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Water Quality and Benthos of a Small East Central Illinois Stream, with a Selected Literature Review

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WATER QUALITY AND BENTHOS OF A SMALL EAST CENTRAL ILLINOIS STREAM, WITH A SELECTED LITERATURE REVIEW

(TITLE)

BY

Kenneth Lloyd Brummett

THESIS

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ABSTRACT

Polecat Creek is an occasionally intermittent stream which drains approximately 18,368 acres in eastern Coles County, Illinois. It travels 15.2 miles through cropland and a partially wooded valley before it enters the Embarrass River 3 miles upstream from Lake Charleston. The stream ranges from 0.5 foot to 5 feet deep at a normal water level, with an average depth of 16 inches. It averages 12 feet wide, with a range from 4 to 20 feet.

A water quality study with 5 stations along the stream was conducted from January 1971 to July 1971. A qualitative benthos study at the same 5 stations was conducted from April 1971 to July 1971. The purpose of the study was to determine the physical and chemical conditions present in Polecat Creek. The water quality tests covered dissolved oxygen, B. O. D., total dissolved solids, alkalinity, hardness, and the more important soluble compounds normally present in the water, such as nitrates, phosphates, iron, and nitrites. The benthic samples were taken from several different points in the stream at each station and were not quantitative. A selected literature review of general water quality criteria for running waters was also written.

Polecat Creek was found to be a fairly clean stream. The fact that it conforms with water quality standards set up by government agencies for surface waters indicates that it is a suitable environment for aquatic organisms. The benthic population is composed of both pollution-tolerant and intolerant species at most of the stations.

This situation indicates that there is a lack of inhibiting factors present in most of the stream. If a model stream were selected for comparison with streams of lesser quality, Polecat Creek would be a good choice.

INTRODUCTION

The value of clean lakes and streams has been greatly stressed in recent years with the greater public awareness of environmental problems. Locke (1934) lists public health as the most important value followed by recreation, business, aquaculture, and the real estate values of adjacent land. When water quality is impaired by the introduction of detrimental substances, it is the responsibility of persons recognizing the devaluation to seek out ways of correcting it and educating violators in ways to help clear up the problem.

The demand for investigation of the effects of water quality on organisms in polluted aquatic environments has pointed out the need to study fairly clean waters for comparative purposes. Polecat Creek is a small stream in eastern Coles County which does not receive any obvious form of pollution. It has a variety of benthic habitats and the water level fluctuates quite a bit during the year. The watershed contains cropland, pasture, and woodland. It was chosen for this study because of the variations in substrate type, the water level, the watershed, and the lack of a serious pollution problem.

A survey of the water quality and benthic organisms was conducted during the first seven months of 1971, and a selected literature review concerning both chemical and biological factors used in assessing surface water quality was made.

GENERAL SETTING OF THE STREAM

Polecat Creek originates just north of the Paris Moraine of the Shelbyville Morainic System in Edgar County in the southeast one-quarter of Section 26, T13N-R14W. It runs westward in Wisconsinan glacial till plains parallel to the north edge of the Paris Moraine and enters the outwash of the ancestral Embarrass River in its last few miles (Figure 1). Polecat Creek enters the Embarrass River 3 miles upstream from Lake Charleston. It travels 15.2 miles with a drop of more than 120 feet before it enters the river.

The creek is occasionally intermittent during late summer and fall when ground water is the primary source of flow. During spring, the water level fluctuates with the rainfall. At normal water level, the depth ranges from 0.5 foot to 5.0 feet with an average depth of 16 inches, and averages 19.3 feet wide. The watershed of Polecat Creek covers 18,368 acres in Coles and Edgar counties. It has been dredged somewhat in the eastern portion. One section, just south of Ashmore, has been mined for gravel, creating a two-acre pool in the creek. A small amount of pollution enters the stream from agricultural runoff and septic tank drainage. The agricultural runoff is the result of heavy use of fertilizers in the watershed. The septic tank drainage comes from private homes along the course of the stream.

The watershed of the creek is nearly 100% cropland with some pasture until it enters the outwash area where it travels mainly in a narrow wooded valley. It is composed of four primary soil associations

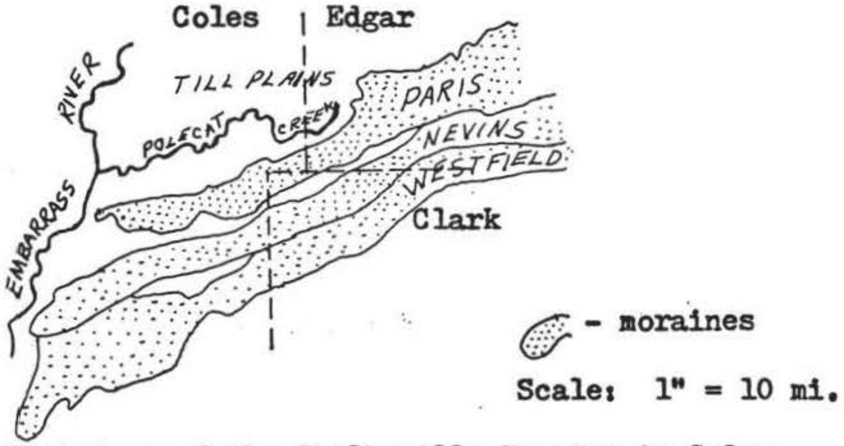
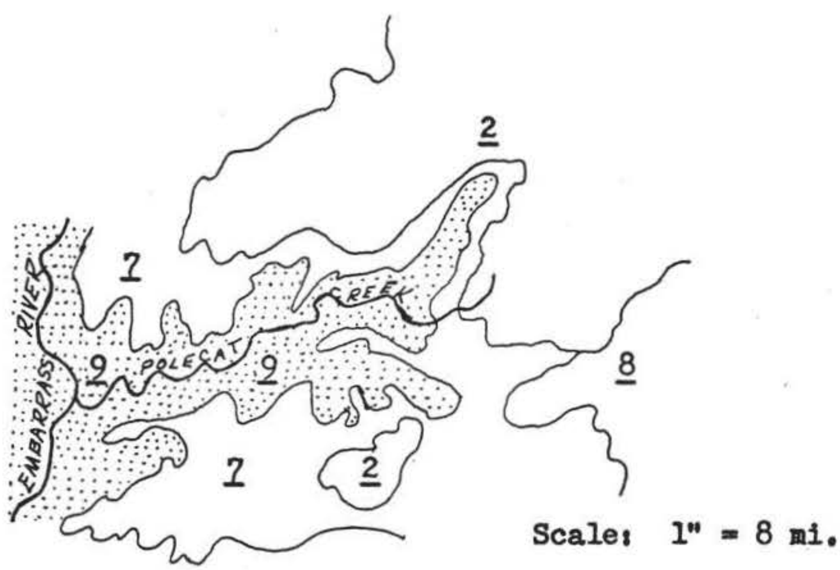


Figure 1. The Subdivisions of the Shelbyville Moraine in Coles, Edgar, and Clark Counties. (Drawn from Willman and Frye, 1970)



2 Flanagan-Raub-Drummer: dark colored, somewhat poorly and poorly drained, nearly level to undulating soils formed in 2 to 4 feet of silty material over loamy material.

7 Fincastle-Xenia: light colored, somewhat poorly to moderately well drained, nearly level to gently sloping soils formed in 1.5 to 3 feet of silty material over loamy material.

8 Russel-Miami: light colored, well drained, gently rolling soils formed in less than 3 feet of silty material over loamy material.

9 Strawn-Lawson: light colored, well drained sloping soils on the uplands adjacent to dark colored somewhat poorly drained, nearly level soils on the bottomlands.

Figure 2. Soil Types Found in the Watershed of Polecat Creek. (Drawn from the General Soil Map of Coles Co., Ill., U.S.D.A., Soil Conservation Service, 1966)

(Figure 2). Each association consists of two or three dominant soil types with several minor types not included in the association name. Soil characteristics are also listed in Figure 2.

METHODS AND MATERIALS

The water samples and benthic samples in this study were taken at five stations along Polecat Creek in eastern Coles County, Illinois (Figure 3). All the stations were located near state or township road bridges for easy access. During the first three months of the year, water samples only were taken at the five stations biweekly. Starting in April, all five were sampled weekly, with both water and benthic samples taken.

At each station, two one-liter plastic bottles were filled by holding below the surface. A one-liter aspirator bottle was filled and the water emptied into a 250-ml. water sample bottle through plastic tubing, filling it 3-times over. This 250-ml. sample was then preserved in the field by the Winkler method (Welch, 1948) for dissolved oxygen. Samples for carbon dioxide determination were also taken in the 250-ml. water sample bottles, with the aspirator bottle. Water temperature was measured to the nearest half-degree Fahrenheit in the field. Several bottom samples were taken with an Army-type entrenching tool at various spots within the area of each station, and placed in a plastic container for transportation to the lab, where they were kept in a cool place until they could be sorted. A Surber sampler was used once a month in the riffles at stations 7, 11, and 11A (Figure 3).

In the lab, dissolved oxygen was determined by the Winkler method (Welch, 1948). Five day biochemical oxygen demand tests were

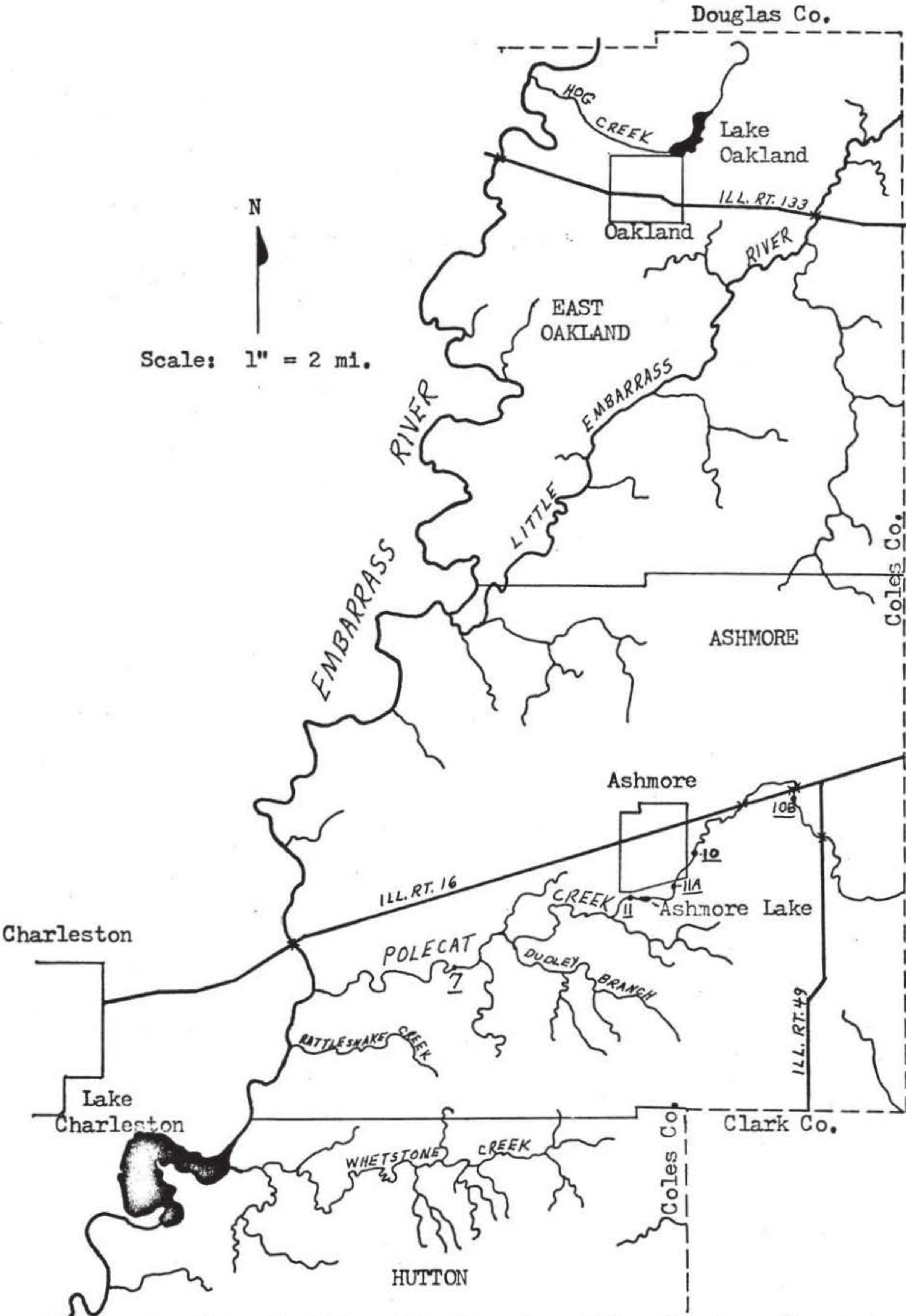


Figure 3. Watershed Map of Northeastern Coles County. (Drawn from the Coles County General Highway Map, Ill. Dept. of Public Works and Planning, 1960)

prepared from the sample water (Anon., 1965). The pH of each sample was titrated for alkalinity (Welch, 1948), using the pH meter as an end-point indicator instead of phenolphthalein and methyl-orange. Determination of the carbon dioxide content was by titration (Welch, 1948), using the pH meter as an end-point indicator.

