STREAM WATER QUALITY AS RELATED TO URBANIZATION OF ITS WATERSHED

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STREAM WATER QUALITY AS RELATED TO URBANIZATION OF ITS WATERSHED

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"America today stands poised
on a pinnacle of wealth and
power, yet we live in a
land of vanishing beauty,
of increasing ugliness, of
shrinking open space, and
of an over-all environment
that is diminished daily by
pollution and noise and
blight."

Udall, 1963

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INTRODUCTION

This study of a 2.63 mile reach of the Red Cedar River is part of an extensive program of studies on the river which began in 1958. Brehmer (1958) reported on a study of nutrient accrual, uptake, and regeneration. He indicated 100 µg. phosphorus per liter and 0.5 mg. inorganic nitrogen per liter are introduced into the river from Williamston's Sewage Treatment Plant during normal river flow. But these nutrients appeared to have been removed within a distance of 0.6 miles downstream. Vannote (1961) investigated the chemistry and hydrology of the river and its tributaries. Vannote reported a significant gradient of phosphorous enrichment with distance downstream. Grezenda (1960) stated runoff is the major source of inorganic nitrogen, while sanitary drains are the main source of phosphorous. Data of these workers indicates there is a significant amount of pollution entering the river. Determinations made at Farm Lane indicated 9.46 metric tons of nitrogen are flushed downstream annually. This does not take into consideration the contribution from East Lansing's Kalamazoo Street Sewage Treatment Plant.

King (1964) states Fowlerville plating plant wastes have eliminated all aquatic macrofauna, except Tubificidae, for a distance of 15 miles downstream from the plating plant. King also reports inorganic sediments from highway construction have reduced Red Cedar aufwuchs production 68 percent.

The study described here was motivated by visible signs of stream deterioration between Hagadorn Road and East Kalamazoo Street. Objectives of this study were to locate pollutant sources, determine the amounts entering the river and to evaluate effects of these pollutants on water quality and on composition of river bottom fauna. For clarification, pollution as used in this study, is defined as every contamination or alteration of physical, chemical, or biological properties of a lake or stream which will or may lower its value to man.

Water pollutants can be separated into three categories: industrial pollutants including pesticides, erosional products, and domestic sewage. Determinations made during this study were directed towards establishing the level of domestic and erosional pollution. These were the most obvious sources of pollution. This is not to underestimate the importance of other pollutants, of which there are many.

In this study an effort has been made to integrate biology, chemistry, and sanitary engineering, for the problem of water pollution is not completely encompassed by any one of these disciplines. Perhaps water pollution studies are best interpreted from the perspective of human ecology--the study of the relationships between man and his environment.

DESCRIPTION OF STUDY AREA

The Red Cedar River is a central, lower Michigan warm-water stream arising from a marshy area near Cedar Lake in Marion Township. The Red Cedar River flows 40 miles through Michigan farmland and woodlots, flowing by several small towns, through city parks, and through the campus of a large university before its confluence with the Grand River at Lansing, Michigan. King (1964) describes aspects of the river biology, Vannote (1961) describes the river hydrology and phosphate chemistry, and Meehan (1958) describes the river climatology.

This study was completed on the river reach located between Hagadorn Road and East Kalamazoo Street. The study section is 2.63 miles in length. Stream width varies from 25 to 80 feet. Water depths vary from 15 inches over silt-covered sand flats to approximately 6 feet in the impoundment formed by a dam located at the study section mid-point.

The dam was constructed primarily to provide a reservoir to be used as a source of cooling water for Michigan State University power plants. A secondary use of the impoundment is for recreation, but poor water quality presently limits this use.

During this study period from August 1964 to November, 1964, volume flow of the Red Cedar River was considerably less than the average summer flow from 1947 to 1963.

Figure 1. Map of study area, showing locations of river sampling stations.

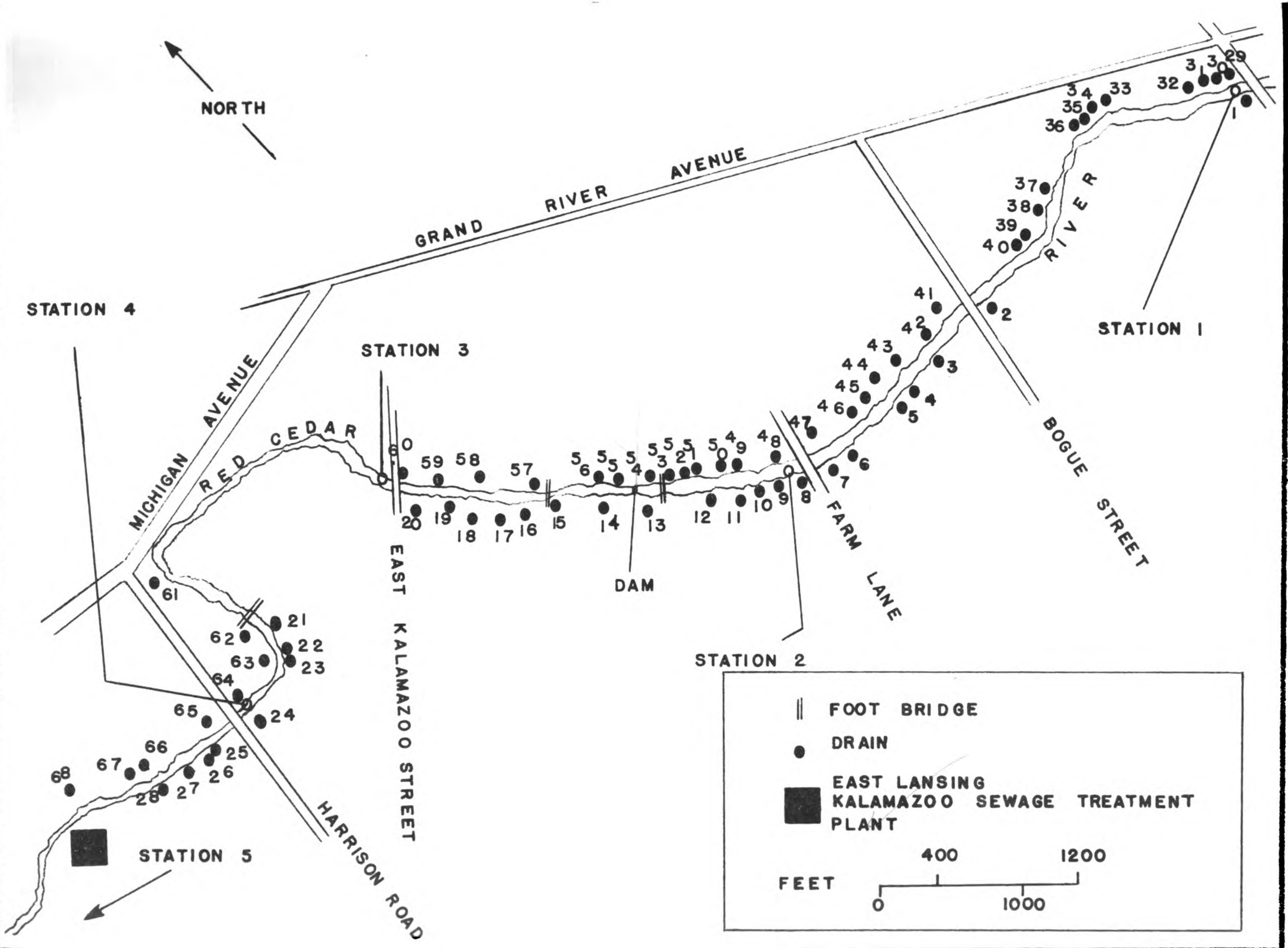

NORTH
GRAND RIVER AVENUE
MICHIGAN AVENUE
RED CEDAR RIVER
BOGUE STREET
FARM LANE
EAST KALAMAZOO STREET
HARRISON ROAD
DAM
STATION 1
STATION 2
STATION 3
STATION 4
STATION 5
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65
66
67
68
FOOT BRIDGE
DRAIN
EAST LANSING
KALAMAZOO SEWAGE TREATMENT
PLANT
FEET
0
400
1000
1200

Figure 2 illustrates a dramatic decrease in volume flow of the Red Cedar during the past several years. A correlation study of ground water, precipitation, and cfs flow of the Red Cedar indicated decreased flow is poorly correlated with both precipitation and ground water. Regression coefficients obtained were 0.35 and -0.16 respectively. A more complete analysis of available data is necessary.

Bottom sampling showed the river bed at Hagadorn Road to be coarse gravel covered with two or more inches of silt. Silt accumulation is thought to be caused by decreased carrying capacity of waters entering the impoundment where velocity decreases, and ability to carry particles in suspension diminishes. Decaying leaves and other detritus blanket the stream bed of the large pond-like area upstream from Farm Lane Bridge.

Above East Kalamazoo Street, below drain 58, a large sludge bed has formed, and extends downstream for nearly a quarter mile. Below the Kalamazoo Street Sewage Treatment Plant sludge beds several feet thick have formed, and in some locations nearly protrude from the water surface.

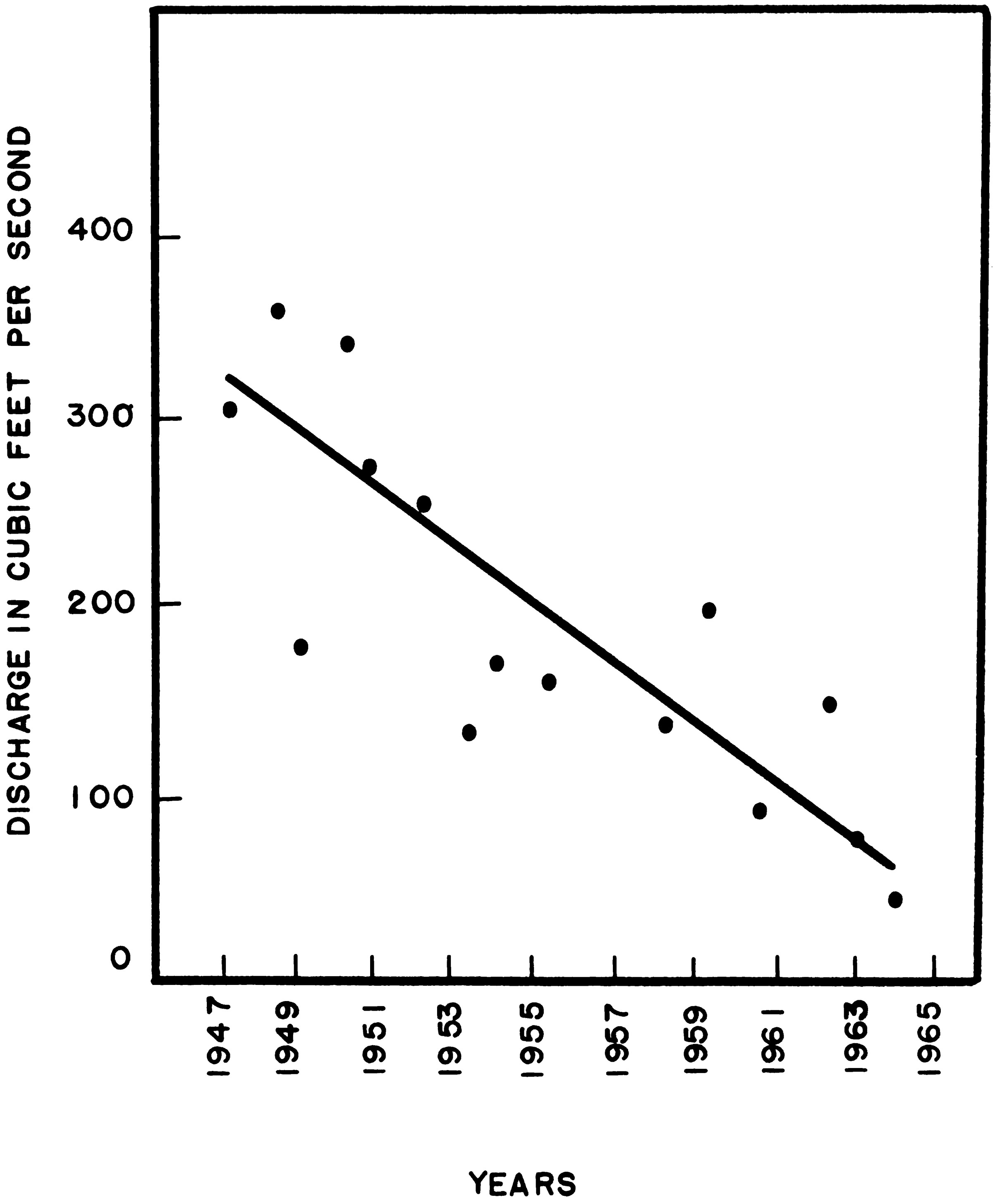
Recent years have brought a large increase in construction along the banks of the Red Cedar River between Hagadorn Road and East Kalamazoo Street. New apartment buildings and university facilities are numerous. Construction of these buildings, roads, and bridges has resulted in the flushing of a huge sediment load into the river. Rapid growth of

Figure 2. Average yearly discharge for the Red Cedar River for 1947-1964. (Data from U. S. Geological Survey.) Regression equation calculated for data is,

$\hat{Y} = 330.81 - 13.95\,X$

$\hat{Y}$ = Estimated discharge in cubic feet per second.

X = Time in years from 1947 = 0.


DISCHARGE IN CUBIC FEET PER SECOND
400
300
200
100
0
1947
1949
1951
1953
1955
1957
1959
1961
1963
1965
YEARS

Michigan State University, East Lansing, and Meridian Township has antiquated their waste-water collection system. And adequate treatment of the increased volume of sewage has required construction of a new sewage treatment plant. This new plant began operations about one year after completion of this study. A further study is planned to determine if construction of this new plant has improved the quality of the Red Cedar River waters.

METHODS

Scientific analyses are subject to two types of error, determinate and indeterminate. Determinate errors can be controlled. Errors of method, operative errors, and instrumental errors are examples of determinate errors. This form of error can be minimized by using an accurate procedure for analysis combined with careful laboratory work (Kolthoff and Sandell, 1952).

Indeterminate errors cannot be controlled. If the same individual repeatedly performs the same analysis, using the same technique, his measurements will always differ among themselves to some extent. It is assumed that this form of error follows the normal distribution (Kolthoff and Sandell, 1952).

Methods of analysis selected for inclusion in Standard Methods for Analysis of Water and Wastewater (1960) are considered by authorities to be the most reliable and accurate procedures available. For this reason all analyses performed in this study were completed using methods outlined in Standard Methods (1960).

Sampling Procedures

Stream physical and chemical sampling programs can be separated into three types (Tindall and Mickley, 1964).

1. Collection of grab samples
2. Long term sampling programs at selected river stations.
3. Time of flow studies utilizing dye markers or radioactive tracers.

The second type of sampling program was used in this study. For this type of program it is assumed the water mass sampled at downstream stations is comparable with the water mass sampled upstream except for substances which have entered the river between sampling stations. Type 3 sampling programs give the most accurate data. But Tindall and Mickley state type 3 sampling programs give nearly the same results as the type 2 sampling program.

Five sampling stations were established in the study area. Station 1 was located at Hagadorn Road upstream from the Michigan State University impoundment. Station 2 was located at the end of the Michigan State University canoe dock in the middle of the impoundment. Station 3 was located about 100 feet downstream from the East Kalamazoo Street Bridge. (You will note that there are two Kalamazoo Street Bridges mentioned in the text, so for clarification station 3 is downstream from the bridge in front of Michigan State University's famous "Sparty".) Station 4 was located a few feet upstream from Harrison Street Bridge, and station 5 was located at the downstream end of the East Kalamazoo Street Bridge which lies a little east of the Lansing city limits. At stations 1, 2, and 5 samples for chemical and physical analyses were collected from mid-stream using a two liter Kemmerer sampler. At stations 3 and 4 shallow water prohibited use of the Kemmerer, so samples were collected from mid-stream at these stations by submerging a bottle about one foot beneath the water surface.

All samples to be used for chemical and physical analyses were placed into 500 ml. dichromate rinsed polyethylene bottles. To one bottle concentrated sulfuric acid was added, adjusting the pH to approximately 2. Contents of this bottle were used for ammonia, nitrate, nitrite, and organic nitrogen determinations.

Drains were located by boating and by walking along the river bank. Distance from each drain to some easily identifiable object was paced off to give approximate drain location. Where possible an estimate of drain diameter was made. Samples of drain effluent were collected where possible by catching the effluent as it spilled into the river. For submerged drains samples were taken from the river directly in front of the drain opening.

Bacteriological Methods

For sampling, sterile sampling bottles with ground glass stoppered wide necks were obtained from the Michigan State University Department of Microbiology stockroom. Water samples were obtained by dropping a sample bottle, with a cord attached around its neck, from a bridge near each sampling station. Sampling bottles were dropped rapidly through the water surface to a depth of approximately one foot. Samples were brought to Dr. Frank Peabody of the Michigan State University Department of Microbiology for analysis using the fermentation tube technique.

Bioassay Procedures

Two bioassays were performed on samples of a drain effluent suspected of contributing to conditions responsible for the 1964 fish kill which occurred below the impoundment. The first bioassay was performed by placing three guppies (*Lebistes reticulatus*) into each of two 250 ml. flasks. To one flask 200 ml. of aquaria water had been added, to the other flask 50 ml. of drain effluent and 150 ml. of aquaria water had been added. The second bioassay was performed using procedures described in *Standard Methods* (1960). River water was used for controls and dilutions. Blackside darters (*Percina maculata*) obtained from the river were used as test organisms and 25 liter aquaria were used to replace the 250 ml. flasks.

