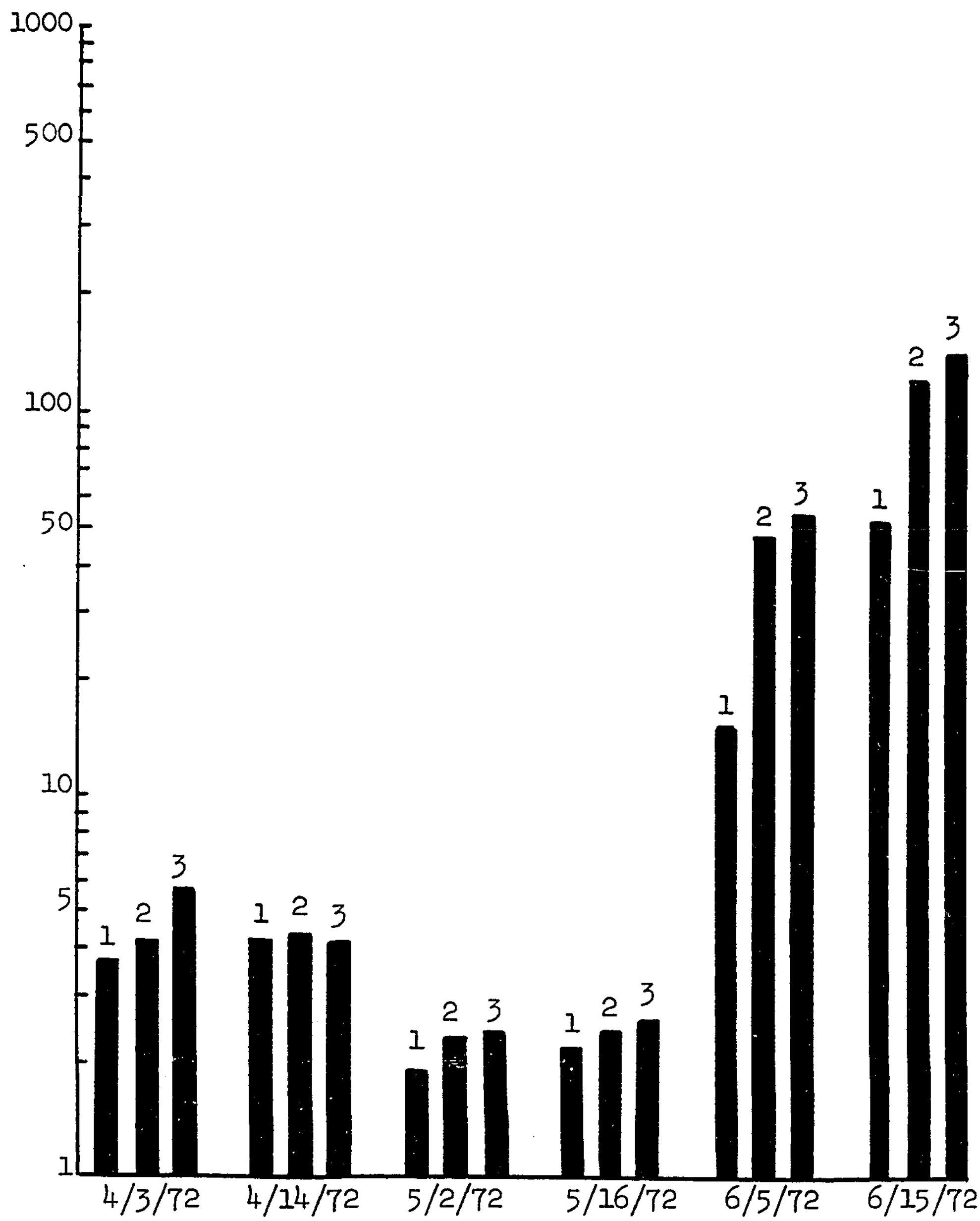
Graph 6 (Cont.) Total Count of Bacteria and Fungi




Date of Collection

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

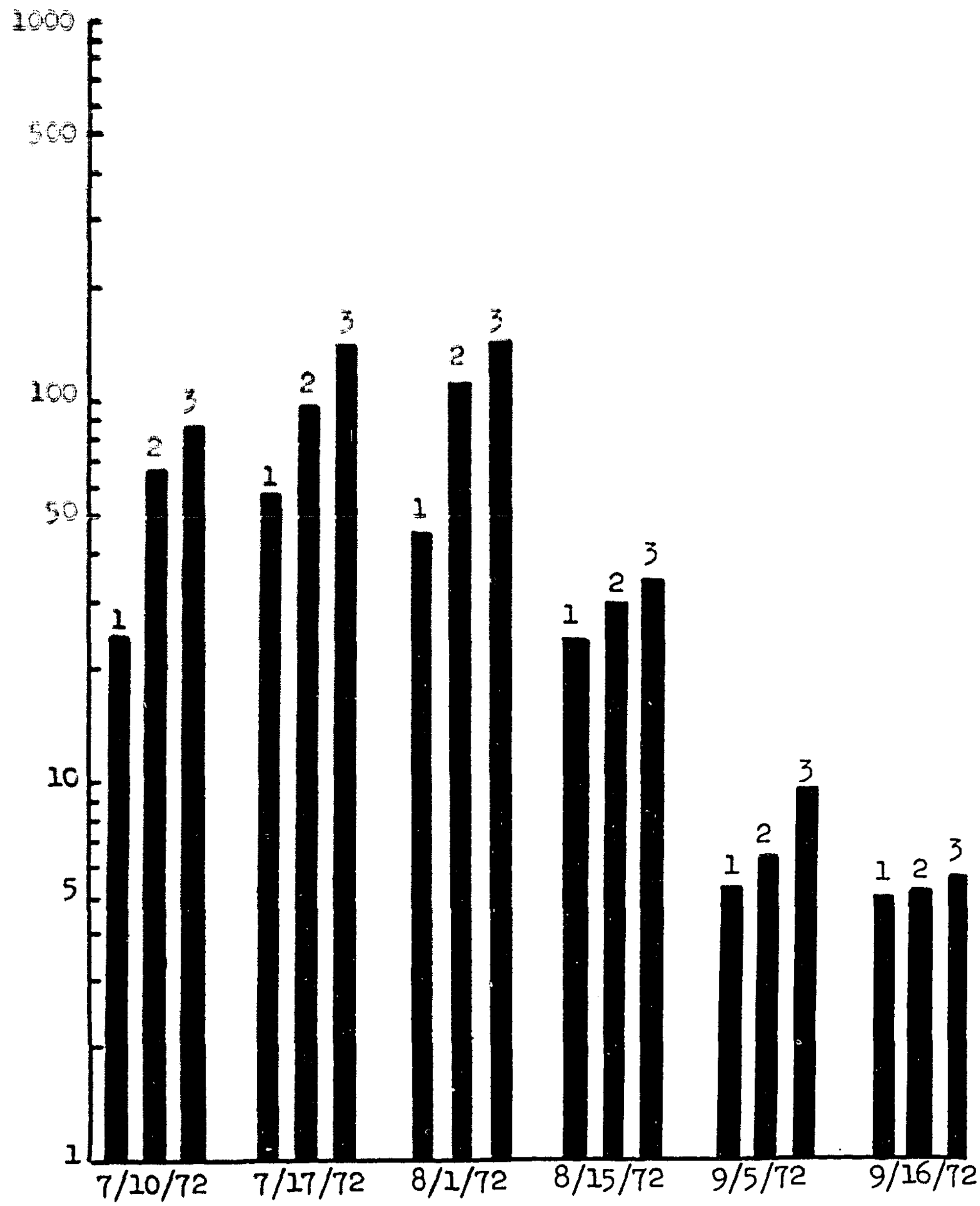
Graph 6 (Cont.). Total Count of Bacteria and Fungi