Total dissolved solids was determined by evaporation of a 200-ml. sample (Anon., 1965). Total suspended solids was determined by filtering 250-ml. of sample water through a fritted glass filter in a Gooch crucible, then drying it and weighing it.

Conductivity was taken with a Hach conductivity meter. A Hach colorimeter was used to determine total phosphates, nitrates(NO_3), nitrites, ferric iron, sulfates, flouride, and turbidity, using their methods and chemicals. Calcium hardness, total hardness, and chloride were determined by titration, using Hach chemicals and methods.

The benthic samples were washed through a series of three sieves (0.25", 0.125", and 0.0625" mesh) and sorted out in a flat white enamal pan filled with water. The benthic organisms were removed from the sample and placed in AFA (100-ml. 70% ETOH, 5-ml. conc. formalin, 5-ml. glacial acetic acid) until they could be identified. Sources for identification of organisms included Chu (1949), Eddy and Hodson (1957), and Pennak (1953).

Station Descriptions

The five stations used in this study are identified with numbers given them in a previous fisheries study. Moving from upstream to downstream they are 10B, 10, 11A, 11, and 7 (Figure 3).

Station 10B is located at the second highway bridge crossing the creek east of Ashmore, Illinois, at T13N-R14W, Sec. 29 (SE quarter).

The creek at this point is 10 feet wide and 1 foot deep at normal level. The surrounding land is 96% cropland and 4% pasture. The creek has been channelized in this area. The bottom consists of a 4 to 6 inch layer of silt over a clay bottom. Aquatic vegetation and algae become quite extensive at this station in summer. Several drainage tiles empty into the creek near this station.

Station 10 is on a township road on the east side of Ashmore at T13N-R14W, Sec. 31 (SW quarter). At this point, the creek is 12 feet wide and 10 inches deep at normal level. The surrounding land is a sheep pasture and the creek is shaded most of the day. The bottom is clay with a thin layer of detritus and some sand covering it. There is some aquatic weed growth and algae during the summer. Some pasture drainage enters the creek in this area.

Station 11A is located at a township road bridge on the southeast edge of Ashmore about one-quarter mile above Ashmore Lake at T12N-R11E, Sec. 6 (NE quarter). There is a pool about 16 inches deep and 15 feet wide and a riffle of the same width at this station. The creek runs through a cattle and hog lot upstream from the station and is shaded most of the day. The bottom is clay with some sand and rubble. The riffle is mostly rubble. Filamentous algae in the riffle is the only aquatic vegetation present. Pasture drainage enters the creek near this station.

Station 11 is located at a township road bridge southwest of Ashmore, about 100 yards downstream from Ashmore Lake at T12N-R11E, Sec. 6 (NW quarter). There is a pool about 2 feet deep with a riffle upstream. The creek is 18 feet wide at this station. It is shaded by a hill on the south most of the day. The bottom is rubble in the riffle and sand with a little detritus in the pool. Filamentous algae

in the riffle is the only aquatic vegetation at this station. Septic tank drainage enters Ashmore Lake above the station.

Station 7 is located at a township road bridge 2 miles west and 1 mile south of Ashmore at T12N-R10E, Sec. 10 (NW quarter). The creek is about 8 inches deep and 15 feet wide. There is a riffle composed of sand and rubble. The bottom is sand over bedrock. The creek is shaded most of the day and at this point is in a wooded valley. There is a little cropland and pasture which drains into it. Filamentous algae in the riffle is the only aquatic vegetation at this station.

RESULTS

The buffering system components of Polecat Creek are in agreement with the finding of other studies on the water quality of streams. The amount of precipitation (Figure 4) is inversely related to values for total dissolved solids, alkalinity, calcium hardness and total hardness, pH, and conductivity (Figure 5). The lowest level of all these parameters was recorded at Station 10 on February 4, 1971 (Table 1). It was raining and the creek was one to two feet above normal, because of melting snow and runoff. Minshall (1968b) points out that low levels are to be expected during periods of heavy runoff due to dilution by the rainwater and the short amount of time the water is in contact with the ground.

Levels of nitrate, iron, and phosphate were shown to be influenced by water level or rainfall (Figure 4). The highest level of iron was recorded on May 7, 1971 at Station 11A. It was raining when the sample was taken and the water level was about six inches above normal (Table 1). The highest weekly average concentration was on February 18, 1971, the day after a rain (Figure 4).

The highest nitrate nitrogen concentration plus the highest weekly average was recorded on May 13, 1971 at Station 11A, a few days after a three-inch rain (Figure 4). Recent application of fertilizer in the watershed probably had a lot to do with the high levels.

Although the highest phosphate concentration was recorded on June 8, 1971 (Table 1), the highest weekly average was on February 18,

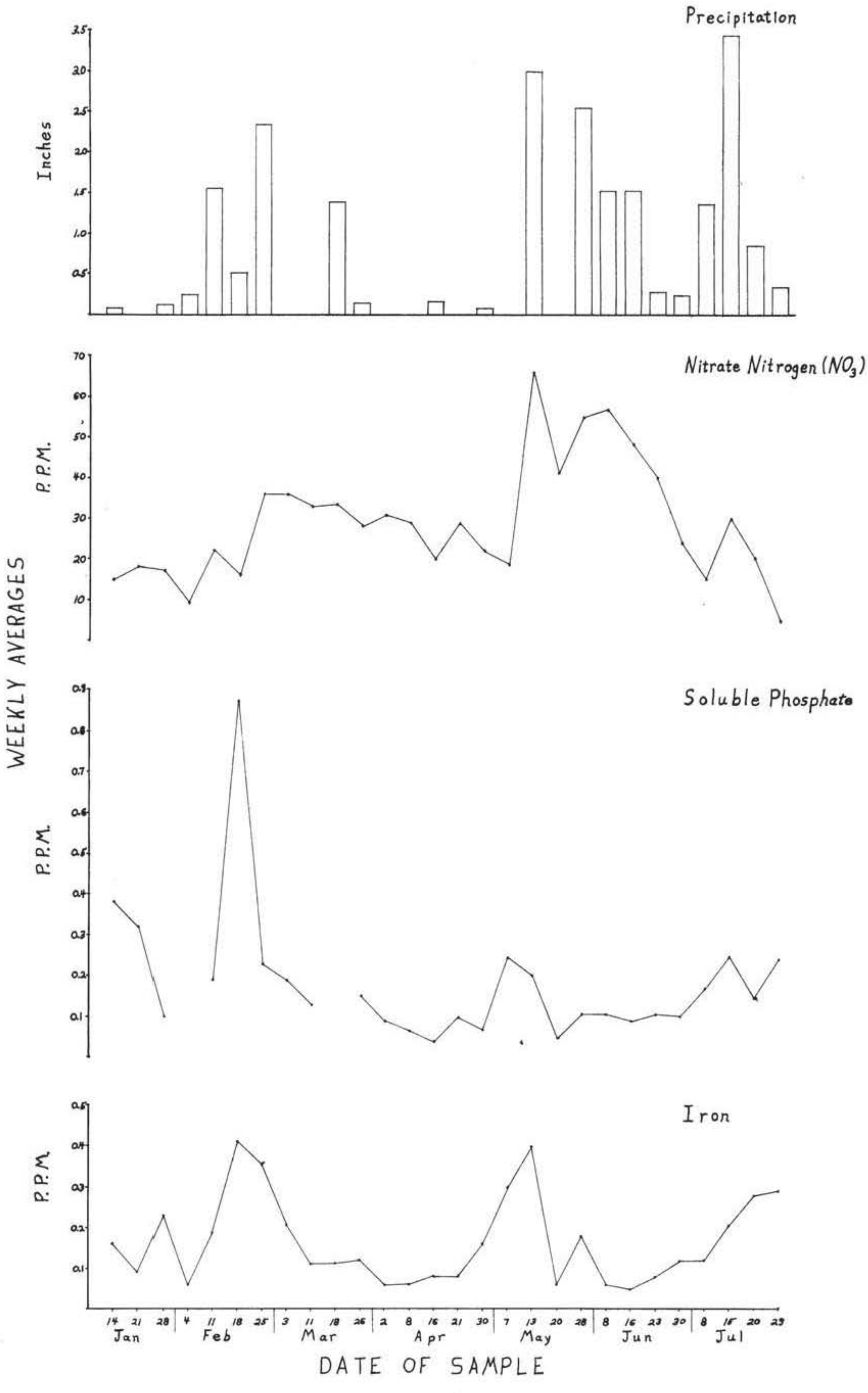


Figure 4c Weekly Average Levels of Precipitation, Nitrate Nitrogen, Soluble Phosphate, and Iron in Polecat Creek 1-14-71 to 7-29-71.

TABLE 1

MAXIMUM AND MINIMUM VALUES RECORDED FOR PHYSICAL AND CHEMICAL PARAMETERS IN POLECAT CREEK FROM 1/14/71 TO 7/29/71

Parameter	Minimum	Date	Maximum	Date
Water Temperature (^{o}F.)	32.0°	1/28	81.0°	6/30
Dissolved Oxygen	*5.3	7/15	16.7	4/8
Biochemical Oxygen Demand	*0.0	2/5 - 3/11	5.3	4/30
pH	*6.8	2/4	8.3	4/30
Total Dissolved Solids	*135.0	2/4	893.0	7/20
Total Suspended Solids	0.8	3/26	*141.0	5/7
Soluble Phosphate	0.01	5/20	*0.95	6/8
Nitrates (NO_3)	1.0	7/29	*71.3	5/13
Nitrites (NO_2)	*0.025	3/18	*0.83	7/8
Iron	0.01	4/16	*0.65	5/7
Calcium Hardness	*55.0	2/4	340.0	1/21
Total Hardness	*100.0	2/4	475.0	1/28
Alkalinity	*43.0	2/4	359.0	1/28
Conductivity (NaCl equivalent)	*70.0	2/4	385.0	1/28
Sulfates	*17.0	2/4	98.0	1/14
Chloride	*17.5	2/18	*95.0	2/4
Flouride	*0.12	2/4	*0.7	2/4
Free Carbon Dioxide	7.0	7/20	25.0	6/30
Turbidity (J.T.U.)	10.0	most of the time	*175.0	2/18
Rainfall	0.0"	see Figure 6	3.45"	7/14

*Sample taken during or following rain.

