A Comparison of Some Limnological Changes Caused By The Brookings Sewage Treatment Plant On Six-mile Creek and the Big Sioux River

Richard Ruelle
A COMPARISON OF SOME LIMNOLOGICAL
CHANGES CAUSED BY THE BROOKINGS
Sewage Treatment Plant on
SIX-MILE CREEK AND THE
BIG SIOUX RIVER

BY

RICHARD RUELLE

A thesis submitted
in partial fulfillment of the requirements for the
degree Master of Science, Department of
Insectology-Zoology, South Dakota
State College of Agriculture
and Mechanic Arts

June 1963

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A COMPARISON OF SOME LIMNOLOGICAL
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This thesis is approved as a creditable, independent investigation
by a candidate for the degree, Master of Science, and is acceptable as
meeting the thesis requirements for this degree, but without implying
that the conclusions reached by the candidate are necessarily the con-
clusions of the major department.

Thesis Adviser

Head of the Major Department
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The information in Table I concerning the pollution of the Big Sioux River and the city water supplies obtained from it were generously contributed by Mr. Don C. Kalda of the State Department of Health, Pierre, South Dakota.

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INTRODUCTION

In the days of the early pioneers in South Dakota and other sparsely settled areas, there was no problem in finding a sufficient supply of water for drinking, cooking, and washing purposes. The problems of waste disposal were taken care of by the microorganisms in the soil, the microorganisms easily being able to keep pace with the few settlers. As cities and towns began to form, usually along a stream where there was an abundant supply of fresh water, sewage disposal became a growing problem. The easiest way to get rid of the sewage was to dump it into the stream below the town and let the current wash it away. This practice is still continued, even in some modern cities.

This system worked well until other upstream settlements began polluting the water before it arrived at the cities downstream. Outbreaks of water-borne diseases were common. This made it necessary to treat the water before it could be used which added to the expense of running the city. It would have been cheaper for each city to have had a sewage disposal plant and release only treated effluent into the stream; but a desire to keep taxes as low as possible, plus the lack of attention given the local governments by state and federal governments, did not help the sewage disposal problem.
The civilization of man has brought with it many problems. One of the reasons that there were no very large cities in the civilizations of the past was due to the inability of people, living under congested conditions, to get enough food to live from day to day. Their waste disposal problems were at a minimum because they just dumped their waste wherever it was convenient. It was not until the rise of the Roman Empire that any form of city waste disposal was used. In Rome an earthen jug containing the wastes from each household was placed on the doorstep each morning, and a man with a horse drawn tank wagon came around and emptied each jar into the wagon and placed the jar back on the step. In this crude way, Rome managed to rid itself of wastes.

It is estimated that 300 billion gallons of water are used daily in the United States. By 1980, it is estimated that 522 billion gallons will be required daily. This is nearly one-half of the present estimated average stream flow of 1,100 billion gallons per day. Of this huge volume of water, 332 billion gallons will be used for the dilution of pollutants. These data were published by the Outdoor Recreation Resources Review Commission (U. S. Department of Interior, 1962).

With this increasing demand for the available water, some of it will have to be shared if there is going to be enough to serve the nation. This means that the water used and released by each municipality or industry will have to meet certain
standards. Much research in the field of water quality must be accomplished to insure that the standards set are high enough to protect the health of the nation.

This dissertation is concerned with one area of pollution control, to wit: the quality of the water released by the Brookings sewage treatment plant and its effects upon the local receiving waters.

Study Area

The study area involved in this investigation of the pollution of Six-Mile Creek and the Big Sioux River by the effluent of the Brookings sewage treatment plant is shown in Figure 1.

Six-Mile Creek is a small intermittent stream that originates at the north edge of Brookings County, directly south of Toronto, South Dakota, and flows for approximately eighteen miles before passing Brookings on the west. It continues flowing to the south for approximately four and one-half miles before emptying into the Big Sioux River.

The Big Sioux River originates in Grant County between Croty and Summit, South Dakota, and flows south until it empties into the Missouri River at Sioux City, Iowa. None of the cities located along the Big Sioux River (see Table I) use the river water for municipal drinking water.

The study area was selected for accessibility during the worst weather in hopes that samples could be taken during all
Figure 1. Map of the study area showing relationship to Brookings, S. D.
Table I. Disposition of Sewage by Towns Along the Big Sioux River

<table>
<thead>
<tr>
<th>City</th>
<th>Type of Treatment</th>
<th>Effluent Emptied in the River</th>
<th>Drinking Water Used from River</th>
</tr>
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<tr>
<td>Watertown, S.D.</td>
<td>2</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Castlewood, S.D.</td>
<td>4</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Haiti, S.D.</td>
<td>4</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Estelline, S.D.</td>
<td>1</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Arlington, S.D.**</td>
<td>3</td>
<td>( )</td>
<td>No</td>
</tr>
<tr>
<td>Volga, S.D.</td>
<td>3 and 4</td>
<td>No</td>
<td>No</td>
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<tr>
<td>Brookings, S.D.</td>
<td>3</td>
<td>Yes</td>
<td>No</td>
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<tr>
<td>Flandreau, S.D.</td>
<td>3</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Dell Rapids, S.D.***</td>
<td>3</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Baltic, S.D.</td>
<td>4</td>
<td>( )</td>
<td>No</td>
</tr>
<tr>
<td>Sioux Falls, S.D.</td>
<td>2</td>
<td>Yes?</td>
<td>No</td>
</tr>
<tr>
<td>Canton, S.D.</td>
<td>4</td>
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<tr>
<td>Hudson, S.D.</td>
<td>1</td>
<td>Yes</td>
<td>No</td>
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<tr>
<td>Hawarden, Iowa</td>
<td>1</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Akron, Iowa</td>
<td>1</td>
<td>Yes</td>
<td>No</td>
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Cities upstream from Brookings are above Brookings on the table. Cities downstream are below Brookings on the table.

Type of treatment: 1-Denotes raw sewage emptied into the river
2-Sewage treatment plant
3-Mechanical sewage treatment plant
4-Sewage stabilization pond
• Stabilization pond is presently being constructed
** Needs expansion and improved operation
*** Needs improvement due to low flow of the river
Figure 2. Station 1. Top photo showing frozen condition of site during November. Lower photo showing site in summer.
for chemical analysis were obtained from this station. Figure 3 shows the station at flood stage.

In May the bottom soil at S-5 consisted of silt, sand and a little gravel. The spring flood secured the bottom, and in July it was mostly sand mixed with very small amounts of silt.

During the winter there were times when there was no continuous flow from station 1 to station 2 caused by the drying up of the creek during the fall and hard freezing during the winter. Most of the water below S-2 during the winter was contributed by the sewage plant. During the spring thaws, a continuous flow of high water down the creek diluted the effluent from the treatment plant so much that some of the results of tests on this water were not distinguishable from those of station 1. The chloride, ammonia, and nitrate tests, however, did indicate that this was the area of pollution along the creek. During this period of high water many fish came up the stream through the polluted water, past the outflow of the sewage plant, and on upstream to spawn. It is believed that these fish must have travelled a considerable distance up the river before entering the creek since it seems highly unlikely, based on results of this study, that many of them could have overwintered in the river. From the bridge, schools of carp could be seen coming up the river to spawn. The water temperature was 59° F, and these fish spawn at about 60° F.
Figure 3. Both photos of station 5 in July following heavy rain.
Station 2 (S-2) was located at the bridge on the first available road crossing the creek after the sewage plant effluent had been added to it (Figure 4). It was chosen because it was located near enough to the outflow of the Brookings sewage treatment plant to represent the most highly polluted portion of the stream and, yet, far enough downstream so that the sewage was thoroughly dispersed throughout the creek water. This dispersion of the sewage occurred only when there was enough water flowing in the creek to add to the flow coming from the sewage treatment plant. During the dry part of the year (late summer and winter) there was no flowing water in the creek, and the total volume of water in the creek between Brookings and the Big Sioux River was contributed by the outflow from the Brookings sewage treatment plant.

The bottom at S-2 was always made up of black, smelly, ooze-like organic material that completely blackened everything in the sample. Usually a few undigested leaves were in the sample. They, along with other materials, were unrecognizable until the sample was washed. The organic sludge here was very deep. When the first sample was removed on January 3, the total depth of the ice and water was 40 inches, but when the last sample was taken on December 12, there was no ice and the water was only nine inches deep, indicating an increase in sludge deposits. Different water levels in the creek could have affected
Figure 4. Station 2. Top photo taken during part of April thaw. Lower photo showing unfrozen stream in November.
this. In any case, most of the material was summer and winter sediment and would be washed away by the floods in the spring.

Station 3 (3-3) was located at the Big Sioux River bridge approximately two miles south and a mile and a half west of station 2 (see Figure 5 for a picture of this station during high water). This station was chosen because it was located above the confluence of Six-Mile Creek with the river. This station served as a quality check of the river water before receiving the water from Six-Mile Creek. The mouth of the creek was located on the river about equidistant between station 3 and station 4. During February and part of March the river was frozen to the bottom, and very little water was flowing from station 3 to station 4. When thaws occurred, the ice layer covering the river melted from the top down about a foot. Water was then flowing on top of the ice. When cold weather returned and the water on top froze, there remained a cover of two layers of ice with a layer of water between them and with a layer of water below. This arrangement prevented photosynthetic oxygen replenishment, and the free exchange of bottom water with surface water was prevented, resulting in a mass die-off of many aquatic organisms in the river. At this time, the river water had a typical putrid smell of organic decomposition.

In January the bottom soil at station 3 was silt. Immediately following the spring flood it was made up of mostly
Figure 5. Station 3. Top photo taken in July after heavy rain. Lower photo taken during April thaw.
During the latter part of the fall it had silted in again, and by winter it was made up of silt with a little sand.

Station 4 (S-4) was located at the bridge on the river a mile downstream from station 3 and approximately one-half mile below the mouth of the creek (see Figure 6). Deep holes were located in the river bed at both station 3 and 4 from which test samples could be taken at any time during the winter even in the coldest weather. In any case, all samples were taken within 300 feet of the original sampling sites.

During the winter, the bottom samples from S-4 were composed mostly of silt. Following the spring floods, the bottom was well scoured and made up of clean, fine sand and was firm enough that one could walk anywhere on the river bottom without sinking. In the late fall the bottom sample contained a large amount of silt mixed with sand.
Figure 6. Station 4. Upper photo taken after several days of heavy rain in July. Lower photo of same site during April thaw.
METHODS AND MATERIALS

There are many water-quality indicators that could have been used to determine the condition of the water concerned, but only the tests that were considered to give the most reliable and most significant results in the preliminary stream survey with the equipment available were used. These indicators can be conveniently divided into three categories: (1) chemical indicators, (2) biological indicators, and (3) physical indicators. It would be speculative as to which indicator is the most reliable, because all have their strong and weak points (Moore, 1928; and others).

The phenomenon whereby substances may be dissolved and retained in solution is exhibited to a greater extent by water than by any other liquid in nature. Of the known chemical elements, about 50 per cent have been reported in water, and it seems probable that at least traces of all elements may occur. This property is, of course, the prime importance to the maintenance of life in the aquatic environment (Reid 1961).

The chemical tests conducted were dissolved oxygen, biochemical oxygen demand (BOD) and its velocity constant, orthophosphate, hardness, pH, nitrate, nitrite, ammonia nitrogen, methyl orange and phenolphthalein alkalinity, sulfate, and chlorides. The analytical techniques used in the study are those described in the 10th edition of Standard Methods (APHA, 1955),
the Hach Water and Sewage Analysis Methods Manual for Spectronic
20 Colorimeter, and the catalog of the Hach Chemical Company,
Ames, Iowa (the last two are hereinafter referred to as the Water
and Sewage Methods Manual and the Hach Chemical Company Catalog).

The dissolved oxygen determinations in this study were
conducted as described in Standard Methods for the sodium azide
modification of the standard Winkler method.

The Hach Chemical Company of Ames, Iowa produces chemical
reagents for testing water for dissolved materials. These
reagents contain chelating agents (versenates) that remove
the chemical interferences that may be in the test sample. By
using these chemicals and a Bausch and Lomb Spectronic-20
spectrophotometer, many lengthy preliminary procedures in water
analyses can be omitted. The Hach chemical-analysis procedures
were used in this study where applicable.

The concentrations of orthophosphate, nitrate, nitrite,
and sulfate were determined in this study as explained in the
Water and Sewage Methods Manual. Water hardness and chloride
were determined by the ManVer hardness test as described in the
Hach Chemical Company Catalog No. 56. The pH determinations were
made colorimetrically using a Taylor slide comparator. The
direct nesslerization method as described in Standard Methods
was used to make the ammonia nitrogen determinations. The
interferences caused by the chemical make-up of the water were
removed by following the procedure given by Ellis, Westfall, and Ellis (1948). The tests for phenolphthalein and methyl orange alkalinity were conducted as described in Standard Methods.