Date of Collection

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Graph 6 (Cont.). Total Count of Bacteria and Fungi



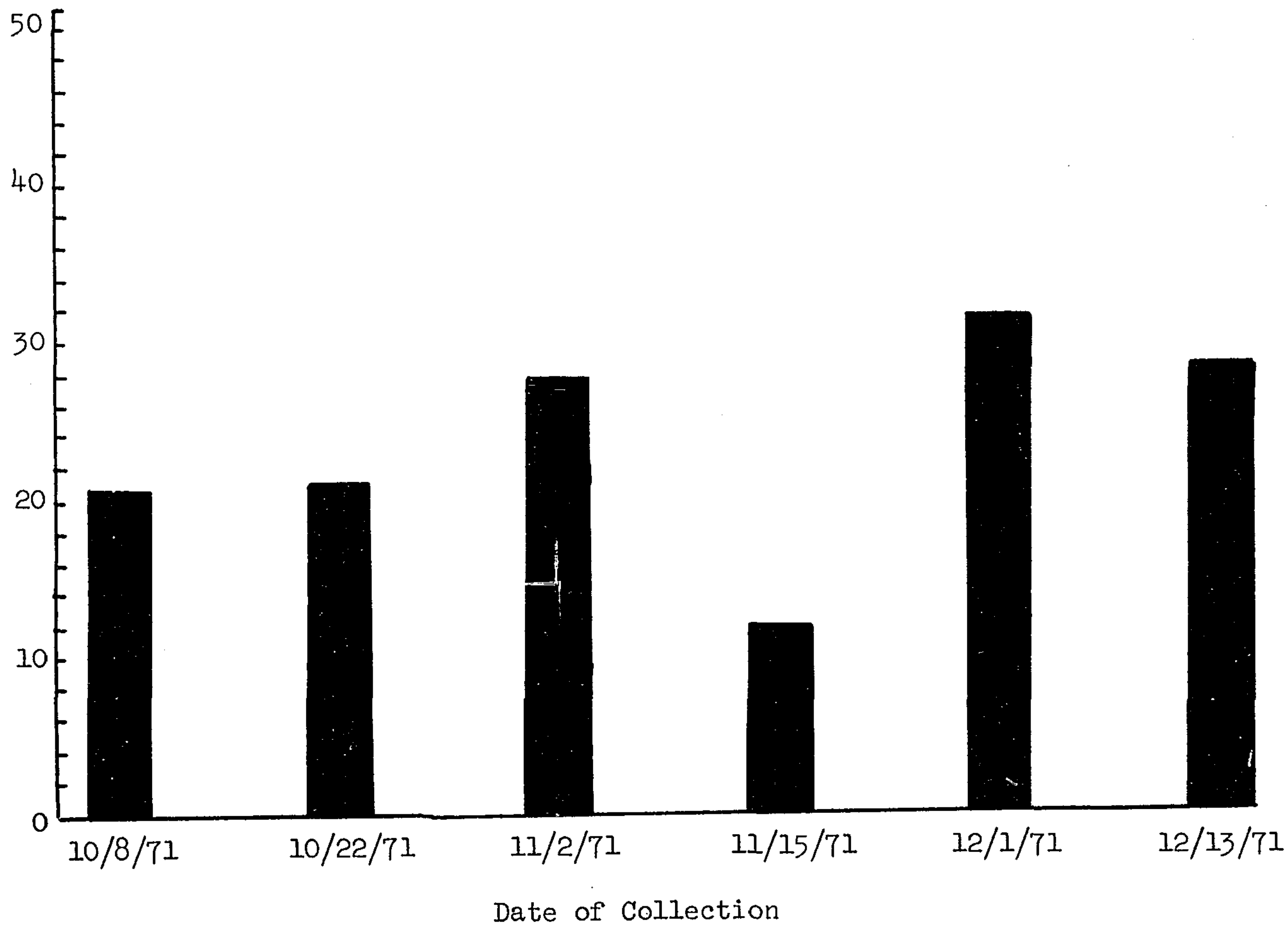

Date of Collection

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Graph 7. Total Flow of Sunset Lake Weir at the Time of Water Collection Expressed as Million Liters per Day.

