A BIOLOGICAL AND LIMNOLOGICAL SURVEY OF A SULFUR SPRING AND CONSTRUCTED TROUT STREAM

Thesis for the Degree of M. S.

MICHIGAN STATE UNIVERSITY

HOWARD D. WANDELL

1973

ABSTRACT

A BIOLOGICAL AND LIMNOLOGICAL SURVEY
OF A SULFUR SPRING AND CONSTRUCTED
TROUT STREAM

by

Howard D. Wandell

Early in 1971 a channel was constructed adjacent to the spring at the Erie Shooting Club and was filled with water from the spring. During the remainder of 1971 and in 1972, a study was undertaken to gather basic ecological information to determine the suitability of this environment as rainbow trout (Salmo gairdneri) habitat.

In addition to chemical and physical analyses of the spring's water, macrophyte and invertebrate samples were collected. Invertebrates were gathered primarily with an Eckman dredge. Macrophyte standing crop was estimated by collecting 1-m^2 samples from the stream bottom.

Water emerges from the spring at a temperature of 10.6 C and reached a maximum high of 18.9 C in the stream. The spring water is initially devoid of dissolved oxygen but reaches concentrations above 7.0 mg/l in the stream. Fluctuations in the diurnal pulse of oxygen increased from 1971 to 1972, undoubtedly due to an increased macrophyte

biomass. Alkalinity ranged from 223 to 249 mg/l as $CaCO_3$, and total hardness (EDTA) varied between 1580 and 1710 mg/l as $CaCO_3$. Sulfate values of over 1200 mg/l were recorded for the spring and stream but sulfide was detected in small concentrations only in the deep water of the spring during stratified conditions.

Only three species of aquatic plants presently grow in the spring pond and stream. Two of these species (*Potamogeton crispus* and *Chara sp.*) are considered indicators of hard, alkaline waters. There has also been a substantial increase in the standing crop of these macrophytes between 1971 and 1972.

Twenty-three forms of invertebrates were collected from the spring and stream. Nearly all of these invertebrates are described as inhabiting pond or stagnant stream environments. The spring and stream species are essentially identical except that the deep basin of the spring is populated only with members of the class Oligochaeta.

A BIOLOGICAL AND LIMNOLOGICAL SURVEY OF A SULFUR SPRING AND CONSTRUCTED TROUT STREAM

by

Howard D. Wandell

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Fisheries and Wildlife

1973

ACKNOWLEDGMENTS

I would like to thank the members of my graduate committee, my major professor Dr. Eugene Roelofs and Drs. P. I. Tack and F. M. D'Itri for their suggestions and recommendations in conducting this research. A special thanks should be given to my parents and brothers for their many forms of assistance. I also appreciate the opportunity to conduct this research at the Erie Shooting Club.

This investigation was made possible through a grant from the Erie Research Committee.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

During the spring and early summer of 1971 a channel was constructed adjacent to a large volume spring in the Erie Shooting Club marsh (T.8S., R.8E., Sec. 22) near the shore of Lake Erie. Contrived as a small recreational trout stream, this channel was filled with water diverted from the contiguous spring. Prior to channel construction this water flowed directly into the surrounding marsh by way of a broad shallow outlet. This recreational trout stream has thus further maximized a valuable natural resource through increased utilization.

This study has been designed to evaluate the described spring and stream as a trout environment. The environmental factors requiring the greatest attention are the dissolved gases; oxygen and hydrogen sulfide, because the waters which issue from the geological formations at the spring are copiously charged with compounds of calcium, magnesium, iron and sulfur (Sherzer, 1900) and devoid of oxygen. The modification of certain chemical properties of this water is thus essential in improving survival of the rainbow trout, *Salmo gairdneri* Richardson, stocked in the stream. The oxygen-free ground water must acquire concentrations of dissolved oxygen sufficient to meet the requirements of the trout. Additionally, the discharge of all hydrogen sulfide (H_2S) present in the spring water is necessary prior to its entry into the stream because this dissolved gas, a product of reduced environments, is extremely toxic to fish (Doudoroff and Katz, 1950). It is also imperative to know if this gas may be produced in the stream, particularly at the soil-water interface, in concentrations deleterious to the trout.

Concentrations of dissolved oxygen should obtain levels sufficient to eliminate stress and allow full activity of the trout. Concentrations at or near reported minimum levels would permit continued survival for only a brief interval. Minimum required concentrations of dissolved oxygen for trout species is approximately 2.0 mg/l (Shepard, 1955), depending upon environmental factors and the age and conditioned experience of the fish. Even oxygen concentrations slightly above minimum levels may be undesirable if normal development, growth and activity of the trout is impaired. A suggested concentration of 6 mg/l (Fry, 1959) for trout, derived from Basu's (1959) manipulation of respiration and metabolic rates, would provide for at least marginal development of the species. Higher concentrations of dissolved oxygen would of course be additionally advantageous if the stream is able to acquire them. Diel fluctuations of dissolved oxygen are also of consequence, for while fish subjected to such fluctuations benefit some from daily exposure to high concentrations, their growth is noticeably influenced by the recurring exposure to low levels of oxygen. These fish, in fact, do only slightly better than fish exposed to continuously low oxygen concentrations (Doudoroff and Warren, 1965).

Hydrogen sulfide is the configuration of dissolved sulfide present at pH values below seven. Between pH 7 and 13 most dissolved sulfide is in the form of hydrosulfide (HS^-), and above pH 13 sulfide ion ($S^=$). Also present in natural waters are the metallic sulfides, which are not dissolved but held in suspension as colloidal material or deposited on the bottom. Ferrous sulfide (FeS) is the principal metallic sulfide encountered in most natural systems. The amount of dissolved sulfide in solution will depend upon the concentration of ferrous ion and the solubility of ferrous sulfide, the solubility being dependent upon the pH of the water. The lower the pH, the greater the solubility of the metallic sulfide (Hutchinson, 1957).

In natural waters sulfide is a result of several chemical and biochemical reactions. As unoxygenated ground waters permeate sulfide mineral deposits, such as pyrite (FeS_2), dissociation of the mineral will result in the production of dissolved sulfide. In streams and lakes, especially at the soil-water interface and under reduced conditions, sulfide is derived from the decomposition, by putrefying bacteria, of sulfur-containing amino acids and the reduction of sulfate ($SO_4^=$) by "sulfur" bacteria. These microbial processes are usually linearly dependent upon the quantities of organic material and sulfate concentrations (Ohle, 1955). Bacteria are also important in the oxidation of sulfide back to sulfate.

With sulfides present in an environment it is advantageous to ascertain the concentrations of the hydrogen sulfide configuration since it is this form which is allegedly responsible for sulfide poisoning of aquatic animals. Work by Longwell and Pentelow (1935) and many others has since demonstrated that the toxicity of a sulfide solution is inversely related to the pH of the solutions. It has also been shown (Jacques, 1936) that the penetration of sulfide into cells is best explained by diffusion of molecular hydrogen sulfide through the cell membrane.

It is thus the purpose of this study to describe the basic limnological and biological properties of the Erie Shooting Club spring and constructed channel, and to relate the findings to the utilization of the system as a recreational trout stream. The major objectives will include:

1. a chemical and physical description of the spring and stream;

2. an account of the relative abundance and distribution of acquatic plants and invertebrates;

3. recommendations for management of the stream as a trout habitat.

The duration of this study extended one year, with two periods of data collection. During the interim between July and October of 1971 data was compiled and analyzed which allowed the stocking of 500 rainbow trout in the stream. Additional data was gathered during September, October and November of 1972 which provided further detailed information of this environment.

Sample collections had been planned for the summer months of 1972, however, difficulties in securing needed equipment and materials precluded sampling during this period. This proved to be unfortunate since the limnology of the spring during the summer stagnation period may have supplied more valuable information.

REGIONAL CHARACTERISTICS

Geological Characteristics

The environment under inquiry is located in Monroe county in the extreme southeastern corner of Michigan. The county is essentially a plain of low relief, sloping to the southeast. The underlying bedrock consists largely of limestones and dolomite. Glacial drift resting over the Paleozoic strata is generally very thin, averaging less than 30 feet for most of the county. The primary water supplies are wells completed in bedrock. Domestic wastes are principally disposed of in septic tanks. The increased commercial and domestic development in the county has resulted in the reported contamination of ground water in places where the glacial till is thin (Mozola, 1970).

A geological investigation by Sherzer (1900) reported a large number of flowing wells and springs along the eastern margin of the county bordering Lake Erie. Many of these wells and springs were characterized by the strong odor of sulfide ion. Presently, however, their numbers have been reduced due to a gradual lowering over the years of the piezometric level (Mozola, 1970). Sherzer (1900) also suggested that the presence of these springs and wells and other geological evidence was indicative of small subterranean channels in the bedrock. Furthermore, he proposed that some of the ground water that emerges from these springs and wells travels via the subterranean channels from collecting basins in the far western part of the county.