All values are mg./L. (ppm.) except pH, temperature, and turbidity

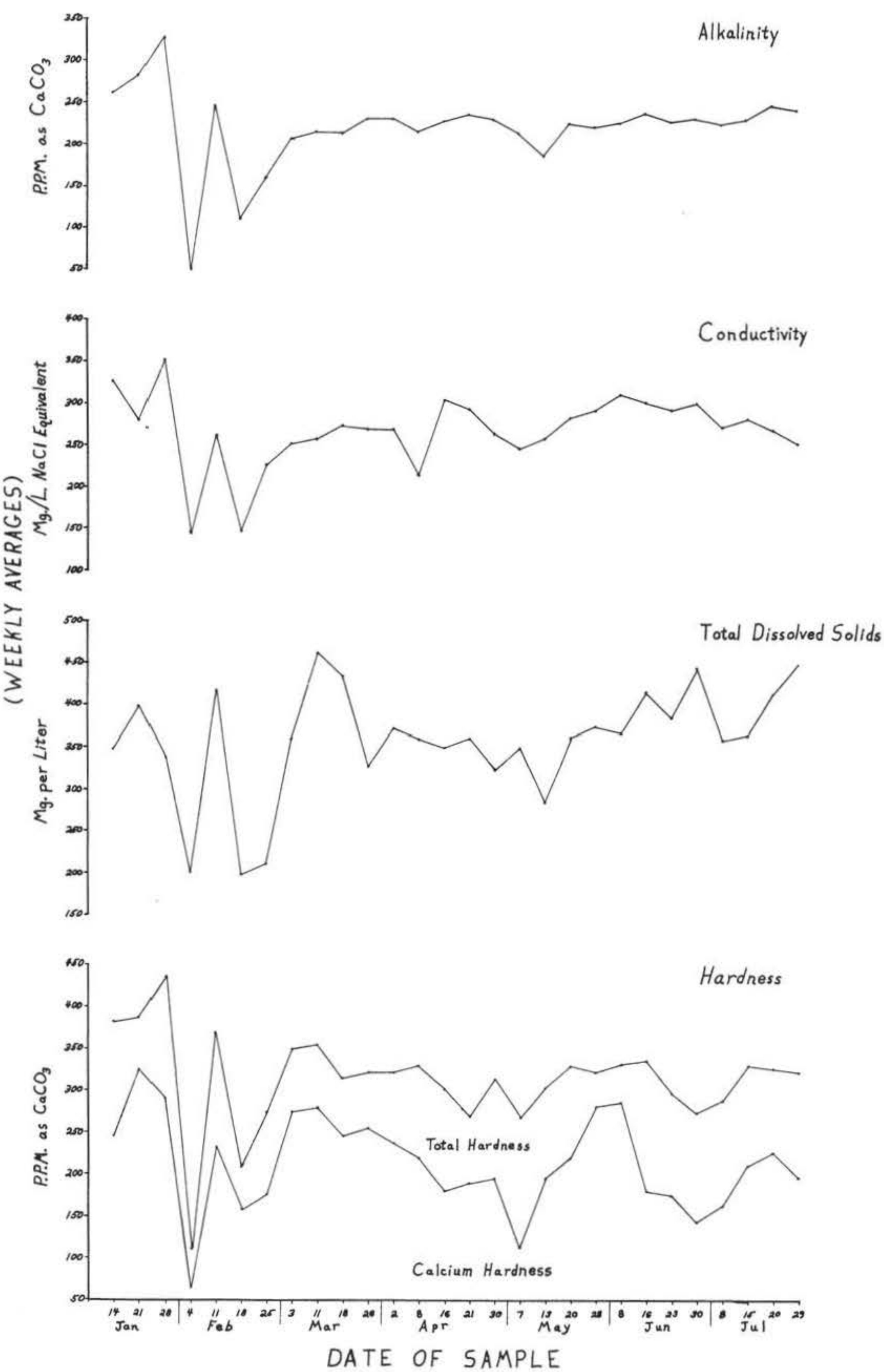


Figure 5. Weekly Average Levels of Alkalinity, Conductivity, Total Dissolved Solids, and Hardness in Polecat Creek 1-14-71 to 7-29-71.

1971 (Figure 4). Slack (1955) explains that the runoff from thawing in early spring contributes more phosphate than any other source during the year.

Dissolved oxygen, biochemical oxygen demand, and nitrites are all shown to be affected by water temperature (Figure 6). The lowest water temperature was taken through the ice on January 28, 1971. The highest was recorded on June 30, 1971 (Table 1).

The inverse relationship between the water temperature and the dissolved oxygen content of the water is clearly illustrated in Figure 6. The biochemical oxygen demand depends, secondarily, on water temperature and the dissolved oxygen concentration, as well as the organic load, which is a primary source. The level of demand is not always inverse to the oxygen content, because oxygen supersaturation of the water at low temperatures is able to absorb the demand with little effect on the overall dissolved oxygen content. The absence of any B.O.D. shown in Figure 6 can be explained by the rainfall recorded for the same period. Heavy rain scours the creek bed, carrying away any organic material which may produce an oxygen demand. The highest demand was recorded on April 30, 1971 at the end of a dry month, with warm water temperature, and high D.O. levels.

Nitrites are formed by the reduction of nitrates by bacterial decomposition at low water periods and warm temperatures (Slack, 1955). Figure 6 shows a parallel increase in the nitrite level and water temperature. Rainfall plays the same role with nitrite levels as it does with B.O.D. levels. The scouring of the stream bed also removes the nitrogen source from the benthic deposits.

Free carbon dioxide, produced during decomposition of organic material by the same organisms that are responsible for nitrite production

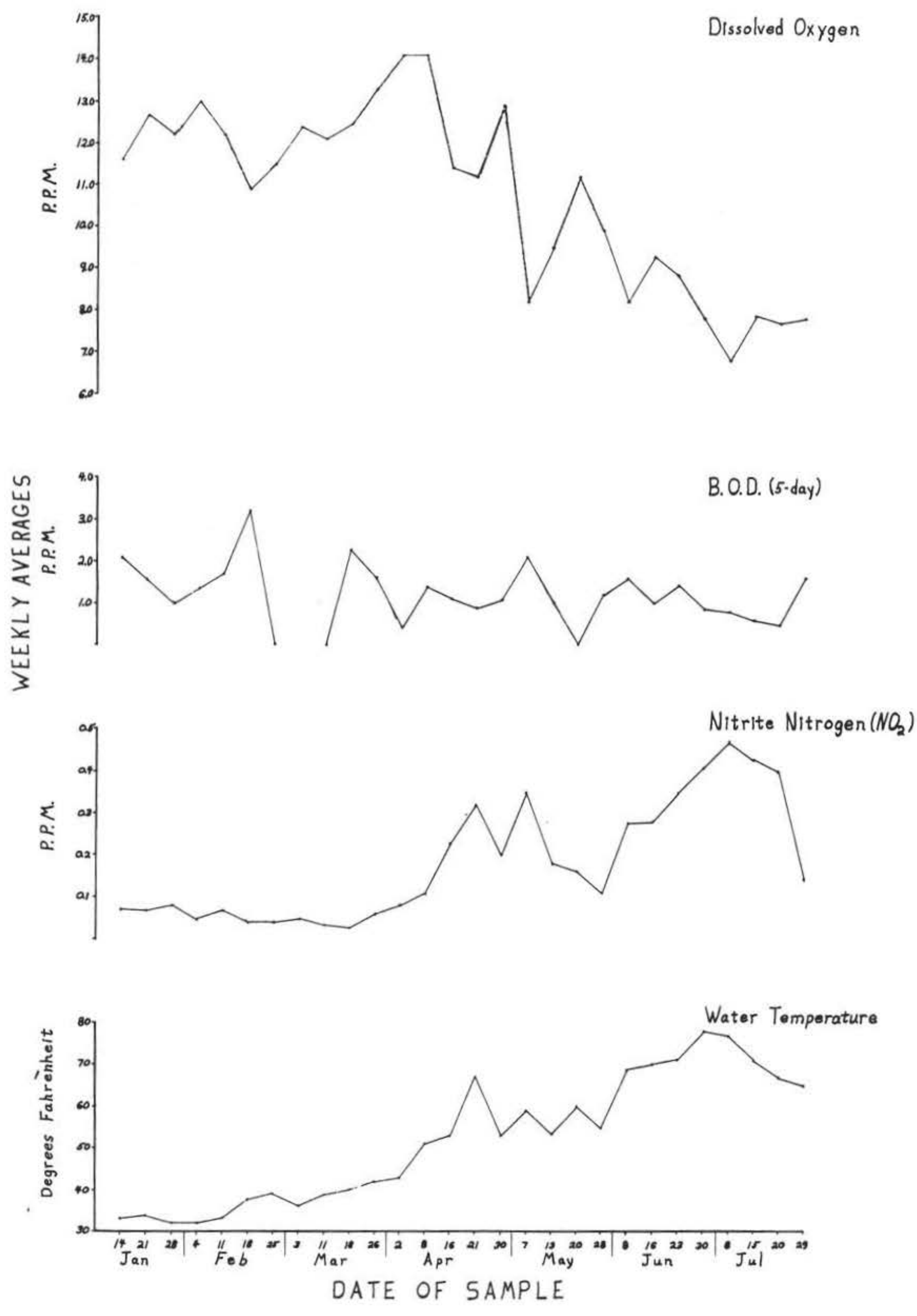


Figure 6. Weekly Average Levels of Dissolved Oxygen, Biochemical Oxygen Demand, Nitrite Nitrogen, and Water Temperature in Polecat Creek 1-14-71 to 7-29-71.

and the biochemical oxygen demand, was recorded at its highest level on June 30, 1971, the same day the highest water temperature was recorded.

Turbidity was only noticeable in the water samples during or following rainfall. The highest was on February 18, 1971, during the first spring runoff. Most of the time, it was less than 10 Jackson Turbidity Units.

Total suspended solids levels in the water depend on the amount of finely divided material washed into it by rain and the amount of plankton organisms in the water. Water temperature and sunlight affect the plankton population which in turn affects the amount of suspended solids. The highest level of suspended solids was reached on May 7, 1971. It was raining at the time the sample was taken.

The sulfates and chlorides did not reach abnormal concentrations in the creek. The sulfates were highest on January 14, 1971, at Station 7 (Table 1). They ranged between 50 to 70 ppm most of the time, and did not seem to be affected by anything except rainfall with its diluting quality. Chloride ion concentration did not approach any level which would be detrimental to aquatic life. The highest level was on February 4, 1971 at Station 10B (Table 1) which is at a highway bridge on Illinois Rt. 16. The highway had been salted to remove ice the day before and it was raining at the time the sample was taken.

Tests for flouride were run only three times in January and February. The minimum and maximum levels are in Table 1. Precipitation of calcium flouride by calcium ions in hard water will remove most of the ions from the water (Anon., 1956).

The benthic organisms present in Polecat Creek include 28 species representing six phyla (Table 2). Table 3 shows the percentage of

TABLE 2

LIST OF BENTHIC ORGANISMS COLLECTED FROM POLECAT CREEK 4/2/71 TO 7/29/71

Phylum Platyhelminthes
- Planariidae - Dugesia sp.

Phylum Nematomorpha
- Horsehair Worms - Gordius sp.

Phylum Bryozoa
- Plumatella sp.

Phylum Annelida
- Tubificid Worms - Tubifex sp.
- Aquatic Earthworms - Naididae
- Leechs - Helobdella sp.