Bottom Sampling Methods

Bottom samples were collected with an Ekman dredge. At each station three scoops were taken for each sampling period. One scoop was taken at mid-stream, and one approximately halfway between mid-stream and each shore. Samples were screened with a 30 mesh sieve to remove silt and fine sand, then placed into glass pint jars for the trip back to the laboratory. Samples were analyzed by hand within two days after collection. Organisms were counted and identified.

Chemical Methods

Total Alkalinity as $CaCO_3$

For each alkalinity determination a titration curve was obtained by recording the sample pH on a Beckman model H2 glass electrode pH meter after addition of 0, 2, 4, 6, 7, 8, 9, 10, 12, 14, and 16 ml. of standardized 0.02 N sulfuric acid to 100 ml. of sample (Kolthoff and Sandell, 1952). Points were plotted on standard graph paper, and ml. of acid required to lower sample pH to 4.5 was recorded. This number was used to calculate total mg. per liter alkalinity as $CaCO_3$ by the following formula (Standard Methods, 1960).

$$\text{Total alkalinity as mg. liter}^{-1}\ CaCO_3 = \frac{(\text{ml. } H_2SO_4)(0.02)(50000)}{100}$$

Ammonia Nitrogen

Mg. per liter ammonia nitrogen was determined by the distillation method described in Standard Methods (1960), except that boric acid buffer solution pH was determined prior to distillation of a 100 ml. sample, and ml. of 0.02 N sulfuric acid required to return sample pH to the original value was determined potentiometrically (Kolthoff and Sandell, 1952). A titration curve was obtained by recording boric acid buffer solution pH on a Beckman model H2 glass electrode pH meter after addition of 0, 0.5, 1.0, 1.5, 2.0, 2.5, and 3.0 ml. of standard acid.

Biochemical Oxygen Demand

Mg. per liter biochemical oxygen demand was determined by the method described in Standard Methods (1960), using a one liter graduated cylinder to mix together samples, dilution water, and mineral nutrients. Samples were not seeded, and were not treated for residual chlorine, other than to set on the laboratory bench for approximately one hour prior to testing. No corrections for temperature were made. Dissolved oxygen determinations for BOD measurements were made using the azide modification of the Winkler Method (Standard Methods, 1960).

Conductivity at 18° Centigrade

Resistance was measured on an Industrial Instruments model RC-7 portable conductivity meter. Resistance measurements were corrected to 18° C. by the formula

$$R_{18} = R_t\ (1 + 0.02\ \Delta\ t).$$

Temperature-corrected resistance was transformed into resistivity by the formula,

$$\text{resistivity} = \frac{\text{resistance}}{\text{cell constant} = 1.8955}$$

Conductivity was obtained by taking the reciprocal of resistivity (Standard Methods, 1960).

Nitrate Nitrogen

Mg. per liter nitrate nitrogen plus nitrite nitrogen was determined by the reduction method described in Standard Methods (1960), the only modification being that ml. of acid were determined potentiometrically rather than colorimetrically. Nitrate nitrogen was obtained by subtracting nitrite nitrogen from the reduction nitrogen determination.

Nitrite Nitrogen

Mg. per liter nitrite nitrogen was determined by the method described in Standard Methods (1960).

Organic Nitrogen

Organic nitrogen determinations were made on the residues remaining from the ammonia determinations using the Kjeldahl method described in Standard Methods (1960).

Dissolved Oxygen

Determinations for mg. per liter and percent saturation dissolved oxygen were made using the azide modification of the Winkler Method as described in Standard Methods (1960). Samples were collected with a Kemmerer water bottle, where possible, and siphoned into 300 ml. glass stoppered bottles, allowing the bottles to overflow about 150 ml. to expel trapped air. $MnSO_4$, H_2SO_4, and alkali-iodide-azide reagents were then added. The samples were titrated upon returning to the laboratory.

Total and Ortho-Phosphorous

The ammonium molybdate, $(NH_4)_2MoO_4$, test with stannous chloride as the reducing agent was used for phosphorous determinations (Standard Methods, 1960).

Physical Methods

Total Residue

Total residue was determined by evaporating a 200 ml. sample to dryness as described in Standard Methods (1960). Samples were boiled nearly to dryness, then removed from the hot plate to prevent popping which would have resulted in loss of residue. Samples were then placed in a Cenco gravity convection oven set at 103° C. and left overnight. Samples were weighed the following morning.

Temperature

Temperature measurements were made using a laboratory thermometer held with the bulb about one foot below the water surface.

pH

pH determinations were made immediately upon returning to the laboratory, using a Beckman model H2 glass electrode pH meter.

Turbidity

Turbidity determinations were made using a Bausch and Lomb photoelectric colorimeter calibrated with a Jackson Candle Turbidimeter. The slit was adjusted to admit light of 410 mμ. wave length. Correction for intrinsic color of sample was made using a filtered sample to adjust the colorimeter to 100 percent transmittance.

Velocity of River Waters

Stream velocity was calculated from U.S.G.S. volume flow data and dimensions of the river channel at Farm Lane. At Farm Lane the river channel is approximately 4 feet deep and 120 feet wide. During the period of this study stream volume flow was 16 cfs. By the calculation $\frac{48}{360} = \frac{16}{\frac{x}{3600}}$, it was estimated that river velocity was 0.03 feet per second.

Distances Between Stations

Distances between stations were estimated by molding a string to the shape of the river on a map, then straightening out the string, and measuring its length. Distance was then obtained from the map scale.

Statistical Methods

Data for each chemical, physical, and biological analysis, except bacteriological, were tested for linearity. For each test that did not deviate significantly from linearity, a regression analysis was calculated to determine if means of sampling stations (treatments), were significantly different. If data deviated significantly from linearity, a one-way analysis of variance or randomized block design analysis of variance was used to test for significance of differences among sampling station means (Li, 1964).

If significant differences did exist among stations, the data were further analyzed to locate the significantly different means.

For all tests the level of significance was taken to be 0.05. The null hypothesis to be tested in each case was that there were no significant differences among sampling station means. The alternate hypothesis in each case was that there were significant differences between sampling station means.

If the regression analysis, one-way analysis of variance, or randomized block design analysis of variance indicated significant differences existed between sampling station means, then the proper modification of Scheffe's test was used to locate those means that were significantly different (Guenther, 1964).

RESULTS AND DISCUSSION

Alkalinity

Total alkalinity, expressed as mg. per liter $CaCO_3$, is a measure of the concentration of hydroxides, carbonates, bicarbonates and other salts of weak acids dissolved in natural waters. Relationships between major ionic species responsible for alkalinity in natural waters are given by the following chemical equations (Sawyer, 1960).

$$CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons HCO_3^- + H^+$$

$$M(HCO_3)_2 \rightleftharpoons M^{++} + 2\ HCO_3^-$$

$$HCO_3^- \rightleftharpoons CO_3^= + H^+$$

$$CO_3^= + H_2O \rightleftharpoons HCO_3^- + OH^-$$

These substances are in dynamic equilibrium as indicated by the double arrows.

Increasing the concentration of a component in the carbonate system increases that components activity and chemical potential $(\frac{\partial G}{\partial n_i})_{T,P,n_j}$, which upsets the equilibrium (Moore, 1962). In re-establishing equilibrium the ratio of mass flow out of the component with higher chemical potential to mass flow in decreases until the chemical potentials for all components are again equal (Moore, 1962).

The formulas for the carbonate and bicarbonate ionization constants K_1 and K_2 derived from the Mass Action law are,

$$K_1 = \frac{[H^+][HCO_3^-]}{[H_2CO_3]} = 4.4 \times 10^{-11}$$

$$K_2 = \frac{[H^+][CO_3^=]}{[HCO_3^-]} = 4.3 \times 10^{-7}$$

The quantities in the brackets represent molar concentrations of components. From the magnitude of the dissociation constants it can be seen that carbonic acid is an extremely weak acid. Carbonate and bicarbonate ions constitute powerful buffers. Carbonates are the main buffer constituents of natural waters (Hutchinson, 1957).

Data for total alkalinity concentrations at river sampling stations deviated significantly from linearity. And a randomized block analysis of variance, Table 1, failed to show any significant differences between means for sampling stations. Figure 3 does illustrate, however, a total alkalinity increase in the pond-like area of the impoundment, and a considerable increase below the Kalamazoo Street Sewage Treatment Plant. The linear regression equation

$$\hat{Y} = 212.85 + 12.65\ X$$

$\hat{Y}$ = Estimated mg. per liter total alkalinity as $CaCO_3$.

X = Miles downstream from Station 1

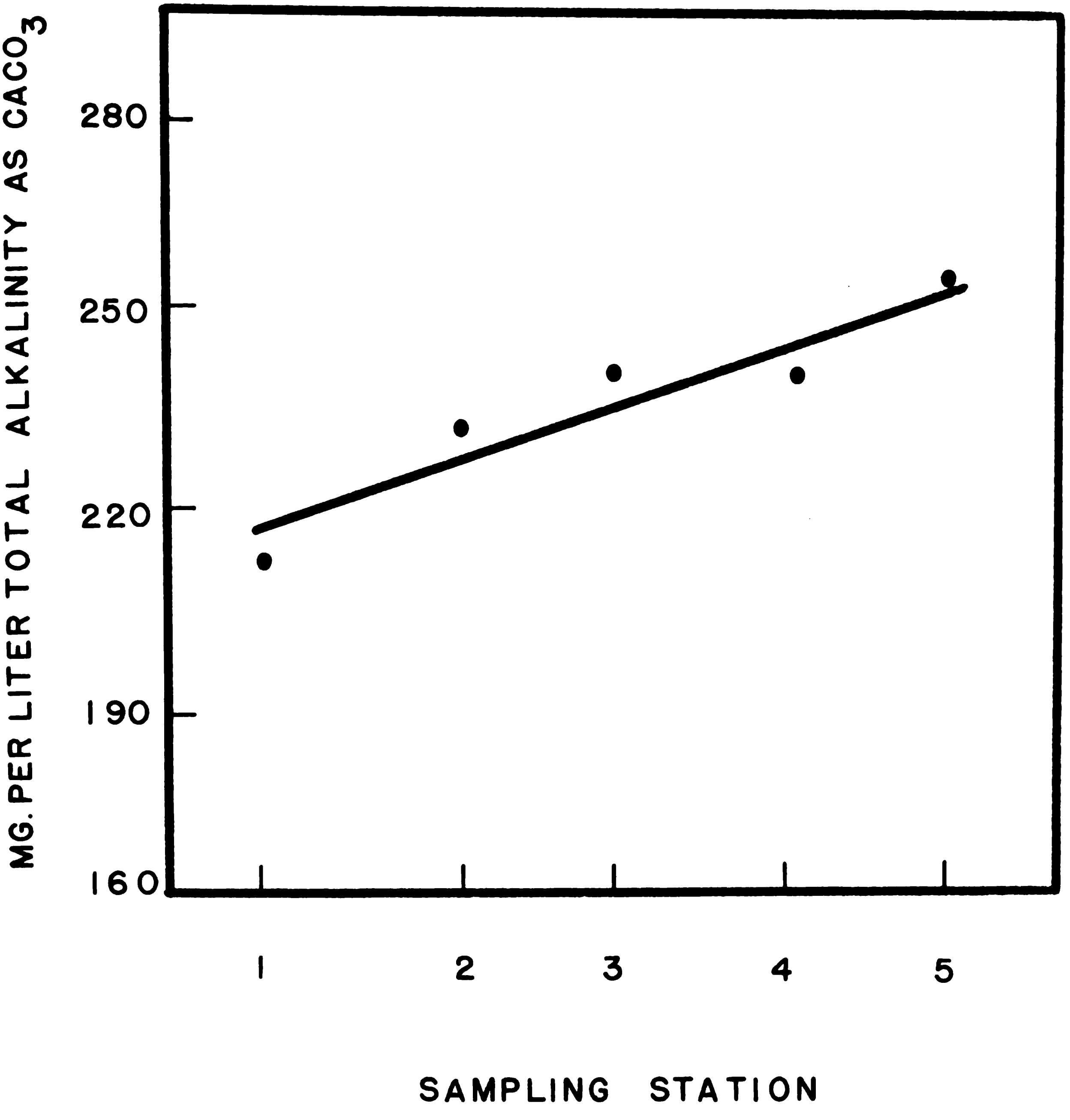
shows a gradual increase in total alkalinity from Station 1 to Station 5.

Increased alkalinity in the impoundment may be due to large algae populations. Sawyer (1960) states that large algae

Table 1. Summary of randomized block design analysis of variance and test for linearity for river alkalinity determinations.

Source	SS	df	MS	F_{expt}	$F_{0.95}$
Treatment	4790.17	4	1197.54	0.94	2.65
Blocks	10400,35	6	1733.39	1.85	2.51
Regression	4719.09	1	4719.09	3.73	4.12
Deviation from linearity	14898.91	3	4966.30	3.93	2.87
Error	22424	24	934.34		
Total	37614.75	34			

Figure 3. Mean values for mg. per liter total alkalinity as $CaCO_3$ measured at river sampling stations. Distances on abscissa are proportional to the distances between stations in miles. Each value is the means of 7 observations.


MG. PER LITER TOTAL ALKALINITY AS $CACO_3$
280
250
220
190
160
1
2
3
4
5
SAMPLING STATION

populations increase alkalinity by removing CO_2 from the water. From the system of equations describing alkalinity dynamics, it can be seen that removal of CO_2 will increase $CO_3^{=}$ and OH^- concentrations. Other sources of alkalinity are animal and plant respiration, sediments, and numerous drains entering the river.

High alkalinity concentrations are not known to have undesirable effects on stream inhabitants. Increased alkalinity is likely to increase populations of mussels which utilize $CaCO_3$ for shell construction (Pennak, 1953). High alkalinity concentrations do, however, decrease usefulness of a river for municipal and industrial purposes. Burroughs (1960) states that salts are the most objectionable pollutant in industrial cooling waters.

Dissolved Oxygen

Dissolved oxygen in natural waters comes from three sources (Reid, 1961).

1. Ground water and surface run-off.
2. Photosynthesis.
3. Physical reaeration.

Ground water has a variable but usually low dissolved oxygen concentration. Surface run-off usually will be near saturation with dissolved oxygen.

Photosynthetic production of oxygen is responsible for diurnal fluctuations in oxygen levels, and may be responsible for other diurnal pulses (Bamforth, 1962). During the day plants remove carbon dioxide from the water and replace it with oxygen. At night, when photosynthesis ceases, plant oxygen production ceases, and then both plants and animals consume oxygen in the process of respiration. Odum (1959) has used diurnal oxygen curves to construct dissolved oxygen rate of change curves from which plant productivity estimates were made.

In this study two diurnal oxygen curves were obtained for each sampling station. These curves could not be used to estimate productivity by Odum's upstream-downstream method as oxygen concentrations consistently decreased rather than increased, as the river flowed downstream. The diurnal curves obtained show an increased "pulse" with distance downstream, indicating the downstream area of the study section may be subsisting on oxygen produced upstream.

From the engineering viewpoint physical reaeration is the most important source of dissolved oxygen in natural waters, as the photosynthetic source does not operate at night and during the winter it is considerably reduced. Saturation deficit, temperature, depth, and degree of agitation determine the rate of physical reaeration (Phelps, 1944). The oxygen diffusion process through unit water surface cross section in unit time can be formulated in the empirical partial differential equation known as Fick's Law (Moore, 1962).

Table 2. Diurnal oxygen determinations at river sampling stations.

8-15-64

Station			ppm Oxygen	
	4:00 AM	8:00 AM	5:00 PM	4:00 AM
1	9.64±0.56	8.70±0.00	9.78±0.02	9.94±0.00
2	5.56±0.00	5.81±0.10	7.08±0.41	6.58±0.10
3	4.81±0.14	5.25±1.00	5.47±0.24	5.05±0.00
4	3.13±0.00	3.43±1.05	4.61±0.20	2.86±0.00
5	1.58±0.49	1.84±1.17	3.27+0.80	1.80±0.07

9-17-64

Station			ppm Oxygen		
	4:30 AM	9:00 AM	1.00 PM	5:00 PM	4:00 AM
1	10.50±0.31	9.57±0.82	9.43±0.49	9.66±0.33	9.97±0.00
2	8.06±0.12	7.80±0.00	7.60±0.16	8.38±0.55	8.06±0.41
3	6.93±0.20	7.13±0.00	7.73±0.70	7.05±0.10	6.41±0.10
4	5.43±0.17	5.73±0.17	6.40±0.18	6.43±0.00	4.91±0.07
5	2.73±0.10	2.97±0.29	3.34±0.14	3.57±0.28	2.03±0.14

Figure 4. Diurnal oxygen curves for each sampling station for 9-17-64. Each value is the mean of 3 observations.