The chemical properties of the ground water discharged from the spring under examination is a product of soil and mineral deposits associated with its flow. Therefore, the high concentration of sulfur compounds, characteristic of the Erie Shooting Club spring is attributed to the action of ground water upon sulfur containing mineral deposits in the spring recharge area. Mineral deposits of the county with a sulfur component include celestite, $SrSO_4$; gypsum, $CaSO_4 \cdot 2H_2O$; anhydrite, $CaSO_4$; epsomite, $MgSO_4 \cdot 7H_2O$; elemental sulfur, S^o; and pyrite, FeS_2 (Sherzer, 1900). Of these minerals celestite and elemental sulfur are practically insoluble in water and would contribute little to the ground water except for their presence as colloidial material. Pyrite, although moderately insoluble, will hydrolyze to some degree to yield dissolved sulfide, which will be readily held in solution by oxygen-free ground water. If oxygen becomes available the dissolved sulfide may be oxidized to sulfuric acid (H_2SO_4), which will react with calcium carbonate and magnesium carbonate of the dolomite to give calcium sulfate (gypsum) and magnesium sulfate (epsomite). The gypsum and epsomite deposits may in turn form dissolved sulfide upon dissociation in oxygen-free ground water.

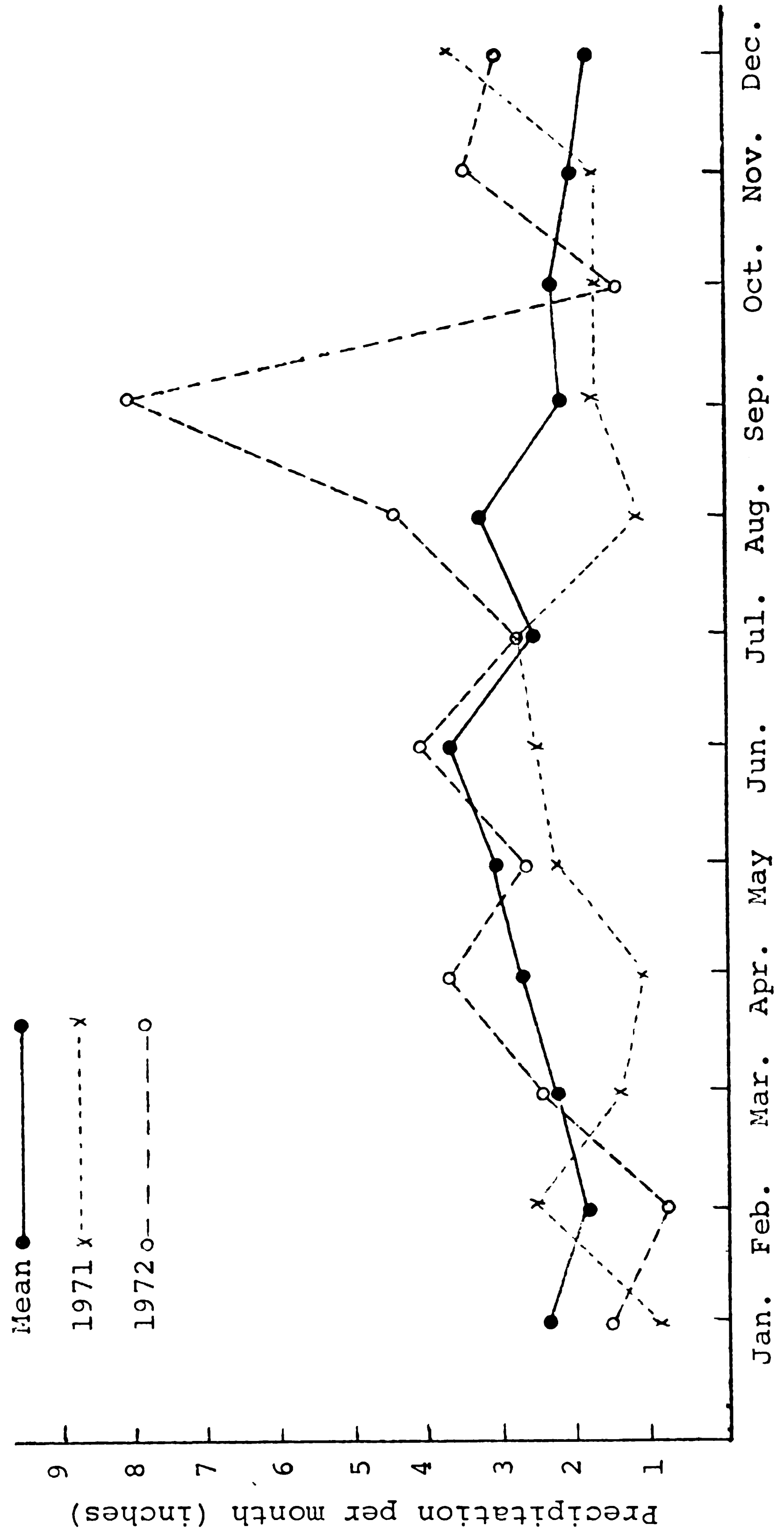
Climate

According to the United States Department of Commerce Narrative Climatological Summary for Monroe, Michigan, this area is influenced only slightly by Lake Erie due to prevailing westerly winds. However, priods of easterly winds and local lake breezes do modify summer temperatures enough to give the county a climate which fluctuates between semi-marine and continental in character. The weather is also controlled by pressure systems moving across the continent, which tend to reduce the extent of prolonged weather extremes.

This region receives its greatest aggregation of precipitation between May and October, a large share of which falls as afternoon showers and thundershowers. While January and February are the driest months, there is no exceptionally dry season in the region, for precipitation is well distributed throughout the year.

Precipitation levels are significant to spring discharge for, in addition to soil and aquifer permeability and recharge area, the water available for recharge will delimit the total volume and fluctuation of spring discharge. During the interim of this inquiry precipitation levels differed markedly (Figure 1). In 1971 only three

Figure 1.--Average monthly precipitation for 1971, 1972 and the monthly mean for Toledo, Ohio, nearest weather station to the study area (data from Environmental Science Services Administration).


Mean
1971
1972
Precipitation per month (inches)
1
2
3
4
5
6
7
8
9
Jan.
Feb.
Mar.
Apr.
May
Jun.
Jul.
Aug.
Sep.
Oct.
Nov.
Dec.

months experienced higher than normal rainfall levels, while in 1972 eight months were higher than normal. Total precipitation for 1971 was 7.32 inches below the annual average while 1972 surpassed the annual average by 7.91 inches.