Phylum Arthorpoda
- Amphipoda - Hyalella sp.
- Decapoda
- Stonefly naiads
- Mayfly naiads
- Dragonfly naiads
- Damselfly naiads
- Caddisfly larvae
- Beetle larvae and adults
  - Dytiscidae
  - Elmidae
  - Haliplidae
- Diptera larvae
  - Chironomidae - Chironomus sp.
  - Tabanidae
  - Ceratopogonidae
  - Simuliidae

Phylum Mollusca
- Fingernail Clams - Sphaerium sp.
- Aquatic Snails
  - Physa sp.
  - Helisoma sp.
  - Stagnicola sp.
  - Amnicola sp.
  - Lymnaea sp.
  - Planorbidae
  - Pleurocera sp.

occurrence of each organism at the five stations. Figure 7 shows the frequency of occurrence of each organism in the 85 samples.

Fingernail clams, tubificid worms, and chironomid larvae are the most common organisms with the chironomids occurring in all the samples. Although these organisms are considered to be pollution tolerant species, they occur with intolerant species in lesser numbers in a fairly clean environment. Table 3 shows the majority of the tubificids to be at Station 10B which has a silt bottom. The chironomid larvae were found mostly at Station 10 which has a sand and rubble bottom and receives some runoff from a sheep pasture. A few were found at Station 10B but seemed to find the habitat more suitable at Station 10. The fingernail clams were most abundant at Station 7, although many empty shells were found at Station 10B, which were not counted.

Submerged aquatic vegetation and riffles yielded most of the insect larvae and nymphs. Many of the snails were also found on the plants. Most of the horsehair worms collected were newly hatched and were among the rubble in the riffles. The Surber sampler was used four times during the sampling period with a noticeable increase in the diversity of organisms when it was used. There were only three stations, (7, 11, 11A), where the sampler could be used successfully. The other two stations, (10 and 10B), had no riffles.

Station 11 yielded a few organisms which were absent at the other stations. Most of the leeches, all of the amphipods, and the only bryozoan were taken at this station below Ashmore Lake.

The life cycles of some of the insects affected their frequency of occurrence. Some did not appear in the samples until late in the summer. The larvae and adults of the Elmidae and Haliplidae were not found until the later samples.

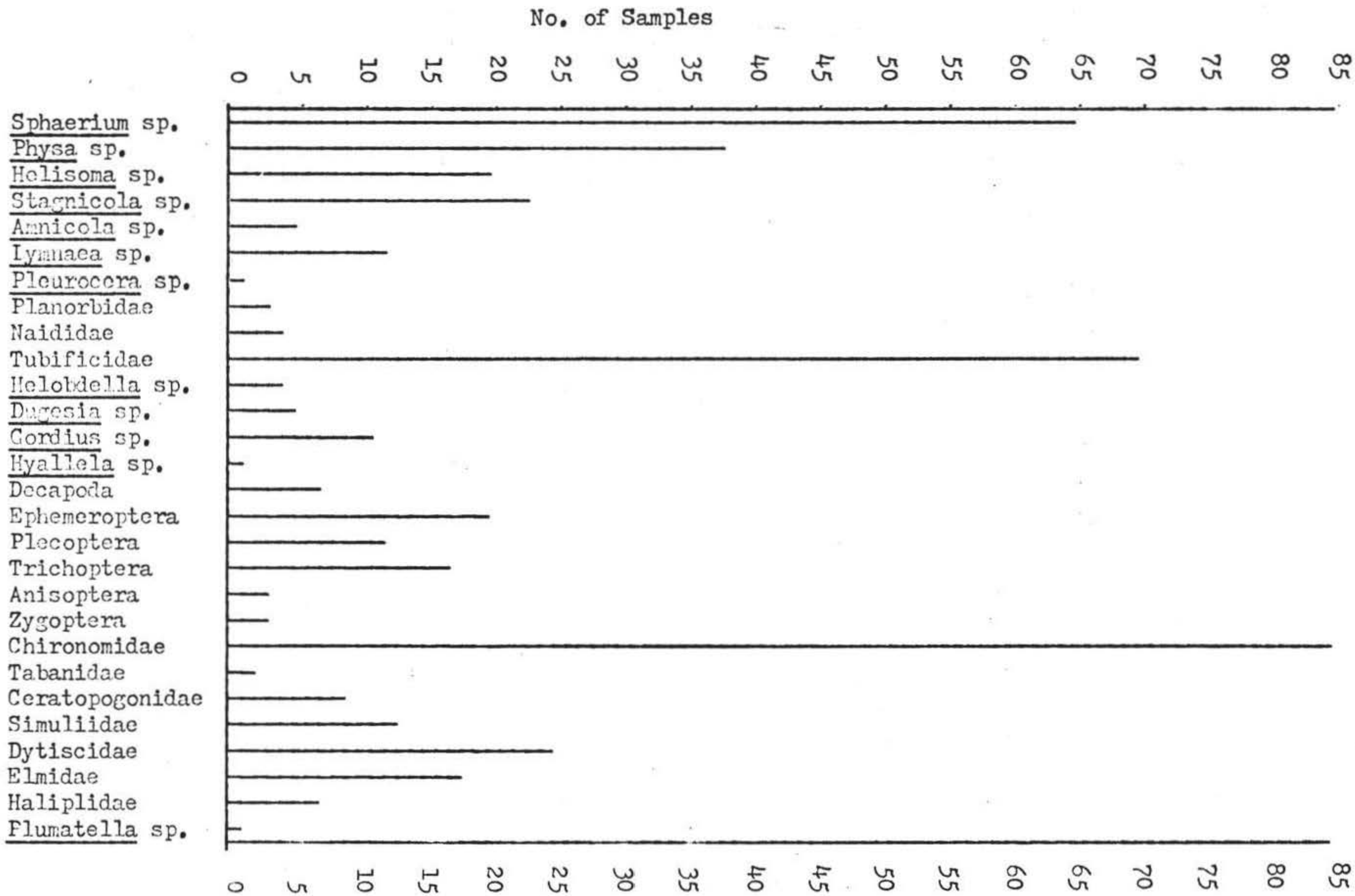


FIGURE 7. Frequency of Occurrence of Benthic Organisms in Polecat Creek 4-2-71 to 7-29-71.

TABLE 3

PERCENTAGE OF OCCURRENCE OF BENTHIC ORGANISMS AT FIVE STATIONS ON POLECAT CREEK 4/2/71 TO 7/29/71

Organism	7	10	10B	11	11A
Sphaerium sp.	45%	32%	5%	11%	7%
Chironomidae	14	47	8	7	24
Tubificidae	2	6	85	4	3
Physa sp.	1	25	69	3	2
Helisoma sp.	0	16	80	4	0
Stagnicola sp.	2	47	47	2	2
Amnicola sp.*	5	0	0	95	0
Lymnaea sp.*	82	6	12	0	0
Tabanidae*	0	60	20	0	20
Ceratopogonidae*	25	33	42	0	0
Ephemeroptera	22	56	10	5	7
Trichoptera	23	2	0	70	5
Anisoptera*	0	0	100	0	0
Zygoptera*	33	0	33	34	0
Gordius sp.*	80	0	0	10	10
Naididae*	0	100	0	0	0
Dytiscidae	71	1	0	15	13
Plecoptera	13	10	3	6	68
Dugesia sp.*	63	6	0	31	0
Simuliidae	5	1	0	76	18
Helobdella sp.*	0	0	20	80	0
Elmidae	51	9	0	17	23
Pleurocera sp.*	13	10	3	6	68
Haliplidae*	0	0	75	25	0
Decapoda	0	23	20	6	51
Hyalella sp.*	0	0	0	100	0
Planorbidae*	0	0	50	50	0
Plumatella sp.*	0	0	0	100	0

*Less than 25 individuals collected.

DISCUSSION

The Buffering System of Natural Waters

In order to consider the importance of the buffering system of natural waters, all the related components of the carbonate-bicarbonate ion must be considered. Free carbon dioxide, pH, carbonate, and bicarbonate alkalinity are all maintained in the aquatic system in equilibrium with the values of each component primarily dependent on the photosynthetic activity of the aquatic plants.

Total alkalinity and hardness levels are higher in winter due to organic decomposition. Carbon dioxide values are inversely related to pH, alkalinity, and hardness. Bicarbonate alkalinity is dependent on the calcium content of the earth in the drainage area and the carbon dioxide content of the water.

Low alkalinity values were found during periods of high discharge after rainfall (Figures 4 and 5), and were due to dilution by the rainwater and the short period of time the water was in contact with the ground (Minshall, 1968b).

Carbon dioxide is present in water as free carbon dioxide, bound carbon dioxide (carbonate), or half-bound carbon dioxide (bicarbonate). It enters the water from several sources. Decomposition of organic detritus is the main source, but, diffusion from the atmosphere, leaching of lime deposits, respiration of soil inhabitants in the ground water, and respiratory activities of the larger animals all contribute a share of the carbon dioxide content at one time or another.

High alkalinity values were recorded during periods of low water when the stream flow was primarily ground water. The glacial till in the watershed contributes the calcium ions during ground water percolation and the carbonate ions are released during decomposition and the other processes which introduce carbon dioxide to the water.

The alkalinity appears to remain fairly constant once plant activity has been allowed to increase by warmer weather (Figure 5). An equilibrium between decomposition and plant activity kept the alkalinity between 200 and 250 ppm. the rest of the sampling period.

The pH of the water ranged from 6.8 to 8.3 during most of the sampling period, with a low of 6.8 on February 4, 1971 and a high of 8.3 on April 30, 1971. It was raining when the lower reading was recorded. This was the same sample in which the alkalinity, hardness, total dissolved solids, and conductivity were at their lowest levels.

The concentration of calcium, magnesium, and other trace ions is expressed as total hardness. Determination of calcium and total hardness in the samples showed a direct, parallel relationship in levels of both (Figure 5). The carbonates and bicarbonates which are important nutrients for plant and animal life are found as compounds of calcium and magnesium. Precipitation of calcium or magnesium carbonate due to high pH is considered detrimental to the nutrient content of the water.

The conductivity of natural waters is a measurement of the specific conductance contributed by each ion in solution. Welch (1952) considers it as the indication of electrolytes present in the water. Figure 5 illustrates the relationship between conductivity and the components of the buffer system.

Total Dissolved Solids

Total dissolved solids is a measurement of the total mineral content of the water and usually can provide a fair indication of conditions which must, in some way, measure the productivity of water. The concentration is reduced in periods of high discharge by dilution or by organisms living in the stream. High levels may be the result of a number of things: silt erosion, low flow, soil leaching, and bedrock erosion. Higher concentrations are usually found in late winter and early spring when the first rains flush salts which have accumulated from rock weathering and soil leaching during the dry, cold months into the stream. Continued weathering during the rest of the year accounts for smaller, more constant, levels (Gunnerson, 1967). All the ions which give values for conductivity, alkalinity, and other soluble minerals are a part of the total dissolved solids, in addition to organic material. The total dissolved solids levels in Polecat Creek fluctuate with the concentration of calcium and total hardness, and alkalinity (Figure 5). Rainfall reduced the concentration by diluting the stream water.

Total Suspended Solids

Suspended solids occur primarily in particulate form and consist of plant debris, organic substances adsorbed on inert particles, and living and dead organisms (Minshall, 1968a). Suspended solids levels are dependent on several factors, because a portion of the suspended material is living. Water temperature, sunlight, nutrient levels, and number of benthic organisms have an effect on the living portion of the suspended solids, which tends to increase during the summer. Some suspended solids are carried into the water by surface runoff,

either as plant debris or with silt particles. Suspended solids levels in Polecat Creek fluctuate with the amount of rainfall, indicating that high concentrations are dependent on surface runoff, although there was a slight upward trend during the warmer months.