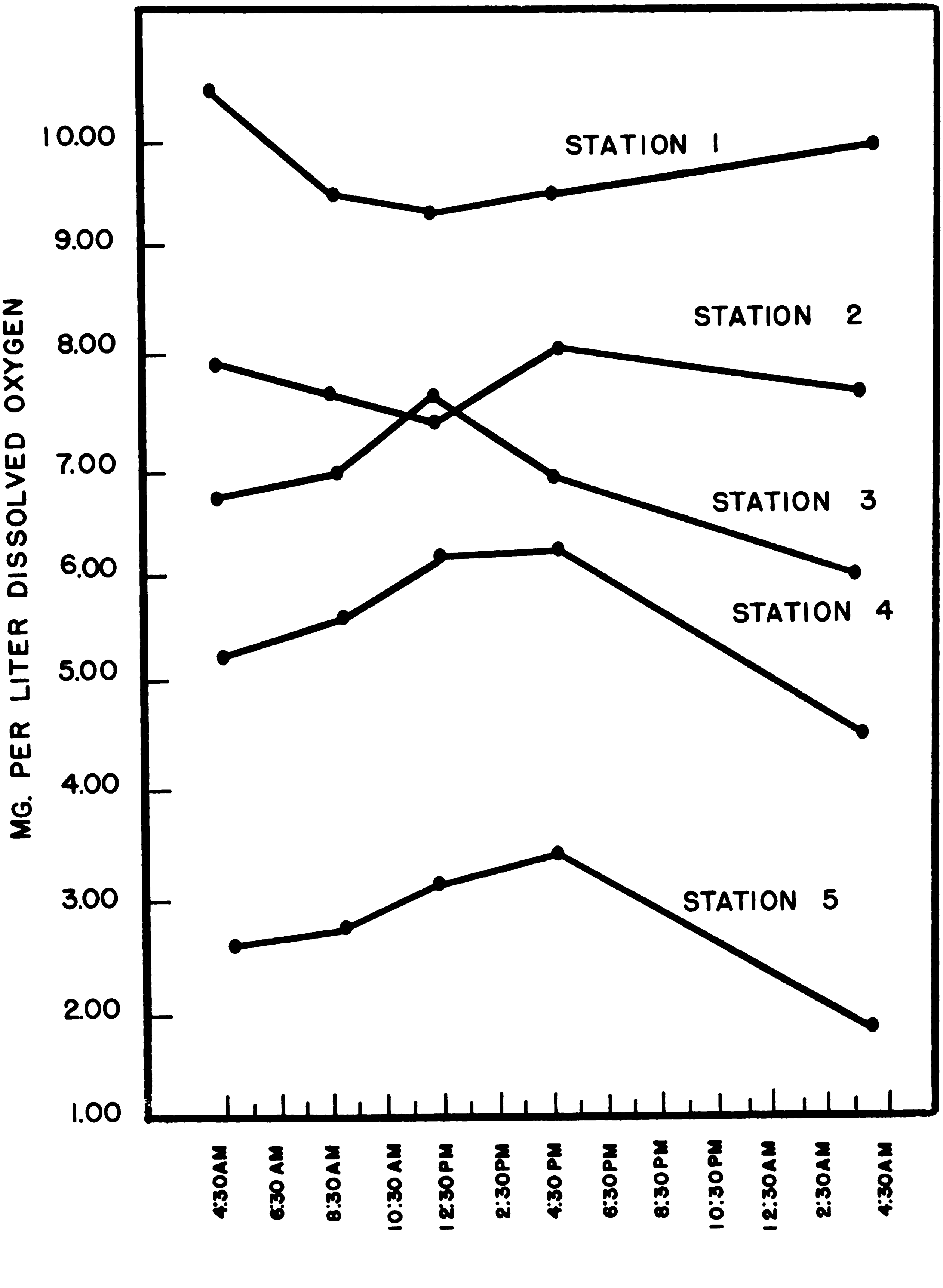
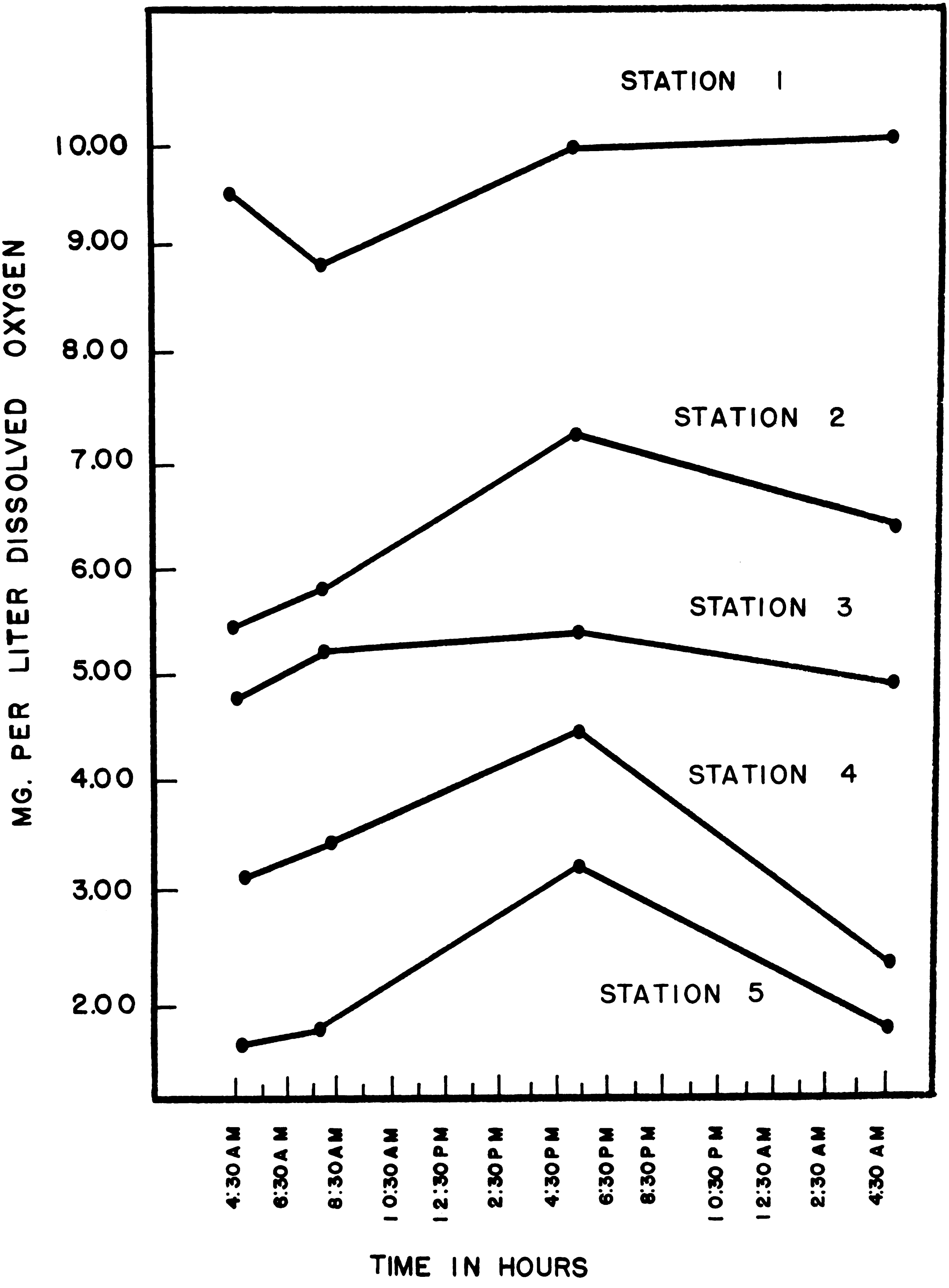

MG. PER LITER DISSOLVED OXYGEN
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
STATION 1
STATION 2
STATION 3
STATION 4
STATION 5
4:30AM
6:30AM
8:30AM
10:30AM
12:30PM
2:30PM
4:30PM
6:30PM
8:30PM
10:30PM
12:30AM
2:30AM
4:30AM
TIME IN HOURS

Figure 5. Diurnal oxygen curves for each sampling station for 8-15-64. Each value is the mean of 3 observations.


STATION 1
STATION 2
STATION 3
STATION 4
STATION 5
MG. PER LITER DISSOLVED OXYGEN
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
4:30 AM
6:30 AM
8:30 AM
10:30 AM
12:30 PM
2:30 PM
4:30 PM
6:30 PM
8:30 PM
10:30 PM
12:30 AM
2:30 AM
4:30 AM
TIME IN HOURS

(10) $$S = \frac{-RT}{N_o f} \left(\frac{\partial C}{\partial x}\right)_T$$

where, S = Oxygen rate of flow across interface.

C = Oxygen molar concentration in unit volume.

x = Gradient of oxygen diffusion.

R = Gas law constant.

N_o = Avogadro's number.

f = The force required to give oxygen particles unit velocity. Termed the molar frictional coefficient.

$D = \frac{RT}{N_o f}$, is termed the diffusion coefficient.

Equation 10 indicates temperature, oxygen molecular properties, saturation deficit, and area of contact between the air-water interface directly influence physical reaeration. As temperature increases it can be seen from equation 10 that diffusion increases, but from the ideal gas law, PV = nRT, it can be seen that as temperature increases oxygen solubility decreases. The solubility factor is the more important and at higher temperatures dissolved oxygen concentrations are lower. From the Nernst equation and the expression for chemical potential, it can be deduced that increased oxygen saturation deficit will increase diffusion rate of flow of oxygen across the air-water interface. Only steady state conditions were considered in the above discussion. Ficks second law of diffusion, $\frac{\partial C}{\partial t} = D\left(\frac{\partial C}{\partial x}\right)_T$, describes the time rate of change of oxygen concentration (Moore, 1962).

An adequate supply of oxygen is an essential prerequisite for survival of aerobic aquatic life. Oxygen requirements of an aquatic organism varies with activity and environmental temperature. Oxygen concentration in ppm. is not a sufficient criterion for determining if oxygen concentrations are adequate. It is rather the oxygen partial pressure that is essential, as oxygen must diffuse into the organism's circulatory system by the same physical laws that govern its diffusion into the water (Ruch and Fulton, 1960). This implies oxygen concentration in ppm. should first be corrected for pressure differences, and then percent saturation calculated.

Tarzwell (1959) reviewed the literature on oxygen requirements for aquatic organisms. Wiebe and Fuller (1934) found oxygen consumption of black bass increased 282 percent when the water temperature was increased from 15° C. to 25° C. Less than 75 percent dissolved oxygen saturation was shown by Graham (1949) to reduce activity of speckled trout (_Salvelinus fontinalis_). Engineers Phelps (1944) and Theralt (1927) concluded it is desirable to maintain oxygen saturation levels at from 70 to 75 percent.

Oxygen data obtained for river sampling stations did not deviate significantly from linearity, and the regression equation derived,

$$\hat{Y} = 76.14 - 20.23\, X$$

$\hat{Y}$ = Estimated percent saturation dissolved oxygen.

X = Miles downstream from Hagadorn Road, indicates a large decrease in oxygen percent saturation as the waters flow downstream. A regression analysis, Table 3, indicated the existence of significant differences between means at sampling stations. Scheffe's test for significance of differences between individual means indicated the mean for Station 5 and the means for Stations 3, 2, and 1 were significantly different. Also the difference between means for Stations 1 and 4 was significant.

Oxygen concentrations decreased significantly from one downstream station to the next, with the average value at Hagadorn Road being only 75 percent saturation. Values at all downstream points were below levels considered permissible for maintaining water quality. Large oxygen deficits are caused by the increased depth and low turbulance of the impoundment, by sludge accumulation, by decomposition of leaves and litter, and to a major extent from the stabilization of large quantities of sewage entering the river.

Addition of municipal pollution to a stream has a dramatic effect on dissolved oxygen concentrations, as bacteria consume oxygen in the process of stabilizing decomposable organic matter abundant in municipal sewage. Municipal sewage also has a high nitrogen and phosphorous concentration resulting from the breakdown of proteins, amino acids, and household detergents.

To illustrate quantitatively the relationship existing between dissolved oxygen and concentrations of components of

Table 3. Summary of one-way analysis of variance and test for linearity for river dissolved oxygen determinations.

Source	SS	df	MS	$F_{exp.}$	$F_{0.95}$
Treatment	19746	4	4936.50	18.46	2.58
Regression	18959	1	18959.00	71.61	4.04
Deviation from linearity	787	3	262.33	0.99	2.80
Error	13501	50	264.72		
Total	33247	54			

domestic sewage effluents, phosphorous, nitrogen, and BOD, a multiple linear regression analysis was made. The following equation was fitted to the data by the method of least squares (Li, 1964),

$$\hat{Y} = 81.50 - 0.47X_1 - 25.11X_2 - 1.76X_3$$

where,

$\hat{Y}$ = Estimated mg. per liter of dissolved oxygen for a given set of (X_1, X_2, X_3).

X_1 = Mg. per liter Biochemical oxygen demand.

X_2 = Mg. per liter total phosphorous.

X_3 = Mg per liter nitrate + ammonia nitrogen.

To test how well this regression equation predicts dissolved oxygen concentrations given the BOD, total phosphorous, and nitrogen values, a correlation analysis was made between values predicted by this equation and values observed in this study. A correlation coefficient R, of 0.83 was obtained. This high value indicates phosphorous, nitrogen, and BOD concentrations are highly correlated with decreasing oxygen concentrations. And it can be concluded sewage entering the river is the factor most responsible for observed oxygen concentrations. This brings us to another important topic, biochemical oxygen demand and stream self purification.

Biochemical Oxygen Demand

Biochemical oxygen demand, BOD, is defined as the amount of dissolved oxygen required by bacteria to stabilize decomposable organic matter in a volume of water under aerobic conditions (Sawyer, 1960). An Englishman, Sir Edward Frankland, formulated the BOD test in 1870. Since then an impressive theory has been established describing the kenetics of the oxidative processes which occur in streams receiving sewage.

Oxidation of organic matter in water takes place in two stages, requiring about 20 days to complete. The first stage involves oxidation of carboniferous material. The second stage is oxidation of nitrogenous material by the bacteria *Nitrosomonas* and *Nitrobacter* as follows,

$$2\ NH_3 + 3\ O_2 \xrightarrow{\text{Nitrosomonas}} NO_2^- + 2\ H^+ + 2\ H_2O$$

$$2\ NO_2^= + O_2 \xrightarrow{\text{Nitrobacter}} 2\ NO_2^- + 2\ H^+$$

To avoid the error which would be introduced by the second stage of this process, the standard BOD determination is run for only 5 days, and measures only 70 to 80 percent of the total BOD which is termed ultimate BOD (Phelps, 1944).

The BOD analysis is essentially a bioassay procedure, and as such the presence of trace amounts of toxic materials like chlorine, copper and arsenic lead to underestimation of BOD values. Chlorine concentrations in the river were high.

If the oxygen concentration is not limiting, decomposition of organic matter in streams can be considered to be a first order chemical reaction, with the reaction rate depending only on concentrations of decomposable organic material. The first stage of the BOD reaction can be formulated in the differential equation for a first order reaction, $\frac{d(BOD)}{dt} = -k(BOD)$, where k is the BOD reaction rate constant (Phelps, 1944). Solution of this equation gives, $BOD_t = BOD_0 e^{-kt}$, where BOD_t is the BOD remaining at time t, BOD_0 is the initial BOD, and t is again time. Engineers often use the retarded exponential, $BOD_t = L(1 - e^{-kt})$, but this formula requires evaluation of L, the ultimate BOD. At the present time there is no satisfactory way to obtain L (Fair and Geyer, 1961). Using the simple exponential, determination of the BOD reaction rate constant k allows prediction of the residual BOD_t at points a known time of flow downstream from the point where BOD_0 was determined.

To estimate the number of persons polluting the river between Station 1 and Station 5, the BOD reaction rate constant was determined, and an estimate of river velocity was made. Results are reported in Table 4. For each station two sets of 5 samples each were started. Two samples were terminated after 1, 2, 3, 4, and 5 days. If the BOD reaction can be treated as being linear, the regression of ln $\frac{(BOD_t)}{(BOD_0)}$ on time should not deviate significantly from linearity. The data for each station were tested for linearity, and the linear regression equation was derived. Only at Station 1 did the data deviate significantly from linearity. The following equations were derived.

Station 1: $\hat{Y} = 0.64 + 0.06\ t$

Station 2: $\hat{Y} = 0.61 + 0.03\ t$

Station 3: $\hat{Y} = 0.49 + 0.12\ t$

Table 4. Data for determination of BOD reaction rate constant. Data expressed as ln(BOD).

Station	Hours before termination					$T_{\cdot j}$
	12	24	36	48	96	
1	1.000	0.587	0.875	0.215	1.197	
	1.000	1.000	1.000	0.631	1.787	
$T_{i\cdot}$	2.000	1.578	1.875	0.864	2.984	9.283
2	0.039	0.693	1.001	0.770	0.324	
	-0.128	0.713	0.565	2.007	1.571	
$T_{i\cdot}$	-0.089	1.206	1.566	2.777	1.895	7.555
3	0.693	0.519	0.859	0.015	1.163	
	1.058	0.940	1.482	1.517	1.778	
$T_{i\cdot}$	1.751	1.459	2.341	2.532	2.941	11.024
4	-0.233	0.589	0.806	0.588	1.238	
	-0.329	0.673	1.151	0.610	1.609	
$T_{i\cdot}$	-0.562	1.262	1.957	1.198	2.847	6.702
5	2.079	2.216	2.407	2.518	2.791	
	1.717	2.253	2.965	2.313	2.708	
$T_{i\cdot}$	3.796	4.469	5.372	4.831	5.499	23.967

$$\text{Station 4:} \quad \hat{Y} = -1.16 + 0.37\ t$$

$$\text{Station 5:} \quad \hat{Y} = 1.46 + 0.19\ t$$

where, $\hat{Y}$ = Estimated ln $\frac{(BOD_t)}{(BOD_o)}$.

t = Time in hours.