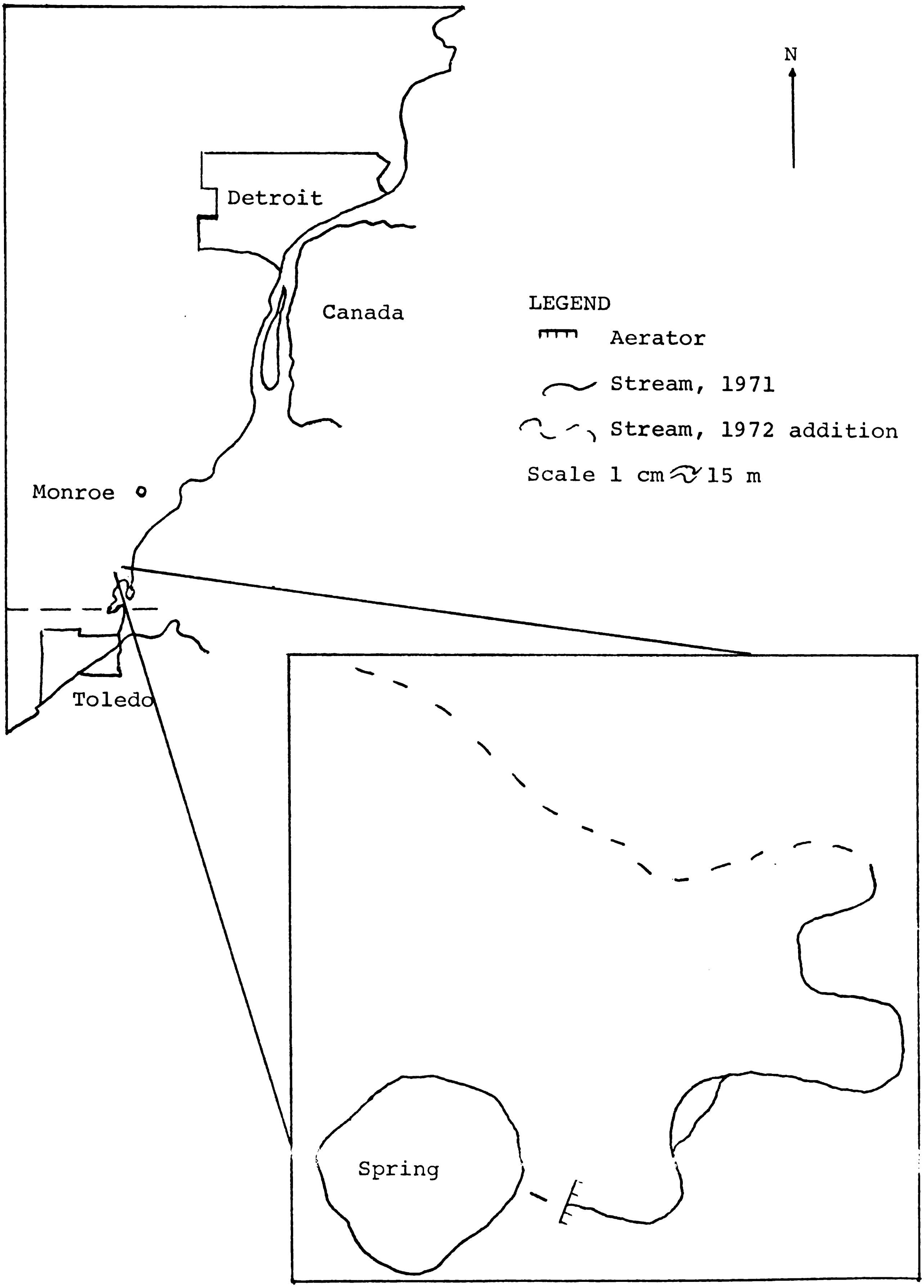
DESCRIPTION OF STUDY AREA

An elementary map of the spring and stream (Figure 2) was constructed by plane-table survey on 20 July 1971. At the time of map construction the steam was 360 m long, with an average width of 4.3 m and depth of 1.3 m. In 1972 the stream was lengthened approximately 300 m and much of the original channel dredged to increase its average width and depth to 5.8 and 1.7 m, respectively.

The emerging ground water forms a pond of approximately one acre, with a surface level two or three feet above stream level. This gradient permits the spring water to pass over a falling water aerator upon entry into the stream. Aeration increases the dissolved oxygen concentration and discharges hydrogen sulfide which may be present. At the stream's outlet a fish screen prohibits undesired fish species entry into the stream from the marsh.

The spring basin is funnel-shaped, with a marginal strip of 10 to 12 m shelving off slowly and then dropping suddenly to a maximum depth of 12.1 m. The water has a greenish-blue color which is intensified in the central portion of the spring pond by the deeper water. *Chara sp.* grows in a thick mat along the shelf and down to a depth

Figure 2.--Map of study area.


N
Detroit
Canada
LEGEND
Aerator
Stream, 1971
Stream, 1972 addition
Scale 1 cm ≈ 15 m
Monroe
Toledo
Spring

of 4 or 5 m. Sediments on the shelf are thin and consist of calareous tufa chips and a fine black mud. In the deep basin the sediment is a black mud several meters thick.

The stream sediments are similar to those of the spring, black mud several centimeters thick with minute tufa fragments distributed through it. No stones or gravel of any appreciable size or quantity are present except a few large pieces of tufa artificially positioned in the stream at two locations.

Stream macrophytes consist of only three species; Chara sp., Potamogeton cripus and a few dispersed Vallisneria americana. Chara sp. invaded the channel soon after completion and rapidly developed a thick bed covering much of the stream bottom below the aerator. Its aggregations diminished with increasing distance from the stream's origin to only a few scattered plants at the stream's termination. By the second year Chara sp. populations directly below the aerator had developed an extensive mat, covering virtually the entire substrate and growing nearly a meter into the water column. P. cripus invaded the downstream areas of the original channel and now grows in luxuriant beds.

BIOLOGICAL AND LIMNOLOGICAL SAMPLING SITES

To insure well distributed biological and chemical sampling, the original stream channel was partitioned into three 120-m sampling sections and the average width and depth for each section determined. Sections were numbered beginning at the stream origin, with each subsequent section receiving the sequential number. Within each section three collecting sites were established for procuring water samples for chemical analyses:

1. within 2.7 cm of the soil-water interface (2.7 cm);
2. 3 to 7 cm from the soil-water interface (3-7 cm);
3. a distance intermediate between substrate and surface (Mid).

These sites were designated by the stream section in which they were collected and their distance from the soil-water interface. No chemical or biological samples were collected from the stream channel constructed in 1972.

The spring was divided into two collecting sections for invertebrate sampling; the shallow shelf and deep basin. Samples for chemical and physical analyses were collected from immediately below the surface and at 3-m intervals to a depth of 9 m.

METHODS

Limnological

Water analysis conducted in 1971 was directed essentially at the constructed channel to promptly establish its qualifications as a trout stream. Samples for analysis were secured from each stream section with a Kemmerer sampler at a distance approximately midway between substrate and surface. Samples for dissolved oxygen analysis by the Azide modification of the Winkler method (Amer. Publ. Health Assoc. *et al.*, 1971) were collected at time intervals normally from 0900 to 1600 but on 27 July from 0530 to 1600. Samples for alkalinity were tested according to Standard Methods (Amer Publ. Health Assoc. *et al.*, 1971). Temperature was measured with a maximum-minimum thermometer and a standard vest-pocket thermometer. On 2 July, water samples were procured and preserved with mercuric ion (42 mg/l as $HgCl_2$) for analyses of Kjeldahl nitrogen, sulfate, total phosphorus, and pH by the Institute of Water Research, Water Quality Laboratory at Michigan State University. On 30 August, a Beckman pH meter became available which then permitted pH readings to be made in the field. During two sampling dates the current of water entering the stream was measured with a

Gurley current meter. Readings were taken as the water passed through an 18-inch culvert that linked the stream to the spring.

During 1972, analytical tests conducted in 1971 were continued with additional sampling sites in both the stream and spring pond. Besides these tests, samples were analyzed for total hardness (EDTA), total sulfide, dissolved sulfide (Amer. Publ. Health Assoc. et al., 1971) and Secchi disc readings were made. Total sulfide was determined by the methylene blue visual color-matching method after a pretreatment of the sample for low-level sulfide analysis. Dissolved sulfide samples were analyzed in a similar manner but were first passed through a 0.45-μ millipore filter to remove suspended metallic sulfides. Un-ionized hydrogen sulfide was calculated from dissolved sulfide values and pH values (Pomeroy, 1941).

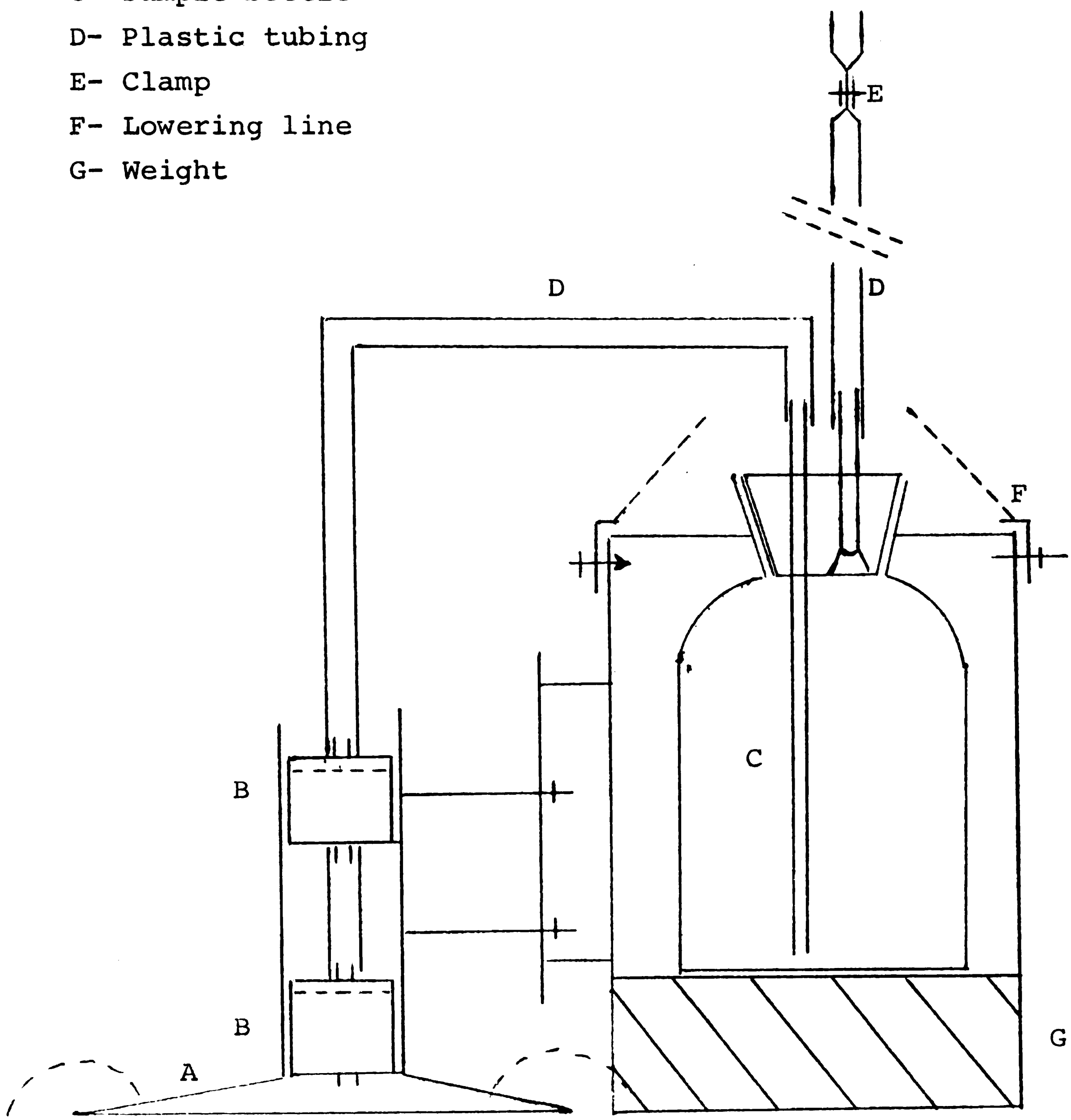
Soil-Water Interface Sampler

To obtain water samples in proximity of the soil-water interface, a sampler was designed which permitted the capture of a 300-ml volume within 2.7 cm of the substrate. Colby and Smith (1967) found the greatest alteration of oxygen and sulfide concentrations to be within 2.0 cm of the substrate.