Dissolved Oxygen

Unpolluted water tends to hold in solution the maximum amount of oxygen which it is capable of containing at the existing temperature and partial oxygen pressure of the atmosphere. In organically polluted streams, the draft imposed upon the dissolved oxygen supply by the progressive satisfaction of the oxygen demand reduces the oxygen content below its saturation value. The sources of available oxygen in a stream are mainly two: the oxygen which is produced as a by-product of photosynthesis, and the oxygen absorbed from the atmosphere in the process of physical reaeration. As the water temperature increases, the solubility of dissolved oxygen decreases (Figure 6). The maximum dissolved oxygen concentration was 16.7 ppm. at Station 11A on April 8, 1971. This is above the saturation level and was probably caused by plant activity in the immediate area. The lowest concentration was 5.3 ppm. on July 15, 1971 at Station 11, just below Ashmore Lake, which slows down the water velocity and reduces mixing and reaeration.

Biochemical Oxygen Demand

Biochemical oxygen demand, according to Wurtz and Bridges (1960), is a measure of the amount of oxygen consumed by bacteria in stabilization of decomposable organic matter in the water. They pointed out that all surface waters have some biochemical oxygen demand load, with unpolluted waters varying from about 1.0 to 2.5 ppm. of oxygen demand.

Streeter and Phelps (1958) suggest that changes in the dissolved oxygen content of a stream are intimately associated with biochemical changes. They are brought about primarily by the oxidation of organic matter discharged into streams as soil wash and as wastes. In the presence of a supply of oxygen, together with certain oxidizing bacteria and oxidizable organic matter, progressive oxidation and stablizing of the organic matter will take place. The biochemical oxygen demand is often inversely related to the dissolved oxygen concentration. However, there are more factors influencing B.O.D. than there are for dissolved oxygen levels. Biochemical oxygen demand is dependent on a supply of decomposable material and dissolved oxygen concentration. A high level of B.O.D. may not be noticed when dissolved oxygen is supersaturated in the water. Zero B.O.D. was recorded following heavy precipitation, due to the removal of detritus from the stream bed by the scouring which results from high water velocity. The highest B.O.D. was 5.3 ppm. at Station 11 on April 30, 1971. This station is just below Ashmore Lake which receives organic wastes from several septic tank tiles.

Nitrates and Nitrites

Nitrates and nitrites are produced in nature as the result of protein breakdown (Inglish, 1967), or by certain plants and soil bacteria which convert atmospheric nitrogen to soluble form (Navone, et. al., 1963). Substantial increases in the concentration of nitrates in food and water supplies are reported in many sections of the world resulting from widespread heavy inorganic nitrogen fertilization and from sewage discharge from rapidly growing suburban areas. High nitrate concentrations were found following heavy rainfall in May and June. Agricultural fertilizer would be the most probable source of nitrates at that time. The nitrate level reached its lowest point on

July 29, 1971 when the water was very low.

Nitrites are produced from nitrates during active bacterial decomposition at low water periods and warm weather (Slack, 1955). Levels are low in winter due to inhibition of bacteria at low temperatures (Moe, et. al., 1968), and tend to increase as the water temperature increases (Figure 6). An increase in water temperature results in an increase in bacterial decomposition of the benthal deposits.

Phosphates

Phosphorus is present in water as soluble phosphate which is inorganic and insoluble phosphate which is organically bound in plants and animals. The method of determination for phosphate used in this study indicates soluble phosphate only. High levels were found in late winter when the first thaw occurred (Figure 4). Low levels were found the rest of the sampling period except when there was excessive rainfall. Soluble phosphate enters the water in runoff from fertilizer, manure or calcium diphosphate rock on the surface and upper part of the soil (Neel, 1951; Keup, 1968; Viets, 1971). High levels occur in late winter or early spring after thawing. The rest of the year it is bound up as organic phosphate until it is released by decomposition of dead organisms in the benthal deposits.

Iron

Iron is absent in natural waters except for the soluble iron released by fission of organic complexes by microorganisms in the soil of the watershed and in the water (Keup, et. al., 1970). Since iron can exist in, or in association with, soil or organic particles, and since levels of iron increase with increasing discharge and turbidity, levels of iron reflect the influx of settleable suspended material to

the stream (MacCrimmon and Kelso, 1970). Iron concentrations in Polecat Creek fluctuated with the amount of rainfall the watershed received (Figure 4). The absence of iron from municipal water supplies is desirable, although the ferric ion is only toxic when in association with other adverse conditions.

Sulfates and Chlorides

Sulfates and chlorides are soluble minerals that show increase in levels with greater stream flow. Both ions can also be introduced with sewage and become toxic at low concentrations in the presence of certain cations of heavy metals. The levels of both ions fluctuated very little during the sampling period, with the greatest variations occurring during rain or excessive runoff (Table 1).

Water Temperature

Although water temperature is not actually an important factor limiting the productivity of a stream, it may create a synergistic effect in association with stress from other sources (Slack, 1955). Water temperature in Polecat Creek rose steadily until late April, then dropped in May during heavy rains and rose again in June and dropped in July following heavy rainfall (Figure 6). The shallowness of the stream accounts for the variation in water temperature. A deep, slow-moving body of water would be more able to maintain a steady water temperature.

Turbidity and Siltation

Turbidity and siltation were shown to be important limiting factors by restricting or eliminating certain members of the benthic population. The silt runoff from the cropland in the watershed has deposited

a layer of silt on the bottom of the stream in the portion above Ashmore. While sorting the bottom samples from Station 10B, I found many empty shells of snails and clams which were imbedded in the bottom material.

Substrate

Substrate and current are the two most limiting physical factors on the inhabitants of the stream. The substrate of Polecat Creek ranges from a thick layer of organic silt to sand and gravel to rubble and clay. It has been channelized in the upper portion which produces a high velocity of water after rains which increases as the water moves through the steep gradient in the lower portion (Figure 1). A large portion of the silt in the upper portion is scoured off the stream bed by the water and deposited in the Ashmore Lake where the velocity is reduced. Downstream from the lake, very little silt is found on the bottom, which is sand, clay, and rubble.

The suitability of the various types of substrates for benthic organisms is still a source of disagreement by several authors in the literature. One believes the detritus deposited in pools to be more suitable than the rubble in riffles (Gersbacher, 1937). On the other hand, Pennak and Van Gerpen (1947) list riffles as being the substrate with the most diverse population. Needham (1938) found that mud is the most productive bottom type for fish food organisms for trout streams. Mackay and Kalff (1969) found that a leaf habitat has a high species diversity, is rich in numbers and biomass, and that leaf and detritus habitats can support about 30% of the total standing crop of a small woodland stream. I found that, although the silt bottom had the greatest number of individuals, the riffles had the greatest number of species.

The stations with a sand bottom yielded the least organisms, but when the riffles at Stations 7, 11, and 11A were sampled with a Surber square foot sampler, more species were taken.

Nutrient Accumulation

Sewage effluents are the number one contributor to the nutrient levels in the majority of the lakes and streams in the country, with farmland drainage being number two. With the absence of any large sources of sewage in the watershed, farmland drainage is most likely the number one contributor of nutrients in Polecat Creek. There is some septic tank drainage into the creek and into Ashmore Lake, but it cannot compare to the enrichment added by field tile drainage, feedlot drainage, and surface runoff.

Nitrates are the predominant type of nutrient because of their solubility. Phosphates are hardly noticeable after the initial leaching in early spring. They are bound up as organic compounds shortly after they are placed on the ground and the portion that does reach the stream is soon incorporated into the vegetation and benthos.

The practice of farming the edge of a stream contributes substantial amounts of silt as well as nutrients to the stream. The lack of shade encourages the growth of aquatic vegetation which sometimes restricts flow. The extensive conversion of forest land to the purpose of agriculture increases the runoff and the drainage, reduces the water-holding capacity of the ground, and results in a fall in the water table. In addition to a decrease in the volume of the water available locally, changes in its quality are induced by its different pathway over and through the ground into the streams, and by its shorter stay in the ground (Kehoe, 1960). Soil types found in the watershed and their characteristics are shown in Figure 2.

The dissolved solids concentration is typical of the loamy soils of the watershed. Glacial till and loam contributes calcium and magnesium ions in the groundwater in sufficient quantities for the stream to be classified as very hard water with total hardness from 300 to 400 mg./L. most of the year. Groundwater is typically more highly mineralized than surface waters. Because of the higher mineral concentration in groundwater, there is a greater effect on stream composition at low stream flow (Gunnerson, 1967).

Benthos

The benthic population of Polecat Creek indicates that it is a fairly clean stream with small amounts of localized pollution. The range of bottom type found in the stream also is a factor in the variety of inhabitants found there.

The silt bottom in the upper portion is a very suitable environment for the organisms that are able to utilize this type of substrate, such as tubificids and the naiads of dragonflies and damselflies. The aquatic vegetation also contains a number of snails and insect larvae that are able to survive on the vegetation without actually utilizing the substrate. However, the substrate is restrictive to the organisms which have exposed gills or are incapable of moving out of the area fast enough to avoid being smothered by the silt, during periods of heavy runoff.

The sand, clay, and rubble substrate with vegetation growing on it found in the area of Station 10 contained the greatest number of organisms, most of which were chironomid larvae, known to feed on aquatic plants, algae, and organic detritus. The lack of silt also permits habitation of this portion of the stream by organisms such as mayfly naiads, crayfish, and aquatic snails, all of which have

partially or fully exposed respiratory structures.

The sand and rubble substrate at Station 11A was devoid of any vegetation due to the slight turbidity caused by cattle and pigs upstream which were allowed to enter the stream, and shading most of the day by overhanging trees. The most common organisms were chironomid larvae which were taken in the riffle when it was sampled, as well as in the bottom of the pool. Other organisms present in moderate abundance were crayfish, elmid beetles, and horsefly larvae, with a few horsehair worms, dytiscid beetle larvae, blackfly larvae, and stonefly naiads. The riffle at this station contained most of the organisms. The sand had very little.

Station 11 is located just below Ashmore Lake. It has a sand, bedrock, and rubble bottom. According to Table 3, this area had the most diverse population. The riffle contributed most of the organisms at this station, also. This station had the most constant temperature of all the stations and the water quality was greatly influenced by the lake upstream. The water was always slightly turbid because of plankton from the lake. This condition is probably the reason for the population diversity, with several of the organisms being filter feeders. The most common organisms were caddisfly larvae, blackfly larvae, and damselfly nymphs with a few dytiscid beetle larvae, elmid beetle larvae, flatworms, haliplid beetle larvae, horsehair worms, snails, and clams. The more constant physical and chemical water conditions and the presence of plankton at this station accounts for the presence of filter feeding organisms not found at other stations. This is the only station where a bryozoan was found.

Station 7 is a rather barren area with its sand and bedrock substrate. There is a riffle which contains most of the organisms. The

most common organisms are fingernail clams, snails, flatworms, dytiscid bettle larvae, and elmid beetle larvae. Most of the young horsehair worms were taken in the riffle. This is a habitat for crawling organisms rather than filter feeders because the current is stronger. Other organisms taken here are listed in Table 3.

SUMMARY

The physical and chemical conditions in Polecat Creek during the sampling period showed it to be a fairly clean stream. This is probably due to the lack of industry or a large municipality in the watershed. The only adverse conditions to occur in the stream were the high nitrates and silting during periods of high discharge.

Levels of iron, phosphate, and nitrate were shown to be in direct relationship to the amount of rainfall, while values for hardness, dissolved solids, alkalinity, and conductivity were found to have an inverse relationship with rainfall. Although high discharge affected the concentrations of dissolved oxygen, nitrites, and biochemical oxygen demand by dilution of ordinary conditions, water temperature appeared to have more effect on these three parameters.

The benthic organisms collected from Polecat Creek in this study include 28 kinds representing 6 phyla. They include both pollution tolerant and intolerant types. The presence of both types at all the stations is an indication that there is no serious problem with excessive enrichment, though there is a small amount entering the stream.