The biological indicators of pollution used in this study were the most probable number (MPN) coliform determinations, qualitative and quantitative algae analyses, and bottom-sample examinations. The coliform determinations were conducted as described by Theroux, Aldridge, and Mallman (1936) on media prepared as described in the DIFCO Manual, 9th Edition (DIFCO Laboratories, 1953). The bottom samples were taken with a 6 inch by 6 inch Ekman dredge.

Turbidity in the water samples was determined on the Spectronic-20 as described in the Water and Sewage Methods Manual.

The ice cores were removed with a 7.5 inch ice-core auger manufactured by the Ice Master Company of Minneapolis, Minnesota.

Discussion of Examinations Conducted

Chemical samples were taken at each station at intervals of one week for a period of one month. This procedure was used to establish the most informative and reliable tests. Samples were then taken at two-week intervals and then one-month intervals except during May and June when no samples were taken. The water samples were taken from the surface at each station.
with a pail on a rope during the summer, and by cutting a hole in the ice during the winter. Care was taken when filling the pail so as not to disturb the water sample. The water was then siphoned out of the pail for all tests. A 300 milliliter (ml) BOD bottle was filled and fixed in the field for the dissolved oxygen (DO) determination. Air temperatures and water temperatures were determined in the field as were tests for pH, alkalinity, and hardness. Two clean jars were used to transport water samples back to the laboratory. The water for the chemical determinations was preserved with a few ml. of chloroform except during the winter. The sample used to set up the BOD’s was not preserved. In very cold weather the water jars were placed in the car immediately after being filled to avoid freezing and breaking. Bottom samples and chemical samples were always taken on separate days. The bottom samples were taken seasonally (spring, summer, fall, and winter) by making two drops with an Ekman dredge from the bridge. During periods of high water the bottom sample had to be taken off to the side of the main channel to prevent the dredge from drifting in the current. The samples were placed in a screen bottom bucket, washed, searched once, placed in a labeled jar, and returned to the laboratory.

The water samples for the coliform determinations were taken in the field by submerging the sterile sample container and unscrewing the cap of the bottle under the water surface and
allowing the bottle to fill. The cap was then replaced and not
removed again until a dilution was to be made in the laboratory.

The water samples to be examined for algae were taken by
filling a gallon jar with the water from the station. The algae
samples were preserved with formalin.

At each station, the water temperature, air temperature,
water depth, time, per cent cloudiness, and the wind direction
and approximate velocity were taken and recorded on a data
sheet. When present, thickness and condition of the ice, snow
thickness, and the per cent snow cover were observed and
recorded.

In the laboratory, the samples to be used for chemical
analyses were preserved by refrigeration while other tests were
conducted. The BOD and velocity constant determination samples
were always set up first to prevent any breakdown of organic
matter and oxygen depletion. When the temperature of the BOD
samples was below 20° centigrade, the sample jars were first
placed in a hot-water bath to raise the water temperature above
the 20° C. temperature of the BOD incubator. If the temperature
of the water was below this, and if the sample was saturated at
the lower temperature, a loss of oxygen would result that would
register as BOD in the final determination. The BOD bottles were
sealed with ground-glass stoppers and a water seal so that there
was no chance of the sample absorbing oxygen from the air when
they were cooled in the incubator. When the water reached a temperature above 20° C., the BOD's were prepared by the dilution method prescribed for 5-day BOD's in Standard Methods (A.H.A., 1955).

A 5-day BOD should give a forty to sixty per cent depletion of available oxygen for greater accuracy. To insure depletions within this range, three different dilution samples were incubated for each station. The bottle numbers and original dissolved oxygen readings and per cent dilution were recorded on a form for the calculation of the BOD.

A BOD velocity constant (Kₜ) is a measure of the dissolved oxygen demand upon a stream caused by the bacterial oxidation of carbonaceous organic material. Although the determinations are made in the laboratory under a constant temperature, it is assumed that the actual oxidation in the stream would follow the same pattern. According to Streeter and Phelps (1925), the law covering biochemical oxidation is: "The rate of biochemical oxidation of organic matter is proportional to the remaining concentration of unoxidized substance, measured in terms of oxidizability." The formula for this law is:

$$\log \frac{L'}{L} = Kt$$

Where "L'" is the initial and "L" the final oxidizability (oxygen demand) of the organic matter in terms of oxygen, "t" is
the elapsed time, and "K" is a coefficient of a constant, defining the rate at which the reaction proceeds. The nature of the substances found in city sewage and the number and kinds of bacteria present have been found to be sufficiently constant under various conditions to give a fairly predictable value of "K" for this reaction at a given temperature.

The receiving waters below the sewage plant were not polluted in any complicated manner and could be described as typical low-volume stream waters that receive the effluent from a domestic sewage treatment plant. The velocity constants were used so a comparison could be made of the velocity constant of Six-Mile Creek and any other polluted water. The results (K = 0.10 to 0.13) indicated that the velocity constants for Six-Mile Creek below the sewage plant were normal for a stream of this size.

All coliform determinations were made with sterile glassware and equipment. Sample dilutions ranged from zero to 1/100,000. The tests were conducted for a 24- and 48-hour period on both lactose broth and brilliant green lactose bile media before they were considered confirmed. The test results were recorded on a report form and the coliform MPN was calculated from a table prepared by Theroux, Eldridge, and Mallman (1936).

The algae samples were held in the refrigerator until they could be concentrated with a Foerst continuous-flow plankton
centrifuge operating at a speed of 20,000 revolutions per minute. The water was regulated to flow into the centrifuge at the rate of a liter every seven to ten minutes. When centrifugation was completed, the concentrated organisms were removed, diluted to a volume of 50 ml with deionized water, and preserved with formalin. Some of the samples were stored and not examined immediately. Due to an error in preservation or the effect of the formalin on the algae some of the samples could not be identified.

To count the algae in the sample after concentrating them, the number of microscope fields within the area of a cover slip was determined by placing a cover slip on a slide under the microscope and counting the number of fields in its length and width. The number of fields in the length times the number of fields in the width equals the number of fields on the entire cover slip.

A 1 ml. dropper was calibrated for uniform drop size. One drop equaled one-tenth ml. One drop (0.1 ml) of sample water was placed on the microscope slide. A cover slip was placed over the drop. The drop spread out evenly under the cover slip provided that the cover slip was not moved.

The algae were counted in three different strips the length of the cover slip and the width of the cover slip and the total number per 0.1 ml. calculated. From this figure the total number of algae per liter was calculated.
In the laboratory the detritus from the bottom samples was placed in white porcelain laboratory pans. Water was added to each sample and the material was spread thinly enough so that any organisms overlooked in the field could be seen. With the aid of a pair of forceps, a series of three-inch strokes was made in the detritus at right angles to the length of the pan, until a strip three inches wide and the length of the pan had been covered. Then successive three-inch strips were covered until the detritus in the entire pan had been searched. The pan was then rotated 180° and examined again as above. This was continued until no more organisms could be found. The organisms found were added to those previously found in the field.

Turbidity was determined by the method given in the Water and Sewage Methods Manual using the Spectronic-20 spectrophotometer to measure the per cent transmittance and converting this to parts per million by means of the table given in the manual.
LITERATURE REVIEW

Water Use and Treatment

The earthly allotment of water is nearly constant, and therefore its purity is very much dependent upon the discretion of those to whom it is allotted. As our country becomes more densely populated, and our watercourses remain the same or become less voluminous in flow, it is apparent that some recourse must be taken if our streams are to continue to serve as receiving waters. The same streams that carry the pollution away also supply drinking water to many cities in the nation.

Berger (1960) reports that modern sewage treatment processes are designed to produce an effluent that will be easily assimilated by the receiving body of water; they are not intended to produce a water suitable as a source of municipal water supply. However, millions of people in this country who depend on surface supplies use water which is partially composed of reconditioned sewage (Bunch, Barth, and Ettinger; 1961).

In some communities, where ground and stream water is in short supply, water is recirculated through the sewage treatment plant, processed, and then used as a source of drinking water. The most outstanding instance of sewage recirculation according to Berger (op. cit.) occurred in Chanute, Kansas, where the water was recirculated eight to fifteen times from sewage to drinking water. The water completed the cycle in about 20 days. He also reported
sewage recirculation for drinking water in Lyndon, Kansas, in
the fall of 1956, and that Ottumwa, Iowa, used Des Moines river
water that contained about sixty per cent raw sewage. Something
short of direct recycling is the rule in hundreds of United
States cities. Most municipalities drawing their water from
inland streams are using the diluted sewage effluents of upstream
cities. He also reports that, although the presence of such
pollution is generally known, consumer acceptance of the water
does not appear to be reduced.

**Water Chemistry**

It was reported by Klein (1959) that many different
elements occur in water supplies. Some of these are very toxic
in small amounts, and others are harmless even in large quantities.

"Pollutants shall be defined as any material introduced
into the stream from without, usually of an organic nature. Most
of this foreign organic material added to the stream is made up
of domestic sewage" (U.S. Public Health Service, 1942).

**Dissolved Oxygen**

Gauffin and Tarzwell (1956) state that among the primary
requisites for animal existence are oxygen and food. Klein (1959)
stated that one of the first indications of the presence of
organic pollution is a decrease in the dissolved oxygen content of
a stream below the source of pollution. According to Brindley (1943), oxygen depletion is often considered to be the sole detrimental effect of putrescible wastes. Putrescible wastes, however, may affect environmental conditions, aquatic life, and water used in a variety of ways.

In fresh water, Tarzwell (1957) reports temperature to be the most important factor affecting the solubility of oxygen. As temperature increases, the amount of oxygen which can be held by the water decreases. Klein (1959) found that the more significant factors affecting the dissolved oxygen concentrations are the amount and nature of the organic matter present, the temperature, bacterial activity, dilution, photosynthesis, and respiration from the atmosphere. Respiration is influenced by the dissolved oxygen deficiency, the character of the stream bed, the depth, volume and velocity of flow of the water, the turbulence, the presence of weirs, the concentration of dissolved solids, surfactant active agents, barometric pressure, and the amount of chloride in the water. Kneese (1962) states that photosynthetic oxygen production is affected by factors such as cloudiness, time of day, turbidity, and temperature.

It was found by Tarzwell (1953) that when collecting data for the calculation of the oxygen sag curve, attention should be directed not only to variations in water level, rate of flow, temperatures, and the character of the stream, but also to
photosynthetic activity and the time of day when samples are taken. Gainey and Lord (1952) explain that the zone of recovery begins at the point where the oxygen content again reaches 40 per cent saturation, or 3.5 ppm. The water begins to clear up, gases disappear, ammonia and hydrogen sulfide decrease, and nitrites, nitrates, and sulfates increase. Since dissolved oxygen depends upon a combination of factors, other tests are necessary to obtain a complete picture of the state of a stream; e.g., BOD, ammoniacal nitrogen, toxic substances, pH, etc. (Klein, 1959).

Key (1956) used dissolved oxygen content to classify the quality of rivers as follows:

<table>
<thead>
<tr>
<th>Dissolved oxygen (per cent of saturation)</th>
<th>Type of river water</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 or more</td>
<td>Good</td>
</tr>
<tr>
<td>75-50</td>
<td>Fair</td>
</tr>
<tr>
<td>50-75</td>
<td>Doubtful</td>
</tr>
<tr>
<td>Below 50</td>
<td>Badly polluted</td>
</tr>
</tbody>
</table>

**Biochemical Oxygen Demand (BOD)**

Biochemical oxygen demand (BOD) is defined in Standard Methods (APHA, 1955; page 260) as: "The biochemical oxygen demand, BOD, of sewage, sewage effluents, polluted waters or industrial wastes is the quantity of dissolved oxygen, in mg/l, required during stabilization of the decomposable organic matter by aerobic biochemical action."
Streett and Phelps (1925) state that in the presence of a supply of oxygen, together with certain oxidizing bacteria and oxidizable organic matter, progressive oxidation and stabilization of the organic matter will take place. According to Kneese (1962), at higher temperatures bacterial action is accelerated, wastes are degraded more rapidly, and dissolved oxygen in the water is drawn upon more heavily. The oxygen-saturation level of warm water is lower than that of cooler water, thus increased temperatures tend to squeeze dissolved oxygen levels in waste-receiving waters, conceivably to the point of producing septic (anaerobic) conditions. Klein (1959) states that it is commonly accepted that the higher the 5-day BOD, the greater is the concentration of oxidizable organic pollution and, conversely, the lower the BOD, the lower the content of organic pollution.

**Hardness**

Hardness is defined by Standard Methods (op. cit.) as originally meaning a measure of the capacity of the water for precipitating soap. Calcium and magnesium ions commonly present in water are the most important precipitants, but other metals, such as iron, aluminum, manganese, strontium, and zinc, and hydrogen-ions also will cause precipitation. The modern definition, because all but the first two are usually present in insignificant concentrations in natural waters, just includes the
total concentrations of calcium and magnesium ions expressed as calcium carbonate.