The sampler (Figure 3) consists basically of a collecting plate, a combination of millipore filters, a

Figure 3.--Sampling device employed to capture a volume of water from close proximity of the soil-water interface for chemical analysis.

A- Collecting plate
B- Millipore filter
C- Sample bottle
D- Plastic tubing
E- Clamp
F- Lowering line
G- Weight



sample bottle, and plastic tubing to link the sampler with the atmosphere. Water is thus drawn into the sampler by means of hydrostatic pressure. Contamination of the procured sample with atmospheric oxygen is reduced since the sample bottle is flushed by water rising in the tubing to the surface. A clamp affixed to the tubing at the surface reduces hydrostatic pressure thus preventing a violent suction which may disturb the sampling area sediments and increases the time required to fill the sampler to 10 or 15 minutes. To minimize the possibility of clogging the 0.45-μ filter a second filter of higher porosity is positioned before it.

The height of the collected sample above the soil-water interface with this sampler is approximately related to the total volume of water displaced and the radius of the collecting plate (5 inches) in the equation:

$$a = \sqrt{\frac{V}{\pi^2 b}}$$

where

a = radius of captured volume,

b = the distance from the center of the collecting plate to its edge, and

V = total volume of water displaced.

The total volume of water displaced is dependent upon the depth to which the sampler is lowered, for samples collected from the stream under study this volume varied from 370 to 390 ml. Current, depending upon its velocity, will alter or negate the value for a. Its moderating influence will promote the securing of a sample incorporating substances conforming to the actual molecular movement along the soil-water interface.

The sampler was operated by carefully lowering it into position to reduce agitation of surrounding sediments. The disturbed area was then allowed ten minutes to return to equilibrium prior to initiating sample collection. In addition to being used in the stream, this sampler was also utilized to collect dissolved sulfide samples from the spring pond.

While this sampler permitted the capture of relatively large water samples reasonably close to the soil-water interface, another sampler has been designed by Colby and Smith (1968) which allows samples to be taken within a few millimeters of the substrate. Additionally, the design of this sampler is such that the deeper the sampler must be lowered to obtain a sample, the greater the loss of proximity to the soil-water interface. Some difficulty is also encountered in manipulating the lowering line and tubing when the sampler is being positioned and retrieved.

Biological

Macrophytes

To establish a value for macrophyte standing crop within the stream, two plots of 1 m^2 were collected twice during each sampling period from each of the stream sections. Samples were obtained by randomly dropping a 1-m^2 frame into the stream and removing the circumscribed macrophytes by hand where possible and by dredge where the water was too deep. A net was attached to the downstream edge of the frame to reduce the loss of broken plant fragments. Collections made in this manner, especially in deep water, proved to be extremely time consuming and resulted in very low sample replication. However, the error introduced by low sample replication may not be irremediable, since variable physical characteristics such as substrate particle size, current velocity, available light and water depth are remarkably uniform throughout the stream. Even the spatial distribution of the macrophytes is reasonably uniform, except for section 3 during 1972.

In stream section 3 during the 1972 collecting period, the macrophytes, Potamogeton crispus and Chara sp., proliferated in well defined species specific beds. Randomly positioned samples would have therefore required a high number of replications to estimate the standing crop adequately. Since time did not allow numerous sample replications, procedures were modified for this section by sampling 1 m^2 from a bed of each species and visually noting percentage of bottom area covered by respective beds.

Collected plant material was placed in plastic bags and returned to the laboratory where it was washed in an enamel pan to remove invertebrates and detritus material. Samples were then oven dried to a constant weight ± 0.5 g at 75 C.

Invertebrates

Invertebrate samples were obtained by securing ten Eckman dredge samples from each of the three stream sections and the two established collecting areas of the spring. During 1971, three collections were made, one each during the months of August, September and October. The succeeding year two collections were made, one in October and the other in November. In addition, periodic collections were made with a stretched screen among the projecting terrestrial vegetation growing along the bank.

The complete dredge grab was placed in a plastic bag and brought to the laboratory. Material from the grabs was concentrated by passage of the sample through a 0.5-mm sieve. The retained material was placed in a white enamel pan and the invertebrates sorted and preserved in 10% formalin.

At a later date the invertebrates were classified to the lowest taxon that the author was able to assign, and counted. The keys of Eddy and Hodson (1961), Burks (1953), Pennak (1953) and Usinger (1963) were employed for the classification.

RESULTS

Limnological

The volume of water entering the spring during 1971 averaged 1.38 cubic feet per second (cfs) for the two measurements conducted (Table 1). Since virtually the entire spring discharge was being directed through the stream at this time, this value is also the spring discharge volume. According to Meinzer's (1923) classification, a discharge of this magnitude would classify the Erie Shooting Club spring as a 3rd order spring, that is, a spring with an average discharge between 1 and 10 cfs. Although no measurements of discharge volume were made during 1972, it was considerably higher than in 1971, undoubtedly due to the increased precipitation.

Ground water emerges from the spring with a temperature of 10.6 C (Table 2). This temperature is moderated by loss or gain of heat to establish an equilibrium with the atmosphere. The greater the time interval and distance from source, the greater the regulating influence of the atmosphere.

The spring pond probably realizes two states of thermal distribution, a summer stratification and a winter circulation. Stratification commences as pond surface

TABLE 1.--Dissolved Oxygen (DO), Surface Temperature, pH, Methyl Orange Alkalinity, Phenolphthalein Alkalinity, and Discharge Volume Values for Selected Stations from the Constructed Stream for 1971.

Date	Sec.	Time (EST)	Water Temp. (C)	DO (mg/l)	pH	Alkalinity M.O. (mg/l $CaCO_3$)	Alkalinity Phth. (mg/l $CaCO_3$)	Discharge Volume (cfs)
23 July	1	0900	15.0	6.3		233	0	
		1200	15.6	6.4		231	0	
		1600	16.1	6.7		231	0	
	2	0900	15.0	6.1		235	0	
		1200	15.6	6.4		230	0	
		1600	16.7	6.8		229	0	
	3	0900	15.0	6.0		234	0	
		1200	16.1	6.2		234	0	
		1600	16.7	6.6		230	0	
27 July	1	0530	13.3	6.2		238	0	
		0900	13.9	6.2		239	0	
		1200	15.6	6.5		234	0	
		1600	16.1	6.7		233	0	
	2	0530	13.9	6.1		338	0	
		0900	14.4	6.3		335	0	
		1200	16.1	6.3		329	0	
		1600	16.7	6.6		330	0	
	3	0530	13.9	6.1		235	0	
		0900	14.4	6.2		237	0	
		1200	16.7	6.3		233	0	
		1600	16.7	6.6		230	0	
2 Aug.	1	0900	16.1	6.4		233	0	1.41
		1200	17.2	6.7		235	0	
		1600	18.3	7.2		230	0	
	2	0900	16.1	6.4		233	0	
		1200	17.2	6.7		230	0	
		1600	18.3	7.1		229	0	
	3	0900	16.1	6.3		235	0	
		1200	17.8	6.4		228	0	
		1600	18.9	6.9		230	0	

Table 1.--Continued.