The average value of the slopes of these lines was calculated to be 0.15. This compares favorably with the value of 0.17 given in the literature (Sawyer, 1960). The average expected BOD value at station 5 was calculated to be 3.57 using the formula $BOD_{0.97} = (3.69)\ e^{-(0.15)(0.97)}$. The value for mg. per liter BOD added between Stations 1 and 5 was determined to be 7.03.

During the period of this study the U.S.G.S. reports 16.7 cfs as the average flow of the Red Cedar River at the Farm Lane gauging station. River velocity was estimated as 0.03 feet per second.

It has been shown that the mean BOD of sewage produced per person per day is 54,000 mg. (Fair and Geyer, 1961). It must then be concluded from the following calculations,

16.7 cfs = 36,072,000 liters per day.

Mg. per liter entering Red Cedar per day = (36,072,000)(7.03) = 252,504,000

Persons polluting Red Cedar in study area. = $\frac{252,504,000}{54,000}$ = 4,674

that 4,674 persons are polluting the Red Cedar River between Hagadorn Road and West Kalamazoo Street. Because of the toxic effect of chlorine introduced at the Kalamazoo Street Sewage Treatment Plant, this value is a minimum.

This method of determining the extent to which a river reach is polluted is in some ways unsatisfactory. First, the BOD reaction is not a first order reaction, but rather a mixture of first, second, and third order reactions. Secondly, the deoxygenation rate constant as determined in a BOD bottle is probably different from the stream deoxygenation rate constant. And finally, the time of flow between stations is difficult if not impossible to determine.

An empirical method can surmount these difficulties. Analysis of variance, Table 5, indicated data had significant curvature, and that significant differences existed between sampling station means. Under any set of environmental conditions BOD is some function of distance downstream from our first sampling station. By Taylor's theorm, this function can be approximated by a polynomial.

The following least squares regression equation was calculated (Li, 1965).

$$\hat{Y} = 3.8 + 5.4\ X - 7.6\ X^2 + 2.5\ X^3$$

$\hat{Y}$ = Estimated mg. per liter BOD.

X = Distance downstream from Station 1.

A correlation coefficient $R = 0.66$ was obtained between observed values and values predicted. This cubic regression equation can be used to estimate mg. per liter BOD added to

Table 5. Summary of one-way analysis of variance and test for linearity for river BOD determinations.

Source	SS	df	MS	$F_{exp.}$	$F_{0.95}$
Treatment	251.69	4	62.92	10.81	2.67
Regression	66.99	1	66.99	11.51	4.15
Deviation from linearity	184.70	3	61.56	10.57	2.90
Error	186.28	32	5.82		
Total	437.97	39			

the river in the study section. Differentiating gives the differential equation,

$$\frac{d\hat{Y}}{dX} = 5.4 - 15.0\ X + 7.5\ X^2$$

which expresses instantaneous change of BOD with respect to distance downstream as a polynomial function. Solving this equation gives,

$$\hat{Y} = \int_0^{2.63} (5.4 - 15.0\ X + 7.5\ X^2)\ dX = 7.05$$

which is nearly the same value obtained by the Streeter-Phelps method. In larger stream reaches, and more heterogeneous stream reaches the values would probably not be so close. The method presented here is thought to be superior to the standard engineering method in that it does not involve determination of the stream deoxygenation constant and time of flow between sampling stations. This same procedure can be used for studying other stream parameters, for example, phosphorous or nitrogen.

Small increments of organic material added to a stream are broken down, by bacterial action, into simple inorganic molecules. Oxygen used by bacteria in stabilizing these organic materials is replaced through physical and photosynthetic reaeration. This process is termed natural stream purification. Engineers have long sought a means for determining what level of BOD can be loaded into a stream without depressing the oxygen to undesired levels. Streeter and

Phelps proposed the following differential equation as a model for the process of stream reaeration and deoxygenation (Streeter and Phelps, 1925).

$$\frac{d(DO)}{dt} = K_1 \text{ (BOD)} - K_2 \text{ (DO)}$$

Solution of this equation gives,

$$DO = \frac{K_1(BOD_0)}{K_2 - K_1} \left(e^{-K_1 t} - e^{-K_2 t}\right) + DO_0 e^{-K_2 t}$$

which can be used to predict DO deficits which will be incurred by a BOD_0 loading a known time of flow downstream. Application of this equation requires determination of K_1, the deoxygenation constant; and K_2, the reaeration constant. Both of these constants are difficult and in some cases perhaps impossible to obtain accurately. K_1 is the rate of chemical and biological removal of oxygen from the water. An estimate of K_1 can be obtained from the BOD reaction rate constant, but this does not take into consideration the oxygen demand of bottom sludges, or the respiratory needs of stream dwelling plants and animals. Velz (1958), has shown that bottom sludges have a considerable oxygen demand. K_2, the reaeration coefficient is equally difficult to estimate. Streeter and Phelps (1925) have empirically estimated that $K_2 = \frac{CV^n}{H^2}$, where,

C = Surface slope and channel irregularities factor.

V = Velocity of water movement.

n = Factor derived from relationship of river stage to velocity.

H = Average water depth.

O'Conner and Dobbins (1956), have derived theoretically the equation,

$$K_2 = \frac{480\ D^{\frac{1}{2}}\ S^{\frac{1}{4}}}{H^{\frac{5}{4}}}$$

where,

D = Coefficient of molar diffusion.

S = Stream slope.

H = Average depth.

From both of these equations it can be deduced that increased depth and decreased slope have a tremendous effect on stream oxygen dynamics.

Moore et al. (1950) have presented a method for obtaining these constants using nomograms. Nemerow (1963) gives the constants simple formulas which, however, yield results of questionable accuracy.

But use of this simple linear model is also a questionable procedure. Dobbins (1964) has found this method fails to consider the following important factors.

1. Removal of BOD by sedimentation or adsorption.
2. Addition of BOD by scour of bottom deposits or by diffusion from bottom deposits.
3. Addition of new increments of BOD from other sources.
4. Removal of DO by diffusion to benthal deposits to satisfy benthal oxygen demand.
5. Addition of oxygen by plants.
6. Removal of DO by respiration of aquatic organisms.
7. Changes in channel configuration.
8. Diurnal fluctuations in BOD, DO, temperature, etc.

It must be concluded that although the Streeter-Phelps model is used in nearly all engineering surveys, it is far too simple to accurately describe reaeration and deoxygenation of a natural stream.

Churchill and Buckingham (1956) have presented a statistical method for evaluation of stream loading capacity. Using the multiple-linear regression equation,

$$\hat{Y} = b_0 + b_1X_1 + b_2X_2 + b_3X_3$$

where, $\hat{Y}$ = DO in ppm. at sag point in stream DO curve

X_1 = 5 Day BOD in ppm.

X_2 = Water temperature

X_3 = Stream discharge,

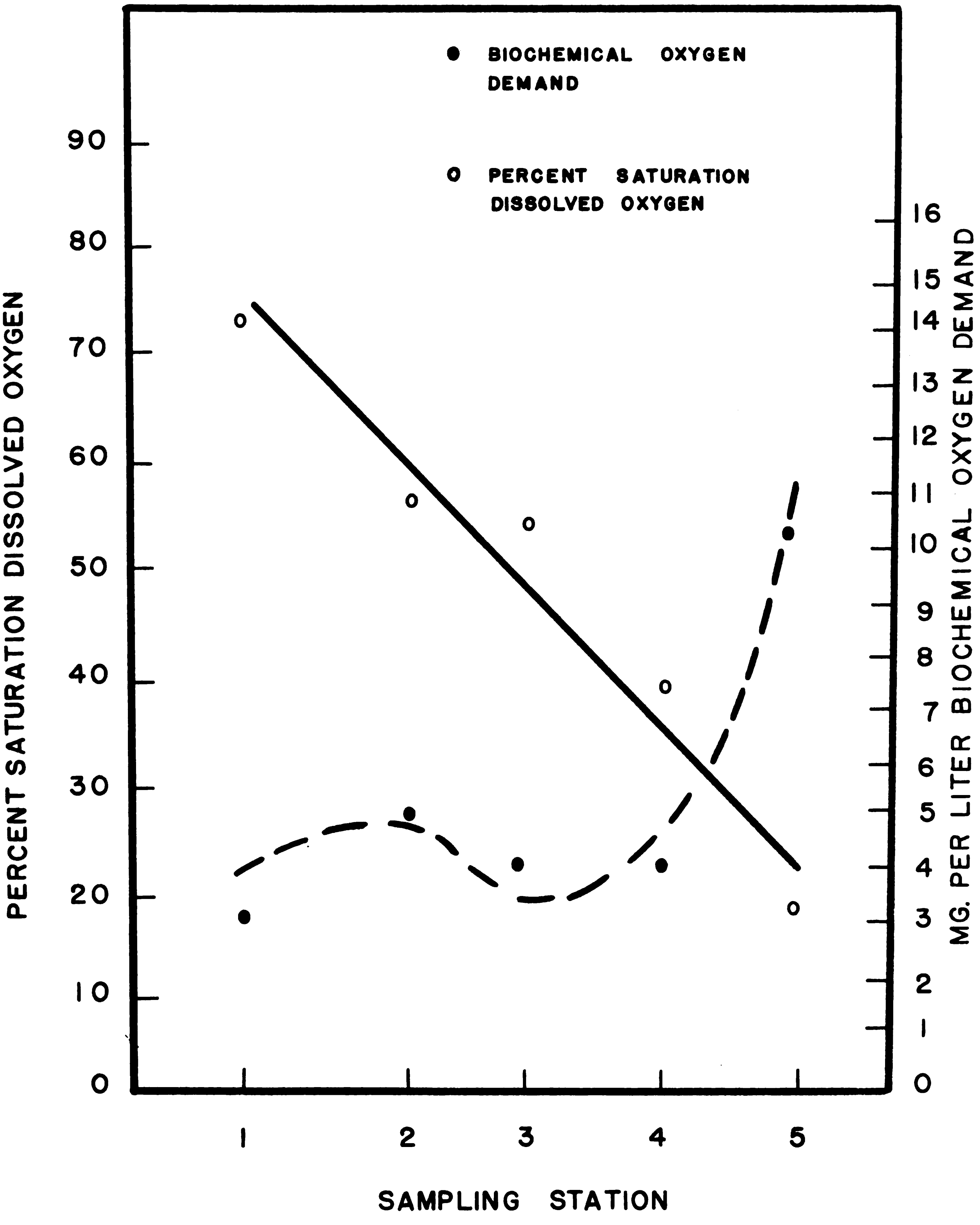
it was possible to accurately predict the maximum downstream DO sag caused by a load of organic pollution. But this method is not applicable if more than one source of pollution exists in the stream reach being studied, or if the stream reach is not homogeneous.

In some cases the natural purification capacity of a stream may be estimated using the following procedure. BOD and DO can be estimated as functions of distance downstream from the first sampling station. This gives two parametric polynomial equations, the graphs of which are shown in Figure 6.

$$\text{BOD} = f_1\ (\text{distance})$$

$$\text{DO} = f_2\ (\text{distance})$$

Figure 6. Means and regression equations for percent saturation dissolved oxygen and mg. per liter biochemical oxygen demand. Distances on abscissia are proportional to distances between stations. Observations were taken at approximately 8:00 A.M. Each oxygen value is the mean of 33 observations. Each BOD value is the mean of 16 observations.


● BIOCHEMICAL OXYGEN DEMAND
o PERCENT SATURATION DISSOLVED OXYGEN
PERCENT SATURATION DISSOLVED OXYGEN
0
10
20
30
40
50
60
70
80
90
MG. PER LITER BIOCHEMICAL OXYGEN DEMAND
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
1
2
3
4
5
SAMPLING STATION

The parameter distance can be eliminated from these equations giving,

$$BOD = f_1(f_2^{-1}(DO)) = g(DO)$$

Differentiating this equation gives a differential equation expressing the rate of change of BOD with respect to DO as a polynomial function of DO.

$$\frac{d(BOD)}{d(DO)} = g'(DO)$$

Solution of this equation for the Red Cedar River study is as follows,

$$BOD = \int_{75}^{75} g'(DO)\, d(DO) = 0$$

Streams do have a capacity to assimilate small increments of organic material. And it may be possible to determine a maximum permissible level of BOD loading. But stream purification capacity is small as compared to the amount of BOD in domestic sewage. Furthermore, when sewage is loaded into a stream so are large amounts of other materials. Presently, the most objectionable of these are inorganic nitrogens and phosphorous.

Phosphorous

Raw sewage before the advent of synthetic detergents contained approximately 2.3 mg. per liter of phosphorous. Now, Sawyer (1962) reports phosphorous content of sewage effluents are two or three times higher. Other sources of phosphorous in streams are organic metabolism, sediments brought in by surface run-off, and wearing away of phosphorous containing geologic formations (Reid, 1960). Phosphorous in streams can be divided into three categories, total-phosphorous (ortho + poly), ortho-phosphorous ($PO_4^{\equiv}$, $HPO_4^{=}$, $H_2PO_4^{-}$, H_3PO_4), and polyphosphorous ($Na_3(PO_3)_6$, $Na_5P_3O_{10}$, $Na_4P_2O_7^{-}$) (Sawyer, 1960).

Liebigs "law" of the minimum states that "growth of a plant is dependent on the amount of foodstuff which is presented to it in minimum quantity" (Odum, 1960). Phosphorous is a scarce mineral nutrient aquatic ecologists consider to be the factor most frequently limiting to aquatic production (Hutchinson, 1957). Total phosphorous concentrations of 0.01 mg. per liter and total inorganic nitrogen concentrations of 0.32 mg. per liter have been shown to be sufficient to produce blooms of aquatic vegetation (Mackenthun, 1965). These blooms of aquatic vegetation destroy recreational and esthetic values of lakes and streams. And death and decay of the masses of vegetation will often cause dissolved oxygen levels to fall below minimal requirements of desirable aquatic inhabitants of lakes and streams.

In this study determinations were made for concentrations of total and ortho-phosphorous. Both ortho and total-phosphorous data collected at river sampling stations deviated significantly from linearity. But means between sampling stations differed significantly when tested using one-way analysis of variance, Tables 6 and 7. Scheffe's test for

Figure 7. Means of mg. per liter ortho-phosphorous at river sampling stations. Distances on abscissia are proportional to distances between sampling stations. Each value is the mean of 6 observations.

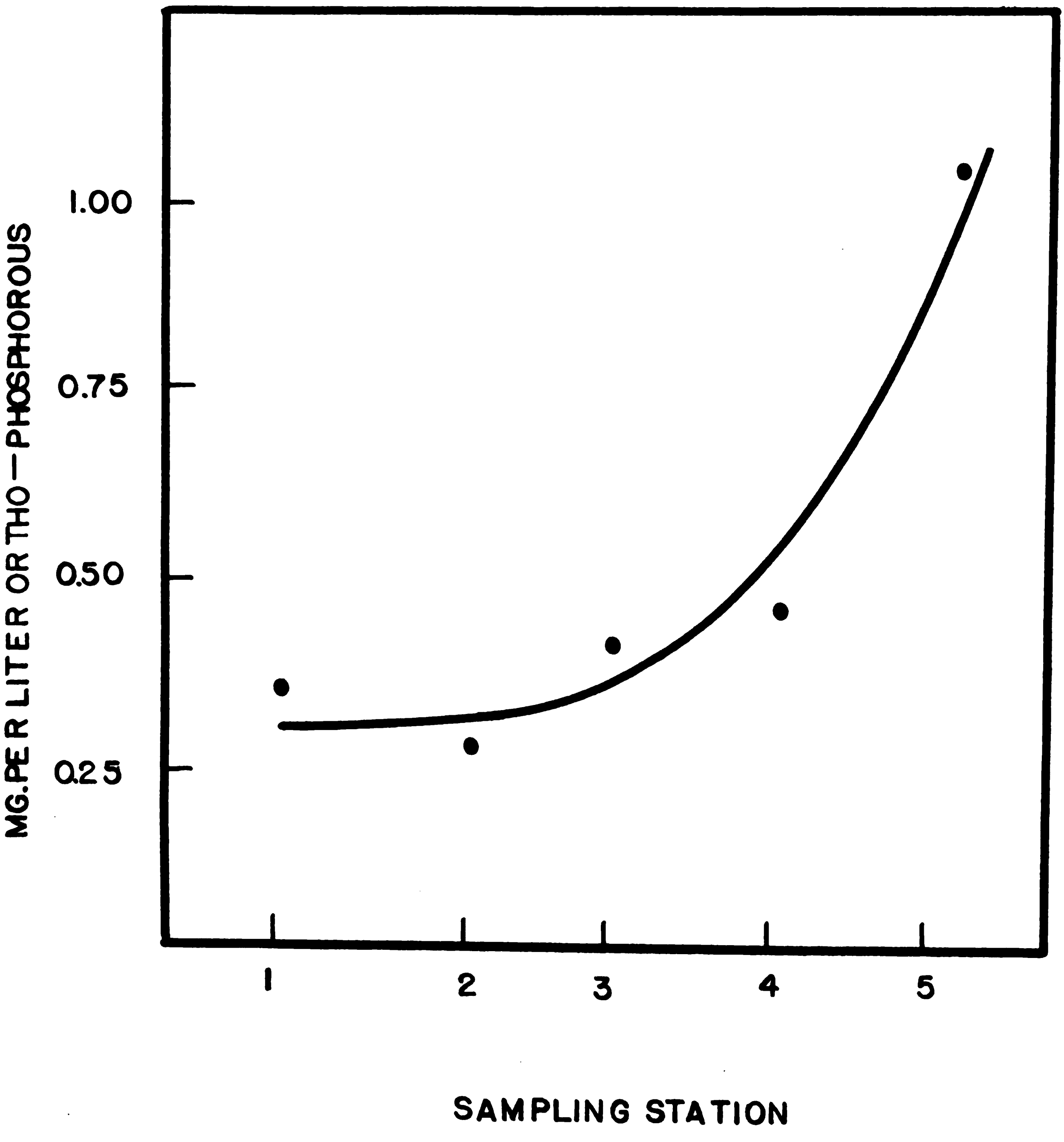

MG. PER LITER ORTHO—PHOSPHOROUS
1.00
0.75
0.50
0.25
1
2
3
4
5
SAMPLING STATION

Table 6. Summary of one-way analysis of variance and test for linearity for river total phosphorous.