Hydrogen Ion (pH)

The pH is the logarithm of the reciprocal of the hydrogen-ion (or more properly, the hydronium-ion) activity (Reid 1961). Alkalinity, hardness, and pH values are very closely related, and it is impossible to discuss one thoroughly without mentioning the interrelationship with the other two. Ellis, Westfall, and Ellis (1956) report that the hydrogen-ion concentration is the result of several, often many, factors—some synergistic and some antagonistic. They conclude that carbon dioxide and the carbonates and sulfates of calcium and magnesium—all normal components of most stream and lake waters—collectively cause marked changes in the pH of the water in which they are dissolved if the amounts of any or all of these components in solution vary even slightly.

A pH change in water is indicative of the production or consumption of carbon dioxide (CO₂) in the water, according to Palmer (1961). Free CO₂ is not present in waters of pH above 8.3; the bicarbonate (HCO₃⁻) present is used as a source of CO₂. If the carbonate (CO₃²⁻) content is high, CO₃²⁻ may be precipitated (as Marl), thereby causing a change in total alkalinity.

Ellis (1937) states that in most uncontaminated fresh-water streams, pH values range from 6.5 to 8.5. Determinations lying outside the range of 6.0 to 8.7 indicate that the usual balance of
carbon dioxide and the carbonates and sulfates of calcium and magnesium have been disturbed either by the presence of too large a quantity of one or more of these compounds or by the addition of other substances to the physico-chemical complex of the water (Ellis, Westfall, and Ellis; 1948). Standard Methods (APHA, 1960) states that three variables control the pH at a given temperature - total alkalinity, calcium, and dissolved solids.

**Alkalinity**

Alkalinity as used here is the equivalent concentration of titratable base and is determined by titration with a standard solution of a strong acid to an equivalence point shown by an indicator solution. Standard Methods (op. cit.) explains that alkalinity in water is usually caused by bicarbonates, carbonates, hydroxides, and sometimes by borates, silicates, and phosphates. Klein (1959) states that during oxidation of sewage there is a decrease in alkalinity caused by oxidation of carbonaceous material to acidic substances, assimilation of ammonia by microorganisms, therefore, give some indication of the degree of oxidation at any stage during the treatment of sewage.

According to Ellis, Westfall, and Ellis (1948) the salts responsible for the carbonate hardness of natural waters usually are much in excess of those salts producing noncarbonate hardness; and, as these same carbonates are chiefly responsible for the total
alkalinity of the water, hardness and alkalinity are obviously very closely related and must be considered together for proper interpretation of the hydrobiological data.

Chloride

The U.S. Public Health Service has set definite standards for drinking water; for example, the upper limit for chloride is 250 milligrams per liter (mg/l). The U.S. Department of Health, Education and Welfare Summary Report (U.S. Public Health Service, 1952) states that normal water contains about 20 to 40 mg/l, and that recycling water through sewage treatment plants increases the chloride content of the water as much as 550 mg/l. Some substances such as sodium chloride increase the chloride content of sewage wastes when added during the cycle. They report that secondary sewage treatment did not remove any chloride from sewage effluent.

Klein (1959) reports that chlorides are found in sewage, farm drainage, certain acid pickle liquors, brine from salt works, effluents from some water-softening plants, oil well water, and in tidal waters containing sea water. The normal chloride content of unpolluted river water is 15 ppm, but polluted river water was from 70 to 500 ppm—most of this coming from urine which contains 4,500 to 5,000 ppm chloride. He states that when the other possibilities have been ruled out, any sudden rise in the chloride
content of a stream usually indicates the presence of sewage or sewage effluents.

Fair and Geyer (1959) conclude that the chloride content of water is not affected by normal passage over the ground or through it. They indicate that chloride is a useful pollution index that does not change with time and that chlorides are stable enough in water to be used to trace water flow, especially through underground sources.

The chloride content of water may rise during the winter months after an ice layer forms as most of the chloride is partially excluded from the ice during its formation. Morris and Water (1962) report that because of this, freezing is a method that has been given considerable consideration as a desalinization method. They also report that the exclusion of chlorides from the ice is largely a function of the salinity of the water.

Farzwell (1957) summed it all up by stating that it is impossible, when dealing with mixed wastes, to generalize as to the relationship between chloride-ion concentration and osmotic, toxic, or over-all pollutional strength.

Nitrogen

Ammonia. When nitrogen is present in the form of ammonia, it can be assumed that the stream has a very low amount of dissolved oxygen available. When sufficient oxygen supply is present, the ammonia is oxidized to nitrate.
The British Royal Commission of Sewage Disposal, as reported by Klein (1959), state that the most delicate chemical index of recent sewage pollution in a river water is the increase in the ammonical nitrogen. However, they stated that the ammonia nitrogen level is not as good an indicator of pollution strength as the biochemical oxygen demand determination.

Klein (op. cit.) reports that ammonia results from the aerobic or anaerobic decomposition of nitrogenous organic matter. He pointed out that if ammonia is present in a stream in amounts greater than 0.2 ppm there is strong evidence of the presence of sewage effluent, especially if there is also a rise in the chloride content.

The U.S. Public Health Service (1962) reports that ammonia appears in even the best effluents. In addition to the ammonia in the effluent, large quantities are released from the digester. They report that during warm weather, ammonia is oxidized. Ellis, Westfall, and Ellis (1948) emphasize that ammonia, in concentrations of 1.0 ppm or more is a good indication of organic pollution, and if present in concentrations above 2.5 ppm it is generally lethal to fish.

Nitrate and Nitrite. The U.S. Public Health Service (1962), et al., report that nitrogenous materials go through a nitrogen-oxidation cycle, producing ammonia, nitrites, and nitrates.
They explain that nitrites are short-lived and are readily oxidized to nitrates, the end product of aerobic stabilization of organic nitrogen. Klein (1955) states further that nitrate in river water is generally an indication of the presence of well-treated sewage effluents. He found that a good final effluent contains nitrate but little or no nitrite. Nitrification is much more intense at the higher temperatures of the summer months when bacterial activity is greater than during the colder winter months. He states that in overloaded or improperly operated sewage treatment plants, the nitrites increase and the nitrates fall. Even a trace of nitrite in a river water may indicate pollution by imperfectly treated sewage, especially if the river water also shows increases in ammoniacal nitrogen and chloride. In highly polluted rivers, nitrates are regarded as advantageous because when the dissolved oxygen of the river falls to zero, nitrates are reduced to nitrites and the freed oxygen helps prevent anaerobic conditions and the production of foul odors.

Kneese (1962) reports that determination of total nitrogen is necessary as a measure of pollution. The normal range of total nitrogen in water, according to the U.S. Public Health Service (1962), is between 20 and 40 ppm. They report that the normal level of nitrate ranges between 0 and 18 ppm. The domestic use
of water increases the total nitrogen by increments of 12 to 42 ppm, while the increase of nitrate from the biological action on organic nitrogen in sewage is in increments of from 0 to 18 ppm. Welch (1952) indicates that in recent years much attention has been given to the nitrogen-phosphorus ratio. He states that there is strong evidence that the two substances closely parallel each other.

Orthophosphate

Phosphates occur in low concentrations in most natural waters, according to the U.S. Public Health Service (1962), but the increment from domestic use, principally from synthetic detergents, may be substantial. They report the normal level of phosphate in water is 20 to 40 ppm, and that the domestic use of water increases phosphates by increments of 2 to 50 ppm. They indicate that 80 to 90 per cent of the non-detergent phosphates may be removed from sewage effluents by secondary treatment.

Sulfate

Very little or no sulfate in the inorganic-ion form is removed by secondary treatment of sewage effluents, according to the U.S. Public Health Service (op. cit.). They note that the normal range of sulfate in water is 15 to 30 ppm and that the
range for increase due to domestic use of water is 0 to 75 ppm. The acceptable upper limit in drinking water, according to the Public Health Service Standards, is 250 ppm.

**Biological Indicators**

Needham and Brinley, as quoted by Tarzwell (1953), state that if at any time during its development, environmental conditions become lethal for a given organism, that organism will be eliminated even though the unfavorable conditions are of very short duration. It is this property of indicating past environmental conditions, especially the extreme conditions of brief duration, that make aquatic populations such valuable indicators of pollution.

Bartsch and Ingram (1959, page 109) describe indicator organisms thusly:

In clean water upstream there is an association of sports fish, various minnows, caddis worms, mayflies, stoneflies, hellgrammites, and gill-breathing snails, each kind represented by a few individuals. In badly polluted zones the upstream association disappears completely or is reduced, and is replaced by a dominant animal association of ratted maggots, sludge worms, bloodworms, and a few others, represented by great numbers of individuals."

According to Gaufin and Tarzwell (1956), all the insects occurring in the septic zone have special adaptations for obtaining oxygen, such as the caudal respiratory tubes of mosquitoes and ratted maggots or the air space under the elytra of beetles.
Bottom Samples

In studying pollution, a determination of the bottom fauna often gives a more exact index of the extent of pollution than does a chemical analysis which may have been taken during a period of either high or low outflow of polluting substances (Tarzwell, 1953).

Bottom samples add impressively to the data supplied by the chemist. This is especially true because of the greater stability and permanence of conditions at the bottom (Moore, 1928).

Mollusca. Richardson (1928) divided pollutional organisms into two groups: (1) cleaner forms (Sphaeriidae and some snails), and (2) pollutional forms (sludge worms and midge larvae). The Sphaeriidae or fingernail clams use two long gills, one on each side of the inner valves, for respiration according to Malek (1962).

Snails. Some snails of the families Physidae, Lymnaeidae, and Planorbidae are highly tolerant of changes in environmental conditions, such as chemistry of the water, temperature, and drought according to Leonard (1959). They are of interest in pollution studies because of their physiological adaptations. Some, the pulmonates, breathe atmospheric oxygen, by filling
their lungs at the surface of the water and are thus not affected by oxygen depletion. Gill-breathing snails cannot adapt to low oxygen levels and must move to more desirable environments or perish. Baker (1922) found that gill-breathing snails (\textit{Musculium} and \textit{Bythinia}) succumbed in five years to increasing sewage pollution in the Big Vermilion River (Illinois), but the air-breathers (\textit{Physa}, \textit{Planorbis}, and \textit{Gelba}) were able to survive for eight years. Weston and Turner (1917) comment on the great increase in snails below the point of pollution. They report \textit{Planorbis trivolvis} as the most common, but \textit{Physa} and \textit{Segmentia} were also present. Malek (1962) and Leonard (1959) classify the following genera of snails as pulmonates (Order Pulmonata):

\begin{tabular}{llll}
\textit{Physa} & \textit{Valveta} & \textit{Aplexa} & \textit{Planorbis} \\
\textit{Planorbula} & \textit{Helisoma} & \textit{Lymnaea} & \textit{Stagnicola} \\
\textit{Cyraulus} & & & \\
\textit{Planorbis} & & & \\
\end{tabular}

\textit{Stagnicola} sp. of the Family Amnicolidae is a gill-breathing snail.

**Insects.** Some clean-water invertebrates do not form successful populations in streams where settleable solids sink to form sludge deposits, according to Bartsch and Ingram (1959), because their appendages may become clogged with sludge as the solids settle, and they may be carried to the bottom and buried alive.

They found that a variety and relative abundance of gill-breathing
insect larvae (mayflies, caddisflies, etc.), and similar forms are normally found in the cleaner streams.

Richardson (1921) regards the chironomids as rather severely limited in their value as indicators of the presence of sewage pollution. It is the belief of Malloch (1915) that the chironomids as a group are much more abundant in relatively clean water than in a foul environment. In contrast to the above views, the U.S. Public Health Service (1942) reports that chironomid larvae apparently are second only to the sludge worms in a polluted stream, but their presence must be interpreted with care. Gaufin and Tarzwell (1956) report that the finding of certain organisms such as rattail maggots, *Eristalis* sp.; sludgeworms, *Tubifex tubifex*; and the bloodworm, *Chironomus terebella*, presents important evidence of the pollutional condition of a stream, and that it is the complex or association of organisms that is important for indicating clean or polluted water.

**Annelid.** Twenty-seven kinds of bottom organisms were listed by Richardson (1928) as being definitely associated with the presence of pollution. He states that the number of bottom forms having dependable index value is surprisingly small, and even these must be used with caution. Of the 27 kinds, only two, an annelid (*limnodrilus hoffmeisteri*) and a bloodworm (*Chironomus plumosus*),
were generally common enough over wide ranges to warrant confidence in their value as indicators when taken by themselves.

Hurdy (1930) found that the organisms in the sediments from the upper sewage-polluted section of the Illinois River consisted chiefly of tubificid worms, which were very numerous—averaging over 2,000 per liter of mud. Certain sewage-tolerant organisms (Ephemeridae and larvae of chironomids) were moderately abundant. Fertch and Ingran (1959) explain that sludge worms feed on sludge by taking it into the digestive tract and removing the organic matter from it, thus reducing the biochemical oxygen demand. Sludge worms 1 1/2 inches long and as thick as a needle have been observed to pass fecal pellets totaling 5 feet 9 inches through the digestive tract in 24 hours. Fecal pellets that are extruded from the anal openings have on occasion been found to have a biochemical oxygen demand of only one-half of that of sludge that was not digested by them. The sludge worms are then actually crawling ECD, in that they incorporate sugars, proteins, and fats that are present in sludge into their body cellular components.