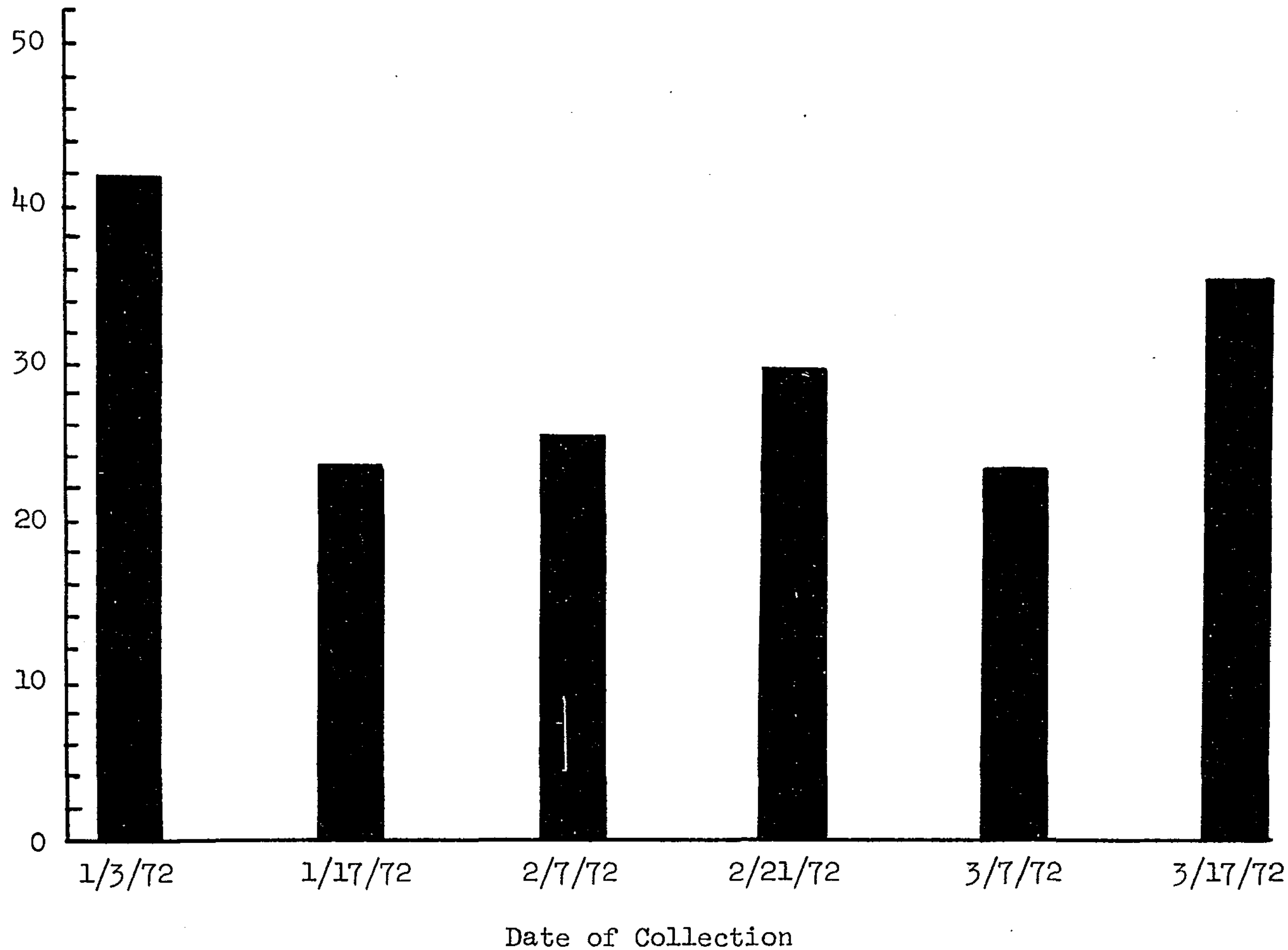
Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Graph 7. Flow of Sunset Lake Weir



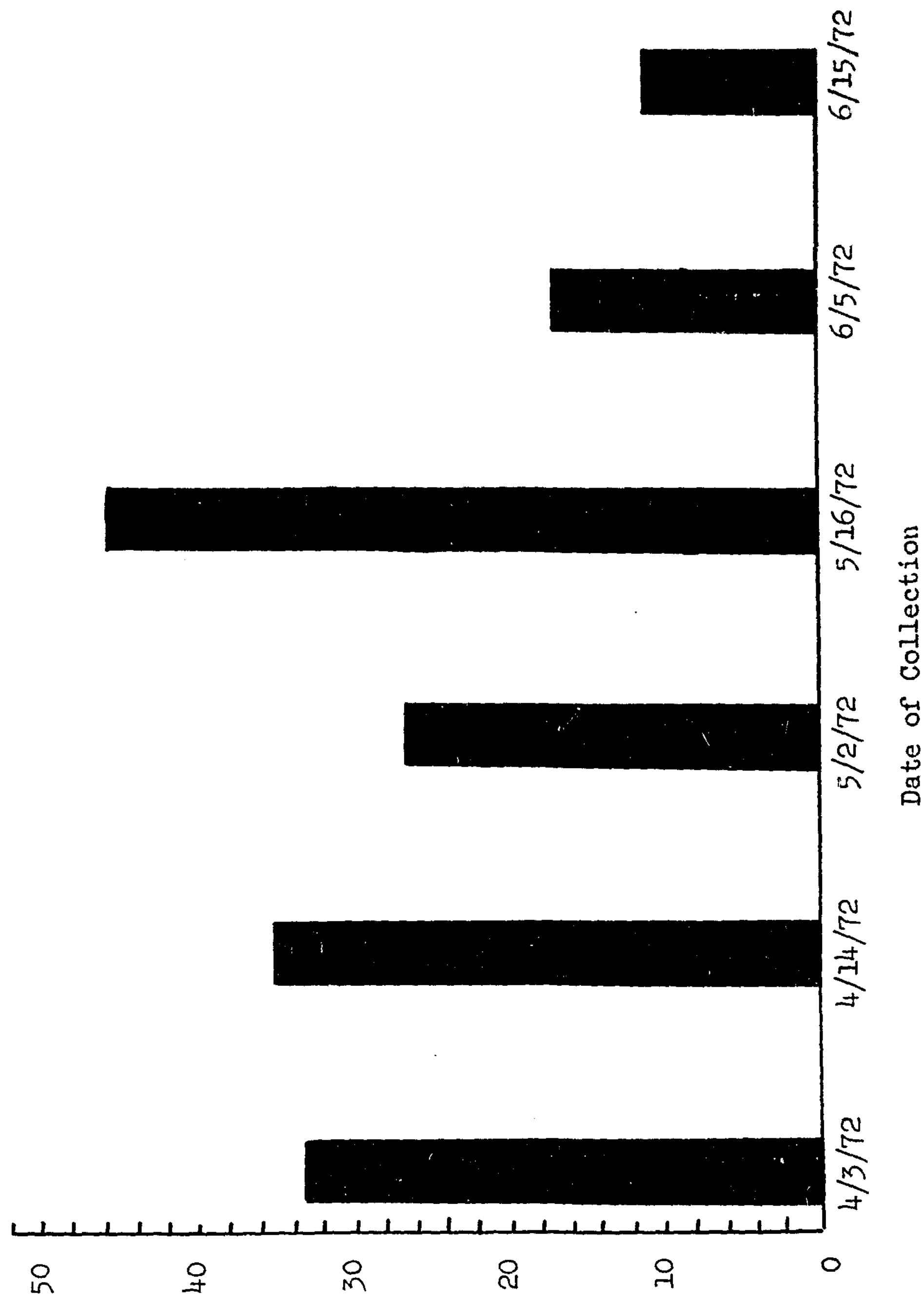

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Graph 7 (Cont.). Flow of Sunset Lake Weir