Date	Sec.	Time (EST)	Water Temp. (C)	DO (mg/l)	pH	Alkalinity M.O.	Alkalinity Phth. (mg/l $CaCO_3$)	Discharge Volume (cfs)
13 Aug.	1	0900	15.0	6.1		231	0	1.35
		1200	16.1	6.5		227	0	
		1600	16.7	6.8		229	0	
	2	0900	15.0	6.3		233	0	
		1200	16.7	6.4		229	0	
		1600	16.7	6.9		228	0	
	3	0900	14.4	6.1		229	0	
		1200	16.7	6.3		233	0	
		1600	17.2	6.9		227	0	
23 Aug.	1	0900	14.4	6.0		233	0	
		1200	15.0	6.2		230	0	
		1600	16.1	6.6		228	0	
	2	0900	15.0	5.9		231	0	
		1200	16.1	6.1		227	0	
		1600	16.1	6.6		228	0	
	3	0900	15.0	6.0		231	0	
		1200	16.7	6.1		231	0	
		1600	16.7	6.8		226	0	
31 Aug.	1	0900	13.6	6.1	7.1	233	0	
		1200	13.9	6.3	7.2	230	0	
		1600	15.0	7.0	7.3	231	0	
	2	0900	13.9	6.1	7.2	236	0	
		1200	14.4	6.4	7.2	233	0	
		1600	15.6	6.9	7.3	231	0	
	3	0900	13.9	6.0	7.1	233	0	
		1200	14.4	6.1	7.2	230	0	
		1600	15.6	6.8	7.2	231	0	

Table 1.--Continued.

Date	Sec.	Time (EST)	Water Temp. (C)	DO (mg/l)	pH	Alkalinity M.O. (mg/l $CaCO_3$)	Alkalinity Phth. (mg/l $CaCO_3$)	Discharge Volume (cfs)
16 Sept.	1	0900	14.4	6.1	7.2	233	0	
		1200	15.6	6.5	7.2	229	0	
		1600	16.1	7.4	7.3	227	0	
	2	0900	15.0	6.1	7.2	237	0	
		1200	15.6	6.3	7.3	231	0	
		1600	16.1	7.4	7.3	230	0	
	3	0900	15.0	6.1	7.2	234	0	
		1200	16.1	6.3	7.3	227	0	
		1600	16.7	7.2	7.3	226	0	
28 Sept.	1	0900	16.7	6.0	7.1	237	0	
		1200	17.8	6.3	7.1	234	0	
		1600	18.3	7.3	7.3	228	0	
	2	0900	17.2	5.9	7.2	239	0	
		1200	17.8	6.3	7.3	235	0	
		1600	18.3	7.2	7.3	235	0	
	3	0900	17.2	5.9	7.2	234	0	
		1200	17.8	6.4	7.2	231	0	
		1600	18.3	7.2	7.3	233	0	

TABLE 2.--Secchi Disc, Temperature, Dissolved Oxygen (DO), Total Sulfide (TS), Dissolved Sulfide (DS), Un-ionized Hydrogen Sulfide (H_2S), pH, Phenolphthalein Alkalinity, Methyl Orange Alkalinity, and Total Hardness Values from Various Depths in the Spring Pond for 1972.

Date	Secchi Disc (m)	Depth (m)	Water Temp. (C)	DO (mg/l)	TS (mg/l)	DS (mg/l)	H_2S (mg/l)	pH	Alkalinity (mg/l $CaCO_3$) M.O.	Alkalinity (mg/l $CaCO_3$) Phth.	Hardness (mg/l $CaCO_c$)
21 Sept.	6.1	0	12.8	1.2	0	0	0	7.0	241	0	1700
		3	11.7	0.4	0	0	0	7.1	239	0	1680
		6	10.6	0	0	0.1	0.06	6.8	242	0	1710
		9	10.6	0	0.4	0.13	0.07	6.8	249	0	1680
25 Sept.	bottom	0	13.3	1.3	0	0	0	7.3	235	0	1620
		3	10.6	0.5	0	0	0	7.3	238	0	1650
		6	10.6	0.2	0	0	0	7.2	240	0	1630
		9	10.6	0.2	0	0	0	7.2	239	0	1630
8 Oct.	bottom	0	11.1	1.3	0	0	0	7.5	229	0	1590
		3	10.6	1.3	0	0	0	7.5	234	0	1610
		6	10.6	1.2	0	0	0	7.5	229	0	1600
		9	10.6	0.5	0	0	0	7.4	237	0	1650

Table 2.--Continued.

Date	Secchi Disc (m)	Depth (m)	Water Temp. (C)	DO (mg/l)	TS (mg/l)	DS (mg/l)	H_2S (mg/l)	pH	Alkalinity M.O. (mg/l $CaCO_3$)	Alkalinity Phth. (mg/l $CaCO_3$)	Hardness (mg/l $CaCO_3$)
16 Oct.	bottom	0	10.0	1.8	0	0	0	7.5	231	0	1600
		3	10.6	1.8	0	0	0	7.4	234	0	1630
		6	10.6	1.7	0	0	0	7.4	235	0	1610
		9	10.6	1.8	0	0	0	7.4	230	0	1620
30 Oct.	bottom	0	9.4	1.0	0	0	0	7.4	234	0	1640
		3	10.0	1.2	0	0	0	7.5	236	0	1660
		6	10.0	1.0	0	0	0	7.4	230	0	1640
		9	10.0	0.8	0	0	0	7.4	233	0	1610
20 Nov.	bottom	0	5.6	1.8	0	0	0	7.5	227	0	1580
		3	5.6	1.7	0	0	0	7.4	233	0	1620
		6	6.7	1.6	0	0	0	7.5	232	0	1610
		9	7.7	1.6	0	0	0	7.4	235	0	1630

temperatures exceed the ground water temperature, 10.6 C. Stratification is arrested and circulation initiated when cold weather again reduces pond surface temperatures below ground water temperature. The spring pond thus stratifies and circulates in accordance with ground water temperature, 10.6 C, instead of the maximum density temperature, 4 C.

A second stratification at 4 C is probably not established in this spring pond. Such a stratification would evolve when sufficient surface water has cooled below 4 C to produce a non-circulating epilimnion. Isolated from the warm ground water, cold atmospheric conditions would continue to decrease surface temperatures until an ice cover develops. Since this spring is reported free of ice, it is the opinion of the author that the spring pond is in a state of incessant circulation throughout the winter months. The temperature and volume of the spring discharge probably prevent the formation of a non-circulating epilimnion.

Temperatures in the stream attained a recorded high of 18.9 C on 2 August 1971 (Table 1). Garside and Tait (1958) reported the preferred temperature of rainbow trout to be approximately 13 C. Stream temperatures are therefore well within limits suitable for the rainbow trout survival, and exceed the preferred temperatures by only a few degrees during the warmest summer periods.

Devoid of dissolved oxygen as it issues from the earth, the spring pond water is able to acquire concentrations of at least 1.8 mg/l (Table 2) by plant photosynthesis and diffusion from the atmosphere. The distribution of oxygen throughout the spring is dependent upon the thermal distribution state of the pond waters (Table 2.) During summer stratification oxygen is recorded only at the surface and 3-m sampling sites. By 25 September the atmosphere has cooled oxygenated surface waters sufficiently to circulate them with the unoxygenated deep basin waters. As water temperatures become uniformly distributed about 16 October, dissolved oxygen is also homogeneous throughout the pond. Continued cooling of surface water produces an oxygen gradient of decreasing concentration with increasing depth.

In the stream dissolved oxygen attains concentrations as high as 7.8 mg/l (Table 3). Even at the soil-water interface dissolved oxygen remains persistently high (Table 4). During 1971, the stream oxygen concentration was usually above 6.0 mg/l and recorded concentrations surpassed 7.0 mg/l on several occasions (Table 1). However, during the 1972 data collecting period the diel fluctuation of oxygen increased, consequently increasing extremes in oxygen levels beyond 1971 values (Table 3). During 1971 oxygen fluctuations for the time interim of compiled data averaged only 0.77 mg/l; they increased, however, to an

TABLE 3.--Surface Temperature, Dissolved Oxygen (DO), Dissolved Sulfide (DS), pH, Methyl Orange Alkalinity, Phenolphthalein Alkalinity, and Total Hardness (EDTA) Values for (Mid) Sample Sites in the Constructed Stream for 1972.

Date	Section	Time (EST)	Air Temp. (C)	Water Temp. (C)	DO (mg/l)	DS (mg/l)	pH	Alkalinity M.O. (mg/l $CaCO_3$)	Alkalinity Phth. (mg/l $CaCO_3$)	Hardness (mg/l $CaCO_3$)
1 Oct.	1	0900	18.3	11.1	5.0	0	7.3			
		1200	22.2	11.6	6.3		7.4	229	0	1680
		1600	23.9	13.3	7.3		7.5			
	2	0900	18.3	11.1	5.1	0	7.3			
		1200	22.2	12.2	6.1		7.4	232	0	1680
		1600	23.9	13.9	7.1		7.5			
	3	0900	18.3	11.1	5.3	0	7.2			
		1200	22.2	12.8	6.0		7.4	235	0	1640
		1600	23.9	14.4	7.0		7.4			
16 Oct.	1	0900	10.0	9.4	5.5	0	7.4			
		1200	12.2	10.0	7.0		7.4	223	0	1600
		1600	11.7	10.0	7.8		7.5			
	2	0900	10.0	9.4	5.3	0	7.3			
		1200	12.2	10.6	6.8		7.4	224	0	1620
		1600	11.7	10.6	7.5		7.4			
	3	0900	10.0	9.4	5.3	0	7.3			
		1200	12.2	10.0	6.5		7.3	229	0	1650
		1600	11.7	10.6	7.4		7.4			

Table 3.--Continued.