The substrate variation throughout the length of the stream yields a benthic population of similar variety. The riffles appear to be the most productive substrate and the sand is the least productive. The silt bottom supported organisms which were able to survive when a new layer was deposited.

If a model stream were to be selected for comparison with other

waters of lesser quality, Polecat Creek would be the ideal choice. It agrees with most predictions which can be made in a general water quality study.

LITERATURE REVIEW

The Buffering System of Natural Waters

In order to realize the importance of the buffering system, all the related components of the carbonate-bicarbonate ion must be considered. Free carbon dioxide, pH, carbonate, and bicarbonate alkalinity are all maintained in the aquatic system in equilibrium, with the values of each component primarily interdependent with the photosynthetic activity of the aquatic plants.

Total alkalinity values nearly always vary inversely with the water level. Values for pH are partially dependent on the photosynthetic activity of the aquatic plants. Free carbon dioxide varies inversely with discharge, also (Slack, 1955).

Total alkalinity and hardness increase in winter as a result of organic decomposition. Carbon dioxide values are often inversely related to pH, alkalinity, and hardness. Bicarbonate alkalinity is dependent on the calcium content of the soil in the watershed and the carbon dioxide content of the water.

Moore (1939) has made a graphical determination of the amount of free carbon dioxide in water in the form of nomographs. He used pH, total alkalinity, carbonate alkalinity, and bicarbonate alkalinity values to determine the amount of free carbon dioxide. He states that "the ion product of water exerts a negligible effect on the values for carbon dioxide, bicarbonate, and normal carbonate at all pH values below 10.0, and therefore the temperature corrections may be ignored for most waters." The waters he refers to are those having temperatures

from 15 to 25 degrees Centigrade, dissolved solids concentrations of 500 mg./L. or less, and pH values below 10.0. He used a pH meter to determine phenolphthalein and methyl-orange alkalinities and found this method to be more accurate than the use of color end-points.

Sechrist (1960) points out that alkalinity and its buffering action in water increases with total alkalinity, that factors other than the three forms of alkalinity (OH^-, HCO_3^-, and CO_3^-) affect buffering capacity, that phenolphthalein alkalinity measures the hydroxyl ions as well as the carbonate ions, and that apparently the pH of natural waters is relatively independent of total alkalinity, conductivity, and the buffer capacity of those waters.

Neel (1951), in his study of a headwater limestone stream outlines the carbonate-bicarbonate cycle. He found that quantities of bicarbonate are always considerable except during winter. An increase of carbonate alkalinity in riffles was generally accompanied by a decrease in bicarbonate alkalinity, due to the influence of photosynthesis by attached algae that removed carbon dioxide from bicarbonate. During warm weather, monocarbonate formed by photosynthesis in riffles is transformed to bicarbonate again in pools by union with free carbon dioxide produced there by decomposition. Monocarbonate in solution normally takes up free carbon dioxide as quickly as the latter is formed in pools, and when quantities of monocarbonate in solution are insufficient to combine with all carbon dioxide being produced, the carbonic acid which is formed will react slightly with the stream bed, increasing bicarbonate alkalinity.

A richness of carbonates and bicarbonates favors high productivity. Bicarbonates are leached from the substrate by the action of carbonic

acid and are converted to monocarbonates if the pH is high enough. As the water proceeds downstream, the carbonates are converted again to bicarbonates by the accumulation of free carbon dioxide from decomposition. Carbonate alkalinity is absent when the pH is below 8.2 and there is a lot of plant detritus (Harrel and Dorris, 1968).

Low alkalinity values found by Minshall (1968b) were obtained during periods of high discharge after rainfall and were due to dilution by the rainwater and the short period of time the water was in contact with the ground.

Carbon dioxide is present in a water course as free carbon dioxide, bound carbon dioxide, or half-bound carbon dioxide. It is probably more important to the production of essential materials for life than any other substance. Carbon dioxide is utilized as a carbon source for all photosynthetic plants and in water it is obtained from bicarbonate compounds of calcium or magnesium with the resulting deposition of marl if there is insufficient free carbon dioxide to become attached and form a new bicarbonate compound (Welch, 1952).

Carbon dioxide enters the water from several sources. It is mainly produced during decomposition of organic detritus. Other sources include diffusion of atmospheric carbon dioxide, leaching of lime deposits in the watercourse, respiration of soil inhabitants in the ground (Pitty, 1968), and the respiratory activities of the larger animals in the water.

Free carbon dioxide is never found in waters above a pH of 8.3. Above this, bound carbonate is the only form present and deposition of marl occurs. This type of condition would be found in waters with a very alkaline substrate. Half-bound carbon dioxide, or bicarbonate, is unstable and occurs between pH range, 4.5 to 8.3. Because of its half-

bound condition it is able to easily give up a carbonate ion in the photosynthetic process. It then becomes a bound carbon dioxide compound and is available to take up free carbon dioxide, if it is present. Carbonate alkalinity and free carbon dioxide are inverse at equilibrium conditions. As the water becomes saturated with oxygen, the pH is raised and the free carbon dioxide concentration drops (Brink and Widell, 1967). Neel (1951) has observed that a decrease in pH shortly after a heavy rain may be due to tremendous dilution with neutral rainwater and not free carbon dioxide production.

The most reliable method of determining alkalinity and free carbon dioxide is the titration method described in Welch (1948) with replacement of the end-point indicators by a pH meter. Verduin (1956) recommends use of a meter to determine end-points for carbon dioxide titration because he has found that waters with a high ion concentration will cause the phenolphthalein to change color prematurely while there is still free carbon dioxide present.

The pH of natural waters is a result of the ion concentration. When the water has a high total alkalinity, the pH will be higher. Waters with abundant ions have been observed as being the most productive. This is true not only because of the amount of ions, but because of its high buffering capacity which keeps the water more able to absorb foreign substances without drastic changes. Hydrogen-ion concentration is regulated by the presence of hydrogen ions and carbonate or hydroxide ions, and the presence or lack of vegetation, aeration, and stagnation.

Conductivity of natural waters is a measurement of the specific conductance contributed by each ion in solution. Williams (1966) found it to be correlated with the concentration of total dissolved solids.

Brink and Widell (1967) proposed that conductivity is determined by the content of calcium and magnesium ions. Edmondson (1956) believes it is directly proportional to salinity and may be affected by changes in the carbon dioxide concentration. Welch (1952) considers conductivity as the indication of the presence of electrolytes in the water. This would include acids, bases, and salts as all being contributors to conductance. There are weakly soluble electrolytes which do not contribute and strong electrolytes which are expressed in the total conductivity. Therefore, an increase in alkalinity would be an increase in conductivity, also, because of the solubility of the bicarbonate ions.

The concentration of calcium, magnesium, and other trace ions is expressed as total hardness. Calcium and magnesium are vital elements in plant and animal growth. Egglishaw and Mackay (1967) found that bacterial decomposition is accelerated by a high concentration of calcium ions. The carbonates and bicarbonates are mostly found as compounds with calcium and magnesium and are indispensible as nutrients. Precipitation of calcium or magnesium carbonate is considered detrimental to the nutrient content of the water.

Total Dissolved Solids

Total dissolved solids is a measurement of the total mineral content of the water and usually can provide a fair indication of conditions in the water. Erosion of the soil into the water increases the dissolved solids content due to the presence of soluble minerals in the soil (Rawson, 1951). Dissolved solids concentration is reduced in periods of high discharge or by organisms living in the stream. Concentration is increased during periods of low flow because most of

the stream flow is ground water, which is generally rich in soluble minerals (Pitty, 1968). High concentrations of dissolved solids are usually found in late winter and early spring when runoff from the first rains flush salts into the water which have accumulated from rock weathering and soil leaching during the preceding dry months. Continued weathering during the rest of the year accounts for smaller more constant amounts (Gunnerson, 1967). All the ions which give values for conductivity, alkalinity, and other soluble minerals are a part of the total dissolved solids. Organic material is also included in the dissolved solids.

Total Suspended Solids

Total suspended solids occur primarily in particulate form and consist of particulate plant materials, organic substances adsorbed on inert particles, and living and dead organisms (Minshall, 1968a). Welch (1952) puts suspended materials into two classes: the large plankton organisms and coarsely divided, non-living substances whose specific gravity is such that they are constantly suspended; and very finely divided, non-living materials and organisms of exceedingly small size, such as nannoplankton.

Many stream bottom-dwelling consumers depend directly upon suspended particulate organic matter for nourishment and, therefore, the existence of suspended particles is of considerable importance to stream trophic ecology. Suspended organic matter is utilized directly by that group of stream fauna usually referred to as passive or filter feeders. The presence of mineral and organic detritus nearly always surpasses the plankton in quantity, and the microscopic component of the suspended matter constitutes most of the total suspended organic matter (Maciolek

and Tunzi, 1968). Minshall (1968a) found that there is a greater quantity of suspended particulate detritus during the summer than during the winter.

Biochemical Oxygen Demand

Biochemical oxygen demand, according to Wurtz and Bridges (1960), is a measure of the amount of oxygen consumed by bacteria in the stabilization of decomposable organic matter in the water. They pointed out that all surface waters have some biochemical oxygen demand load, with unpolluted waters varying from about 1.0 to 2.5 mg./L. of oxygen use. Streeter and Phelps (1958) suggest that changes in the dissolved oxygen content of a stream are intimately associated with biochemical changes. They are brought about primarily by the oxidation of organic matter discharged into streams as soil wash and as wastes. In the presence of a supply of oxygen, together with certain oxidizing bacteria and oxidizable organic matter, progressive oxidation and stabilizing of the organic matter will take place.

Benthic Oxygen Demand

Benthic oxygen demand is exerted on the oxygen resources of a stream by organic material carried to the bottom of the stream by silt during high flow or by decomposition of autochthonous or allochthonous detritus present as settleable solids (Ellis, 1936; McKeown, _et_. _al_., 1968). Various conditions present in the overlying waters, namely, flow, nutrient balance, and mixing, also are related to the oxygen demand of the deposit (McKeown, _et_. _al_., 1968). Ogunrombi and Dobbins (1970) describe the processes of benthic oxygen demand as "the addition to the supernatant water of organic material which exerts an oxygen demand on the water, and the removal of dissolved oxygen from the super-

natant water to satisfy the oxygen demand of organic materials within the top, aerobic layer, and the immediate chemical oxygen demand of end-products of anaerobic decomposition which diffuse to the upper aerobic layer." Oldaker, et. al., (1968), in their work with benthic oxygen demand of river bottom sediments thought that part of the oxygen demand attributed to the sediments was the result of oxidation of nitrogenous compounds and that the nitrification process appeared to play an important role in the aerial oxygen demand of shallow sediments.

Dissolved Oxygen

Unpolluted water tends to hold in solution the maximum amount of oxygen which it is capable of containing at the existing temperature and partial oxygen pressure of the atmosphere. This is the so-called saturation value and ranges at normal sea level barometric pressure from approximately 14.0 mg./L. at just above freezing to about 7.6 mg./L. at 30 degrees Centigrade.

In polluted streams the draft imposed upon the dissolved oxygen supply by the progressive satisfaction of the oxygen demand reduces the oxygen content below its saturation value; but as soon as this depression occurs, absorption of oxygen from the atmosphere occurs. The sources of available oxygen in a stream are mainly two: the oxygen initially dissolved in the water, with its maximum possible equilibrium value at the saturation point; and the oxygen absorbed from the atmosphere by partially deoxygenated water in the process of physical reaeration, in addition to that produced by photosynthesis.

In a quiescent stream, the surface film becomes saturated and will dissolve no more of the gas until that which has already been dissolved at the surface is passed to a greater depth by diffusion or "streaming".

The rate of saturation is directly related to the diffusion of the gas.