Source	SS	df	MS	$F_{exp.}$	$F_{0.95}$
Treatments	13.18	4	3.29	32.90	2.69
Regression	7.37	1	7.37	73.70	4.17
Deviation from linearity	5.81	3	1.93	19.30	2.92
Error	3.23	30	0.10		
Total	16.41	34			

Table 7. Summary of one-way analysis of variance and test for linearity for river ortho-phosphorous determinations.

Source	SS	df	MS	$F_{exp.}$	$F_{0.95}$
Treatment	9.07	4	2.26	28.25	2.87
Regression	5.21	1	5.21	65.12	4.35
Deviation from linearity	3.86	3	1.28	16.00	3.10
Error	1.26	20	0.08		
Total	10.69	24			

significance of differences between individual means indicated the differences between the mean for Station 5 and means for Stations 4, 3, 2, and 1 were significant.

Extremely high phosphorous concentrations were found below the Kalamazoo Street Sewage Treatment Plant. Phosphorous concentrations in unpolluted rivers average two or more magnitudes less than minimum values obtained in this study (Reid, 1960).

These data indicate large quantities of phosphorous were being loaded into the river at the East Lansing Kalamazoo Street Sewage Treatment Plant. High phosphorous concentrations together with other sewage components contribute significantly to the unsightly growths of aquatic plants abundant in the study area.

Summary of Nitrogen Determinations

Hutchinson (1957) gives as the sources of nitrogen in streams, fixation in the stream and its sediments, run-off and ground water, precipitation, decomposition of aquatic organisms, and sewage effluents. Brehmer (1958) indicated run-off was the main source of nitrogen in the Red Cedar River and nitrogen rather than phosphorous was the nutrient limiting plant productivity. Results of this study indicate neither phosphorous nor nitrogen is limiting, but rather that productivity is limited by high turbidity and siltation.

In this study concentrations of nitrate nitrogen, nitrite nitrogen, organic nitrogen, and ammonia nitrogen were determined. Means for nitrate nitrogen concentrations at river sampling stations were significantly different when tested using one-way analysis of variance, Table 11. It was found that nitrate nitrogen data deviated significantly from linearity. Scheffe's test indicated significant differences existed between the mean for Station 2, and the means for Stations 3, and 4. Means for Station 1 and Station 3 also were significantly different. Nitrate concentrations appear to be highest in the impoundment.

Traces of nitrite nitrogen were obtained at Stations 3 and 5. Sawyer (1960) states nitrite nitrogen seldom appears even in sewage treatment plant effluents.

Means for organic nitrogen determinations were not significantly different, Table 10. But organic and nitrate nitrogen concentrations appeared to be higher at Stations 1 and 2.

Means for ammonia nitrogen determinations did not differ significantly, Table 8. The regression equation,

$$\hat{Y} = 2.12 + 0.32\,X_i$$

$\hat{Y}$ = Estimated mg. per liter ammonia nitrogen.

X_i = Miles downstream from Station 1,

indicates a gradual downstream increase of ammonia.

Nitrogen levels at all stations were above levels commonly found in unpolluted streams. Reid (1961) states that in unpolluted streams ammonia concentrations rarely exceed 1

Table 8. Summary of one-way analysis of variance and test for linearity for river ammonia nitrogen determinations.

Source	SS	df	MS	$F_{exp.}$	$F_{0.95}$
Treatment	8.73	4	2.18	1.96	2.65
Regression	3.22	1	3.22	2.90	4.12
Deviation from linearity	5.51	3	1.83	1.64	2.87
Error	33.49	30	1.11		
Total	42.22	34			

Table 9. Summary of randomized block design analysis of variance for river ammonia nitrogen determinations.

Source	SS	df	MS	$F_{exp.}$	$F_{0.95}$
Treatment	8.73	4	2.18	2.03	2.65
Blocks	7.77	6	1.29	1.20	2.51
Error	25.72	24	1.07		
Total	42.22	34			

Table 10. Summary of one-way analysis of variance and test for linearity for river organic nitrogen determinations.

Source	SS	df	MS	$F_{exp.}$	$F_{0.95}$
Treatment	2.21	4	0.55	0.48	2.69
Regression	0.09	1	0.09	0.07	4.17
Deviation from linearity	2.12	3	0.70	0.61	2.92
Error	34.42	30	1.14		
Total	36.63	34			

Table 11. Summary of one-way analysis of variance and test for linearity for river nitrate nitrogen.

Source	SS	df	MS	$F_{exp.}$	$F_{0.95}$
Treatment	28.67	4	7.16	6.45	2.69
Regression	0.30	1	0.30	0.27	4.17
Deviation from linearity	28.37	3	9.45	8.51	2.92
Error	33.36	30			
Total	62.03	34			

mg. per liter, and nitrate concentrations in natural waters average 0.30 mg. per liter. Blank determinations verified that the methods were sufficiently accurate providing interfering substances not present in blanks were not present in samples. Sawyer (1960) states the nitrate nitrogen analysis has serious limitations, and that the reduction method is poor. High alkalinity may also interfere with nitrogen determinations (Standard Methods, 1960). Hutchinson (1957) quotes work which indicates binding of ammonia to colloidal particles significantly decreases values of ammonia determinations in turbid waters. It must be concluded from this work as from other work (Phelps, 1944) that nitrogen determinations are unsatisfactory for routine determinations of water quality.

Results and Discussion of Physical Tests

pH

Data for pH measurements, the negative logarithm of the hydrogen ion concentration, deviated significantly from linearity. But a one-way analysis of variance indicated significant differences existed among sampling stations, Table 12. pH values were highest in the impoundment. Increasing pH values indicate CO_2 concentrations are decreasing. This implies, as did the alkalinity data, that primary production is greater in the impoundment than in other parts of the river.

Temperature

Using a randomized block design analysis of variance, significant differences were shown to exist between station means for water temperature. Scheffe's test indicated the mean water temperature at Station 3 was significantly higher than the mean water temperature upstream at Station 1. Figure 9 shows that water temperatures increase to a maximum at Station 3, located near the East Kalamazoo Street Bridge.

The pool-like area upstream from the dam may be expected to have a higher temperature than shaded portions of the stream. A more certain cause of high temperatures at Station 3 was hot power plant effluents which enter the river between Stations 2 and 3.

Coutant (1962) showed that effluents 20° F. to 25° F. above normal river temperatures decreased the macroinvertebrate bottom fauna standing crop biomass from 1.04 gm. per square foot to 0.09 gm. per square foot for a distance of 1600 feet below the outfall. Heat must be considered a pollutant. On one occasion effluent temperature of power plant drain 17 was 45° F. higher than the river temperature upstream from the outfall (the river temperature was 68° F.).

Total Residue

Total residue is a measure of the dissolved and suspended matter in water. Residues obtained at all stations except Station 1 were a greasy black, and emitted a dense white smoke on drying. The data deviated significantly from linearity, and differences between sampling station means were not statistically significant. The data did, however, indicate a slight increase in the impoundment.

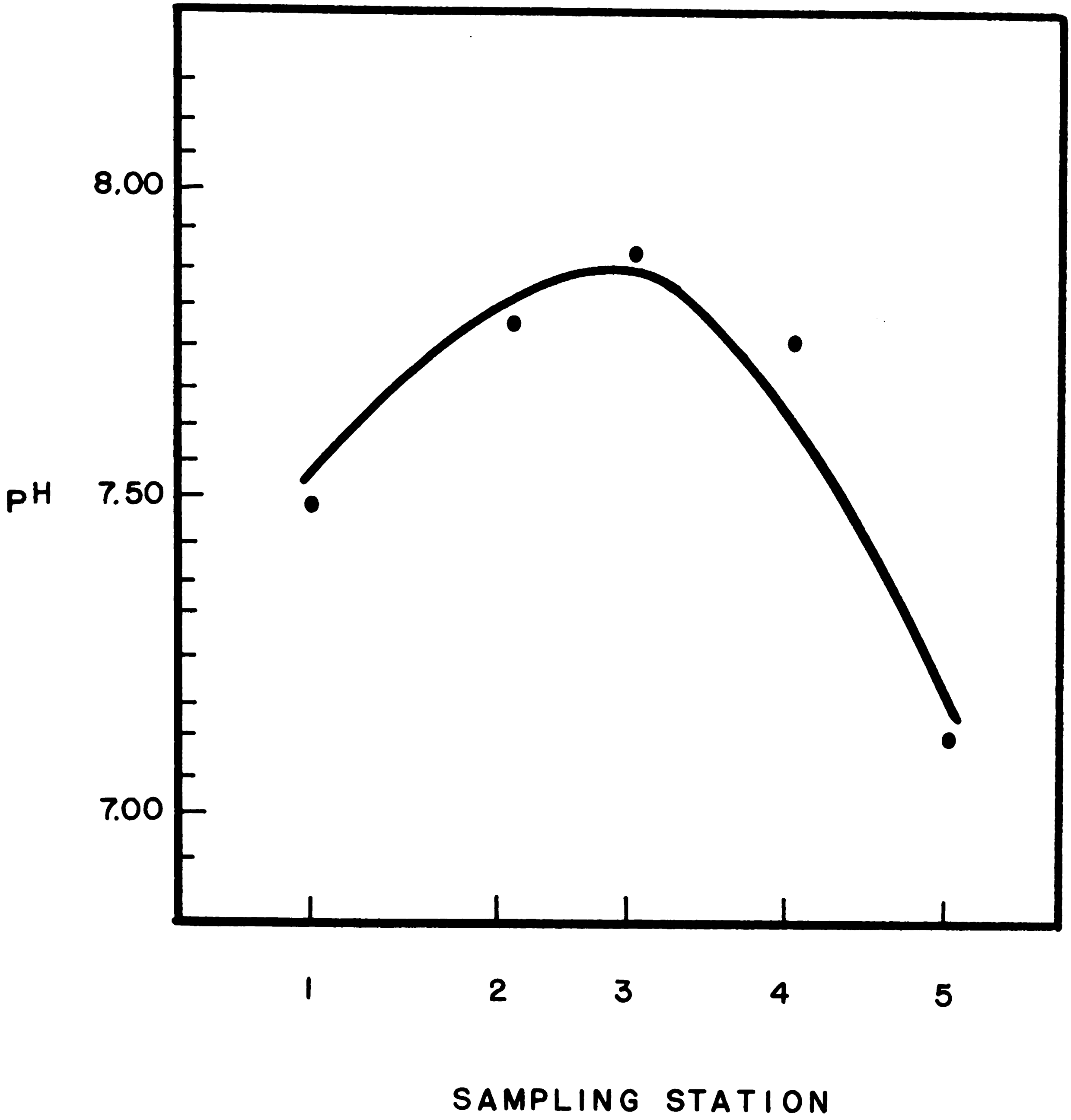
Turbidity

Water turbidity is a measure of the suspended matter interfering with passage of light through water. High turbidity is detrimental to aquatic ecosystems, as photosynthesis is inhibited by lack of light, and the abrasive action of suspended particles is an important source of biological stress (King and Ball, 1964). Ellis (1936) states that silt alters aquatic communities through screening out light, changing heat radiation, blanketing stream bottoms, and by retaining organic materials and other substances which create unfavorable conditions on the stream bottom.

Means for sampling stations were significantly different, but data deviated significantly from linearity, Table 13. Scheffe's test indicated the mean turbidity at Station 1 was significantly less than the mean turbidity at Stations 2, 3, and 4. Turbidity at Station 3 was significantly greater than the turbidity at Stations 4 and 5.

This peak turbidity at Station 3 with lesser values both upstream and downstream is thought to be caused by construction on the Michigan State University campus in progress during this study period.

Figure 8. Mean values for pH measurements at sampling stations. Distances on abscissia are proportional to distances between stations. Each value is the mean of 8 observations.



pH
8.00
7.50
7.00
1
2
3
4
5
SAMPLING STATION

Figure 9. Mean values of temperatures at river sampling stations. Distances on abscissia are proportional to distances between sampling stations. Each value is the mean of 26 observations.

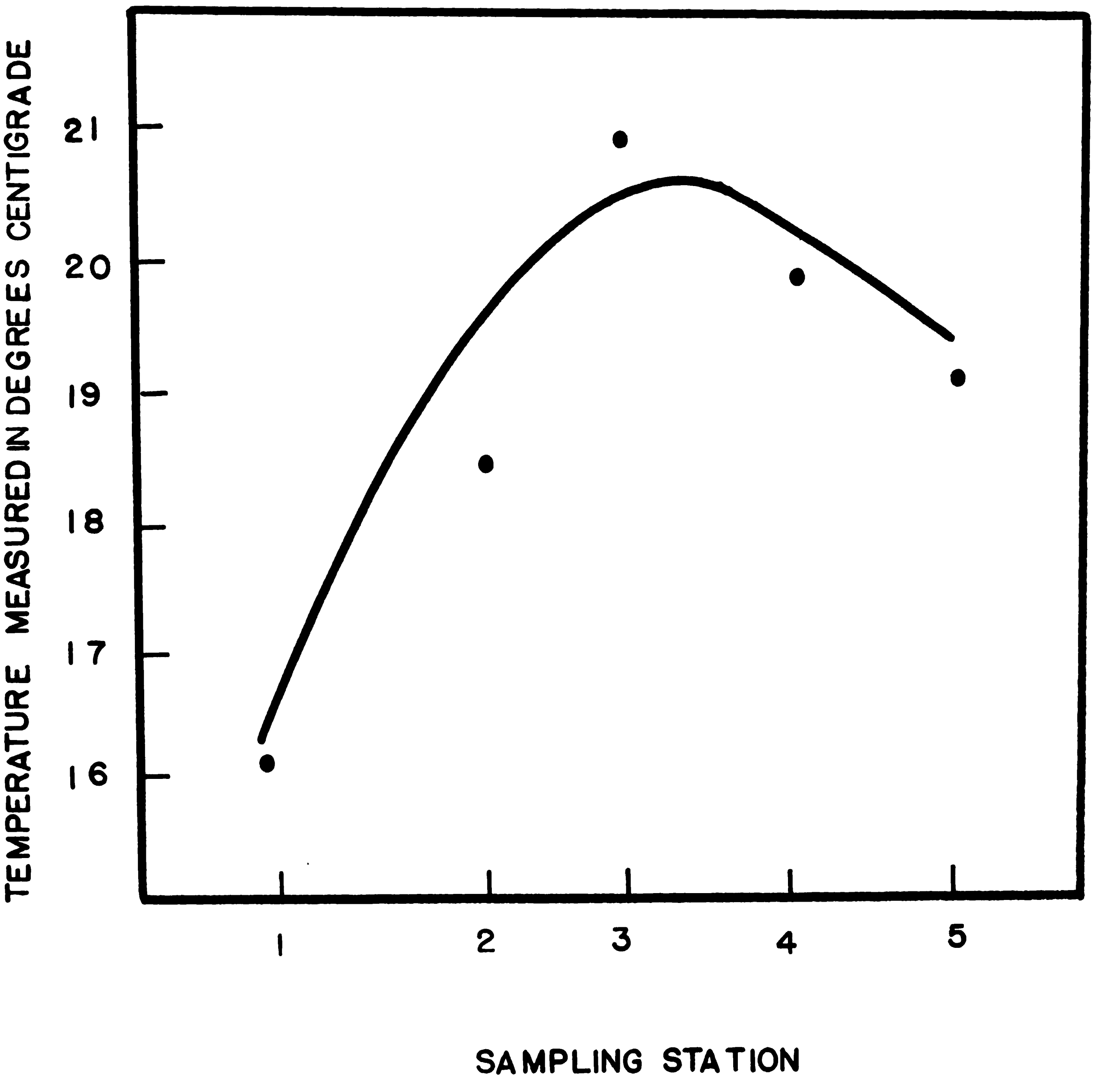

TEMPERATURE MEASURED IN DEGREES CENTIGRADE
21
20
19
18
17
16
1
2
3
4
5
SAMPLING STATION

Figure 10. Turbidity measured as Jackson turbidity units for river sampling stations. Distances on abscissia are proportional to distances between stations. Each value is the mean of 7 observations.