The U.S. Public Health Service (1942) offers this resume on the appearance of sludge worms in their environment.

In bottom samples from a polluted stream it is desirable to learn the approximate abundance of the sludge worms, because of the apparent significance of this worm and its activity. Half or two-thirds of its body is underground and the worm slowly tunnels about, undermining and ingesting the soft bottom mud. The anal end of the worm,
projecting an inch, more or less, up into the water, waves about rhythmically in the process of breathing. One of the most outstanding characteristics of sludge worms is their tendency to occur in groups or patches. In the writer's experience collections have been made from depths varying from 1 or 2 inches up to 35 feet. Color of the worms is reddish, like that of an earthworm. A group the size of one's hand is easily visible in shallow water, even if the observer is 20 feet distance. The apparent importance of this worm as an indicator of the presence of pollution makes it all the more necessary that the bottom samples show, as accurately as possible, the real situation as to the relative numbers of worms occurring in that particular sampling place.

Ostracoda. Ostracods probably are not found in the polluted areas due to low oxygen levels and high rates of sedimentation. Ward and Whipple (1945) state that the respiratory process in the fresh-water Ostracoda takes place through the entire upper surface of the body and through cell layers of the shell. A number of respiratory plumes are fastened to the mouth parts, the motion of which keeps a continuous stream of fresh oxygen-laden water pouring between the valves.

Algae. Palmer (1961) states that algae have a significance that is being emphasized in relation to self-purification, radioactivity, water treatment, fish and other aquatic animal life, industrial and sewage pollution, taste and odor production, and recreational uses of the stream water. Much has been written on the problems caused by algae in receiving waters; this has been largely a description of the species causing the damage and the
location (Palmer, 1962, gives a good description of problems caused by algae blooms, etc.). Bartsch (1960) describes the cause of the problem. He states that streams and lakes, needed as water supplies or for other uses, have been receiving quantities of sewage that serve as nutrients for excessive growths of algae.

**Coliform Bacteria**

*Standard Methods* (1960, page 477) explains the development of the coliform most probable number count in relation to polluted waters:

For many years the coliform group of bacteria, ..., has been used to indicate the pollution of water with sewage and wastes and thus the suitability of a particular water supply for domestic and dietetic uses. The cultural reactions and characteristics of the coliform group have been studied extensively.

Experience has established the significance of coliform group densities as criteria for establishing the degree of pollution and thus of the sanitary quality of the sample under examination. Developments in bacteriologic techniques and culture media have increased the sensitivity of the multiple-tube fermentation test and have resulted in the acceptance of that test as a standard method. The significance of the tests and the interpretations of the results are well authenticated and have been used as the basis of standards of bacteriologic quality of water supplies.
Bacterial pollution, along with the degradable organic materials, has, therefore, been the major focus of pollution control policy.

Graham (1956) states that a well-operated conventional water treatment plant can reduce very heavy loadings of coliform bacteria to practically zero.

Sewage Fungus

According to Tarzwell (1953), sewage fungus (Sphaerotilus) develops during periods of normal or low water and is removed by the first flood. After its removal the area is practically barren of bottom life and some time is required for it to be repopulated. The direct effect of sewage fungus on larger forms was well illustrated by the fate of stoneflies, mayflies, and caddisflies, and other insects which were washed into polluted sections of the stream he was studying (Lytle Creek). These insects soon become so covered with growths that they were overwhelmed and smothered. It has been shown (Butcher, 1932) that these prolific growths are not produced by oxygen deficiencies but by concentrations of organic matter, chiefly nitrogenous and carbohydrate material. Butcher (op. cit.), and Purdy (1952) state that the low oxygen concentrations usually associated with sewage fungus are incidental and the result of the decomposition of the organic material upon which the fungus is dependent for existence. They state that the designation of
these growths as "sewage fungus" is somewhat unfortunate because, while they may contain some fungi such as Geotrichum, Leptosites, and Fusarium, they are often chiefly composed of the bacteria Sphaerotilus, Zoorlea, and Becriaton, and certain ciliated protozoans such as Vorticella, and Carchesium. During the summer, at Station 2, "sewage fungus" growth was observed from the bridge.

Physical Examinations

Ice

Ice is one of the physical factors that affects dissolved oxygen and, consequently, the chemical components related to it in an environment during the winter. Bartsch and Allum (1957) found that generally there was no measurable oxygen production in sewage ponds during winter under ice. Anaerobic conditions were continuous from the onset of ice cover until breakup. They report that their findings parallel those of Greenbank in that "cloudiness" of ice caused by minute air bubbles or dirt had great influence upon light transmission. They observed that where transmission is concerned, ice quality appeared more important than thickness, and that quality generally increased as BOD loading decreased. Johnson (1960) reports that ice, when free of snow, did not greatly affect the light penetration as far as euphotic zone depth was concerned. He reports that ice over 76
centimeters thick transmitted light for a considerable depth.
He states that slushy ice or cloudiness of ice would reduce the amount of penetration considerably.

**Turbidity**

Welch (1952) states that turbidity in streams is due largely to silt, detritus, and other nonliving materials. Domestic sewage and other forms of stream pollution commonly increase turbidity, sometimes markedly. According to Fair and Geyer (1954), when sewage is discharged into a stream it ordinarily separates into two parts—that which is heavy enough to settle and form a sludge deposit and that which is in solution or is finely enough divided to be carried along by the current. It was reported by Reid (1961) that in the lower stream courses (and in the spring in upper stream courses) turbidity becomes a dominant and characteristic feature of most running waters.

**Bottom Soils**

Ludwig (1932) states that—"the nature of the bottom itself indicates pollution, being relatively clean mud, silt, and sand above the pollution and black muck and organic debris, with a foul privy odor, below the pollution." Welch (1952) states that different kinds and amounts of bottom deposits maintain different organisms and are an aid in determining, within limits, differences in quantitative biological productivity.
DISCUSSION OF RESULTS

The changes in one particular characteristic of the water, whether it be chemical, biological, or physical, are not intended as the sole criteria for measuring the extent of organic pollution caused in Six-Mile Creek and the Big Sioux River by the effluent from the Brookings sewage treatment plant. Complimentary factors such as temperature, dilution, light penetration, etc. also influence the changes in the water. However, the chemical data, when considered with biological evidence, give a good indication of the pollution load in the receiving waters.

Chemical Examinations

Chloride

The chloride content of the water at S-1 was usually very low. The results of the chloride-ion determination are shown in Figure 7. Chloride varied from 2.00 ppm to 8.00 ppm. Four factors affect the chloride concentration at this station. One is the evaporation of surface water, thus concentrating the chloride in a smaller volume of water. Another is the drainage from the surrounding pasture into the water. (No cattle were pastured on the surrounding land except during the summer.) The partial exclusion of the chloride from the water when it freezes in the winter is another important factor. Also, it is not known exactly how much chloride was contributed from upstream drainage.
Figure 7. The ammonia nitrogen-chloride ion level during the study.
It is interesting to note that the low occurred in January when there was 17 inches of ice at the station. The chlorides continued to increase in concentration as the ice became thicker until the stream froze to the bottom. The high concentration occurred in February following a thawing and refreezing that produced a layer of water trapped between two layers of ice—the top layer 2 inches thick, the lower layer 5 inches thick.

When the ice melted in the spring the subsequent dilution contributed to the decrease in the chloride concentration from 8.00 ppm in February to 3.50 ppm in March. The flood water may have flushed some of the chloride laden water downstream which would also partially account for the lower level at that time.

Station 5 was used as a sampling station only during the summer when there was a sufficient amount of water moving through it to provide a representative sample. The chloride concentration varied from 2.50 ppm in March to 8.00 ppm in August (3.50 ppm in March and 6.50 ppm in August at S-1). All the stations had the lowest chloride level during March due to the great amount of dilution brought about by the runoff from melted snow. Since no samples were taken from station 5 during the winter, it is not possible to compare the lows at S-1 with those at S-5.

The average chloride level from all the water samples taken at S-5 was 5.60 ppm. The average during this sample period for S-1 was 5.00 ppm chloride.
At station 2 the low of 4 ppm occurred at the end of March and the high of 423 ppm occurred at the end of October. In addition to the chlorides contributed to this station from upstream many other factors affect their concentrations. Among these are the amount of rain water received at the sewage plant from the storm sewers of Brookings, the concentration of the chloride in the pollution load, the time of day and the day the test sample was taken below the plant, the amount of body wastes in the influent, and possibly the concentrations of other compounds in the water.

The chlorides are well diluted in the spring, but begin to build up in the latter part of the summer. This build up continues until they reach their normal level of between 200 and 300 ppm at this station. It can be assumed that the difference between the normal level (4 to 6 ppm) at station 1 and the normal level (199 ppm) at station 2 was contributed by the sewage load.

The ice cores from S-1 and S-2 were examined for chlorides. The cores contained 4.5 and 18 ppm chloride respectively, as compared to 8.00 ppm in the water at S-1 and 249.00 ppm chloride in the water at S-2 on the date the cores were removed. The chloride content of the ice core at S-1 was 2.50 ppm higher, and the core at S-2 was 14.00 ppm higher than the lowest level recorded at these two stations. The high chloride content of S-2's core could have been due to water trapped in the core and not actually tied up as ice.
Station 3 had a high of 60 ppm during the last of January when there was 16 inches of ice. The water was six inches deep below the ice. It is well known that the thickness of the ice controls, to a degree, the amount of chloride in the water, however, very little attention has been given to the ice thickness-water depth ratio. In this instance where the ice was only 2 inches thicker than on the previous test date, but the chlorides were 54 ppm higher, the ice thickness is not believed to be so much the cause of the increase as upstream pollution. The high of 60 ppm may have been contributed by an upstream source of pollution at either Watertown or Arlington. This is by no means a reflection on the efficiency of operation of their treatment plants since chlorides are not altered appreciably by chemical reactions and dilution is the most effective way to reduce the concentration.

There were times when the ice was thicker than 16 inches at S-3, but the chloride test was lower because the water under the ice was deeper, and the chlorides were less concentrated. The chlorides increased rapidly as the ice became thicker and the flow subsided during the winter months. From July to early winter, the chlorides continued to rise at this station.

The chloride levels at station 4 are higher than the levels at the other stations, with the exception of station 2, and reflect the increment from the Brookings sewage treatment plant. This station had a high of 127 ppm in February and a low
of 3 ppm during the last of March. When the high occurred, the water was flowing on top of the original ice surface. This inhibited the dilution of the sewage by the water in the river. Consequently, the water chemically was more like creek water than river water. On the date that this determination was made, the water at station 4 had a chloride level 188 ppm higher than the level at station 3. The influence of the chloride contribution at station 4 from Six-Mile Creek is very evident.

**Ammonia Nitrogen**

Ammonia and nitrate levels in water are dependent upon the dissolved oxygen level of the water. If the DO level is high the ammonia will be oxidized to nitrate, if the DO level is approaching zero the nitrate will be reduced to ammonia. The DO is related to BOD in the same inverse manner.

The ammonia nitrogen (NH$_3$) levels are graphically displayed in Figure 7.

The ammonia nitrogen at S-1 reached a high of 2.76 ppm in February and a low of 0.00 in October. When the ammonia was at its maximum concentration, the DO level was 7.80 ppm. However, there were two layers of ice with a layer of water between them and one below both of them. The ammonia may have been highly concentrated in the lower water layer and actually the test would have indicated a higher level had the lower water not been diluted with the water trapped between the two ice layers.
In October, when the ammonia level was zero, the water contained 9.10 ppm DO (90 per cent of saturation). All of the ammonia had been oxidized to nitrate. During the warmer months ammonia is present in very small amounts or not at all. During the summer, when there is a sufficient oxygen available from photosynthesis, the NH₃ is oxidized to nitrate. During the winter the ice and snow cover reduce the light penetration enough to prevent photosynthesis and the water becomes anaerobic. When the DO level of the water nears zero, almost all of the NO₃ is reduced to ammonia.

Station 5 had a low of 0.02 ppm in April and a high of 1.95 ppm during August. The low at S-5 during April could not be compared with the level at S-1 because no sample was taken from S-1 on this day. The high at S-5 in August was 0.78 ppm higher than the level at S-1 on this date. These are considered to be normal unpolluted levels for ammonia in a stream in this area and any difference in the levels at S-1 and S-5 are probably within the limits of the accuracy of the test and within the range of normal fluctuation of the ammonia level in the water.

Station 2 had a high of 22.50 ppm during January and a low of 1.84 ppm during March. The lowest levels present during the study approached lethal levels for fish, although fish passed through this station during the spring on the way upstream. A school of fish (probably fathead minnows, Pimephales promelas)
was seen swimming upstream late in the spring. How long they remained in the polluted section of the stream is unknown. The same area was seined during the fall and no fish were taken.

The chloride anion shows somewhat of an inverse relationship to the ammonia cation.