In a flowing stream there is constant vertical mixing and overturning which the water receives as it flows along. Since such a small percentage of water actually reaches the exact surface layer, mechanical mixing of the water constantly breaks up the saturated surface film into small masses of water which are brought into contact with less saturated masses with an intimacy and frequency depending upon the degree of agitation (Streeter and Phelps, 1958).

Saturation of dissolved oxygen was observed on sunny days in a spring when algal photosynthesis was at its peak and supersaturation was noted in flowing water (Neel, 1951; Schneller, 1955; Slack, 1955). Hynes (1961) stated that the percentage saturation rather than the amount of dissolved oxygen is the important factor in determining effects on fauna.

Nitrates and Nitrites

Nitrates and nitrites are produced in nature as a result of protein breakdown (Inglish, 1967), or by certain plants and soil bacteria which convert atmospheric nitrogen to soluble form (Navone, et. al., 1963). Nichols (1965) estimated the introduction of nitrogen compounds to soil by rainfall to be approximately 2 to 6 pounds per acre per year.

Substantial increases in the concentration of nitrates in food and water supplies are reported in many sections of the world resulting from widespread heavy inorganic nitrogen fertilization of farmlands and from sewage discharge from rapidly growing suburban areas. Reports indicate that contamination of streams and lakes by surface drainage from heavily fertilized farmlands is equal to that of sewage nitrate contamination (Singer, 1968).

Nitrate levels are influenced by surface runoff and by decomposition of organic debris. They decrease in autumn and winter due to more available light, which increases the photosynthetic rate (Stern and Stern, 1969).

The presence of nitrates is an indication of the production capacity of a stream. Levels should be high in winter, low in June and July, and increasing in early fall due to stagnation (Slack, 1955). Navone, et. al. (1963) have observed that the presence of nitrates indicates the end product of bacterial metabolism which would mean that organic material entered the water prior to sampling. Inglish (1967) believes that nitrates in water, without nitrites, are an indication of and an index to pollution. According to Viets (1971), nitrate accumulation in previously polluted water is a sign that biochemical oxygen demand is reduced, and that other factors are limiting growth of aquatic organisms.

Nitrate is only dangerous in anaerobic systems when it is reduced to highly reactive nitrite, as in the rumen of ruminants and the stomachs of human infants (Viets, 1971; Waring, 1959; Singer, 1968). Nitrates are also reduced to nitrites during active decomposition at low water periods and during warm weather (Slack, 1955). Levels are low in winter due to inhibition of bacteria at low temperatures (Moe, et. al., 1968). The presence of nitrites above 6.0 mg./L. is an indication of heavy pollution and signifies active bacterial action and the presence of organic matter (Miner, et. al., 1966; Inglish, 1967).

Nitrate is a storage form of nitrogen in soils, water, or plants. It can accumulate or persist in a medium only when there is insufficient demand for it. It is the product of nitrification of ammonium ion arising from organic matter ammonification, ammonium-containing

fertilizers, or urea of fertilizer or animal origin by *Nitrosomonas* spp. and *Nitrobacter* spp. acting in that order (Viets, 1971).

Phosphates

Total phosphorus in water is regarded as divisible into two forms, inorganic (soluble) phosphate and organic phosphate (Welch, 1952). Soluble phosphate enters the water in runoff from fertilizer, manure, or calcium diphosphate rock on the surface and upper part of the soil (Neel, 1951; Keup, 1968; Viets, 1971). High soluble phosphate levels occur in early spring runoff after thawing. The rest of the year it is bound up as organic phosphate until decomposition of dead aquatic plants and animals releases it. Heavy rains at any time during the year may contribute more soluble phosphate to the water (Slack, 1955). Organic phosphate is the more common form and is not detected in tests for soluble phosphate. At least 90% of the phosphates in fertilizer is utilized by plants both on land and in the water (Smith, 1959; Keup, 1968). Another way soluble phosphate enters the water is as adsorbed material on erosion silt which settles to the bottom and is available for the primary removers of phosphate in the water, the benthic organisms (Keup, 1968).

Iron

Iron in natural waters is normally absent except for the soluble iron released by fission of organic complexes by microorganisms in the soil of the watershed and in the water (Keup, *et. al.*, 1970). Brink and Widell (1967) believe iron introduced into the water by leaching and erosion of the ground adjacent to the stream to be the most important source of iron in the water. Keup, *et. al.* (1970) also suggests that leaching of leaf litter is a source of iron.

Keup, et. al. (1970) recommends that iron in water supplies not exceed 0.3 mg./L. and that its absence is desirable. The toxicity of iron present depends on other characteristics of the water; it is more soluble in the absence of oxygen, acidic water, and when organic materials are present.

Since iron can exist in, or in association with, soil or organic particles, and since levels of iron increase with increasing discharge and turbidity, levels of iron reflect the influx of suspended material to the stream (MacCrimmon and Kelso, 1970).

Sulfates and Chlorides

Sulfates and chlorides are soluble minerals that show increase in levels with greater stream flow, which is expressed as an increase in conductivity (Harrel and Dorris, 1968). Both ions can also be introduced by sewage and become toxic at low concentrations in the presence of certain cations of heavy metals. Sulfate ions are typically abundant in hard waters due to the leaching of rocks composed of sulfate compounds (MacCrimmon and Kelso, 1970). Chloride ions are significant as a nutritional requirement, a toxic substance, and as an osmotic factor. The Aquatic Life Advisory Committee (Anon., 1956) is of the opinion that an expression of chloride ion concentration has, in itself, no practical significance as far as aquatic life is concerned since the cations are the potentially toxic agents.

Flouride

The toxicity of flourides is increased in soft waters. Calcium ions in hard water will precipitate calcium flouride and reduce the concentration. The A.L.A.C. (Anon., 1956) recommends that the fouride ion level in any stream not exceed 1.5 mg./L., which is the safe level

for human consumption. There is no real data on the chronic effects of flouride on aquatic life.

Temperature

Water temperature is not actually a factor limiting the productivity of a creek. However, it may intensify the effects of chemical conditions which develop in special situations (Slack, 1955). Because of the relationship between temperature and solubility, dissociation, and stability of substances dissolved or suspended in water, a temperature change will have an indirect effect on aquatic organisms (Anon., 1956).

Crisp and LeCren (1970) found that there are large fluctuations in the water temperature during the course of a day. Sunshine and precipitation give higher values during the daytime. Daily fluctuations in water temperature effect the metabolic rate and general activities of the aquatic organisms, though they are only limiting at extremes such as very cold or very hot temperatures.

Turbidity and Siltation

Turbidity and siltation are the result of suspended solids being introduced into the water by several sources: glaciers, wind-eroded particles, topsoil loosened by plowing or animals, soil exposed to erosion by cover destruction, and placer mining (Lackey, 1949).

When the silt particles settle out they often carry planktonic organisms to the bottom (Brehmer, 1965). Silt accumulation on the bottom produces a drastic change in the fauna (Mackenthun, 1966). Inorganic silt will smother the existing biota and inhibit repopulation of the area (Brehmer, 1965; Tebo, 1955). The composition of the suspended silt will also affect aquatic organisms by clinging to them

enough to smother them, or by abrasion of the membranes of the more delicate forms (Lackey, 1949).

Organic silt will smother or drive out the original inhabitants and a new fauna will repopulate the area and become established. Organic silt is mostly the result of suspended solids being introduced by sewage. Ellis (1936) found that erosion mud taken from surface runoff streams usually carries less than one percent organic matter. The organic material carried to the bottom of the stream by silt creates a change in biochemical oxygen demand, chemical oxygen demand, and carbon dioxide as well as any other chemicals or minerals it carries with it.

Flooding and its associated erosion are considered the most important limiting factors put upon the aquatic fauna in southwestern streams by Tarzwell (1937). He also points out that the productivity of inorganic silt is only a fraction of the productivity of organic silt.

The Aquatic Life Advisory Committee (Anon., 1956) places no limits on settleable solids and turbidity except that the formation of sludge deposits be prevented.

Nutrient Accumulation

Nutrients most commonly accepted as valid criteria of water productivity are nitrogen, phosphorus, silica, sulfate, iron, chloride, and the various carbon forms occurring in the buffer systems of water (MacCrimmon and Kelso, 1970).

The various nutrients are contributed by sewage, rural drainage, stormwater runoff, cropland erosion, woodland runoff, and ground water. Sewage effluents are the number one contributor to the nutrient levels in the majority of the lakes and streams in the country. Farmland drainage is number two in importance as a nutrient source in the temperate

zones. Even in early spring, farm manure spread on the frozen ground, is flushed into the streams during spring thaws and rains (Hasler, 1969; Timmons and Holt, 1970). Sawyer (1968) calculated that manure spread on snow contributes almost 100% soluble nutrients when leached by rain or the snow melting.

Nitrogen and phosphorus are the two most important and the most limiting of the mineral nutrients available to the primary producers in the aquatic community. Brink and Widell (1967) proposed that a normal nitrogen/phosphorus ratio in the aquatic vegetation is 10 to 1 and that in natural waters, a ratio of 15 to 1 is not uncommon. The nitrogen in the stream bed itself is more easily washed out even at small discharges, while the less easily affected phosphorus is eroded only at great discharges.

All land, regardless of use, contributes nitrogen and phosphorus to drainage, and it is difficult to distinguish between the contribution of fertilizer, washout from dead plants, and normal degradation products of the soil (Viets, 1971).

Timmons and Holt (1970), in their study of the leaching of crop residues as a source of nutrients in surface runoff water, list several factors in concentrations and amounts of nutrients: the type of crop, cultural and conservation practices, length and steepness of slope, amount and distribution of precipitation, soil infiltration and percolation characteristics, and the size of the contributing watershed. They found that high levels of nutrients in runoff occur by leaching of plants killed by frost or by dehydration. Different types of crops in the watershed contribute varied amounts of nutrients to the watercourse. Timmons and Holt have found that rotation alfalfa crops are consistently greater in runoff values than other crops. Bluegrass pastures and lawns

could also contribute varied soluble nutrients to surface waters during spring runoff if the dormant grass was leached by snowmelt. Less nutrient runoff later in the spring would verify the release by freezing and thawing in the snowmelt.

Henderson (1962) pointed out that stream pollution by rural drainage from a watershed with a farm animal population can be significant in terms of total demand on oxygen resources of a stream. Farm animals in the Midwest alone provide unsewered and untreated excrement which is equivalent to that of a population of 350 million people. City streets provide sources of phosphates and nitrates (Hasler, 1969). Prophet (1969) found that feedlots introduce large amounts of organic matter to a body of water. Lackey (1949) observed that agricultural drainage is a slow fertilization method for aquatic plants as compared to sewage and industrial wastes.

Stormwater runoff from rural areas represents one source of water pollution which is not susceptible to the usual abatement procedures. In order to determine what effect rural runoff has on rivers and streams, the quality and the amount of water that runs off must be ascertained (Weidner, et. al., 1969). Feeble rain of long duration or heavier rains with amounts of more than 5 mm. per day are required to produce significant runoff (Brink and Widell, 1967).

Cropland erosion has resulted from extensive conversion of forest lands to agricultural practices. Weidner, et. al. (1969) found that runoff is greatest when row crops are planted, less when wheat is planted, and least with meadow and sod. Duley and Miller (1923) showed that nitrates are lost most readily on land which has been eroded down to the subsoil and is still cultivated. They found that the topsoil soaks up most of the rainwater, thus keeping the nutrients in the soil.

Moe, et. al. (1968) observed that significant losses of nitrogen can occur under both sod and fallow conditions. While total nitrogen losses in surface runoff water are not great enough to be of major importance to crop production, their results indicate that significant losses can occur in this manner. Under present recommended application rates, the amount of nitrogen in runoff water would not contribute appreciably to nitrate pollution of surface water resources, but the possibility of future nitrate pollution from this source should not be ruled out as use of nitrogen fertilizer increases.