Date	Section	Time (EST)	Air Temp. (C)	Water Temp. (C)	DO (mg/l)	DS (mg/l)	pH	Alkalinity M.O. (mg/l $CaCO_3$)	Alkalinity Phth. (mg/l $CaCO_3$)	Hardness (mg/l $CaCO_3$)
30 Oct.	1	0900	4.4	7.7	3.5	0	7.3			
		1200	5.0	7.8	5.1		7.4	225	0	1620
		1600	7.7	7.7	6.7		7.5			
	2	0900	4.4	7.7	3.6	0	7.4			
		1200	5.0	7.8	5.0		7.4	230	0	1610
		1600	7.7	7.8	6.6		7.5			
	3	0900	4.4	6.7	3.5	0	7.3			
		1200	5.0	7.7	5.3		7.4	228	0	1680
		1600	7.7	7.7	6.6		7.4			
20 Nov.	1	0900	2.8	5.6	5.0		7.2			
		1200	3.9	5.6	6.1		7.3	225	0	1610
		1600	5.6	5.6	6.6		7.4			
	2	0900	2.8	5.6	5.1		7.3			
		1200	3.9	5.6	6.1		7.3	233	0	1640
		1600	5.6	5.0	6.6		7.4			
	3	0900	2.8	5.0	5.1		7.2			
		1200	3.9	5.0	6.1		7.3	229	0	1660
		1600	5.6	5.0	6.8		7.3			

TABLE 4.--Dissolved Oxygen, Dissolved Sulfide and pH Values for Sample Sites at the Soil-Water Interface in the Constructed Stream for 1972.

Date	Time (EST)	Section	(Site)	Dissolved Oxygen	Dissolved Sulfide	pH
1 Oct.	1000	1	(2.7 cm)	5.6	0	7.5
	1400	1	(3-7 cm)	6.3	0	7.5
	1000	2	(2.7 cm)	5.7	0	7.5
	1400	2	(3-7 cm)	6.1	0	7.5
	1000	3	(2.7 cm)	5.4	0	7.3
	1400	3	(3-7 cm)	6.2	0	7.4
16 Oct.	1000	1	(2.7 cm)	5.8	0	7.5
	1400	1	(3-7 cm)	6.9	0	7.5
	1000	2	(2.7 cm)	5.7	0	7.4
	1400	2	(3-7 cm)	6.6	0	7.5
	1000	3	(2.7 cm)	5.8	0	7.3
	1400	3	(3-7 cm)	6.7	0	7.3
30 Oct.	1000	1	(2.7 cm)	4.2	0	7.3
	1000	2	(2.7 cm)	4.3	0	7.5
	1000	3	(2.7 cm)	4.0	0	7.4

average of 2.08 mg/l by 1972. This intensification of diel fluctuation was undoubtedly due to increased macrophyte production.

Thus at the present time dissolved oxygen concentrations appear to be at least satisfactory for the survival and growth of rainbow trout. However, further increases in the diel fluctuations may effectively reduce conditions below those favorable for trout growth, development and activity.

Values for pH were invariably slightly above neutral (Tables 1, 2, and 3) except for 21 September 1972 in the spring below 6 m. The pH values of 6.8 in the stratified non-oxygenated water may have resulted from mineral acids derived from the association of ground water with sulfide sources or from organic acids produced from decaying vegetation. Values for pH also, as would be expected, increased during daylight hours (Table 3). In addition there appears to have been an increase in the overall pH values of the system between 1971 and 1972. In 1971, pH never equaled or exceeded 7.4 (Table 1) while in 1972 readings of 7.4 and 7.5 (Table 3) were the most frequently recorded values. This narrow rise in pH values may have resulted from the combined effects of increased precipitation and plant production. Increased rainfall could have a diluting effect upon ground water chemistry as enlarged volumes of surface water permeate the recharge area and elevate pH values (Minckley, 1963). Greater macrophyte production would also raise pH values through increased utilization of available free CO_2.

The sulfate concentrations of the spring pond surface waters and sections 1 and 3 of the stream from samples collected on 22 July 1971 were 1520 mg/l, 2470 mg/l and 1250 mg/l respectively (shown in Appendix Table A1). Sulfide, however, was detected only in the deep basin of the spring pond under stratified conditions (Table 2). Most of this sulfide is suspended ferrous sulfide with a lesser fraction as dissolved sulfide. At a pH of 6.8 some of the dissolved sulfide present in solution is in equilibrium with ferrous sulfide dissociation.

On 21 September 1972, while the pond was still stratified, secchi disc readings averaged 6.1 m (Table 2). As circulation commenced transparency extended to the spring bottom and remained in that state for the completion of the study period. The change in transparency was conceivably due to the disruption of conditions which had favored sulfur oxidizing bacteria proliferation. Two forms of these bacteria could presumably flourish in the environmental conditions present in the waters of the spring during stratification. The aerobic sulfur oxidizing forms, Beggiatoa and Thiobacillus, are restricted to waters charged with both oxygen and dissolving sulfide. The photosynthetic anaerobic forms are dependent upon the presence of light and the absence of oxygen. These bacteria would mediate the oxidation of sulfide to sulfate and thus reduce the concentrations of sulfide present in solution. Circulation of the spring would oxygenate the deep basin water, eliminating the dissolved sulfide, and thus dissipate the zone favorable for sulfur bacteria, reducing their numbers and increasing the transparency.

Dissolved sulfide was not detected in the stream or at the soil-water interface, with the sampler used, at any of the collecting sites (Tables 3 and 4). If dissolved sulfide is present at the soil-water interface its concentrations are below detection with the methods employed or restricted to only a few millimeters above the substrate. At such concentrations it would be of exiguous consequence to adult fish. If present in even small concentrations it would be of some significance to the eggs and fry of the trout, which are adversely affected by concentrations of hydrogen sulfide as low as 0.02 mg/l (Smith and Oseid, 1970). This is of limited concern, however, since successful natural reproduction will probably be impeded in this stream by the particle size of the substrate material, which is too fine to allow adequate movement of water and oxygen through a redd, a factor which will seriously limit natural reproduction (Phillips et al., 1966).

There may be several reasons why dissolved sulfide is not present in detectable concentrations at the soil-water interface. As a newly constructed channel there may be insufficient amounts of deposited organic matter undergoing microbial decomposition to produce much dissolved sulfide. Additionally, dissolved oxygen concentrations are high even at the soil-water interface, thus rapidly oxidizing any sulfide which may be produced. Finally, the current, although not swift, may be adequate to distribute formed sulfide throughout the water column quickly, assisting in its dispersion and oxidation.

The results of other chemical analyses indicate, as would be expected from pH values, that no phenolphthalein alkalinity is present, so that the alkalinity is entirely equivalent to bicarbonate alkalinity. Alkalinity values varied from 226 mg/l as $CaCO_3$ to 235 mg/l in the stream during 1971 and from 230 mg/l to 242 mg/l during 1972 (Tables 1 and 3). Total hardness (EDTA) measured only during the 1972 collection period varied from 1580 mg/l to 1710 mg/l as $CaCO_3$ (Table 3).

Biological

Macrophytes

The values obtained for macrophyte standing crop (Table 5) can only be presented as imperfect estimates of actual values. Sampling techniques and lack of time prevented adequate numbers of samples from being collected. In addition, although every effort was made to prevent loss of plant material during sampling, occasional bits of

TABLE 5.--Estimated Macrophyte Standing Crop (g/m^2, dry weight) for the Constructed Trout Stream at the Erie Shooting Club for 1971 and 1972. (T = averaged standing crop for entire stream, Tr. = trace, less than 0.5 g/m^2.)

Year	Stream Section	Chara sp.	Potamogeton cripus	Vallisneria americana	All Macrophytes
1971	1	107.0	0	0	107.0
	2	23.0	0	Tr.	23.0
	3	4.5	0	Tr.	4.5
	T	44.8	0	Tr.	44.8
1972	1	378.5	0	0	378.5
	2	121.3	5.1	Tr.	126.9
	3	62.3	105.4	Tr.	167.7
	T	107.7	38.8	Tr.	209.7

plant tissue would be observed to drift around or over the catch net. It was also impossible to completely remove all plant material from the m^2 plots, especially in section 1 in 1972 when Chara sp. growths were extremely thick. Thus the values obtained have probably underestimated the actual values.

The two predominant species, Potamogeton crispus and Chara sp., are both considered indicators of hard water environments and often prone to grow too luxuriantly (Fassett, 1966). Chara sp. is described as a valuable food producer, especially for young trout (Fassett, 1966), and in fact, the trout were often observed to strike at the Chara sp. plants in what were conceivably attempts to dislodge invertebrates from among the macrophyte.