Station 3 had a high of 5.20 ppm during January and a low of 0.00 ppm during October and November. On the day that the high level of ammonia occurred, the DO level was at 3.00 ppm. On the day that the low level was recorded, the water was 141 per cent saturated with oxygen, the highest DO saturation level that occurred at this station during the study. Very little evidence of pollution in the form of ammonia was detected at this point. The ammonia was oxidized in the stream or never released into the water. The low for this station occurred on the same day as the low for station 1. With the exception of station 5, this station had the lowest level of ammonia during the study.

Station 4 had a high of 7.10 ppm in February and a low of 0.03 ppm in April. The ammonia and chloride highs occurred at this station on the same day and for the same reason. The sewage was flowing over the ice and was essentially undiluted by river water. The oxygen levels were reasonably high (61 per cent saturated) on this date, but the ammonia was not oxidized in the short time it took it to flow from station 2 to station 4. The high at station 4 was 7 ppm higher than the ammonia level at
station 3 on the same day. On one occasion the ammonia level was higher at station 4 than at station 2. This occurred during the spring floods and was probably due to a fluctuation in the ammonia level of sewage.

Sulfate

The sulfate levels are graphically displayed in Figure 8. The sulfate high at station 1 was 1400 ppm during September and the low of 130 ppm occurred during February. This was the highest sulfate level recorded during the study at a clean-water station. Station 2 had a high of 2072 ppm on this same date. No sample was taken at station 5. There is an apparent direct relationship between sulfate and pH at most stations (compare Figure 8 with Figure 9).

Station 5 had a low of 130 ppm in April and a high in August of 250 ppm. The lows for stations 1 and 5 were the same, but they occurred on different dates. At station 5 the sulfate climbed steadily from April until the station dried out in August. While this was happening, it is highly probable that evaporation caused the increase in concentration. On the other hand, rain water and heavy runoff from rain water appear to be low in sulfate and dilute it considerably when added to a stream.

The highest sulfate concentration at S-2 occurred in September when 2072 ppm was recorded. This was the same day that the high was recorded at station 1. A low of 92 ppm was recorded
Figure 8. Sulfate ion concentration during the study.
Figure 9. Alkalinity, pH, and hardness. Note the close relationship of the results for these three tests.
in February. The breakdown of sulfate-containing compounds in the sewage probably accounts for the higher concentration at 2 than at 1.

Station 3 had a high of 736 ppm during August and a low of 51 ppm during September. The high of 355 ppm at S-4 also was recorded on this date. The low at S-4 occurred in January, the same as all the other stations except S-3 where the low occurred in September. It is interesting to note that S-3 had a higher sulfate level than S-4 in 10 out of 15 determinations but seldom when the river was ice-free. Station 4 had a higher level of sulfate than S-2 in three out of 15 determinations. In all three instances there was a heavy ice cover over the river. It almost appears that after the sewage was diluted to a certain level it acquired something that had a synergistic effect in the breakdown of sulfates.

A very close relationship was noted between the sulfate concentration and the hardness level during the study (compare Figure 7 with Figure 9).

Hydrogen-Ion Concentration

It is obvious that pH is greatly influenced by dilution from the runoff of melted snow and rainwater. The poorly buffered rain water (pH usually about 7.0) has, through dilution alone lowered the pH of the water. In connection with this, several other factors should be explained. First, the flood waters flush
the algae responsible for removing CO₂ from the water downstream. Without these algae in the water, the pH level remains low.

Second, the silt carried by the runoff water has raised the euphotic zone of the stream to a point where the remaining algae are not receiving an optimum amount of light, thus holding the rate of photosynthesis to a minimum. The process of photosynthesis is noted for raising pH levels above 7. The pH levels are shown in Figure 9.

The highest pH recorded for S-1 was 8.1 during September and November. The lowest pH of 7.4 was recorded during March.

Station 5 had a high of 8.1 in April and a low of 7.6 in March. As in the case of S-1 the low was recorded during a period of high runoff when the water level in the creek was very high; the pH levels were, however, usually higher in the spring and fall than during the rest of the year. The pH's at S-1 and S-5 were very similar and both were usually a little higher than the pH's at S-2.

The pH reached its low in February at S-2, and a high of 8.6 was reached in September. During the study S-2 and S-3 were the only stations that had a pH above 8.4; however, the pH readings were usually lower at S-2 than at the other stations due to the acids released by the decomposition of the sewage. The pH levels at S-2 were individually low on 50 per cent of the sample days. Station 3 had the highest pH level or shared the highest
level with another station on 50 per cent of the sample days. The close relationship between alkalinity, hardness, and pH can be seen by comparing their levels for station 2. The relationship is especially noticeable for January, February, and March.

The highest pH at S-3 was recorded in September and the lowest in January. They were 8.6 and 7.4 respectively. A low of 7.4 was recorded in January at S-4. A high of 8.4 was recorded on two different occasions, September and October, during the study. The pH levels at S-3 and S-4 paralleled each other very closely.

On October 20, the pH at S-3 and S-4 was 8.4. On this same day a trace of phenolphthalein (pHth) alkalinity was recorded. It can be seen in Figure 9 how a rise in the pH accompanied this rise in phenolphthalein alkalinity. On September 15, S-2 had a pH of 8.6 and 10 ppm pHth alkalinity. On this same date, S-3 and S-4 had pH values of 8.6 and 8.4 respectively. Both had pHth alkalinitieys of 8.0 ppm. Phenolphthalein alkalinity was present on this date and not on the others because the samples were obtained in the afternoon between 3:30 and 4:30 when photosynthetic activity was at a relatively high level. By this time in the afternoon, photosynthesis had removed a large amount of \( \text{CO}_2 \) from the water and caused a rise in the pH (see "Alkalinity" below).
Keeping the insignificance of pH averages compared to the more reliable pH ranges in mind, the effects of the sewage on the average pH values can be observed. Station 2 had an average pH of 7.7, while the other stations (except 5) had averages of 7.6. Sewage-receiving waters (when unaffected by photosynthesis) are usually more acid than natural waters.

**Alkalinity**

Alkalinity is caused in water by hydroxide, OH; carbonate, CO$_3^-$; and bicarbonate, HCO$_3^-$. During photosynthesis below pH levels of 8.3, HCO$_3^-$ (loosely bound CO$_2$) furnishes CO$_2$ to the phytoplankton. At pH values above 8.3, CO$_3^-$ (tightly bound CO$_2$) furnishes CO$_2$ to the phytoplankton during photosynthesis. Unbound carbon dioxide in water is acidic as it associates and disassociates readily as carbonic acid (H$_2$CO$_3$) and H$^+$ + HCO$_3^-$. Photosynthesis removes the CO$_2$ from the HCO$_3^-$ leaving the CH$_2$O, which causes a rise in the pH. The greater the amount of photosynthesis, the higher the pH, and the more OH$^-$ that is present in the water. There is a direct relationship between pH, alkalinity and pH. The higher the pH above 8.3, the more pH alkalinity (OH$^-$ and CO$_3^-$) that is present. Below pH values of 8.3, only HCO$_3^-$ alkalinity (HCO$_3^-$) is present. The total alkalinity determinations during the study are shown in Figure 9.
A high of 350 ppm occurred at S-1 during January and a low of 16 ppm occurred during March. On November 13, a trace of phth alkalinity was recorded. This sample was taken at 11:05 A.M. when the water temperature was 34° F and the pH was 8.1. This is the only time that phth alkalinity was recorded for this station.

Station 5 had a high of 242 ppm in July and a low of 22 ppm in March (S-1 had 16 ppm in March). The low alkalinity level occurred on March 30 for all the stations. When the high occurred at S-5 in July, station 1 had 22 ppm less alkalinity (222 ppm) than S-5. The pH at both stations was the same. The determination was made an hour later in the morning at S-5 than at S-1 and it is possible that photosynthesis during that time accounts for the difference. Station 5 had no phth alkalinity at any time during the study, probably because the highest pH reading obtained was 8.1.

Station 5 does not exhibit the entire alkalinity picture for the year as samples were only taken during high water and just during warm weather when it would be most susceptible to changes caused by photosynthesis.

The high alkalinity of 288 ppm was recorded at S-2 in January. The low of 22 ppm was recorded in March. On September 15, 10 ppm of phth alkalinity and 36 ppm of M.O. alkalinity were
recorded. This was the highest level of alkalinity recorded at any station on this date and the highest level of pH alkalinity recorded during the study. The pH was 8.6 on this date (also the highest pH recorded).

Station 2 had the highest alkalinity of any station on 9 out of 16 test days. The most interesting thing about the alkalinities was that S-2 had the highest level of any station from July on, for 7 consecutive tests until the ice formed. When S-2 did not have the highest alkalinity level, and this was under ice cover, it had the lowest alkalinity 5 times out of the remaining 9 determinations.

At station 3 a high of 318 ppm was recorded in January and a low of 22 ppm was recorded in March. A trace of pH alkalinity was noted in April and again in September; 8 ppm was recorded in October. The low level of the river during the fall appears to be an important factor in determining alkalinity and pH levels. The 8 ppm was recorded only on the day that the test samples were taken in the afternoon when the pH was 8.6.

At S-4 a high of 304 ppm total alkalinity was recorded in January and the low of 20 ppm was recorded in March. The low alkalinity level occurred in March for both S-3 and S-4, and the high level occurred in January for both stations.

The high alkalinity levels for all stations sampled were recorded on January 3. The low levels were all recorded on March
From these observations it can be seen (Figure 9) that the lower levels of pH, alkalinity and hardness were reached when the samples were highly diluted with runoff waters. The effect of the water contributed from the sewage plant on the alkalinity is evident when the yearly averages are considered. The average at S-1 was 101 ppm while the averages for S-1, S-3, and S-4 were 111, 103, and 98 ppm respectively.

During the winter, under ice cover, station 1 had the highest alkalinity level of any station on 2 out of 7 determinations and station 3 had the highest level of any station on 3 out of 7 determinations. Stations 2 and 4 each had the highest level once. From these data it can be seen that under ice cover, the clean-water stations have a higher level of alkalinity than do the polluted-water stations. This is due to the acids formed in the sewage effluent that neutralize the alkalinity, especially under ice cover when the decomposition of pollutants is slower. The sewage effluent is being decomposed at a slower rate during the winter due to the low temperatures which inhibit bacterial action and the low DO levels. Bacteria use the DO to oxidize the sewage. Ice cover inhibits a build up of DO by photosynthetic action, and thus indirectly prevents sewage oxidation.

**Hardness**

The theoretical hardness of water is the sum of the concentrations of all metallic cations other than cations of the
alkali metals, expressed as calcium and magnesium ions, but in some waters other metals must be considered.

Alkalinity is caused by OH, HCO$_3^-$, and CO$_3^{2-}$ in combination with Ca, Mg, Mn, and Fe. Hardness is caused by Ca, Mg, Mn, and Fe, in combination with OH, HCO$_3^-$, and CO$_3^{2-}$, and also sulfates and some chlorides. Temporary hardness is caused by Ca or Mg in combination with bicarbonate and carbonate while permanent hardness is caused by Ca or Mg in combination with sulfate. The alkalinity test will measure the temporary hardness, but it does not measure the permanent hardness such as sulfate. The difference between the total hardness and the alkalinity hardness is, therefore, the permanent hardness.

In January a high of 872 ppm hardness was recorded at S-1. The maximum hardness recorded for S-5 was recorded in August when 442 ppm was present (410 ppm at S-1). The flow was so low that no samples were taken during the winter months when the readings were comparatively high for the other stations. The hardness levels at S-5 were very similar to the levels obtained at S-1. For example, the averages for S-1 and S-5 during the period when the test samples were taken on the same dates were 301 ppm and 306 ppm, respectively, as compared to 329 ppm average for S-2.

Station 2 had a high of 530 ppm in October and a low of 68 ppm in March. Figure 9 shows that the hardness was lowest at this station during the winter months but highest during the summer. Ground water is usually harder than surface water; and, since the water supply for the City of Brookings comes from ground waters and
most of the river and creek water comes from surface runoff, during
the summer the water at S-2 is harder than at the other stations.
Hardness can be concentrated in water by evaporation though, as can
be seen by the steady climb in hardness at S-5 from summer to fall.

The highest level of hardness for S-3 was reached in January
when 649 ppm was recorded. The low of 68 ppm was recorded in March.

During the winter, when a heavy ice layer covered the river
and the creek, the elements causing hardness were probably concen-
trated in the water below the ice (at S-1, S-5, and S-3) and there-
fore the hardness was higher during the winter (not at S-2, and S-4).
During the winter months the hardness at S-3 was greater than the
hardness at S-2 or S-4. During the spring, summer, and fall, the
hardness levels at S-3 and S-4 were very similar. The reason that
the water was softer below the sewage plant in the winter than dur-
ing the summer is that on most occasions when samples were taken
the water layers and ice layers were stratified. The water from
the plant would flow on top of the ice the distance from the plant
to S-2. This would prevent any mixing or dilution of the sewage
effluent with the water under the ice surface. Much of this water
had passed through a water softener of a home in Brookings a short
time before passing through the sewage treatment plant and out as
effluent.