Ross (1963) outlines conditions imposed by temperate deciduous forest on woodland runoff: dense shade in the summer, a heavy autumal fall of leaves into the water, and a low volume of soil erosion because of dense accumulations of litter on the adjacent forest floor.

Maciolek and Tunzi (1968), Minshall (1968a), and Schneller (1955) all agree that allochthonous leaf materials provide the primary source of energy for primary consumers and, indirectly, for the entire benthic community. Schneller (1955) observed an abundance of leaves in the water to produce a "black water" condition for a few week in October and November, from the decomposition of the excess detritus.

Land clearance for agricultural purposes along small streams increases light and increases the algal and faunal population. Cleared land has more runoff resulting in increased fertility (Allen, 1959). Davidson and Wilding (1943) found that cleared land contributed a silt layer to the stream over which a dense mat of vegetation had grown. Bartsch and Ingram (1959) state that an increase in runoff which produces an increase in organic detritus in flowing streams does not become a real problem as they stimulate plant growth which aids the dissolved oxygen content of the water. Brehmer (1960) also observed that

aquatic flora removed most of the nutrients as the water moved downstream.

Species diversity and total numbers of individuals showed a decrease in an area where the forest had been removed. The most important effect of the removal was alteration of the temperature conditions. Removal of forest vegetation could, under more severe conditions, cause the depletion of primary food supplies essential to the maintenance of the woodland stream community (Minshall, 1968b).

The extensive conversion of forest land to the purposes of agriculture increases the runoff and the drainage, reduces the water-holding capacity of the ground, increases the suspended metals in the streams, and results in a fall of the water table. In addition to a decrease in the volume of the water available locally, changes in its quality are induced by its different pathway over and through the ground into the streams, and by its shorter stay in the ground (Kehoe, 1960).

Ground waters are typically more highly mineralized than surface waters. Because of this, the effects of rising ground water are implicitly included with the effects of runoff. Because of the higher mineral concentration of ground water, it has a greater effect on stream composition at low streamflow (Gunnerson, 1967).

Substrate

The substrate, or composition of the stream bed and the speed of the water current over the substrate are the two most limiting physical factors on the benthic community (Whitehead, 1935; Bishop and Hynes, 1969; Scott, 1958; and Mottley, et. al., 1938). The presence or absence of higher aquatic plants makes a difference, also (Whitehead, 1935).

The substrate is classified into as many as 12 types by various

workers. Percival and Whitehead (1929) list seven: loose stones, stones cemented to the bottom, mixed small stones, stones with Cladophora, loose moss, thick moss, and higher plants, with loose stones containing 70% of the total. Anon. (1956) lists twelve, showing gravel and rubble with plant beds to be the most productive. Pennak and Van Gerpen (1947) list six types in decreasing order of production as: silt, rubble, bedrock, clay, gravel, and sand. Mackay and Kalff (1969) list five types: sand, gravel, stones, leaves, and detritus, with fewest species on sand, and leaves with the most. The detritus had little diversity and a great number of individuals. Tebo (1955), Gersbacher (1937), Pennak and Van Gerpen (1947), and Mackay and Kalff (1969) all list sand as the least desirable habitat because of its lack of adequate microhabitats. Mackenthun (1966) has found that, in an unpolluted stream, rock and coarse gravel are the most suitable substrate for the greatest variety of organisms.

Gersbacher (1937) observed that the natural pools of a stream develop a better food supply than the running water because of the deposited detritus and plankton able to remain in the calm water, and that current is a definite factor in inhibition of community development. On the other hand, Pennak and Van Gerpen (1947) list riffles as being the most suitable type of bottom. Needham (1938) found that mud is the most productive bottom type for trout streams. Mackay and Kalff (1969) found that a leaf habitat has a high species diversity, is rich in numbers and biomass, and that leaf and detritus habitats can support about 30% of the total standing crop of a small woodland stream.

Cummins and Lauff (1969) summarize the discussion by stating that: "Whereas current, temperature, or concentration of a physical factor may limit the general ranges of habitat tolerance, it seems that substrate

particle size or food supply probably exert microdistributional influences." Silting has minor effects on substrate selection in most species except those which prefer the interstices of coarse sediments.

Biological Indicators

While chemical surveys of the water are indicative of conditions at the time of sampling, macro-invertebrate populations are indicative of past and present conditions (Van Horn, 1959; Patrick, 1950; Wilhm, 1967).

Immature aquatic insects have been used extensively as indicators because many possess useful characteristics such as sensitivity to changes in their environment, aquatic stages lasting from months to several years, sufficient size for ease in collection, and the ability to move out of an area without the great mobility of fish (Olson and Rueger, 1968).

Lackey (1949) suggests that organisms with a wide range of tolerance of environmental conditions are rarely useful as indicators. The best organisms are those which are very tolerant of one or a combination of conditions highly restrictive to most organisms. At the same time, they are rarely found under "normal" conditions, either because of the absence of some necessarily favorable condition, or because they cannot meet competition. Indicator organisms are those which are constant in appearance, with the appearance of polluted conditions.

Gaufin (1958) points out that many organisms which occur in large numbers in extremely enriched waters may also be found in limited numbers in cleaner situations. The mode of occurrence of the forms is just as important as their presence or absence in a

given area. Consideration of their structural and physiological adaptations is often very important as a better definition of the habitat preference of the forms being studied.

Gaufin and Tarzwell (1956) emphasized that in evaluating the reliability of aquatic organisms as indicators of polluted conditions, the different indicator organisms must not be considered separately, but as biological associations or populations.

Paine and Gaufin (1956) believe that because of the selectivity of habitat of the various species of Tendipedidae, they constitute the most important group of indicator organisms among the Diptera.

Gaufin and Tarzwell (1956) summarize the value of indicator organisms by saying that mere lists of indicator organisms are invalid as there is much disagreement as to their value as indicators. There has been an oversimplification of the problem by the supplying of lists which might be used by many without adequate investigation of the clean water communities. The foremost reason for lack of agreement is that little reliance can be placed on the occurrence of a single species in a given locality. Many organisms abundant in polluted waters are found in limited numbers in clean water. A second reason for lack of agreement is that several environmental factors other than the presence of a pollutant may affect or limit the distribution of certain species such as: geographical location, erosion, floods, size of stream, type of bottom, and range of the insect. Type of bottom, speed of current, depth of water, and many other factors affect the distribution of stream fauna in any given section. A third reason is the lack of keys and descriptions for species, and little reliance can be placed on the occurrence of a single species.

Species Diversity

The range and diversity of species in the aquatic environment depends on water quality, substrate, current, food supply, and season. The most restrictive factor in aquatic inhabitants would probably be water quality. An organism must be able to survive in its surrounding medium in order to inhabit its niche successfully. Mathis (1968) found that mountain streams with the highest temperature and highest alkalinity tended to have the most diversity, whereas, polluted streams should have less diversity than non-polluted streams since many species are unable to survive.

Experiments with the influence of artificial substrate particle size on the distribution of organisms by Cummins and Lauff (1969) showed that, although current, temperature, or concentration of a chemical factor may limit the general ranges of habitat tolerance, it seems that substrate particle size or food supply probably exert indirect influences on organisms.

Gersbacher (1937), Bishop and Hynes (1969), and Scott(1958) all believe that current is a definite factor in inhibition of community advancement. They state that organisms are found in running water not because of any preference for current, but rather because they need a set of conditions that exist only where water is flowing. Water velocity is decreased near the stream bed and edge and rubble affords protection for some organisms, so they need not be fully adapted to current. Other organisms have become adapted by many means of maintaining themselves in the current.

The summer months, including late spring and early fall, have been found by Harrel and Dorris (1968) and Mackay and Kalff (1969) to be the season for the highest numbers of species and the highest total biomass.

Flooding during early spring and early fall decimate the populations, but recovery is fairly fast during the warm months.

Wurtz (1955) divided stream inhabitants into five basic life forms: burrowing; sessile or limited motility; foraging on bottom organisms, rarely swimming; pelagic, free-swimming; and plankton. He divided them into groups of pollution-tolerant, non-tolerant, transition forms, and clean forms. He then made histograms for percentage of tolerant species of the first four types and illustrated the changes occurring in diversity from polluted water through clean water zones.

Various types of diversity indices have been presented by a few workers in the field of aquatic biology. Wilhm (1967, 1970) believes that an index must work regardless of sample size, and should reflect not only the distribution of species but should include the relative importance of each species in the community. He also believes that diversity indices must be applied accordingly with the special characteristics of the stream being tested. Wilhm (1970) illustrates a workable diversity index which depends on the amount being sampled being of a quantitative nature. Wurtz and Dolan (1958) believe that total numbers is the most reliable comparative index of stream bottom fauna. The productivity of bottom fauna is expressed by them in three ways: the number of organisms per unit area; the total weight (wet or dry) of organisms per unit area; and mass or volume of organisms per unit area.

Biglane and Lefleur (1954) described a healthy stream as one which supports a great variety of organisms. Keup (1966) has listed the three basic requirements of organisms for optimum diversity: a suitable habitat, which is a product of the physical and chemical properties of the waterway; protection from predators, a natural hiding

place or constructed concealment; and food, elementary nutrients for plants or plant tissue or animal tissue for animals.

Scott (1958) and Kaushik and Hynes (1968) both believe leaf detritus to be a more important food source for benthic organisms than plankton, in a woodland stream. In an agricultural drainage system, algae and plankton would be more important as a food supply, because of the increased sunlight and supply of nutrients from the farmland.

Water Quality Criteria

Seasonal and short-term changes may differ markedly at various locations in a water system and may have a profound influence on the productivity and well-being of stream life (MacCrimmon and Kelso, 1970). Lackey (1949) defines water pollution as "any material increase in turbidity, any marked change in mineral or organic content, and any gross change in gaseous content, especially oxygen diminution." He defines a clean stream as being clear; having a dissolved oxygen content over 3.0 mg./L.; being relatively free of other than atmospheric gases; containing no appreciable amounts of toxic substances; having a pH range between 5.8 and 8.4; containing no large amounts of salts, even those whose buffering action maintains pH in the above range; and containing an abundance and diversity of living things.

Stroud (1967) defines pollution as: the specific impairment of water quality by agricultural, domestic, or industrial wastes (including thermal and atomic wastes) to a degree which has an adverse effect upon any beneficial use of water, yet which does not necessarily create an actual hazard to the public health. If there is no impairment of use by the presence or addition of material, there is no pollution.

Patrick (1950) defines pollution as any condition of the water which upsets the biodynamic cycle of energy at any point along the food chain.

Many different committees and advisory boards have been set up in the past twenty years to evaluate pollutional problems and set limits on levels of nutrients and other materials composing the mineral and gaseous content of surface waters. Some materials have been subjected to specific limits and others to conditional limits varying with the stream itself.

Technique

Standard procedures for testing water quality are outlined in Welch (1948) and Standard Methods (1965). Procedures for sampling the benthos and nekton are also found in Welch (1948). Verduin (1956) has developed a method for use of an aerated reference sample when measuring dissolved carbon dioxide.

Waters (1961) discusses the advantages of analyzing drift organisms and standing crop, and outlines the procedure and equipment necessary for successful sampling. Leonard (1939) claims that for shallow streams of 18 inches or less in depth and with an adequate current, the Surber square foot sampler is the most satisfactory for benthic sampling. Scott (1958) recommends "Brush box" artificial substrates for use in shifting sands. Dickson, et. al. (1971) evaluated the use of a basket-type artificial substrate for use on gravel bottoms, and found it to be fairly accurate when sampling error was considered.

After the benthic sample has been collected, several methods for sorting out specimens are available. Washing down the sample in a series of sieves is a tedious job, so a few methods of flotation of live organisms have been developed by Anderson (1959) and others.

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