From values obtained for standing crop it is apparent that there has been a substantial increase in macrophyte biomass from 1971 to 1972 (Table 5), a fact also indicated by the increased fluctuations in daily oxygen pulse. While the stream as an entirety does not have an exceptionally high standing crop compared to other environments (Tesar, 1971), stream section 1 has developed a biomass of Chara sp. that may soon, if not already, be considered a nuisance. If its biomass continues to expand, this entire section of stream may become completely obstructed with the plant.

While some plant production may be desirable to increase dissolved oxygen concentrations, excessive plant growths may have undesirable effects upon the environment. Unusually large populations of benthic macrophytes may greatly increase fluctuations of the daily oxygen pulse. Not only would the lowered oxygen levels have a direct effect upon the fish but would also enhance the possibility of hydrogen sulfide formation and increase its toxicity to the trout (Smith and Oseid, 1970). The macrophytes may increase the potentiality of hydrogen sulfide formation by reducing current velocities, increasing organic material available for decomposition, and upon death form dense mats of decaying matter which could reduce soil-water interface oxygen concentrations. Once formed hydrogen sulfide may persist for considerable time even in the presence of very high dissolved oxygen concentrations (Colby and Smith, 1967). For while the chemical oxidation of sulfides is thermodynamically favored it proceeds very slowly (Chen and Morris, 1971) under most circumstances. The presence of large populations of sulfide oxidizing bacteria are necessary for the rapid transformation of sulfides to higher oxidized states.

Some level of aquatic macrophyte control may be necessary if plant biomass continues to increase or severely reduces dissolved oxygen by increasing the daily oxygen pulse. Control of the aquatic flora may be accomplished by either chemical or mechanical means, both of which have their advantages and disadvantages. Persistent reinfection from the spring by Chara sp. and other macrophytes from the surrounding marsh may make aquatic plant regulation a continual necessity in this environment.

Chemical control is the most frequently employed method because of its minimum expenditure of time, effort, and finances. Chemical treatment, however, provides only temporary relief and for best results treatments must be repeated on an annual basis. Care must also be taken to avoid severe depletion of oxygen levels when using herbicides. If dead plant material is not removed, its decomposition could greatly reduce oxygen levels and supply stored nutrients for support of new growths. Since fish must filter more water to obtain the same levels of oxygen, the toxic effects of chemical residues and environmental toxicants will be increased. One means of avoiding this difficulty is to treat only small sections of the stream at a time, thus preventing the decomposition of large amounts of plant tissue.

Mechanical aquatic plant control tends to be more expensive and time consuming, however it has several advantages. First, no foreign and possibly toxic substances are added to the environment. Secondly, the removal of plant tissue from the water reduces nutrients that would otherwise be available for further plant production.

Invertebrates

A total of 17 different groups of invertebrates were collected from the spring and stream in the Eckman dredge samples (shown in Appendix Table A2). An additional six species, three of which were Coleoptera, were gathered from the terrestrial vegetation which dipped into the water along the stream banks (shown in Appendix Table A3). The species inhabiting the spring were identical to those found in the stream with the exception that the deep basin was populated exclusively with species of the Oligochaeta, a fact undoubtedly due to the prolonged periods of oxygen-free water.

The species of invertebrates present in both the spring and stream are almost entirely pond and stagnant stream environmental forms (Pennak, 1953 and Usinger, 1963). In addition, at least 11 of the species are described as being associated with at least moderate amounts of macrophyte growths (Pennak, 1953). The flatworm, *Phagocata velata*, collected from this environment is a cold stenothermal, standing-water triclad. It is thus specified as typical of cold water springs and spring brooks and becomes active in ponds and ditches only during the cold months (Pennak, 1953).

Springs and adjacent sections of spring brooks have been characterized (Minckley, 1963 and Pennak, 1953) as typically having faunas limited in species numbers and with two or three species being numerically superior. This diversity index of benthic invertebrates and many of the species which characterize springs are similar to those recorded for polluted waters. This similarity in species composition and diversity has been accounted for by Sloan (1956) as being related to the low dissolved oxygen content prevalent in both environments. Of the 23 forms of invertebrates collected from the system under study, five were numerically dominant to all others. Representatives from the class Oligochaeta, the family Chironomidae, the gastropod *Physa sp.* and the crustaceans *Hyalella azteca* and *Asellus militaris* constituted the principal invertebrates collected. Most other forms were present in only small numbers.

When the 1971 and 1972 invertebrate collections are compared the represented forms remain essentially identical; however, several species increased notably in numbers present. Oligochaeta species, *H. azteca*, and *A. militaris* were all eminently more numerous in 1972. Their increased numbers can conceivably be associated with the enlarged macrophyte standing crop (Barber, 1970). *H. azteca* and *A. militaris* in particular are both very closely associated with macrophytes for shelter and food (Pennak, 1953).

SUMMARY

1. This study is designed to determine the suitability of the Erie Shooting Club spring as a source of water for a constructed trout stream and to evaluate the constructed stream as a trout habitat. The principal concerns of this investigation are the existence and concentrations of the dissolved gases, oxygen and hydrogen sulfide.

2. The spring forms a pond of approximately one acre, and has a maximum depth of 12.1 m. Its basin is funnel-shaped, with a marginal strip shelving off slowly and then dropping sharply to its maximum depth. *Chara sp.* grows in a thick mat along the marginal shelf. The stream is presently approximately 660 m long with an average depth and width of 5.8 and 1.7 m, respectively.

3. The chemistry of the water emerging at the spring is largely influenced by the geological deposits in the recharge area. The underlying bedrock consists basically of limestones and dolomite reportedly interlaced with subterranean channels which allows for movement of groundwater through the bedrock. Springs are common in the surrounding area; however, their numbers are diminishing due to a lowering of the piezometric level. There

was, however, a noticeable increase in spring discharge volume from 1971 to 1972, presumably due to the 15.23 additional inches of precipitation received during the latter year.

4. According to Meinzer's (1923) classification the Erie Shooting Club spring is a 3rd order spring. Its waters issue from the bedrock at a temperature of 10.6 C and devoid of oxygen. The surface waters of the pond are capable of acquiring concentrations of oxygen of at least 1.8 mg/l by plant photosynthesis and diffusion from the atmosphere. The spring pond probably experiences two states of thermal distribution, a summer stratification and a winter circulation. Some sulfides are present in the deep unoxygenated water of the spring pond during stratification but none was detected in the surface waters or throughout the pond during circulation.

5. After passing over the falling-water aerator into the stream, the spring water has obtained an additional 4 to 6 mg/l of dissolved oxygen. The daily oxygen pulse of the stream during 1971 was very narrow. It, however, increased during 1972, undoubtedly due to the enlarged macrophyte biomass. No dissolved sulfides were discovered in the stream even at the soil-water interface where they are most frequently generated.

6. Only three species of macrophytes presently grow in the stream, with Potamogeton crispus and Chara sp.

being by far the predominant forms. Both of these macrophytes are considered indicators of hard water and often prone to grow too luxuriantly. Estimated values for standing crop reveal that there has been a substantial increase in macrophyte biomass from 1971 to 1972. Control of macrophyte production may become desirable if aquatic plant biomass continues to increase or if oxygen concentrations reach unfavorable levels during the night phase of the daily oxygen pulse.

7. Of the 23 forms of invertebrates collected from the spring and stream, almost all are described as pond and stagnant stream types. In addition, at least eleven species are associated with macrophyte growths. The spring and stream have essentially the same species of invertebrates except that the deep basin of the spring is populated only with members of the class Oligochaeta.

LITERATURE CITED

LITERATURE CITED

American Public Health Association. 1971. Standard methods for the examination of water and waste-water. 13th ed. New York. 874 p.

Barber, W. E. 1970. Ecological factors influencing macroinvertebrates in the Pine River. Ph.D. thesis, Mich. State Univ. 77 p.

Basu, S. D. 1959. Active respiration of fish in relation to ambient concentrations of oxygen and carbon dioxide. J. Fish. Res. Bd. Canada 16:175-212.

Burks, B. D. 1953. The mayflies, or Ephemeroptera, of Illinois. Bull. Ill. Nat. Hist. Surv. 26:1-216.

Chen, K. Y. and J. C. Morris. 1971. Oxidation of aqueous sulfide by O_2. I. General characteristics and catalytic influences. Proceedings 5th International Conference on Water Pollution Research 32:1-17.

Colby, P. J. and L. L. Smith, Jr. 1967. Survival of walleye eggs and fry on paper fiber sludge deposits in Rainy River, Minnesota. Trans. Amer. Fish. Soc. 96(3):278-296.

________, and ________. 1968. A microstrata water sampler for stream study. Prog. Fish-Cult. 30:116-117.

Doudoroff, P. and M. Katz. 1950. Critical review of literature on the toxicity of industrial wastes and their components to fish. 1. Alkalies, acids and inorganic gases. Sewage Industr. Waste 22:1432-1458.

________, and C. E. Warren. 1965. Dissolved oxygen requirements of fish. In: Biological problems in water pollution. Third Seminar, 1962 (Transactions of the 1962 seminar). Public Health Service Publ. 999-WP-25 Robert A. Taft Sanitary Engineering Center, U.S. Public Health Service, Cincinnati, Ohio, p. 145-155.