With the exception of S-2 and S-5, maximum hardness levels
occurred under the ice in January at all stations and the lowest
levels of hardness occurred during the spring flooding in March.
Station 2 had a range from 68 to 530 ppm; station 3 had a range from 68 to 649 ppm, and S-4 had a range of 68 to 581 ppm. Both S-3 and S-4 had higher maximum hardness readings than S-2 during the study. The maximum high determination recorded at S-3 was 68 ppm higher than the maximum recorded for S-4. It is assumed that the softer water contributed to S-4 from the City water of Brookings is responsible for this difference.

Orthophosphate

Phosphate tests discussed in this study were a measure of the orthophosphates \((\text{H}_2\text{PO}_4^-)\) only. These phosphates were contributed to the sewage effluent from the breakdown of phosphorus containing products in the wastes and bacteria associated with the wastes. These phosphates are not the same phosphates associated with synthetic detergents, and any differences between orthophosphate values below the sewage plant and those at the clean-water stations probably were not due to the presence of detergents in the water.

The orthophosphate was usually high at S-2. In July it was recorded at 2.0 ppm. From September through December it was above 1 ppm. The low of 0.37 ppm was recorded in April. This highest orthophosphate level occurred on the same day that the maximum flow was recorded at the sewage plant (see Table II for the incoming volumes of flow at the sewage treatment plant). When the water levels were very high, much water was bypassed at the sewage treatment plant but was not recorded on the flow charts kept at the plant.

Non-detergent phosphate in sewage can be removed by secondary sewage
Table II. Incoming Flow, Brookings Sewage Treatment Plant

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<th>Date</th>
<th>Flow 1</th>
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<th>Chlorine 4</th>
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1 Total gallons flow for 24 hour period
2 COD at Station 2, for this date
3 Any flow bypassed around the plant on this date
4 Any chlorine added at the plant on this date

Treatment, and sometimes as much as 90 per cent is removed. When this water bypassed the treatment plant, it may have carried some orthophosphate with it that had not been recorded on previous tests because it was removed by the secondary treatment. Although station 2 had the highest orthophosphate level of any station during the
Figure 10. Orthophosphate levels during the study.
study, station 1 had the lowest level of orthophosphate on 8 out of 15 determinations, and S-5 was lowest once out of 5 sampling days, and once S-5 and S-1 were tied for the low. Therefore, 10 out of 15 times, S-1 or S-5 had the lowest level of orthophosphate. Station 5 had the lowest level once and S-4 was low 3 times, and once they were tied for the lowest value.

The high at S-3 was 1.6 ppm in July, and a low of 0.03 ppm was present in August. The amount of orthophosphate present, especially in the winter (see Figure 10) indicates that it was being concentrated in the water from some source.

At S-4 the highest orthophosphate level of 1.70 ppm was recorded in July. A low of 0.02 ppm was recorded in January. The high levels were recorded at all stations on July 19. The high determinations were recorded following several days of rain that raised the water level in the creek and river. On Figure 10 it can be seen that the orthophosphate levels at S-3 were sometimes higher than those at S-4 during the winter and spring months but that S-4 had higher levels during the fall and early winter. Comparing Figure 9 with Figure 10 it appears that orthophosphate is directly related to hardness and possibly to H.O. alkalinity and pH.

Fluctuations in the orthophosphate values at S-2 and S-4 represent the difference between the amount of orthophosphate in the raw sewage and the amount removed by the sewage treatment plant, which is affected to a degree by the weather. The release of orthophosphates by sewage plants upstream may affect its level at S-3.
Figure 11. Nitrite-nitrate relationship during the study. (Low nitrite levels indicate well treated sewage effluent).
The nitrite (NO\textsubscript{2}) levels are shown in Figure 11. The highest level of nitrite was recorded at S-1 in July when 0.16 ppm was present. On two occasions, one in October and one in December, there was no nitrite present. It is assumed that these concentrations are normal levels and mostly due to natural nitrites present, especially since the highest levels were recorded during periods following a heavy rainfall (rainwater picks up traces of nitrite rapidly).

The highest nitrite level recorded at S-5 was 0.14 ppm recorded in April. The low of 0.01 ppm was recorded in August. These levels appear to be very little changed from those at S-1. The short distance, and rapid flow of water from S-1 to S-5 was probably responsible for the similarity of the two stations.

The low nitrite level of 0.01 ppm was recorded in January at S-2, and the high of 0.94 ppm was recorded in July. By comparing the volume of flow received at the sewage plant on January 13 from Table I with Figure 11 it can be seen that the lowest NO\textsubscript{2} level was recorded at S-2 on the same date that the lowest volume of water was received at the plant.

At S-2 the highest nitrite level was recorded on July 19 when the largest volume of flow was received at the plant. The otherwise comparative low NO\textsubscript{2} levels recorded at S-2 would seem to indicate that the sewage treatment plant is doing a good job of breaking down nitrogenous wastes in the sewage. Part of the low NO\textsubscript{2} level is due
to the fact that under anaerobic conditions some of the NO₂ has been reduced to NH₃. By comparing the high NH₃ of S-2 on January 13, Figure 7 with the low NO₂ level for the same date, Figure 11, it can be seen that this low level of NO₂ was due in part to the low NH₃ levels that prevailed during this period.

A NO₂ level of zero was recorded three times during the study at S-3--March, September, and December. The highest level recorded was 0.36 ppm in July. It is also possible that the sewage plants upstream were bypassing sewage into the river during this period of high water. The absence of NO₂ indicates that if any sewage was entering the river from upstream it was well treated, or that the stream was capable of handling the sewage load. The high level was recorded on July 19 following a heavy rain.

The highest level recorded for S-4 was 0.34 ppm in July. The high for S-3 was recorded on the same date, but the nitrite at S-3 was 0.02 ppm higher than at S-4. There was about one-third as much nitrite at S-4 than there was at S-2 on July 19. Everything else being equal, this would indicate that the nitrites from the treatment plant are being rapidly oxidized in the creek and river.

The lowest level of nitrite recorded for S-4 was 0.01 ppm recorded on January 21. It was -7° F on this day and the river was frozen to the bottom in all but the deepest holes. There is a possibility that very little sewage was getting downstream as far as S-4 before it froze, thus the only nitrites present were those that were left in the unfrozen water of the river.
The clean-water stations—S-1, S-2, and S-5 had the lowest level of nitrite in 9 out of 16 determinations. On one occasion S-3 and S-4 had the lowest values and once S-1 and S-5 had the lowest values, bringing the total number of low values at clean-water stations to 11 out of 16. The clean-water stations had the highest level of NO₂ on 4 out of 16 test days (3 of these were at S-3). The polluted-water stations (S-2 and S-4) had the highest level of NO₂ present 10 times out of 16.

**Nitrites**

The highest nitrate level at S-1 was 1.55 ppm in December. A zero reading in September was the low. It is possible that the low occurred during the time when any available nitrogen was being tied up biologically. It can be seen on Figure 11 that the highest level of NO₃ occurred just after the ice formed over the creek. Undoubtedly a large number of aquatic organisms died off following this freeze-up and increased the nitrate level to the high recorded on this date.

The nitrites at S-5 reached the high of 1.70 ppm in March after the spring thaw. The low of 0.09 ppm was recorded in April (this level is the same as that determined at S-3 on the same date) and occurred between the spring thaw of March 30 and a rainy period before July 19, when the nitrites began to rise again (see Figure 11). It appears that heavy rainfall will raise the nitrate level just as effectively as ice formation.
The highest level of nitrate recorded at S-2 was 1.70 ppm in March. A low of zero was recorded in September. Most of this was probably contributed by a combination of absence of runoff water along with a well-treated sewage effluent. Figure 11 indicates that with the exception of periods when ice cover is present or in periods of heavy rainfall, the nitrite-nitrate ratios are inversely related to each other. When the sewage is low in volume, due to a decrease in the number of students in Brookings, and with high oxygen levels, the nitrates are high and the nitrites are low. The average levels of nitrate at S-1 and S-5 were 0.64 and 0.69 respectively on the dates when samples were taken from both stations. The average at S-2 for the same period was 1.39 ppm NO$_3^-$. This average increase of 0.72 ppm nitrate between S-2 and the clean water stations upstream has been contributed to the creek by sewage effluent.

There were two low levels of nitrate at S-3 and S-4. One during the winter under the ice and one during the fall of the year before ice formation. The high nitrate level of 1.90 ppm at S-4 occurred on March 30 (1.24 ppm at S-3). A low of 0.0 ppm was recorded during January, September, and October (also 0.00 ppm at S-3 on these days and on March 16). The two weeks following March 16 were very warm and all of the ice had melted by March 30. After the ice and snow had melted and the spring rains started, there was a very rapid climb in the nitrate levels. On October
the weather was warm and the nitrate level was low (0.00 ppm) at S-3 and S-4. By December 22, the ice was 18 inches thick and the nitrate level rose to 1.88 ppm at S-3 and 1.72 ppm at S-4.

When the nitrate levels were higher at S-3 than at S-4, so were the nitrite levels (and vice versa) with two exceptions. Once there was a difference of 0.02 ppm when the samples were taken in the rain and once the NO₃ was higher at S-3 and the NO₂ was higher at S-4; however, in this instance S-4 also had 0.31 ppm more NH₃ than S-3.

Out of the 16 times that samples were taken from each station during the study, S-4 had a higher NO₃ value than S-3 five times, six times the NO₃ level at S-4 was lower than at S-3, three times the levels were equal, and two times NO₃ was absent at both stations.

On the days that the NO₃ was lower at S-4 than at S-3, either the NH₃ or the NO₂ or both were higher. Table III shows this relationship.

It appears that the nitrate level in the river can be predicted by the oxygen levels of the water more readily than by fluctuations in sewage flow. This prediction is dependent upon the oxidation of the nitrogenous wastes by the sewage treatment plant and receiving waters. In the river, when the nitrate is at a high level, so is the DO level, and vice versa. This was true in 13 out of 16 examinations, with the exceptions all occurring when there was an ice cover on the river.
Table III. A Comparison of the Ammonia-Nitrite-Nitrate Relationship at S-3 and S-4

<table>
<thead>
<tr>
<th>Days that NO₃⁻ was lower at S-4 than S-3</th>
<th>Days that NO₂ was higher at S-4 than S-3</th>
<th>Days that NO₃ was higher at S-4 than S-3</th>
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<tr>
<td>April 27</td>
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<td>July 19</td>
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<td>December 22</td>
<td>X</td>
<td>X</td>
</tr>
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Dissolved Oxygen

When water is highly polluted with organic material (has a high BOD), a wide range of diurnal-nocturnal oxygen fluctuation is common, especially during warm weather. The two extremes in this DO fluctuation are more widely separated in polluted water than in unpolluted water. The polluted water may have more DO during the daylight hours than the unpolluted water, but after dark the DO will drop rapidly to a near-zero value whereas the DO in unpolluted water will drop only slightly. The DO of the polluted water will remain near zero until a few hours after sunrise, and then will be rapidly increased by the photosynthetic action of the algae present in the water.
The highest dissolved oxygen value recorded at S-1 was 14.5 ppm recorded on November 10. A low of 0.5 ppm was reached January 13. When the high level was recorded the water temperature was 34°F and there was one-half inch of ice on the creek. The combination of cold water and thin ice were probably responsible for the supersaturation of the water (103 per cent). As seen in Table IV, this was also the day on which the water at S-2 reached its saturation peak.

Station 5 had a high of 10.9 ppm DO in April and a low of 5.2 ppm in August. No sample was taken from S-1 on this day in April, but in August S-1 had a DO of 7.9 ppm. It is believed that the more pond-like conditions at S-1 were more conducive to a photosynthetic oxygen build-up which accounts for the higher DO at S-1. The water at S-5 was never supersaturated during the study.

Station 2 had a DO level of 15.2 ppm on November 18 (121 per cent saturated). The DO values can be misleading. It can be seen from Table IV that on September 15 when the water held only 13.4 ppm DO, it was 171 per cent saturated. On this day the sample was taken at 3:30 p.m., while on most of the other sampling days, the samples were obtained in the morning. The high DO value of this sample was due to photosynthetic oxygen. It is likely that the DO level dropped to near zero a few hours after dark because of the high BOD.

There is an inverse relationship between the dissolved oxygen at S-2 and the chloride level of the water. A comparison can be
### Table IV. Relationship of Dissolved Oxygen to Water Temperature Corrected for Altitude

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<tr>
<th>Station</th>
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<th>Water Temp. Degrees C</th>
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<th>Per cent Saturation</th>
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Table IV. (Continued)

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<th>DO</th>
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<th>Per cent Saturation</th>
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made by comparing the chlorides on Figure 7 with the DO on Figure 12. A direct relationship between turbidity and dissolved oxygen on most sampling days can be seen at S-2, by comparing the DO on Figure 12 with the turbidity levels on Figure 13.

The highest level of DO at S-3 was 15.4 ppm on October 20. The water was 141 per cent saturated. The lowest level was 0.5 ppm on March 16; the ice was 33 inches thick and covered with 18 inches of snow. The chloride test indicated 12 ppm present. There was no nitrate or nitrite.