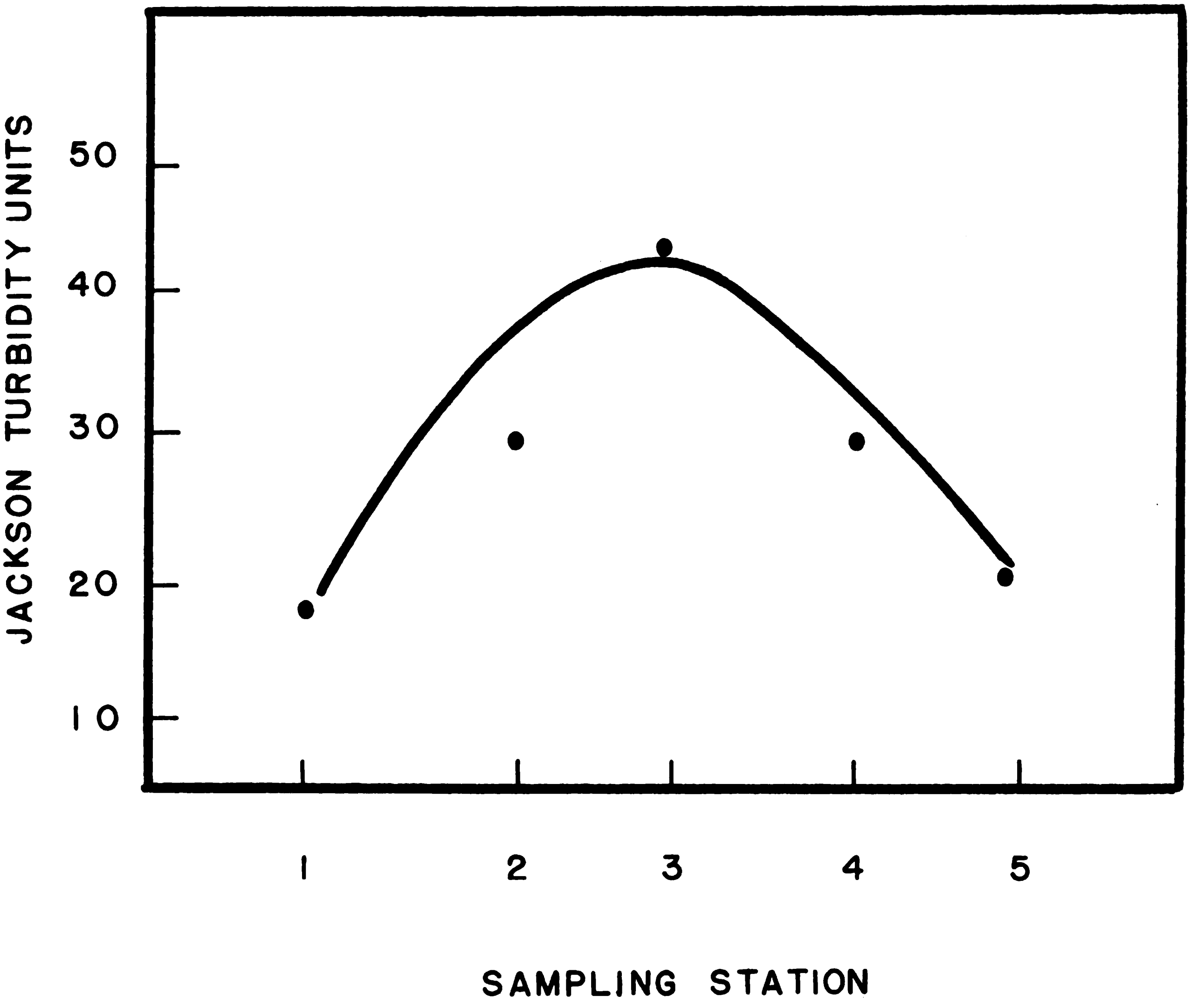

JACKSON TURBIDITY UNITS
50
40
30
20
10
1
2
3
4
5
SAMPLING STATION

Table 12. Summary of one-way analysis of variance and test for linearity for river pH determinations.

Source	SS	df	MS	$F_{exp.}$	$F_{0.95}$
Treatments	0.87	4	0.21	3.00	2.65
Regression	0.04	1	0.04	0.57	4.12
Deviation from linearity	0.83	3	0.27	3.85	2.88
Error	2.67	35	0.07		
Total	3.63	39			

Table 13. Summary of one-way analysis of variance and test for linearity for river turbidity determinations.

Source	SS	df	MS	$F_{exp.}$	$F_{0.95}$
Treatments	2883.26	4	720.81	17.57	2.69
Regression	426.17	1	426.17	10.39	4.17
Deviation from linearity	457.09	3	152.36	3.71	2.92
Error	1260.43	30	41.01		
Total	4143.69	34			

Table 14. Summary of randomized block design analysis of variance for river temperatures.

Source	SS	df	MS	$F_{exp.}$	$F_{0.95}$
Treatment	266.23	4	66.55	4.88	2.47
Blocks	2751.83	25	110.07	8.08	1.60
Non-additivity	3.91	1	3.91	0.28	3.95
Remainder	1358.32	99	13.72		
Error	1362.23	100			
Total	4380.29	129			

Conductivity

Ohm's law for metallic conductors states that $I = \frac{E}{R}$, where $R = \frac{pL}{A}$, is termed the resistance. p Is the specific resistance or resistivity of the conducting medium, L the length of the resistor, and A the cross sectional area of the resistor. As soon as sufficiently sensitive measuring devices became available it became apparent that solutions of electrolytes as well as metallic conductors followed Ohm's law. According to the Debye-Huckel theory, ions in solution migrate towards the pole with electrical charge opposite to their own when placed into an electric field. This migration creates a measurable electric current proportional to concentrations of the dissolved ions. Conductance, conductivity, and molar equivalents concentration of solute are related by the expression (Moore, 1962),

$$\pi = \frac{\Lambda C_{eq.}}{1000}$$

where, π = Conductivity = the reciprocal of resistivity. Measured as (ohm^{-1} cm^{-1}).

Λ = Conductance = the reciprocal of resistance. Measured as (ohm^{-1}).

$C_{eq.}$ = Molar equivalents solute.

It can be seen from this equation that as concentrations of solutes increase conductivity of the solution increases. An approximation of the mg. per liter of cations or anions in a solution can be obtained by multiplying μ-ohms^{-1} conductance by 0.01 (<u>Standard Methods</u>, 1960).

Analysis of conductivity data for stream sampling stations indicated significant differences existed between sampling station means, and that data do not deviate significantly from linearity, Table 15. The linear regression equation,

$\hat{Y} = 39.1 + 8.0\ X$

$\hat{Y}$ = Estimated conductance in ohm^{-1} x 10^{-3}

X = Miles downstream from Station 1,

indicates a consistant large increase in conductance at downstream sampling stations. Results of Scheffe's test indicated means for conductance measurements at Stations 4 and 5 were significantly different from that at Station 1. The mean for Station 5 is also significantly different from the mean for Station 2.

As every box of salt purchased in the East Lansing community eventually finds its way down the drain, it is not difficult to account for the pattern of conductivity measurements illustrated in Figure 20. Run-off may also account for some increase in conductivity. But Ellis (1936) states that erosion silt does not significantly alter the salt complex, or the amount of electrolytes in river waters.

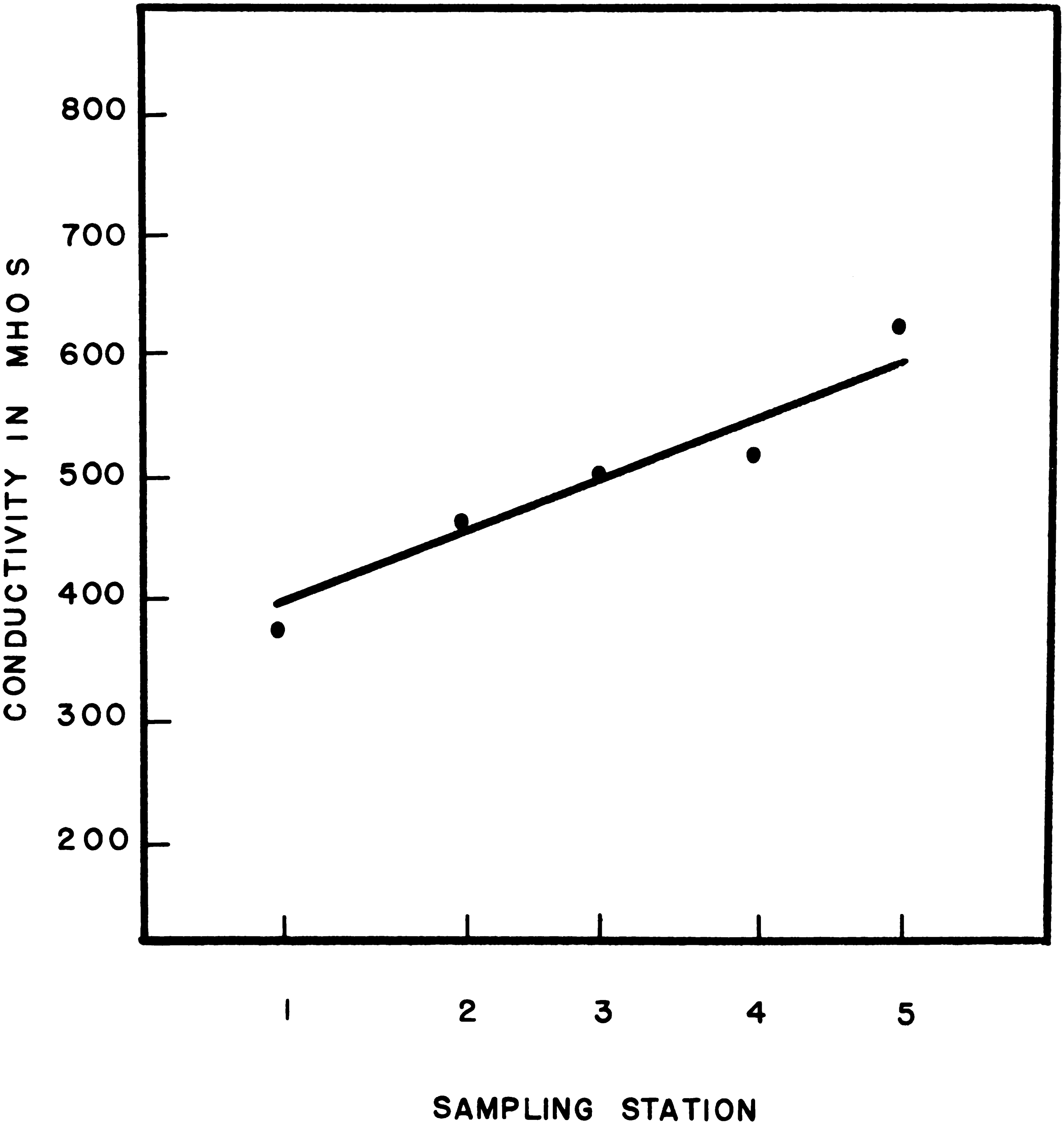
Bacteriology

Water has long been known to be a possible transmitter of disease. Hippocrates recommended drinking water be filtered and boiled (Frank, 1955). Typhoid fever, paratyphoid fever,

Table 15. Summary of one-way analysis of variance and test for linearity for river conductance determinations.

Source	SS	df	MS	$F_{exp.}$	$F_{0.95}$
Treatment	0.227	4	0.056	8.00	2.69
Regression	0.190	1	0.190	27.14	4.17
Deviation from linearity	0.037	3	0.012	1.71	2.92
Error	0.215	30	0.007		
Total	0.442	34			

Figure 11. Conductivity determinations for river sampling stations expressed as mho's. Distances on abscissia are proportional to distances between sampling stations. Each value is the mean of 5 observations.



CONDUCTIVITY IN MHOS
800
700
600
500
400
300
200
1
2
3
4
5
SAMPLING STATION

bacillary dysentery, amebic dysentery, asiatic cholera, diarrhea, infectious hepatitis, infectious jaundice, poliomyelitis, and anthrax are some diseases commonly associated with water.

Unpolluted streams contain an abundant bacterial population averaging, for example, 1900 per 100 ml. in a Great Britain survey of twenty English rivers (Gainy and Lord, 1952). But the number of free living bacteria is usually only a dozen or so per 100 ml., composed primarily of species of Micrococcus, Flavobacterium, Achromobacterium, Bacillus, Proteus, and Leptospira (Frobisher, 1957). Surface run-off contributes considerable numbers of bacteria to streams, causing bacteria counts to be significantly higher after heavy showers (Frobisher, 1957). Cultivated soils contains up to several billion bacteria per gram.

It has not been possible to devise specific tests for water-borne disease producing micro-organisms. It is therefore common procedure to test for relatively high numbers of coliform bacteria rather than to attempt tests specifically for Salmonella typhi, the typhoid producing bacilli, or other disease producing organisms.

The coliform group of bacteria includes all aerobic or facultative anerobic Gram-negative non-spore forming bacilli capable of fermenting lactose broth with gas formation (Gainy and Lord, 1952). Although most coliforms are harmless, high populations are associated with the presence of pathogenic bacteria and water containing large numbers are regarded as dangerous (Gainy and Lord, 1952).

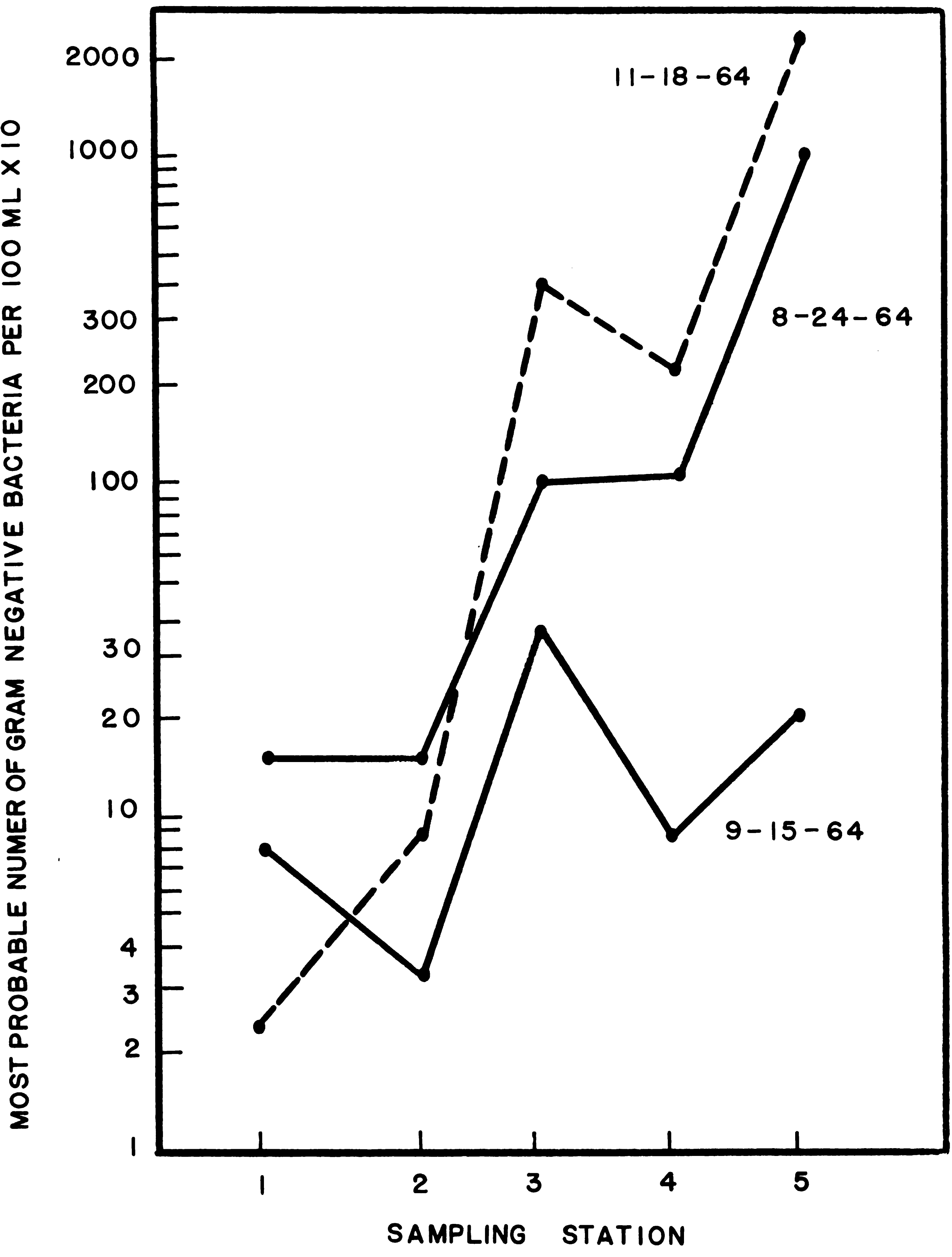
The United States Treasury Department prohibits interstate common carriers to serve drinking water with more than one *Escherichia coli* (a common coliform bacteria) per 100 ml. Sewage plant effluents usually contain between 10,000,000 and 1,000,000,000 *Escherichia coli* bacteria per 100 ml. prior to dilution (Gainy and Lord, 1952). The most probable number (MPN) is an index of the number of coliform bacteria which, more probably than any other number, would give the results shown by the laboratory examination (*Standard Methods*, 1960).

As can be seen from Figure 12, the most probable number of coliform bacteria in the Red Cedar River is considerably higher than is desirable. At one point the bacteria count exceeds a value commonly found in sewage plant effluents. Bacteria counts upstream at Hagadorn Road are excessively high, indicating, as does BOD and dissolved oxygen data, that considerable pollution is entering the river above this point. The source of these upstream pollutants may be saturated septic tank leaching fields. As the river flows through the Michigan State University campus the MPN of coliform bacteria increases exponentially on logarithmic graph paper, indicating several sources of domestic sewage enter the river in the study area.