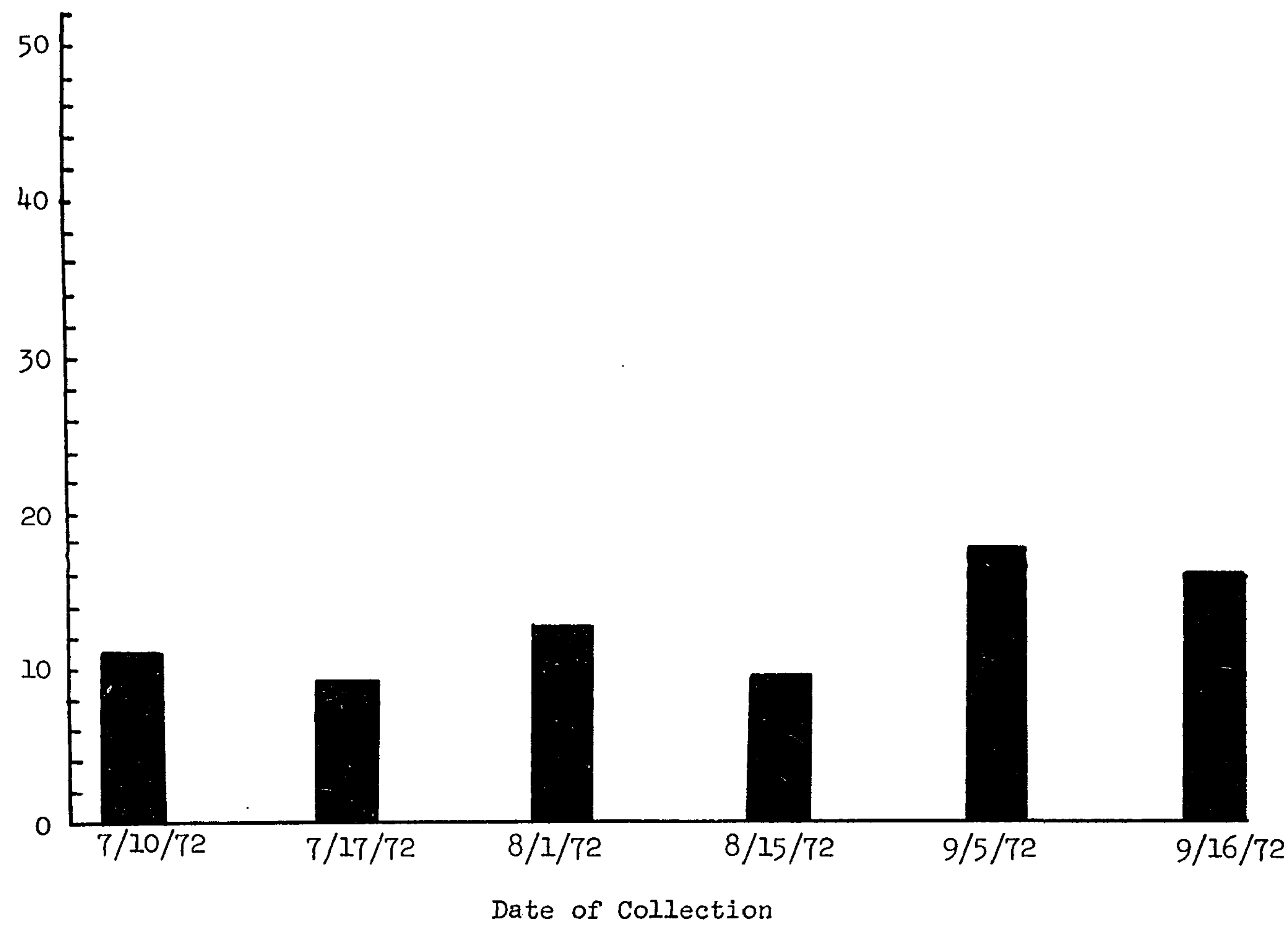

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Graph 7 (Cont.). Flow of Sunset Lake Weir




Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Graph 7 (Cont.). Flow of Sunset Lake Weir





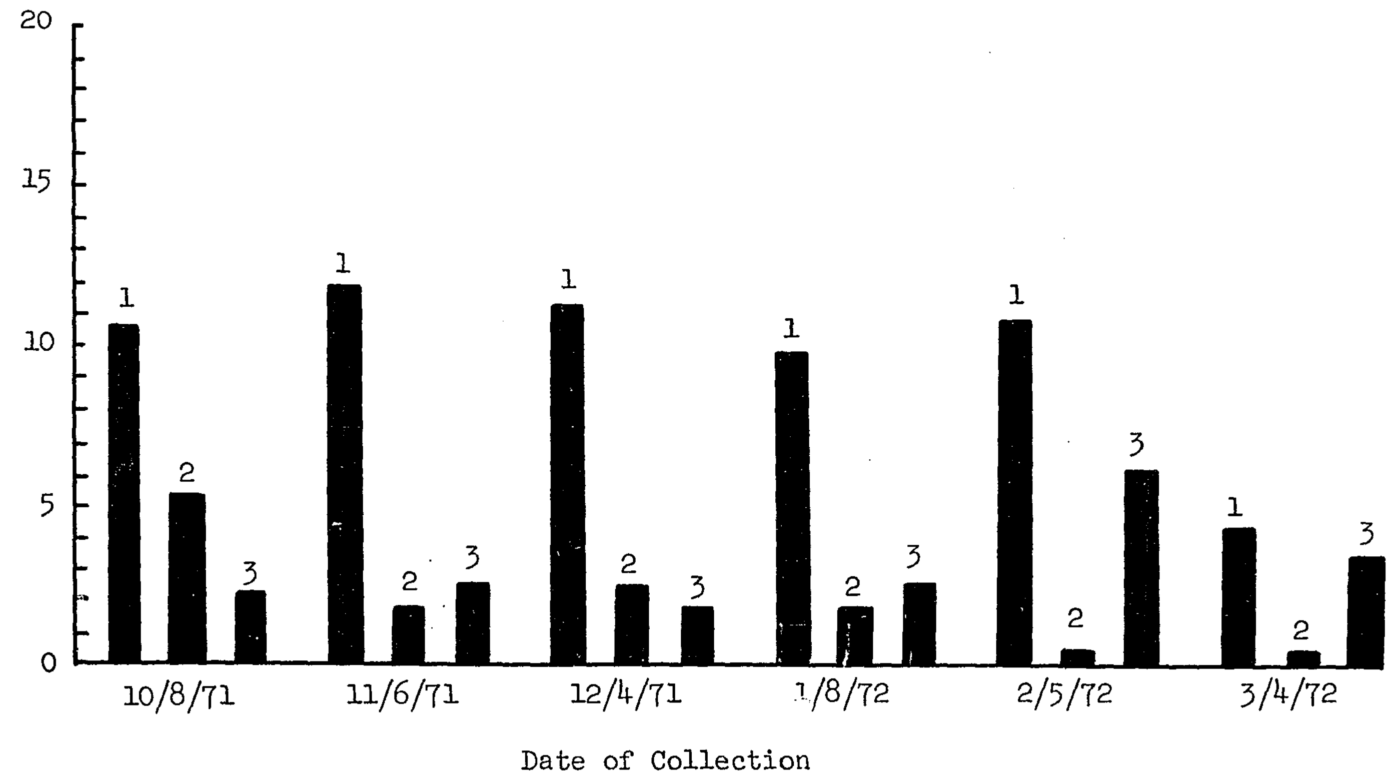

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Graph 8. Population Densities of Benthic Macrofauna at the Time of Collection Expressed as Thousands per Square Meter.