The lowest dissolved oxygen recorded at S-4 was 4.8 ppm January 3 and July 19 (3.00 and 4.9 ppm DO on these dates respectively at S-3). A high of 14.4 ppm (14.7 ppm DO at S-3) was recorded on November 18. The water was 35 per cent saturated on January 3 (4.8 ppm). This was the lowest DO level of any station on this day. It was also the only station where the ice was completely covered with snow.

During the study period, S-3 reached a supersaturated state four times, compared to three times for S-4. In 13 out of 16 determinations, S-2 had the lowest DO level. When S-2 did not have the lowest level of DO, S-4 did, with one exception--S-1 had the lowest level (6.7 ppm on September 15). One of the clean water stations (S-1, S-3, or S-5) had the highest DO reading on 11 out of 16 determinations. Station 2 had the highest DO level on two different occasions during the fall and S-4 had the highest reading twice.
Figure 12. Dissolved oxygen and biochemical oxygen demand levels during the study.
Figure 13. Turbidity readings during the study.
during the winter under ice cover and once during the period of spring runoff. Stations 2 or 4 never had the highest DO level during the summer.—See Figure 12 for the dissolved oxygen levels.

**Biochemical Oxygen Demand**

The biochemical oxygen demand of water is primarily a change in the DO of the water caused by a few select organisms of the biota (bacteria) that oxidize organic matter. The metabolic rate of these bacteria is directly proportional to the temperature of their environment; the higher the temperature, the faster the oxidation of the waste, and therefore the faster the depletion of the DO. Klein (1959) reports that an increase in temperature of 1°C will increase the BOD value 4 to 7 per cent and vice versa. During the summer when the temperatures are higher, a large amount of DO is removed from the water to satisfy the BOD. The DO is replaced in the water through photosynthesis by algae during the daytime but is removed by BOD both in the daytime and at night. For this reason there is a nocturnal oxygen sag in polluted waters.

In a polluted situation during the summer it is quite common to have a low BOD value accompanied by a low DO in the stream, whereas in the winter, one often finds a high BOD value and a near-zero DO level. In the summer situation, the BOD has been satisfied, which accounts for the lower DO level, but in the winter the DO is almost entirely depleted and little or none of the BOD has been satisfied.
The highest biochemical oxygen demand recorded for S-1 was 12 ppm on August 17 (6.6 ppm at S-5). The lowest level (0.7 ppm) was recorded on December 22. The difference (5.4 ppm) in the BOD levels at S-1 and S-2 on this date is thought to be due to the presence of a larger number of algae that accumulated in the pond-like conditions at S-1 and caused an increase in the BOD value due to respiration in the unlighted confines of the BOD incubator.

The highest BOD, 71.2 ppm, was recorded at S-2 January 13; the DO was 0.2 ppm. Very little of the oxygen demand of the organic material in the creek was being satisfied. The ice was 18 inches thick and covered with one inch of snow. The low on July 19 was probably due to the dilution of the creek water by rain water.

When the BOD levels on Figure 12 are compared with the available nitrate levels on Figure 11, the inverse relationship between the BOD level and the nitrate nitrogen level can be seen, especially at S-2. Nitrate is a product of biochemical oxygen demand when there is a sufficient supply of oxygen available. If there is no oxygen available, no oxidation takes place, and there is a low level of oxidized nitrogen and large amounts of NH₃ and a potential BOD. Station 2 always had higher BOD values than any other station during the study.

The highest BOD recorded at S-3 was 14.0 ppm on March 16 when the river was covered with 33 inches of ice and 18 inches of snow. There was no nitrate or nitrite nitrogen (1.6 ppm ammonia) in
the sample and the DO was 0.5 ppm. When the oxygen in the river dropped to this level, many aquatic organisms died, and their decomposition placed an even higher biochemical oxygen demand upon the river. When a hole was cut through the ice the water underneath had the typical odor of decaying organic matter at both S-3 and S-4.

The highest BOD at S-4 also occurred on March 16 when there was 15.0 ppm present (1.0 ppm higher than S-3), and 26 inches of ice and 16 inches of snow. A low of 1.2 ppm occurred on January 6. In 8 out of 16 determinations, the BOD's at S-4 were lower than the BOD's at S-3. During the summer, from March 30 until September 15, the BOD's at S-4 were higher (and DO's lower) than at S-3. The Brookings sewage effluent is responsible for the increase in BOD at S-4.

Station 2 had the highest BOD on 13 of 16 test days. One day, during the spring runoff, the BOD's for S-2, S-3 and S-4 were the same. Stations 4 and 5 never had the highest BOD value during the study. Stations 1, 3, and 5 had the lowest BOD levels on 14 out of 16 determinations. Station 4 had the lowest BOD level on two occasions.

**Biological Examinations**

**Alice**

Of the samples taken, only the one taken on May 24 was
Identifiable. Diatoms were predominant at all stations. Station 1 had the smallest number of cells per volume of any station (calculated as 250,000 cells per liter). Station 2 had the largest number (calculated as 612,000 cells per liter). Ankistrodesmus sp. was the only alga found at all stations during the study. Chlorella was found at all the stations except 2. Oscillatoria was found at all the stations except 5. Closterium sp. was found at S-1, S-2, and S-3, and Cyclotella sp. was found at S-2, S-3 and S-4 only. Scenedesmus sp. was found at S-3, S-4, and S-5. Microspora sp. was found only at S-1, Actinastrobus sp. was found only at S-4, and Bacillariopsis sp. (?) was found only at S-2 on May 24. Very few conclusions can be drawn from the results obtained by one sample of algae taken during the study.

Bottom Samples

A deviation from the order of discussion of previous components is necessary to clarify the discussion of bottom samples, since the bottom soil type at each station varied with the seasons and were not stable between sampling periods, especially at the polluted water stations. The organisms in the individual bottom samples are discussed, therefore, under the date taken and are not analyzed as a composite group taken throughout the period of the study.
January 12

Only living organisms of the sample of this date were preserved. No sample was taken at S-1 or S-5 because they were frozen to the bottom. Snails were taken only at S-4, where one Physa sp. was found. The organisms found in the bottom sample taken on this date are summarized in Table V.

May 12

A small number of Amnicola sp. (gill-breathers) was found only at S-3 and S-5, the clean-water stations. No snails were found in the sample from S-4. Lymnaea sp. and Physa sp. (pulmonates) were the only snails found at S-2. The highest number of snails was found at S-3, and the lowest number was found at S-2. The data for the bottom samples taken on this date are summarized in Table VI.

July 20

One each of Gyraulus sp. and Lymnaea sp., and six Physa sp. were found at S-1; Planorbula sp. was found only at S-3. The pulmonates, Lymnaea sp., Physa sp., and Planorbula sp. were found at S-2. Amnicola was found only at S-3 and S-4. See Table VII for a numerical taxonomic list of species by station taken in the bottom samples.
Table V. Organisms Found in the Bottom Sample at Each Station on January 12, 1962

<table>
<thead>
<tr>
<th>Organisms</th>
<th>Station</th>
<th>S-1**</th>
<th>S-2</th>
<th>S-3***</th>
<th>S-4</th>
<th>S-5**</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ALGAE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cladophora sp.</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>(small group)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>INSECTS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chironomus sp.</td>
<td></td>
<td>-</td>
<td>24</td>
<td>18***</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ephemerochohy larvae?</td>
<td></td>
<td>-</td>
<td>7</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Tipula sp. (pupae)</td>
<td></td>
<td>-</td>
<td>3</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Corixidae</td>
<td></td>
<td>-</td>
<td>5</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ephemoptera larvae</td>
<td></td>
<td>-</td>
<td>-</td>
<td>9</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>MOLLUSCA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physa sp.</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Ceratium sp.</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
</tr>
</tbody>
</table>

* Only living organisms kept
** Frozen to the bottom, no sample taken
*** More of these were present, not all were preserved
**** Sample taken at one of the deeper holes in the bottom of the river; a sandy bottom material predominant.
Table VI. Organisms Found in the Bottom Sample at Each Station on May 12, 1962

<table>
<thead>
<tr>
<th>Organisms</th>
<th>S-1</th>
<th>S-2</th>
<th>S-3</th>
<th>S-4</th>
<th>S-5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Annelida</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tubifex tubifex</td>
<td>-</td>
<td>56</td>
<td>-</td>
<td>-</td>
<td>36</td>
</tr>
<tr>
<td><strong>Arthropoda</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chloroame sp.</td>
<td>42</td>
<td>40</td>
<td>48</td>
<td>-</td>
<td>66</td>
</tr>
<tr>
<td>Ostracoda</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Limulina sp.</td>
<td>-</td>
<td>-</td>
<td>233</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**Ostracoda**

| Arsecola sp.     | -   | -   | 2   | -   | 2   |
| Euchura sp.      | 7   | 1   | 6   | -   | 1   |
| Physoc sp.       | 1   | -   | 1   | -   | 2   |
| Subarion sp.     | -   | -   | 1   | -   | -   |
| Nolussa sp.      | 1   | -   | -   | -   | -   |
| Flanorbis sp.    | 1   | -   | -   | -   | -   |
| Noliscina sp.    | 1   | -   | 2   | -   | -   |
| Flanorbula sp.   | -   | -   | 3   | -   | -   |
### Table VII. Organisms Found in the Bottom Sample at Each Station on July 20, 1962

<table>
<thead>
<tr>
<th>Organisms</th>
<th>S-1</th>
<th>S-2</th>
<th>S-3</th>
<th>S-4</th>
<th>S-5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ANELLIDA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lumbriculus sp.</td>
<td>8</td>
<td></td>
<td></td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Tubifex tubifex</td>
<td>-</td>
<td>86</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>ARTHILODE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chironomus sp.</td>
<td>95</td>
<td></td>
<td></td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Siphonurus sp.</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sisyulus sp.</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>POLYCHAETA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amphiloe sp.</td>
<td>-</td>
<td>-</td>
<td></td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>Gyraulus sp.</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Helicora sp.</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Limmata sp.</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Lueculum sp.</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Phryca sp.</td>
<td>6</td>
<td>7</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sidiculum sp.</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Placochaeta sp.</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sporoerium sp.</td>
<td>-</td>
<td>4</td>
<td>2</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
No sample was taken from S-5. No snails were found in the sample from S-2. Amnicola was found at all sampling stations except S-2. Twice as many snails (mostly Amnicola sp.) were found at S-3 as any other station. Some snails were found at S-4 and a few at S-1. The data are summarized by species and stations in Table VIII.

No gill-breathing snails (Amnicola) were found at S-2 during the study. The total number of snails found by station gives a good indication of the effects of pollution. Of the polluted water stations, S-2 had 18 snails, and S-4 had 26 snails. The clean water stations, S-1, S-3, and S-5, had 31, 24, and 9 snails respectively (only one sample was taken at S-5).

Class Pelecypoda (Freshwater Clams)

January 12

No clams were found at any station except S-4 where one Sphaerium sp. was found.

May 12

No clams were found at S-2 or S-4. Sphaerium sp. was found at S-1, S-3, and S-5. Musculum sp. and Pisidium sp. were found at S-3 only.
Table VIII. Organisms Found in the Bottom Sample at Each Station on December 29, 1962

<table>
<thead>
<tr>
<th>Organisms</th>
<th>S-1</th>
<th>S-2</th>
<th>S-3</th>
<th>S-4</th>
<th>S-5**</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ANOMALIDA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Helobdella stagnalis</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tubificid tubifex*</td>
<td>23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>ARTHROPODA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calliphoridae (adult)</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chironomus sp.</td>
<td>210</td>
<td></td>
<td>10</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Corixidae (adult)</td>
<td>-</td>
<td>324</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gyrinidae (adult)</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Svalolla sp.</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Odontota wing</td>
<td>-</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ostracoda</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>MOLLUSCA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amnicola sp.</td>
<td>2</td>
<td></td>
<td>43</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>Atheta sp.</td>
<td>-</td>
<td></td>
<td>4</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Gyrculus sp.</td>
<td>-</td>
<td></td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Helciona sp.</td>
<td>-</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hyalea sp.</td>
<td>-</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Musculina sp.</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Naidopsis sp.</td>
<td>-</td>
<td></td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Planorbus sp.</td>
<td>3</td>
<td></td>
<td>6</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Planorbulina sp.</td>
<td>-</td>
<td></td>
<td>27</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>Planorbusina sp.</td>
<td>-</td>
<td></td>
<td>3</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Teganius sp.</td>
<td>-</td>
<td></td>
<td>4</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

* Badly broken up  
** No sample taken this date
July 20

*Musculum* sp. was found at S-1 only and *Sphaerium* sp. were found at S-3 and S-4 only. One *Pisidium* sp. specimen was found at S-2 and S-4.

December 29

No sample was taken from S-5. No clams were found at S-2. *Musculum* sp. was found only at S-1, and *Sphaerium* sp. was found only at S-3 and S-4. *Pisidium* sp. were found at S-3 and S-4.