Table 16. Most probable number of gram negative bacteria per 100 ml. of river water for five sampling stations.

Station	Dilution								MPN
	10	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}	
8-24-64									
1		3/3	2/3	1/3	0/3	0/3			15000
2		3/3	2/3	1/3	0/3	0/3			15000
3		3/3	3/3	2/3	0/3	0/3			15000
4		3/3	3/3	2/3	0/3	0/3			110000
5		3/3	3/3	3/3	2/3	0/3			1100000
9-15-64									
1			2/3	0/3	0/3	0/3	0/3	0/3	9100
2			1/3	0/3	0/3	0/3	0/3	0/3	3600
3			3/3	1/3	1/3	0/3	0/3	0/3	43000
4			2/3	0/3	0/3	0/3	0/3	0/3	9100
5			3/3	0/3	0/3	0/3	0/3	0/3	23000
11-18-64									
1	3/3	3/3	3/3	0/3	0/3	0/3			2400
2	3/3	3/3	2/3	0/3	0/3	0/3			9300
3	3/3	3/3	3/3	3/3	2/3	0/3			430000
4	3/3	3/3	3/3	0/3	0/3	0/3			24000
5	3/3	3/3	3/3	3/3	3/3	0/3			2400000

Figure 12. Most probable number (MPN) for coliform bacteria per 100 ml. of river water at sampling stations. Distances on abscissia are proportional to distances between sampling stations.


MOST PROBABLE NUMER OF GRAM NEGATIVE BACTERIA PER 100 ML X 10^{-3}
2000
1000
300
200
100
30
20
10
4
3
2
1
11-18-64
8-24-64
9-15-64
1
2
3
4
5
SAMPLING STATION

Bottom Sampling Data

In natural ecosystems the initial source of energy is solar insolation. Photosynthetic members of ecosystems fix and store small amounts of solar radiant energy by forming chemical bonds, producing large molecules from simple components. A portion of this stored energy is dissipated by plant respiration, but some is transferred along the food chain to herbivores. Herbivores utilize stored plant energy to build and maintain their bodies, dissipating energy in the process through work on the environment, through friction within their bodies, and by respiration. Some herbivores may fall prey to carnivores, and the processes of bioenergetics continue.

Increased energy input into an ecosystem will produce a comparable increase of biological productivity if other factors are not limiting (Odum and Hoskin, 1957). Slobodkin (1962) cites work by Hairston _et al_. which indicates the biosphere is energy limited as a whole. If the energy input is in the form of complex organic molecules, the producer trophic level should not be noticeably affected by this energy increase. But standing crop biomass of other trophic levels may increase greatly.

It is also necessary to consider biogeochemical cycles when discussing physical phenomena that regulate productivity of aquatic ecosystems. Phosphorous and nitrogen are two essential plant nutrients, the scarcity of which is commonly limiting to biological productivity (Odum, 1959). Both of these elements are involved in biogeochemical cycles, being constantly removed from and added to the biosystem in small increments. The atmosphere serves as a reservoir for nitrogen, and phosphate rocks are the phosphorous reservoir. To summarize, biological productivity in aquatic ecosystems is limited by the energy input into the system and by the availability of some mineral nutrients.

Sewage effluents are rich in both energy containing organic molecules and mineral nutrients. This influx of energy and nutrients results in a potential for high biological productivity. But influx of sewage is accompanied by other factors such as low dissolved oxygen, toxic materials, and high turbidity. These factors are limiting to most species of fish and bottom fauna. Sewage effluents, therefore, have the potential to support large populations of aquatic organisms able to tolerate adverse environmental conditions.

Bottom samples obtained from the Red Cedar River indicate productivity was high but diversity was extremely low. At Hagadorn Road most bottom fauna appears to have been destroyed by heavy siltation. Sewage worms (Tubificidae) and blood worms (Chironomus) are abundant at all sampling stations. On one occasion numerous Chaoborus larva were obtained at Station 1. Chaoborus, a predatory midge, is usually found in deep lakes (Pennak, 1953). Samples taken at Station 3 near the East Kalamazoo Street Bridge indicate this section of the river has a meager bottom fauna. Coliform counts also were low at this station. Bottom materials were of a black cinder composition. A large sludge bed rich in Tubificidae and chironomus larvae is forming at mid-stream immediately upstream from Station 3. Drains 58 and 60 appear to be the source of sludge forming materials.

Animals are not randomly distributed. Deviations between sample means for a population of clumped organisms is expected to be large. But deviations in this work are not as large as would have been the case if the Ekman dredge were not a poor sampling device. All samples were of necessity taken where the bottom materials were soft muck, as gravel fouled the dredge jaws preventing them from closing. Usinger (1956) also concludes that present bottom sampling techniques are biased.

Table 17. Summary of bottom organisms expressed as number per square foot.

Station	Sample Period			Total	Mean
	8-29-64	9-15-64	9-26-64		
		Tubificidae			
1	81	24	34	139	46
2	131	258	15	394	105
3	36	11	145	186	61
4	64	250	93	107	132
5	438	258	318	1014	339
		Chironomus			
1	24	106	6	180	45
2	1	6	2	9	3
3	0	0	0	0	0
4	3	0	1	4	1
5	17	87	905	1005	335

In addition to the above mentioned organisms, the following were obtained.

ORGANISM	NUMBER	STATION
Margaritanidae	2	4
Vivparidae	1	4
Sphaeriidae	8	2,4,5
Chaoborinae	20	1
Opisthopora	8	1,2,4
Planaria	27	4

Figure 13. Number of Tubificidae per square foot at river sampling stations. Distances on abscissia are proportional to distances between stations.

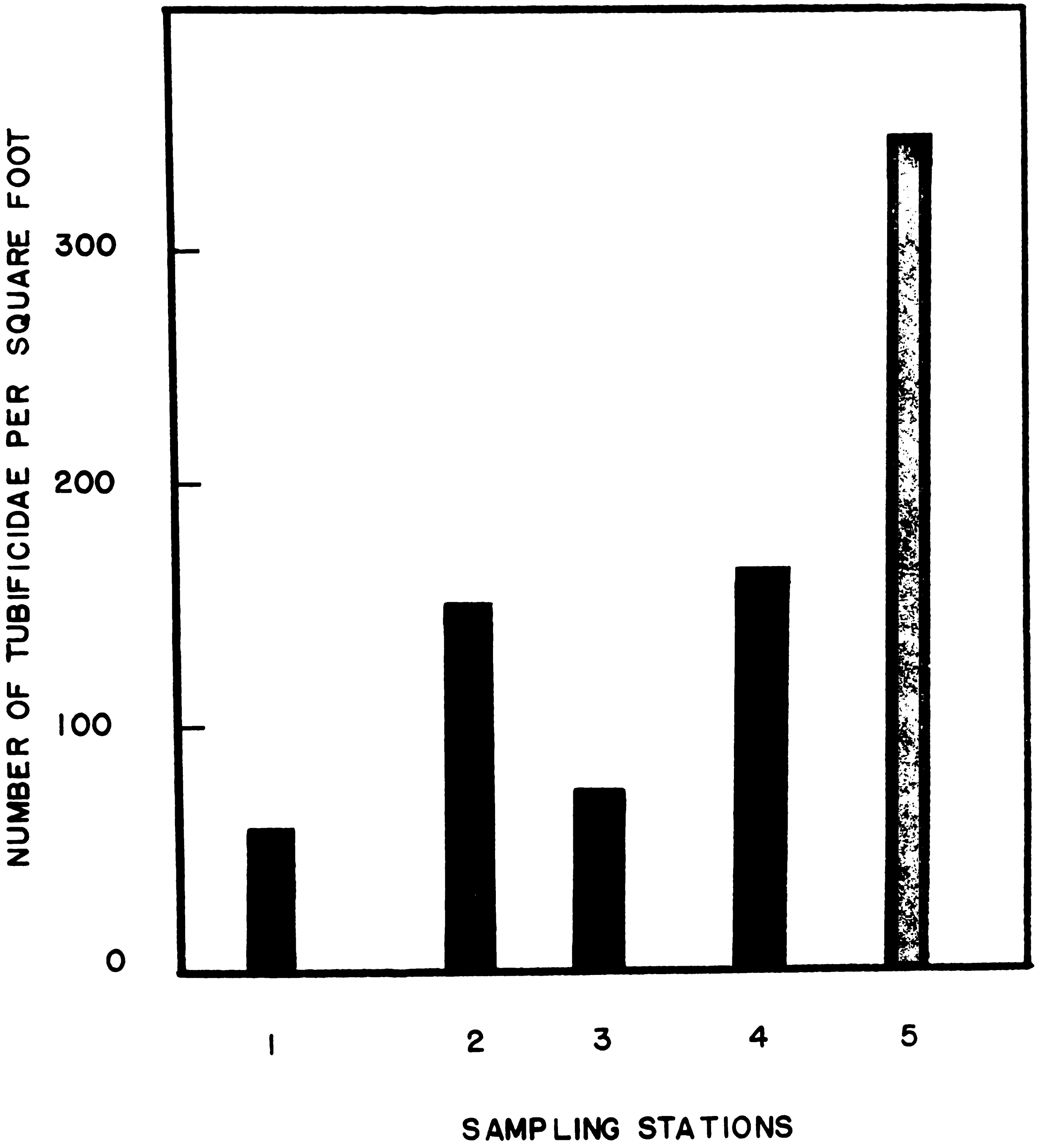

NUMBER OF TUBIFICIDAE PER SQUARE FOOT
300
200
100
0
1
2
3
4
5
SAMPLING STATIONS

Table 18. Summary of one-way analysis of variance and test for linearity for river Tubificidae.

Source	SS	df	MS	$F_{exp.}$	$F_{0.95}$
Treatment	104285.6	4	26071.4	1.51	3.11
Regression	37430.5	1	3743.5	0.21	4.60
Deviation from linearity	66855.1	3	22285.0	1.29	3.34
Error	171562.4	10	17156.2		
Total	275848.0	14			

Table 19. Summary of one-way analysis of variance for Chironominae.

Source	SS	df	MS	$F_{exp.}$	$F_{0.95}$
Treatment	163244	4	40811	1.28	3.11
Error	317429	10	31742		
Total	480673	14			

RESULTS AND DISCUSSION OF DRAIN EFFLUENT ANALYSES

Results of drain effluent analyses indicated effluents of nearly one-third of the 68 or more drains located within the bounds of the study area contained materials detrimental to the water quality of the Red Cedar River. Several drain effluents consisted of untreated domestic sewage. One or more drain effluents contained a lethal chemical, suspected to have contributed to conditions responsible for the fish kill in the spring of 1964. Several other factors such as low dissolved oxygen, high turbidity, and pesticides probably were also responsible for the kill. A brief summary of results for the more important drains follows. For location of drain being discussed and complete data refer to Figure 1 and appendices.

Drain 15: Drain 15 is the power plant drain near the library foot bridge. Effluent temperatures were extremely high. A temperature of 45° C. was recorded for this drain.

Drain 23: Drain 23 is located behind Jenison Field house. This drain was found to flow regularly. The effluent appears to be domestic sewage.

Drain 47: Drain 47 is located below the water surface at the upstream end of Farm Lane on the north side of the river.

A BOD value of 17.65 was recorded for the water in front of this drain. Turbidity measurements were also high.

Drain 48: This drain is located a few yards downstream from Farm Lane Bridge. Usually this drain flows backwards, but during rains and late in the afternoon it flows sewage.

Drain 55: The source of drain 55, which is located below the dam, appears to be a natural stream. BOD and phosphorous concentrations were extremely high on some occasions.

Drain 40: Drain 40 is the large metal covered drains upstream from Bogue Street. Evidence indicates drain 40 flows large quantities of untreated sewage. The river below this out-fall often has an effervesent appearance due to emission of gaseous products escaping from bottom sludges.

Drain 49: Two bioassays were performed on the effluent of drain 49. In the first bioassay three guppies placed into a container of 50 ml. drain sample and 150 ml. aquaria water were killed in 96 hours. Three guppies placed into a container of 200 ml. aquaria water were not killed. A second bioassay was performed as suggested in Standard Methods (1960). Water for dilution of drain sample and controls was obtained from the river at the end of the canoe dock. Test organisms were blackside darters obtained from the Red Cedar River. Six darters of the group assigned to the 1/20 drain effluent to river water dilution mixture were dead after 12 days.

Four days later another was dead. None of the darters in the control group died.

Results of this bioassay indicate materials contained in the effluent from drain 49 can be harmful to higher aquatic life even after considerable dilution.

Drain 58: This drain regularly flows raw sewage. High BOD values were obtained. Fecal material and toilet paper were frequently observed coming from this drain opening. This drain is the major cause of stream deterioration behind the Michigan State University women's gym.

Drain 64: Drain 64 is located under Harrison Street Bridge. A BOD value of 525 mg. per liter, a phosphorous value of 7.50 mg. per liter, and a nitrate nitrogen concentration of 5.88 mg. per liter were recorded for this drain. Further evidence that this drain flows raw sewage are the pieces of toilet paper and fecal material abundant in the effluent.

Drain 65: Drain 54 is the power plant out-fall above the dam. Because of the large volume flow of this drain the heated effluent is thought to have a significant effect on quality of the Red Cedar River.

Drain 59: This is the large drain, surrounded by broken sidewalk, located behind the women's gym. This drain flows irregularly, but on one occasion had a voluminous effluent with a BOD of 82.10 mg. per liter. Drain 59 appears to be connected to the power plant drain located above the dam, as white colored effluents were observed flowing from both drains simultaneously on several occasions.

In summary, between Hagadorn Road and East Kalamazoo Street there are several sanitary sewers flowing into the Red Cedar River. Most of these drains were overflows connected to a main intercepter sewer which is located under the north bank of the river, and crosses under the river just upstream from the East Kalamazoo Street Bridge. Effluents from these numerous sewer outfalls have produced the low oxygen levels, high BOD values, and high coliform counts reported in this study. It must be noted that the waters of the Red Cedar are of poor quality even at Hagadorn Road, indicating considerable quantities of untreated or poorly treated sewage enter the river above Hagadorn Road.

To remedy the situation on campus requires installation of a larger intercepter sewer capable of carrying the increased load of sewage produced in the East Lansing, Michigan State University, and Meridian Township areas.

To reclaim the river for recreational uses will require a more extensive program, which may first need to include creation of some form of watershed management district. For abatement of pollution of the Red Cedar will require cooperation of all citizens in the watershed who are presently contributing pollutants.

SUMMARY

1. At least 68 drains are located between Hagadorn Road and East Kalamazoo Street at the eastern edge of the Lansing City Limits.

2. About 4,674 persons are polluting the river between Hagadorn Road and East Kalamazoo Street.

3. Percent oxygen saturation decreases linearly from a mean value of 75 percent at Hagadorn Road to a mean value of 18 percent at East Kalamazoo Street.

4. The most probable number (MPN) of coliform bacteria increases from a few thousand at Hagadorn Road to over a million per 100 ml. at East Kalamazoo Street.

5. Bottom fauna consists almost entirely of sewage worms and blood worms. Some sections of the study area appear to be devoid of even these sewage resistant organisms.

6. Bottom sediments are composed of coarse gravel, mixed with larger rocks, covered over in nearly all locations with either several inches of silt or sludge beds.

7. The impoundment and power plant drains increase water temperature significantly.

8. Volume flow of the River was extremely low during this study period, and average yearly discharge is rapidly decreasing.

9. Coliform counts and biochemical oxygen demand appear to reflect fluctuations in the Michigan State University-East Lansing population density.

10. Plant photosynthetic production appears to be low in the study area, with the main source of oxygen being physical reaeration.

11. Turbidity and siltation prevent abundant nitrogen and phosphorous from supporting large blooms of aquatic vegetation.

12. Ortho-phosphorous concentrations increased exponentially from 0.36 mg. per liter at Hagadorn Road to 1.12 mg. per liter at East Kalamazoo Street.

13. BOD values increased from a mean of 3.69 at Hagadorn Road to a mean of 10.60 at East Kalamazoo Street. Waters with a BOD of 3 are of poor quality, and those with a BOD of 4 are of bad quality (Hynes, 1960).

14. Turbidity increases to a maximum of 45 Jackson units at East Kalamazoo Street.

15. All nitrogen concentrations were higher than is normal for a non-polluted river.

16. Sediments appear to be one of the most serious pollutants from a biological point of view.

17. Concentrations of dissolved salts increases linearly from Hagadorn Road to East Kalamazoo Street.

18. Aquatic biological sampling devices are presently inadequate for reliable, and discriminatory test for degree of municiple pollution.

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APPENDIX A

DRAIN SAMPLING DATA

Total alkalinity measurements for drains, as mg./liter $CaCO_3$.

Drain Number	Sample Period 1	2	3	4	5	Total	Mean
46	228					228	228
47	286	264	244	190		984	246
48	194					194	194
55	142	60	100			302	100
56	310	332	346	380	390	1758	351
58	224	240				464	232
64	354	406	366	400	392	1918	383
36	274	146	144	220		784	196
1	204	175	312	302		993	248
3	200	490				690	345
52	296	296	300			892	297
54	210	186	278	236		910	227
15	122	166	124	176	220	808	161
25	234	98	148	146		626	156
60	292	288	292	312	268	1452	290
19	104	300				404	202
62	300					300	300
23	408					408	408
49	376					376	376
45	294	300				594	297
65	236					236	236
16							
17	274	308				582	291
59	410					410	410
6	196					196	196
42	266	46				312	156
9							

Mg./liter BOD measurements for drains.