Each bar is identified by the station number at the top. The paper mill discharge was removed on 12/17/71.

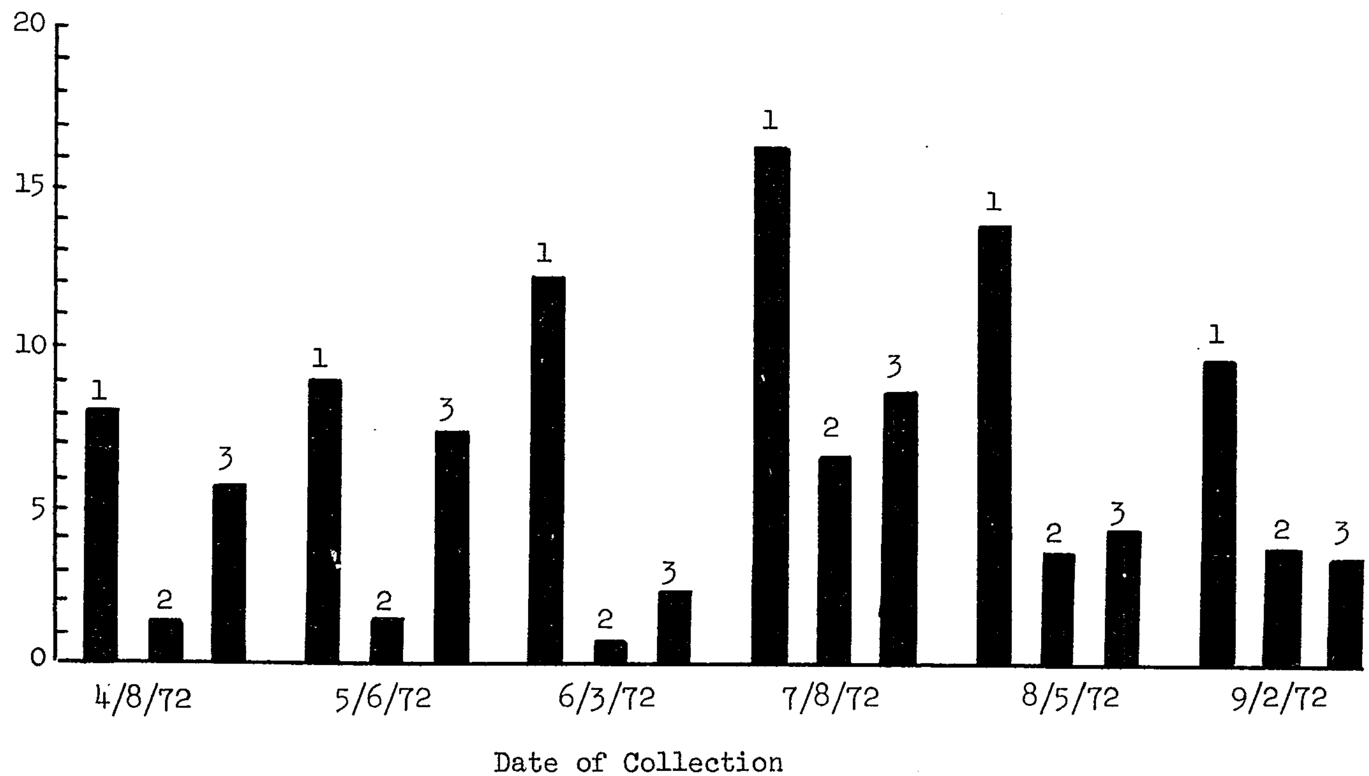
Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Graph 8. Population Densities of Benthic Macrofauna




Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Graph 8. Population Densities of Benthic Macrofauna
(Cont.)





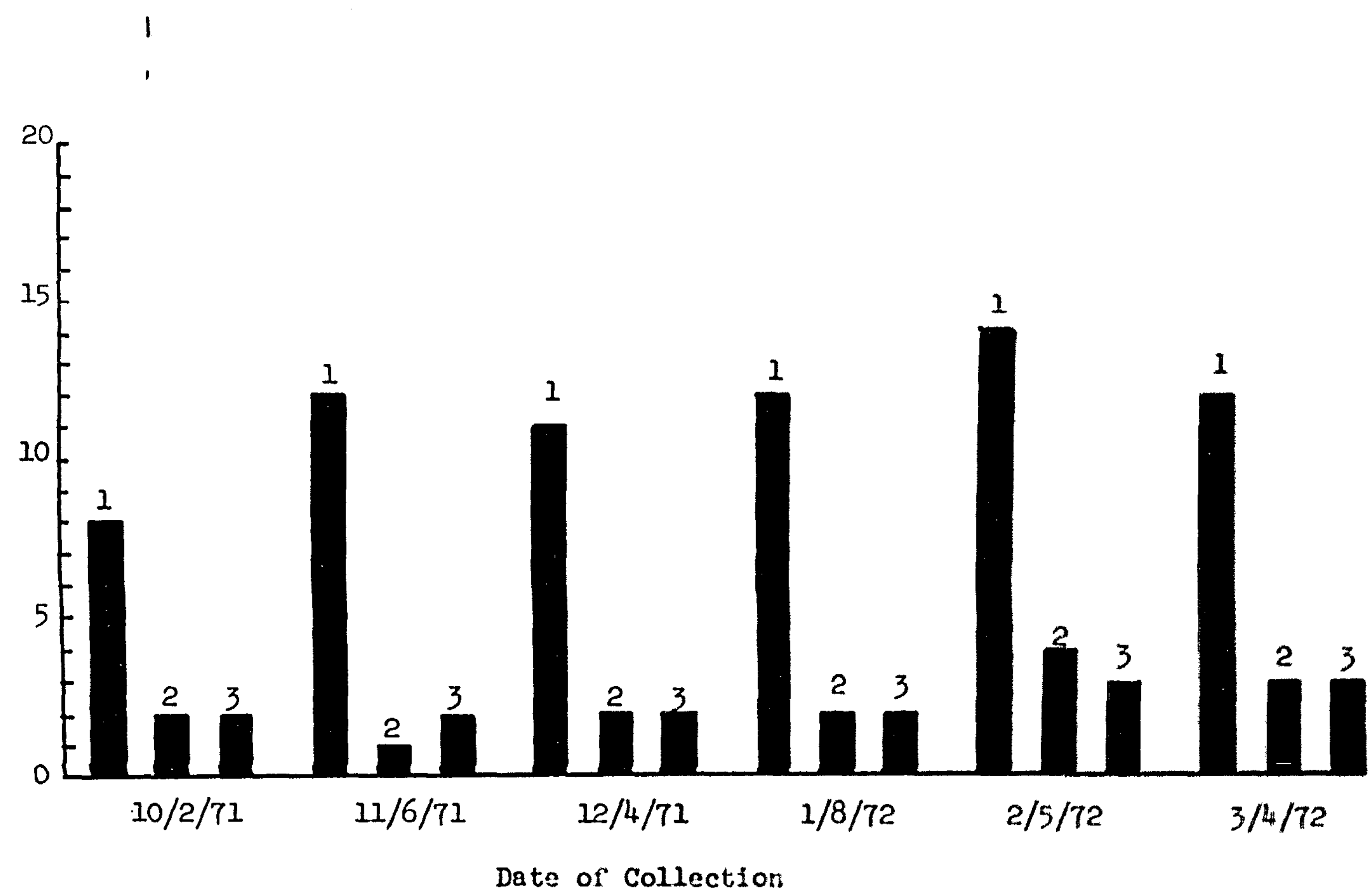

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Graph 9. Number of Benthic Taxa Found at the Time of Collection at Each Station.