*Sphaerium* sp. are considered to be somewhat pollution tolerant, but no *Sphaerium* were found in any of the bottom samples from S-2. *Musculum* sp. are considered to be clean-water indicators and were never found at S-2 or S-4. Of the four samples taken from the polluted water stations, a total of 1 clam was found at S-2 and 50 clams were found at S-4. At the clean-water stations, S-1 had a total of 4 clams, S-3 had a total of 65 clams and S-5 had a total of 2 clams during the study.

*Insects.* Generally, the bottom type and sedimentation rate control the number of insect species that are present if there is an available supply of oxygen.

*Chironomus* sp. were only found at S-2 and S-3. No samples were taken from S-1 or S-5 because they were frozen to the bottom. Some species of chironomid larvae are very resistant to pollution
and were found at S-2 during the entire year. *Tipula* sp. (crane fly) pupae were found at S-2 only.

Ephemeroptera (mayfly) larvae were found only at S-3. This was due mainly to the water quality and the location from which the sample was taken.

Five dead Corixidae (water boatmen) were found at S-2 and at no other station. As other parts of the creek became covered with ice, the water boatmen were forced into this last open area of water to enable them to surface for a supply of air. When the last open water area finally froze over they suffocated. Many distressed water boatmen were noticed swimming under the first thin ice in the fall. Three small Bytiscidae (predacious diving beetles) were found in the bottom sample from S-4.

May 12

No organisms were found at S-4 on this date because of the unstable sand bottom. Chironomid larvae were found in about equal numbers at all stations. It is evident that some chironomids were capable of overwintering in the bottom sediment at each station. A large number of immature *Simulium* sp. (buffalo gnats) were found at S-3 attached to a submerged piece of wood.

July 20

Chironomids were found only at S-1 and S-5. If there were any present at the other stations they were washed away by the fast
moving flood waters in the spring or covered with sediment. One each of Ephemeroptera and Simulidae was found at S-3. They probably survived the flood waters due to their association with submerged vegetation.

December 29

No sample was taken at S-5. Chironomus sp. were present in the samples from all stations, with a large number (210) at S-1 and a small number (1) from S-2. One adult blowfly (Calliphoridae) was found in the sample at S-2. Its habit of laying eggs in decaying organic material was probably the reason for its being found at this station. A large number of dead adult Corixidae (324) was found at S-2, probably for the same reason that they were found at this station on January 12. One adult Gyrinid (whirligig beetle) was found at S-1 on this date.

Aquatic Annelids

January 12

No annelids were observed at any station.

May 12

Tubifex tubifex (sludge worms) were found at S-2 and S-5. It was calculated that 2,016 were present per square yard at S-2 and 1,296 per square yard were found at S-5. There are several possible reasons for the absence of organisms under the ice on January 12 and
the presence of a large number on May 12. The January 12 sample was taken in the winter through the ice at one of the deeper parts of the stream, while the sample of May 12 was taken from the bridge in a shallow area. The organisms reproduce more rapidly during the summer when the habitat is more ideally suited for them. Sludge worms are colonial and are found in larger numbers in some polluted areas and are absent in others. Their seasonal fluctuation in numbers and ability to adapt more readily to some areas than to others probably accounts for the wide variation in the number of organisms found.

July 20

*Lumbriculus sp.* were found at S-1 and S-4. *Tubifex tubifex* were found at S-2 only and in large numbers (13,896 per square yard).

December 29

*Helobdella stagnalis* (leech) was found at S-1. This was the only leech found in a bottom sample during the study, but the presence or absence of this organism is not considered significant because it is not normally associated with bottom materials. *Tubifex tubifex* were found at S-1 in a small colony (23). They were badly broken up and hard to count which may indicate the animals were dead when sampled.
Ostracoda

January 12

No ostracods were found at any of the stations on this date.

May 12

One Ostracoda was found at S-1 on this date.

July 20

No ostracods were found at any of the stations on this date.

December 29

Five ostracods were found at S-1 on this date. They probably succumbed after ice formation and were yet to be covered with silt.

Coliform Bacteria

The coliform tests conducted during this study were undoubtedly affected by pasture and barnyard drainage. During the winter months when the water samples were taken through the ice, the results were uniform; S-2 having the highest count and S-4 the next highest count. See Figure 14 for a graphic display of the results.

After the spring thaw, the number of bacteria at S-2 and S-4 dropped until it was the same as at the other stations, or just a little higher. It is thought that rainfall may have been partially responsible for the erratic results. During the summer the rain water, along with the fact that no water is tied up as ice, dilutes
Figure 14. Coliform MPN results during the study.
the organisms; however, it also washes through polluted pastures where more organisms are picked up and added to the count.

Although the results from the coliform tests were interesting, they were terminated about half way through the study because, although the results fluctuated during some seasons, the higher coliform numbers were present in the polluted zones as one would expect and a continuation of the study was not deemed necessary.

**Sewage Fungus**

Sewage fungus was present only at S-2. During the spring it developed very slowly, and was not evident during the spring runoff or other periods of high water. When the high water levels subsided it began to form on anything submerged in the polluted water. During the middle of the summer and early fall it was easily seen anywhere along the creek from the sewage treatment plant to S-2. As the water level continued to drop, much dried remains of this growth could be seen stranded on exposed objects.

**Physical Examinations**

**Turbidity**

The turbidity levels are shown in Figure 13. The highest turbidity recorded at S-1 was 69.0 ppm in January. This unusually high level was recorded just before the creek froze to the bottom; when this sample was taken, much of the bottom silt was disturbed and was washed up into the ice hole. The low of 6.0 ppm was recorded
In November just after ice formed. The turbidity appeared to be slightly lower under the ice than during periods of open water. Periods following a heavy rainfall raised the turbidity, especially on July 19.

The highest turbidity observed at S-5 was 72.0 ppm on August 17. The stream had a maximum depth of less than one foot at this time. The low occurred between the spring thaw and the first period of heavy summer rainfall when runoff was at a minimum.

The highest level of turbidity at S-2 was 108.0 ppm recorded on February 16. A low of 19.0 ppm was observed in April. Most of the water taken at S-2 on the date of the high was trapped between two layers of ice. It had been warm and raining before the samples were taken and much of the turbidity was caused by silt and not sewage sediment. (BOD was 7.6 ppm.) There did not seem to be a correlation between the turbidity readings and the BOD. This would seem to indicate that only a small amount of the turbidity was due to the sewage sediment.

The highest level of turbidity (86.0 ppm) was recorded at S-3 on July 19. The lowest level (6.0 ppm) was recorded on November 13. The river turbidity is affected more by heavy rains along its drainage than is the creek. The period of highest turbidity followed a period of general rainfall which caused a large amount of sediment to be washed into the stream. The lowest turbidity at S-3 occurred on the same date that the lowest turbidity was recorded at S-1.
There was no ice or wind at S-3 on this date. If an algae bloom is
not present and it has not rained just before the sampling period,
high wind and cows wading in the water upstream would probably be
the next most likely cause of turbidity. Carp also cause much
turbulence in river water as they stir up the mud while feeding.

As at S-3 the highest level of turbidity at S-4 (89.0 ppm)
was recorded on July 19. The lowest level of turbidity (6.0 ppm)
was recorded on December 22, just after the ice formed over the
river. On the date that the low values were recorded, S-4 had 6 ppm
less turbidity than S-3. The turbidity of the river did not always
remain at a low level when covered with ice; warm weather would
cause an influx of sediment laden runoff water to flow over the ice
and increase the turbidity. Usually the turbidity at S-4 was higher
during the warmer days in the winter than the turbidity at S-3
because of the continuous flow of sewage on top of the ice.

Ice

Figure 15 is a picture of the ice cores taken from S-2, S-3,
and S-4 on January 16. At this time station 1 was frozen to the
bottom. The ice core from each station had an opaque layer that
made up the first few inches of the core. This white layer (made
up mostly of gases in the ice) was evidence that a cloudy surface
layer was common in the ice covering of the streams. This layer was
very impervious to light penetration and, consequently, photo-
synthesis was inhibited.
Figure 15. Ice cores taken during the study. From left to right, S-4, S-3, and S-2.
It can be seen in Figure 15 that the ice core from S-2 has a second opaque strip in it. This one is located about in the middle of the core and together with the surface layer, acts as a double barrier to the penetration of light and prevents any oxygen formation by photosynthesis.

The lower frosty layer on the core from S-2 represents the surface of the original ice formed in early winter. The flow of effluent from the sewage plant into the creek fluctuates, being higher in the daytime and lower at night. When the flow decreases during very cold winter nights, the thickness of the ice layer is increased at the bottom. When the flow is increased during the daytime, the hydrostatic pressure forces the water up over the original ice layer causing it to be stratified and another frosty layer is formed at the surface.

The dark rings seen are sediments that have been washed up by the overflow. Some of this consists of algae (Microcystis sp.) and some of it consists of wind blown dirt that had settled on the ice surface. The ice cores from stations 1 through 4 had 17.2, 39.0, 52.2 and 12.4 ppm turbidity respectively. The high turbidity found at S-3 was due partially to fine dirt and leaves trapped in the ice core.

The ice core from S-2 is longer because it was formed by freezing from the bottom up and the top down. At S-2 on several occasions when the days were warm the sewage effluent would flow
over the ice and only the first two inches of it would freeze at night. When this happened, there would be a 2 inch layer of ice, about 4 inches of water, and then another 18 or so inches of ice with a layer of water below it. It was possible to remove a sample from the upper layer of water without getting some from the lower layer mixed with it, but it was impossible to get a water sample from the lower layer without also getting some of the upper layer mixed in with it.

Two ice layers also formed at S-3 and S-4. The one at S-3 was mostly made up of melt water while the one at S-4 was made up of a mixture of melt water and sewage. There is a possibility that some variation in the chemical analyses of the water samples could occur because of this situation; however, if the water was well aerated it may have aided the oxidation of the sewage.

Temperature.

During the winter the water at S-2 was about one-half of a degree warmer than the other stations (see Figure 16). When the water was released from the sewage treatment plant into the creek, it did not lose enough heat to freeze a solid layer over the surface by the time it reached S-2. When the last samples were taken on December 22, stations 1, 3, and 4 had 10, 6, and 8 inches of ice respectively. At S-2 there was a little ice along the edge, but the creek was open in the middle.
Figure 16. Temperatures. Note wide range of fluctuation between air and water temperature.
Dilution

The addition of dilution water is one of the principal methods of treating sewage and reducing the sewage load of a stream. When the desired volume of dilution water is unavailable at the time it is needed, problems arise. Too much dilution water is not a problem.

The Brookings sewage treatment plant bypasses some sewage directly into Six-Mile Creek during periods of high water in the spring. This water dilutes the sewage enough so that the BOD's taken at this time of year are lower than those taken at any other time.

The water is bypassed for three reasons. One, it comes into the plant in such large quantities from the storm sewers of Brookings that the plant cannot possibly treat all of the water; two, most of the water is melt water from snow and ice and contains very little sewage; three, in its diluted form it is less detrimental to the creek than the treated sewage effluent is—during periods of low water levels—after having been treated by the plant.
SUMMARY AND CONCLUSIONS

This study was initiated on January 3, 1962, and terminated on December 29, 1962. It was directed toward determining the affect, if any, of the Brookings sewage treatment plant effluent upon Six-Mile Creek and the Big Sioux River. Chemical, biological, and physical indicators were used to measure the extent of pollution. During the initial phases of the study, samples were collected bi-monthly for water chemistry examinations; later, after a trend was observed, the samples were collected monthly. The algae and bottom samples were collected seasonally. Coliform MPN determinations were made during the initial part of the study.

Ice core examinations were made during the winter to determine the physical affect of the pollution effluent upon the ice layer and to determine to what extent the chloride-ion was excluded from the ice.

The different examinations, when studied collectively, were used to establish the degree of pollution caused in the creek and river as a result of the Brookings sewage treatment plant effluent.

The results indicate that the Brookings sewage treatment plant does add a pollution load to Six-Mile Creek that could be toxic to some species of fish, especially during the period of low stream flow, but in general the aquatic fauna of the stream is not altered to any great extent because the flow drops to such a low
level during the winter that the stream froze to the bottom in all
but the deepest holes after approximately a week of cold very
weather.

The sewage from Six-Mile Creek did not appreciably alter the
water quality of the Big Sioux River. This can be attributed to a
number of factors, but mainly the sewage effluent was treated before
entering the creek and was well diluted during the spring and summer
before entering the river. In conjunction with the sewage effluent,
the low volume of flow and thick ice and snow cover during the winter
were other factors that had an adverse affect on the river water.

Water volume in a stream such as Six-Mile Creek is regulated
almost entirely by the amount of rainfall received over a very
limited area. This can cause a wide variation in the stream flow
during the year and from year to year. During the winter of 1962
an above average amount of snow fell, and during the spring and
summer an above average amount of rainfall was received at Brookings.
Consequently, the creek had a sufficient amount of water with which
the sewage effluent could be diluted before entering the river. It
is possible that during a dry year, the river would show a more
marked change caused by the more highly polluted creek water than it
did during this study.

It is concluded that lack of water volume has more of a detri-
mental effect on the water quality of Six-Mile Creek and the Big Sioux
River than the effluent from the Brookings sewage treatment plant.
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