Eddy, S. and A. C. Hodson. 1961. Taxonomic keys to the common animals of the north central states. Burgess Publ. Co. Minn. 162 p.

Fassett, N. C. 1966. A manual of aquatic plants. U. of Wis. Press. Madison. 405 p.

Fry, F. E. J. 1959. The oxygen requirements of fish. In: Biological problems in water pollution. Transactions of the 1959 Seminar. R. A. Taft Sanitary Engineering Center Tech. Rept. W60-3.

Garside, E. T. and J. S. Tait. 1958. Preferred temperature of rainbow trout (Salmo gairdneri Richardson) and its unusual relationship to acclimation temperature. Can. J. Zool. 36:563-567.

Hutchinson, G. E. 1957. A treatise on limnology, vol. 1, geography, physics, and chemistry. John Wiley and Sons, Inc. New York. 1015 p.

Jacques, A. G. 1936. The kinetics of penetration. XII. Hydrogen sulphide. J. Gen. Physiol. 19:397-418.

Longwell, J. and F. T. K. Pentelow. 1935. The effect of sewage on brown trout (Salmo trutta L.). J. Exp. Biol. 12:1-12.

Meinzer, O. E. 1923. Outline of ground-water hydrology. U.S. Geol. Surv., Water-supply Pap. 494:1-52.

Minckley, W. L. 1963. The ecology of a spring stream, Doe Run, Meade County, Kentucky. Wildl. Monogr. 11:1-124.

Mozola, A. J. 1970. Geology for environmental planning in Monroe county, Michigan. Mich. Geol. Surv. Rept. Inv. 13:1-34.

Ohle, W. 1955. Die Ursachen der rasunten Sceneutrophierung. Verh. int. Ver. Limnol., 11:373-382. (As cited in Hutchinson, 1957).

Pennak, R. W. 1953. Fresh-water invertebrates of the United States. Ronald Press Co. New York. 769 p.

Phillips, R. W., W. L. Hug, and E. W. Claire. 1966. A study of the effect of logging on aquatic resources, 1960-66. Progress Memorandum, Fisheries 3. Research Division, Oregon Game Commission. 28 p.

Pomeroy, R. D. 1941. Hydrogen Sulfide in sewage. Sewage Works J. 13:498-505.

Shepard, M. P. 1955. Resistance and tolerance of young speckled trout (Salvelinus fontinalis) to oxygen lack, with special reference to low oxygen acclimation. Jour. Fish. Res. Bd. Canada 12:563-567.

Sherzer, W. H. 1900. Geological report on Monroe county, Michigan, Mich. Geol. Surv. vol. 8:1-240.

Sloan, W. C. 1956. The distribution of aquatic insects in two Florida springs. Ecology 37:81-98.

Smith, L. L., Jr. and D. Oseid. 1970. Toxic effects of hydrogen sulfide on juvenile fish and fish eggs. Proc. 25th Purdue Ind. Waste Conf. p. 739-744.

Tesar, F. J. 1971. Primary production in a Michigan stream. M.S. thesis, Mich. State Univ. 153 p.

U.S. Department of Commerce. Environmental Science Services Administration. 1971. Climatological summary, Monroe, Michigan. Loose leaf. n.p.

Usinger, R. L. 1963. Aquatic insects of California. U. of Cal. Press. Berkeley. 508 p.

APPENDIX

TABLE A1.--Kjeldahl Nitrogen, pH, Total Phosphorus, and Sulfate Values for Spring and Stream Determined by Institute of Water Research, Water Quality Laboratory at Michigan State University. (Samples preserved with 42 mg/l $HgCl_2$.)

Analyses	Spring Surface	Stream Sec. 1	Stream Sec. 3
Kjeldahl Nitrogen (mg/l)	0.94	0.61	0.67
pH	7.28	7.39	7.35
Total Phosphorus (mg/l)	0.18	0.14	0.13
Sulfate (mg/l)	1520.0	2470.0	1250.0

TABLE A2.--Benthic Invertebrates Collected from the Erie Shooting Club Spring and Stream during 1971 and 1972.

Invertebrate	August 1971				
	Stream			Spring	
	Sec. 1	Sec. 2	Sec. 3	Shelf	Basin
Insecta					
Callibaetis sp.					
Caenis sp.					
Ischnura sp.			1		
Somatochlora sp.					
Corixidae	1				
Berosus sp.		1			
Chironomidae	151	103	88	151	
Palpomyia sp.		1		1	
Oligochaeta	140	10	3	35	34
Gastropoda					
Physa sp.	64	32	14	21	
Amnicola sp.	4	1	6	2	
Gyraulus sp.					
Valvata tricarinata					
Encrustacea					
Hyalella azteca	8			119	
Asellus militaris	1	1		114	
Turbellaria					
Phagocata velata	3				
Hirudinea					
Helobdella stagnalis					

Table A2.--Continued.

Invertebrate	September 1971				
	Stream			Spring	
	Sec. 1	Sec. 2	Sec. 3	Shelf	Basin
Insecta					
Callibaetis sp.	1				
Caenis sp.		12	27		
Ischnura sp.		2	10		
Somatochlora sp.			2		
Corixidae					
Berosus sp.					
Chironomidae	404	135	85	131	
Palpomyia sp.	1		8		
Oligochaeta	212	6	1	20	152
Gastropoda					
Physa sp.	192	118	63	14	
Amnicola sp.	16	13	6		
Gyraulus sp.	5		2		
Valvata tricarinata			1		
Encrustacea					
Hyalella azteca	12	2	4	101	
Asellus militaris		6	2	150	
Turbellaria					
Phagocata velata	1	6			
Hirudinea					
Helobdella stagnalis					

Table A2.--Continued.

Invertebrate	October 1971				
	Stream			Spring	
	Sec. 1	Sec. 2	Sec. 3	Shelf	Basin
Insecta					
Callibaetis sp.					
Caenis sp.			4		
Ischnura sp.	2		3		
Somatochlora sp.			1		
Corixidae					
Berosus sp.			1		
Chironomidae	108	55	16	130	
Palpomyia sp.	2		4	10	
Oligochaeta	235	9	23	4	94
Gastropoda					
Physa sp.	111	80	17	14	
Amnicola sp.	10	21	7		
Gyraulus sp.	5	2			
Valvata tricarinata					
Encrustacea					
Hyalella azteca	13	2	2	91	
Asellus militaris				109	
Turbellaria					
Phagocata velata			1		
Hirudinea					
Helobdella stagnalis	13				

Table A2.--Continued.

Invertebrate	October 1972				
	Stream			Spring	
	Sec. 1	Sec. 2	Sec. 3	Shelf	Basin
Insecta					
Callibaetis sp.					
Caenis sp.		4			
Ischnura sp.			3		
Somatochlora sp.					
Corixidae					
Berosus sp.					
Chironomidae	167	131	134	130	
Palpomyia sp.	5	6	10	6	
Oligochaeta	419	160	135	14	171
Gastropoda					
Physa sp.	69	45	11		
Amnicola sp.	5				
Gyraulus sp.			1		
Valvata tricarinata					
Encrustacea					
Hyalella azteca	49	62	34	121	
Asellus militaris	11	14	51	136	
Turbellaris					
Phagocata velata		3	3	3	
Hirudinea					
Helobdella stagnalis					

Table A2.--Continued.

Invertebrate	November 1972				
	Stream			Spring	
	Sec. 1	Sec. 2	Sec. 3	Shelf	Basin
Insecta					
Callibaetis sp.					
Caenis sp.					
Ischnura sp.					
Somatochlora sp.					
Corixidae					
Berosus sp.					
Chironomidae	168	145	107	170	
Palpomyia sp.	4	12	23	11	
Oligochaeta	405	137	107	12	200
Gastropoda					
Physa sp.	28	11	4		
Amnicola sp.					
Gyraulus sp.	1		1		
Valvata tricarinata					
Encrustacea					
Hyalella azteca	83	60	131	126	
Asellus militaris	12	36	65	146	
Turbellaria					
Phagocata velata	2		1	5	
Hirudinea					
Helobdella stagnalis					

TABLE A3.--Invertebrates Collected from Submerged Terrestrial Vegetation Growing along the Stream Banks.

Class	Family	Genus	Species
Encrustacea	Asellidae	*Asellus*	*militaris*
	Talitridae	*Hyalella*	*azteca*
Insecta	Baetidae	*Callibaetis*	sp.
	Coenagrionidae	*Ischnura*	sp.
	Aeshnidae	*Aeshna*	sp.
	Corixidae		
	Nepidae	*Ranatra*	sp.
	Gerridae	*Gerris*	sp.
	Hydrophilidae	*Tropisternus*	sp.
		Berosus	sp.
	Dytiscidae	*Hydrovatus*	sp.
	Haliplidae	*Peltodytes*	sp.
Gastropoda	Physidae	*Physa*	sp.
	Amnicolidae	*Amnicola*	sp.