Each bar is identified by the station number at the top. The paper mill discharge was removed on 12/17/71.

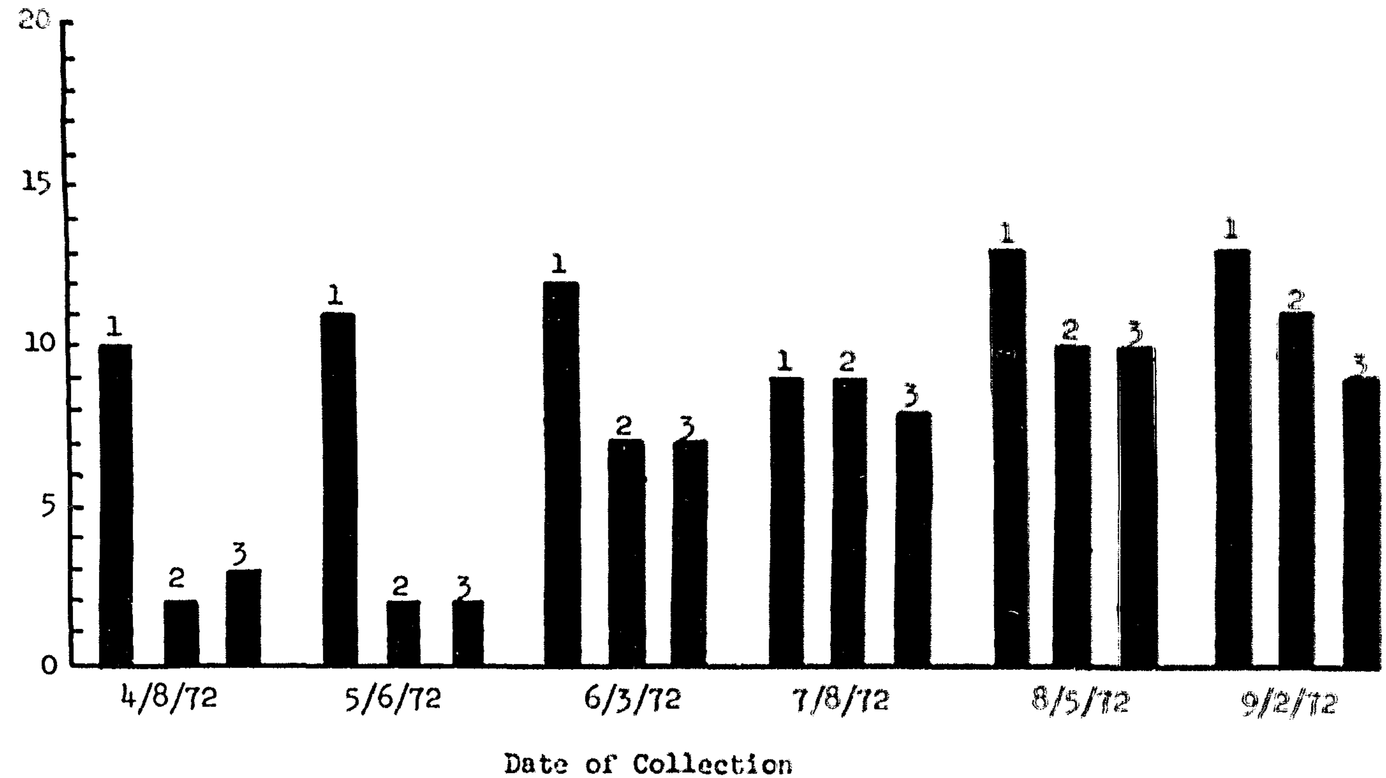
Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Graph 9. Number of Benthic Taxa




Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Graph 9 (Cont.). Number of Benthic Taxa




Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

## DISCUSSION

From the results of this study, it was apparent that the presence of the paper mill effluent resulted in numerous alterations of Portage Creek. A many fold increase in the levels of total coliforms was one of the consequences of the discharge. Following the removal of the discharge, the level of coliforms remained essentially equal throughout the winter months until May, and then the two test stations began to show an increase as compared to the control station.

The total coliform group includes a number of non-fecal groups such as Aerobacter aerogenes as well as fecal types. All of the paper mill's sewage is pumped to the Vicksburg Municipal Waste Treatment Plant and not through the clarifier. A. aerogenes is known to be hosted by a multitude of sources, including plants, soil, and certain industrial effluents.

Blosser, Carpenter, and Owens (1970) reported that many of the total coliforms failed to pass verification as fecal coliforms when they tested pulp and paper mill effluents. Currently, they reported, there is very limited knowledge of the presence or absence of fecal coliforms in pulp and paper mill effluents.

The total count of bacteria and fungi also showed increased levels due to the addition of the discharge. As with the total coliforms, the total count of all three stations remained nearly equal until May when the test stations began to show a more apparent divergence from the control station. These increases corresponded



Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

with the rise of water temperature to 20°C in the latter part of May; an increased drop in dissolved oxygen over the test stations, as contrasted to the control station, was also noted.

As many workers have reported, Heukelkian (1953) and Ostertag (1952), the bacterial action on the benthal deposits is perhaps the most important phase of self-purification. As the test stations have large amounts of deposits, one should expect an increase in bacterial numbers with an increase in benthal decomposition.

Hurwitz (1961) found that the decomposition of benthal deposits was influenced by both retention time and temperature. In a study by Leclere (1964), the intensity of self-purification was found to be reduced in the winter and an increase was reported in the summer. Klust and Mann (1954) found that the rate of decomposition of cotton thread was increased by increasing temperature, the most rapid rise being after 20°C was reached.

Gehn (1953) stated that only after the stream velocity exceeded that which allowed the formation of the benthal deposits, would scouring occur. In comparing the BOD, COD, suspended solids, and turbidity of station three to the control station, slight measurable differences could be seen. One thing to be remembered is that the decomposition of the deposits would change its nature, thereby possibly allowing scouring to occur.

Heukelkian (1953) stated that the anaerobic decomposition of benthal deposits tends to be beneficial on the oxygen economy of a stream because the products, reduced gases such as methane and hydrogen sulfide, tend to escape into the atmosphere. This removal

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

into the atmosphere would not add to the BOD and COD load or decrease the dissolved oxygen of the creek. In work reported by McKeown, Benedict, and Locke (1968), it was observed that there was little significant change in oxygen demand of benthal deposits after thirty centimeters of depth, and they suggested that this depth dependency may be significantly less. This would indicate that only the upper surface layer would be undergoing aerobic oxidation, and the larger lower portion would be undergoing anaerobic reactions. As a large portion of this material would have been reduced by the time it reached the surface of the deposits, the dissolved oxygen would not be as affected by the lower anaerobic level as by the upper aerobic level of the deposits.

During the stream's recovery, there was no measurable change in either pH or alkalinity of the two test stations as contrasted to the control station. The pH of the paper mill effluent was essentially neutral, and was composed of approximately fifty percent inert organic matter such as fiber fragments, starches, and gelatins. This should, therefore, represent the composition of the benthic material.

On several occasions during this study benthic samples of the upper ten centimeters from the three stations were obtained and their pH was measured. In all cases, their pH did not vary by more than one and a half pH units from neutrality. Thus, there would not appear to be any reason why the decomposition of the benthal deposits, over the area studied, would have any measurable effects upon the pH or alkalinity.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

On several test periods when the discharge was present, there was a slight apparent increase in nitrates and phosphates caused by the discharge; neither were found to be significant to the five percent level of significance. One would expect that there would be a significant increase in organic nitrogen caused by the presence of gelatin and other nitrogen containing materials in the discharge. After the removal of the discharge, the three stations were essentially equivalent in nitrate and phosphate levels throughout the remainder of this study.

Both nitrates and phosphates showed seasonal fluctuations in their concentrations throughout the study. Both increased during the spring and was most probably due to a combination of surface runoffs, upper lake turnover, and increased biological activity. Reid (1961) reported that both nitrogen and phosphorus compounds normally exhibit noticeable seasonal fluctuations in their concentrations, and that the concentrations of inorganic phosphates tend to increase in the summer due to biological activity and surface runoff.

The temperature of the water of the two test stations was raised by several degrees centigrade. This, and the dilution caused by the discharge, was part of the explanation for the rapid drop of dissolved oxygen levels of the test stations. Further, the increased dissolved matter and oxidation of the discharge would have lowered the dissolved oxygen of the creek.

The two test stations were found to have only Limnodrilus sp. and chironomid larvae present at the start of this study; by contrast,

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

the control station was found to have community of varied taxa. Cairns and Dickson (1971), along with other workers, have found that these organisms tend to increase in numbers under polluted conditions until checked by space or food availability.

While the control station had a dense growth of four species of submersed vegetation and four species of emergent vegetation, the test stations' vegetation consisted of only sparse growths of Potamogeton filiformis. With the advent of Spring, both types of vegetation of the control station had migrated downstream to the test stations. Their mass was still much less than the control, although, at the conclusion of this study.

The dense growth of vegetation at the control station provided a rich source of food and cover against predation. This may be one of the reasons why Viviparus sp. was found to nearly cover the entire floor of the control area. This dense growth also apparently provided the proper environment to allow the high numbers of Hyalella sp. and Sphaerium sp. to develop.

From the chemical data collected, when the discharge was present, and the data reported by Olsen and Reugar (1968), it does not appear that the dissolved oxygen levels of the test stations could account for the absence of a varied benthic biota. Further, it is doubtful that the pH or alkalinity deviation from the control would explain the absence of the organisms found at the control station. Finally, if the work reported by Smith, Kramer, and Cameron (1963) on the toxicity of various pulps to fish could be applied to the benthic macrofauna, there simply would

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

not have been sufficient fibers in the creek to account for the absence of these organisms. To be certain, the toxicity of the fibers to the benthic macrofauna may have been higher than what they found for fish. As Hynes (1966) and others have reported, even species of the same genus show different responses to the same pollutant.

While the toxicity of each agent present in the stream may not have been toxic in itself, their combined action may have acted synergistically to affect the organisms. Also, the factors of stress on the organisms must have played an important role in the elimination of some species from the discharge zone of the creek.

It has been long recognized that the nature of the stream bed plays an important role in determining the types of organisms found in a stream. In fact, many workers such as Hynes (1966) have implied that this is the most important factor. Before the removal of the discharge from the creek, the test stations represented a depositing stream bed in contrast to the eroding nature of the control station. Thus for many of the organisms such as the gastropods and pelecypods, the simple physical action of deposition would have limited their emergence into the area; also the effects of the suspended matter on their respiratory and feeding mechanisms should be taken into consideration. Finally, the turbidity and sediments limited the type and numbers of submersed vegetation which would have provided food and cover for many of the organisms; only sparse growths of *Potamogeton filiformis* was found at the test stations. In contrast, the morphological features of the oligochaetes

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

and chironomid larvae allowed their successful adaptation to the environment of the discharge area.

With the removal of the discharge, a new set of environmental conditions were set up. New plant species migrated downstream from the control area, establishing cover and food source. As with the results reported by Patrick in 1959, those organisms with short life spans such as the Hyalella sp. and the various insect larvae became the first benthic macrofauna to become established in large numbers at the test stations. Further, due to their small body mass, they could be more easily carried downstream by the creek's current from the control station. Also, the spring and summer breeding season of the insects introduced new members into the test areas.

The larger organisms such as the snails became apparent after June. Physa sp. was the first of the gastropods to become established in the test areas. The larger Viviparus sp. and Helisoma sp. became apparent in August. The Physa sp. occurred in larger numbers at the test stations than did the Viviparus sp. This was just the reverse at the control station.

Members of the Pelecypoda class and the Libellulidae family were the only other major groups of organisms absent from the test stations which were found at the control station. Although the bottom of the creek had compacted and eroded to some extent, there still remained a large amount of material in the creek's bed which would not offer the ideal environment for clams. Finally, those various incidental organisms such as fish and amphibians were found to be present at all three stations at the conclusion of this study.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

## SUMMARY

1. The addition of the paper mill discharge resulted in the elimination of the creek's normal benthic biota and caused a change in a number of its chemical parameters.
2. The creek showed a remarkable ability for self-recovery after the removal of the discharge. The rate of degradation of the benthal deposits increased with the advent of spring, corresponding to an elevation of water temperature. This increased rate of decomposition could be followed by a decrease in dissolved oxygen, and increases in the levels of bacteria and fungi, suspended solids, turbidity, and chemical oxygen demand over the discharge area of the creek.
3. With the advent of Spring, a re-population became apparent at the test stations. Organisms from the control station migrated downstream to the test stations. At the conclusion of this study, nearly all of the benthic taxa present at the control station were represented at one or both of the test stations; the exceptions were *Anodonta* sp., *Sphaerium* sp., and the dragonfly family, Libellulidae. The total population densities of the benthic taxa of the test stations were roughly one third of that of the control station at the conclusion of this study.
4. An undeterminable amount of time will be necessary for the benthal deposits to compact and completely degrade, for normal detritus to accumulate, and for the vegetation to become as



Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

established as it is in the control area before any true equivalency is reached.

5. In evaluations of streams, both the chemical and biological parameters must be obtained to formulate a description of an aquatic ecosystem and its state of recovery from pollution. Correlations between these should provide a rich subject for future research.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

## BIBLIOGRAPHY


Allen, W.B., Miller, J.B., and Wood, W.W. 1972. Availability of Water in Kalamazoo County, Southwestern Michigan. Geological Survey Water-Supply Paper 1973. United States Government Printing Office, Washington.

APHA. 1965. Standard Methods for the Examination of Water and Wastewater (12th ed.). APHA, New York.

Beak, T.W. 1964. A biotic index of polluted streams and its relationship to fisheries. Proc. of the Second Intern. Conf. on Water Pollution Research, Tokyo. 1:191-219; Water Pollution Abstr. 40:A147.

Berg, B., Hofsten, B.V., and Goransson, B. 1968. Properties of cellulolytic cell-vibrio strains from polluted water. Appl. Microbiol. 16:1424-5.

Biglane, K.E., and Lafleur, R.A. 1954. Biological indices of pollution as observed in Louisiana streams. Bull. La Eng. Exp. Sta. 43:1-7.; Water Pollution Abstra. 28:A1658.

Blosser, R.O., Carpenter, W.H., and Owens, E.L. 1970. A guide to the conduct of indicator organism tests used to study the sanitary quality of effluents and receiving waters. NCASI Bull. No. 235.

Cairns, J. Jr., and Dickson, K.L. 1971. A simple method for the biological assessment of the effects of waste discharge on aquatic bottom-dwelling organisms. JWPCF 43:755-72.

Campbell, N.J. 1969. Report to the International Joint Commission on the Pollution of Lake Erie, Lake Ontario, and the International Section of the St. Lawrence River (Vol. 1).

Carpenter, W.L., and Owens, E.L. 1968. Biochemical oxidation characteristics of cellulosic fibers in aqueous suspensions and in the soil. NCASI Bull. No. 224.

Colby, P.J., and Smith, L.L. 1967. Survival of walleye eggs and fry on paper mill fiber sludge deposits in Rainy River, Minnesota. Trans. Am. Fisheries Soc. 96: 278-96.

Cooke, W.M., Moore, W.A., and Kabler, P.W. 1956. Biochemical oxygen demand satisfaction by fungi. Sewage and Ind. Wastes 28: 1075-86.




Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Foster, D.H., Hanes, B.H., and Lard, S.M. Jr. 1971. A critical examination of bathing water quality standards. JWPCF 43: 2229-41.

Ganczarczyk, J. 1959. The kinetics of self-purification of the Biala Przemsza River from pollution by sulfite mill effluent. Acta Microbiol. Polon. 8: 77-85; ABIPC 31: A4821.

Gaufin, A.R., and Tarzwell, C.M. 1956. Aquatic macroinvertebrate communities as indicators of organic pollution in Lytle Creek. Sewage and Ind. Waste 28: 906-24.

Gehm, H.W. 1953. Industrial Wastes and Their Disposal and Treatment (ACS Monograph No. 118). Reinhold Pub. Corp., New York.

Halme, E. 1961. The destructive capacity of cellulose-decomposing organisms in the polluted waters of Helsinki. Vesitalous 2: 23-8; Water Pollution Abstra. 35: A783.

Heukelekian, H. 1953. Industrial Wastes and Their Disposal (ACS Monograph No. 118). Reinhold Pub. Corp., New York.

Hurwitz, E. 1961. Degradation of cellulose by activated sludge treatment. JWPCF, 33: 1070-83.

Hynes, H.B.N. 1966. The Biology of Polluted Waters. Liverpool University Press, Liverpool.

Klust, G., and Mann, H. 1954. Experimental investigations on the decomposition of cellulose in water. Vom. Wasser, 21: 100-9; Water Pollution Abstra., 29: A796.

Lardieri, N.J. 1954. The aerobic and benthal oxygen demand of paper mill waste deposits. Tappi, 37: 705-8.

Leclerc, E. 1964. Self-purification of fresh water streams as affected by temperature, and by the content of oxygen, nitrogen, and other substances. Proceedings of the International Conference held in London. Advances in Water Pollution Research, 1:51-9. Pergamon Press Ltd., Oxford.

Macan, T.T. 1963. Freshwater Ecology. John Wiley and Sons, Inc., New York.

McDonnel, A.J., and Hall, S.D. 1969. Effect of environmental factors on benthal oxygen uptake. JWPCF, 41: 353-63.

McKeown, J.J., Benedict, A.H., and Locke, G.M. 1968. Studies on the behavior of benthal deposits of paper mill origin. NCASI Bull. No. 219.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

____, 1967. Techniques for Microbiological Analysis. Technical Brochure No. LTAD M40 01. Millipore Corp., Bedford, Mass.

Olsen, T.A., and Ruegar, M.E. 1968. Relationships of oxygen requirements to index-organism classification of immature aquatic insects. JWPCF, 40: 188-201.

Ostertag, H.Z. 1952. Micro-organisms which decompose cellulose. Hyg. Infektkr., 133: 489-509; Water Pollution Abstra., 26: A1075.

Patrick, R. 1952. Aquatic life in a new stream. Water and Sewage Works, 106: 531-5.

Reid, G.K. 1961. Ecology of Inland Waters and Estuaries. Van Nostrand Reinhold Company, New York.

Smith, L.L., and Kramer, R.H. 1964. Some effects of paper fibers on fish eggs and small fish. Proceedings of the 19th Industrial Waste Converence, Purdue University Engineering Extension Series No. 117.

Smith, L.L., Kramer, R.K., and Cameron, J. 1963. The effects of pulpwood fibers on fathead minnows and walleye fingerlings. JWPCF, 37: 130-40.

Van Horn, W.M. 1961. Aquatic biology and the pulp and paper industry (Report No. 1). NCSI Bull. No. 148.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

# VITA

The author was born to George H. Herbert and Joyce B. Herbert on January 17, 1947 in Kalamazoo, Michigan. He was married to Kaye Lynn Mills on December 23, 1967.

The author received his primary and secondary education at Plainwell Community Schools. After four years, he graduated with a degree of Bachelor of Arts in Chemistry from Western Michigan University in April 1969. During the last two years of his undergraduate work, he was a research assistant to Dr. Robert E. Harmon in organic chemistry. In March, 1971 he was admitted to the Master of Arts program in Biology. During his course of study he worked under the direct supervision of Dr. Clarence J. Goodnight.



Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.