Drain	Sample Period						
Number	1	2	3	4	5	Total	Mean
46							
47	6.80	17.65				24.45	12.22
48	5.60					5.60	5.60
55	30.50	3.87	3.14	10.13		47.64	11.91
56	60.40	171.00	77.50	77.10	80.60	466.83	93.36
58	59.10					59.10	59.10
64	61.10	388.00	82.00	88.00	525.10	1144.20	228.84
36	7.00					7.00	7.00
1	28.15	11.52	22.10			61.77	20.59
3	14.50	18.25				32.75	16.37
52	10.20	12.42				22.62	11.31
54	11.51	22.10	8.06			41.67	13.89
15	14.12	19.90				34.02	17.01
25	17.47	11.50	8.69			37.66	12.55
60	20.11	11.90	13.43			45.44	15.14
19	40.25	12.10	6.27			58.72	19.57
62	9.99					9.99	9.99
23	123.00	74.60				198.10	99.05
49	14.85					14.85	14.85
45	4.52					4.52	4.52
65	7.12					7.12	7.12
16	1.93					1.93	1.93
17							
59	82.10					82.10	82.10
6	15.68					15.68	15.68
42							
9							

Conductance x 10^{-3} measured as Ω^{-1} for drains.

Drain Number	Sample Period 1	2	3	4	5	Total	Mean
46	0.117					0.117	0.117
47	0.388	13.700	0.648	0.336		15.072	3.768
48	1.100					1.100	1.100
55	0.268	0.388	0.352	0.206	0.111	1.497	0.249
56	0.820	0.770	0.728	0.417	0.185	2.920	0.584
58	0.453	0.572				1.025	0.512
64	0.590	0.720	0.625	0.582		2.517	0.629
36	2.390	0.750	0.680	0.446		4.270	1.067
1	0.282	0.462	0.434			1.178	0.392
3	0.951	0.512				1.463	0.731
52	0.282	0.462	0.434			1.178	0.392
54	0.493	0.358	0.461			1.312	0.437
15	0.594	0.860	0.680	0.624	0.585	3.343	0.668
25	0.840	0.148	0.230	0.230	0.342	1.560	0.390
60	6.330	0.490	0.338	0.262	0.365	2.088	0.417
19	0.289	0.715				1.004	0.502
62	0.424					0.424	0.424
23	1.720	0.154				1.874	0.937
49							
45	0.376	0.367	0.481	0.346		1.570	0.392
65	0.417					0.417	0.417
16							
17	0.464	0.485				0.949	0.474
59	0.397					0.397	0.397
6							
42	0.488					0.488	0.488
9							

Mg./liter ammonia nitrogen for drains.

Drain	Sample Period						
Number	1	2	3	4	5	Total	Mean
46							
47	3.64	2.46	2.00			8.10	2.70
48							
55	1.85	3.92	0.00	1.96	1.77	9.50	1.90
56	15.18	0.49	0.00	2.69		18.36	4.59
58	2.45					2.45	2.45
64	11.76	10.78	1.57	3.20		27.31	6.82
36	36.40	2.91	2.61	1.96		43.88	10.97
1	7.27	4.90	3.53	2.16	3.14	21.00	4.20
3	1.96	0.98				2.94	1.47
52	2.46	1.96	0.78			5.20	1.73
54	2.75	2.94	0.47	2.47		8.63	2.15
15	1.85	1.96	11.97	0.98	1.87	18.63	3.72
25	15.68					15.68	15.68
60	3.93	6.86	28.90	1.37	2.45	43.51	8.70
19							
62	5.36					5.36	5.36
23	2.45					2.45	2.45
49							
45	2.94	1.47	3.66			8.07	2.69
65	1.87					1.87	1.87
16							
17	1.47					1.47	1.47
59							
6							
42	1.72					1.72	1.72
9							

Mg./liter nitrate nitrogen for drains.

Drain	Sample Period						
Number	1	2	3	4	5	Total	Mean
46							
47	4.11	1.89				6.00	3.00
48							
55	2.55	2.75	1.68	2.35	1.47	10.80	2.16
56	1.68	1.68	1.86	1.28		6.50	1.62
58	2.35					2.35	2.35
64	1.68	5.88	3.14	22.55		33.25	8.31
36	4.70	2.55	3.36	2.84		13.45	3.36
1	3.47	2.75	1.71			7.93	2.64
3	1.68	1.57				3.25	1.62
52	1.87	2.63	1.57			6.07	2.02
54	1.96	7.14	2.20	2.76		14.06	3.51
15	2.16	1.79	3.00	1.96	1.96	10.87	2.17
25	3.73	1.96	2.35	2.20		10.24	2.56
60	1.96	2.75	3.05	2.16	94.00	103.92	20.78
19							
62	2.55					2.55	2.55
23	2.94					2.94	2.94
49							
45	1.96	1.79				5.28	1.76
65	2.69					2.69	2.69
16							
17	3.14					3.14	3.14
59							
6							
42	3.92					3.92	3.92
9							

Drain pH determinations.

Drain Number	Sample Period 1	2	3	4	5	Total	Mean
46	7.65	8.30				15.95	7.97
47	7.80	7.65	8.14	7.90		31.49	7.87
48	7.00					7.00	7.00
55	7.75	6.90	4.00	9.50	6.89	35.04	7.00
56	6.94	7.08	7.50	7.12	7.35	21.90	7.30
58	7.40	7.08				14.48	7.24
64	7.15	7.00	7.34	7.73		29.22	7.30
36	7.80	6.88	6.70	8.37		29.75	7.43
1	7.94	7.70	8.10	7.90		31.64	8.33
3	8.45	7.20	6.90			22.55	7.51
52	8.25	8.60	8.00	8.50		33.35	8.33
54	7.49	7.93	8.59	7.80		31.81	7.95
15	7.70	7.91	8.00	8.10	8.30	40.01	8.00
25	7.43	7.12	7.35			21.90	7.30
60	7.89	8.20	8.80			24.89	8.29
19	8.91					8.91	8.91
62	8.91					8.91	8.91
23	7.63	7.42				14.78	7.93
49	8.55					8.55	8.55
45	8.12					8.12	8.12
65	7.45					7.45	7.45
16							
17	8.10					8.10	8.10
59	7.71					7.71	7.71
6	7.60					7.60	7.60
42	7.72					7.72	7.72
9							

Mg./liter total phosphorous for drains.

Drain Number	Sample Period 1	2	3	4	5	Total	Mean
46							
47	0.90	0.39				1.29	0.64
48							
55	0.78	0.58	2.50	0.52		4.38	1.09
56	3.10	4.20	7.50	6.00		20.80	5.20
58							
64	3.50	5.20	7.50	6.80		23.00	5.75
36	0.18	0.28	0.44			0.90	0.30
1	0.14	0.61	0.44			1.19	0.39
3	0.36	1.65				2.01	1.00
52	1.60	1.10	2.20			4.90	1.63
54	0.40	0.34	2.50	0.52		3.76	0.94
15	2.50	4.60	7.00	5.60		19.70	4.92
25	0.00	0.05	0.70	0.43		1.18	0.29
60	0.71	0.27	2.40	1.70		5.08	1.27
19							
62	1.90					1.90	1.90
23	5.52					5.52	5.52
49							
45	0.95	1.30				2.25	1.12
65	0.42					0.42	0.42
16							
17	0.31					0.31	0.31
59							
6							
42							
9							

Drain temperatures in degrees centigrade.

Drain Number	Sample Period				
	1	2	3	4	5
46					
47	26.0	20.5	19.2		
48					
55	26.5	30.0	27.0	34.0	35.2
56	20.0	19.9	22.0	21.0	
58	36.0				
64	26.0	24.0	21.2	25.0	
36	25.0	20.0	18.5	21.5	
1	16.0	17.7	15.8	15.0	
3	24.5				
52	19.0	20.0	24.5		
54	31.0	29.0	33.0	33.5	
15	36.0	45.0	34.5	39.0	39.0
25	16.5	21.2	22.9	24.0	
60	18.4	19.0	20.5	22.0	
19	19.8	20.0			
62	22.0				
23	23.5	22.5			
49	20.9				
45	25.0	23.5	26.0		
65	18.5				
16					
17	19.8				
59	22.0				
6					
42	28.5				
9					

Jackson turbidity units for drains.

Drain	Sample Period						
Number	1	2	3	4	5	Total	Mean
46	39					39	39
47	18	20				58	19
48	44	20				64	32
55	94	39	94	32	17	277	55
56	300	17	81	200	157	1055	211
58	50					50	50
64	300	300	180	180	250	1210	242
36	26	24	25			75	25
1	1000	31	230	16		1277	319
3	102	19				121	60
52	16	10	28			54	18
54	45	39	39	26		149	37
15	16	10	17	23		66	16
25	15	10				25	12
60	17					17	17
19	225	15				220	115
62	18					18	18
23	171	165				336	168
49							
45	19					19	19
65	16					16	16
16							
17	19					19	19
59	20					20	20
6	500					500	500
42							
9							

APPENDIX B

DESCRIPTION OF DRAINS ENTERING RIVER

DESCRIPTION OF DRAINS

September 1, 1964

Drains on South Side of River

Drain Number	Approx. dia. in inches	Description
1	72	Located 20 feet downstream from Hagadorn Road. This drain has a large cement retaining wall and the opening is covered with wire gates.
2	24	Located 100 feet upstream from Bogue Street Bridge. This drain has a large cement retaining wall.
3	12	Located 180 yards downstream from Bogue Street. Drain has a cement retaining wall.
4	14	Located 150 yards upstream from Farm Lane. This drain is one-half submerged, and has a large cement retaining wall.
5	8	Located 20 yards downstream from above drain. This drain has a small retaining wall.
6	24	Located 50 feet upstream from Farm Lane. This drain has a small retaining wall, the opening is located three-fourths below the water, and the drain flows only during rain.
7	6	Located 10 feet upstream from Farm Lane. This drain is a steel pipe sticking out from the river bank about one foot above the water surface.
8	28	Located 50 feet downstream from Farm Lane. This drain has a cement retaining wall surrounded by broken brick.
9	12	Located behind bushes behind Michigan State University canoe shelter. Cement retaining wall.

Continued

Drains on South Side of River - Continued

Drain Number	Approx. dia. in inches	Description
10	10	Located 10 feet downstream from above drain. This drain appears as a hole in the river bank.
11		Located 60 yards downstream from Farm Lane Bridge. This drain is not visible, it appears as a cement retaining wall.
12	12	Located 10 feet upstream from power plant water intake. This drain has a small cement retaining wall and is hidden behind bushes.
13	6	Located one-half the distance between dam and first foot bridge. This drain is a long metal pipe high on the river bank.
14	12	Located 28 yards downstream from dam. This drain has no retaining wall and is high on the river bank.
15	24	Located 10 feet upstream from second foot bridge. This drain which is the power plant drain, has a large retaining wall.
16	16	Located 25 yards downstream from second foot bridge. This drain has a large cement retaining wall. The opening is partly below water.
17	8	Located 10 feet downstream from above drain. This drain has a small retaining wall.
18	36	Located across from botanical gardens. This drain has no retaining wall, and the opening is hidden behind bushes.
19	12	Located across from the women's gym. This drain has a large cement retaining wall.
20	8	Located across from the women's gym. This drain has no retaining wall and is located high on the river bank.

Continued

Drains on South Side of River - Continued

Drain Number	Approx. dia. in inches	Description
21	20	Located 60 yards downstream from third foot bridge. This drain appears as a hole in the river bank. There is no retaining wall.
22	24	Located across from the northeast corner of Kellogg parking lot. This drain is high on the bank, has no retaining wall, and is a cement drain.
23	24	Located one foot downstream from above drain. The end section of this drain has broken off.
24	12	Located under Harrison Street Bridge. This a metal pipe high on the river bank. This drain appears to be a storm drain.
25	72	Located 60 yards downstream from Harrison Street Bridge. This drain has wire gates over the opening.
26	24	Located across from Brody parking lot. This drain has no retaining wall, and is a metal drain located high on the river bank.
27	24	Located across from Brody parking lot. This drain has no retaining wall. Drain is metal, and is located right at the water surface.
28	12	Located 30 yards downstream from above drain. Drain has small dark retaining wall.

Drains on North Side of River

Drain Number	Approx. dia. in inches	Description
29	4	Located 20 yards downstream from Hagadorn Road Bridge. This drain is a small metal pipe difficult to see, located in a gully high on the bank. Apparently is a septic tank drain.
30	4	Located downstream from above drain. A small metal pipe below what appears to be a hot water tank.
31	12	Located 100 yards downstream from Hagadorn Road Bridge. This drain has no retaining wall. Source is Cedar View Apartments.
32	4	Located 30 feet downstream from above drain. Pipe extends below water. Appears to be a septic drain.
33	72	Located 75 yards upstream from Riverside East apartments. This drain has a large cement retaining wall, and a large tree has fallen across the opening.
34	12	Cement drain, no retaining wall.
35	12	Located below parking lot of Riverside East apartments. This drain is a steel pipe that protrudes out about four feet from the river bank.
36	72	Located adjacent to west side of Riverside East apartments. This drain is one-half submerged, and has a large cement retaining wall.
37	12	Drain from Beta Theta Pi fraternity house on Grand River Avenue. No retaining wall.
38	12	Located downstream from drain 37. This drain has recently been installed. Drain has no retaining wall, and soil around the opening is eroded.

Continued

<u>Drains on North Side of River</u> - Continued

Drain Number	Approx. dia. in inches	Description
39	6	Located near east end of Eaton Rock Apartments parking lot. This drain is a steel pipe with wire covers, located about one foot above the water.
40	72	Located 200 yards upstream from Bogue Street. Two drains, a small one and a large one, both covered with steel covers.
41	12	Located 50 feet downstream from Bogue Street Bridge.
42		Located across from drain 3. This drain appears as a large cement retaining wall. Drain opening is not visible.
43	24	Located near far east corner of Kresge. This drain has no retaining wall.
44	12	Located behind Kresge. Drain has no retaining wall, is very dark in color, and is about one foot above the water. Drain is hidden behind bushes.
45		Located behind Kresge. Drain appears as a large cement retaining wall. Hidden behind bushes.
46	12	Located behind Kresge. Drain is one-half submerged, and has a white chalk material around the opening.
47		Located 20 feet upstream from Farm Lane Bridge. Drain is beneath the water.
48	24	Located 10 feet downstream from Farm Lane. Drain is three-fourths below the water. No retaining wall.
49	12	Located a few feet upstream from the Michigan State University canoe shelter. This drain has a small retaining wall.

Continued

Drains on North Side of River - Continued

Drain Number	Approx. dia. in inches	Description
50	20	Located 50 yards upstream from the power plant water intake. This drain has a small cement retaining wall.
51	12	Located 25 feet upstream from power plant water intake. This is a cement drain surrounded by broken sidewalk.
52	12	Located 40 yards downstream from drain 51. This drain has a small retaining wall, but the end section of the drain is broken off.
53	12	Located 10 yards upstream from the first foot bridge. This drain has no retaining wall. Effluent spills out onto a block of cement.
54		Located right above dam. Drain is the outflow from the power plant.
55	12	Located 30 yards below the dam. Effluent flows from a hole in the ground. This drain appears to be a natural stream.
56	24	Located 5 feet downstream from above drain. This drain is three-fourths buried in the mud. Drain is surrounded by sludge banks.
57	12	Located 20 yards downstream from the second foot bridge. Drain is hidden behind trees. Drain has a small retaining wall.
58	24	Located between library and women's gym. This drain has a large cement retaining wall.
59	24	Located behind women's gym. This drain has a large cement retaining wall surrounded with broken sidewalk.
60	36	Located 10 feet upstream from the Kalamazoo Street Bridge. This drain has a large cement retaining wall.

Continued

Drains on North Side of River - Continued

Drain Number	Approx. dia. in inches	Description
61	72	Located across from north-east corner of the athletic field. Drain has a large cement retaining wall. Drain opening is cover with steel cover.
62	24	Located 10 yards downstream from third foot bridge. This drain has a small cement retaining wall.
63	20	Located across from Kellogg Center parking lot. Drain has a small cement retaining wall.
64	24	Located under Harrison Street Bridge. This drain has no retaining wall.
65	12	Located across river from drain 22. Drain has a large cement retaining wall.
66	36	Located across from Kalamazoo Street sewage treatment plant. This drain has a large cement retaining wall.
67	12	Located 10 feet downstream from above drain. Drain has a large cement retaining wall.
68	12	Located 10 feet downstream from above drain. This drain has a large cement retaining wall.

APPENDIX C

RIVER STATION SAMPLING DATA

Total alkalinity measurements for river sampling stations, as mg./liter $CaCO_3$.

Station	Sample Period							Total	Mean
	8-7-64	8-14-64	8-24-64	9-5-64	9-12-64	9-24-64	10-17-64	$T_{.j}$	$\bar{X}_{.j}$
1	226	88	200	240	226	234	260	1474	210 ± 55
2	214	196	220	240	234	242	268	1614	230 ± 23
3	210	294	208	234	232	266	266	1644	235 ± 25
4	240	214	220	216	242	224	266	1622	231 ± 19
5	268	224	210	230	268	248	280	1728	248 ± 27

Percent dissolved oxygen saturation at river stations.

Station	Sample Period (1964)											Total	Mean
	8-5	8-7	8-12	8-15	8-25	8-28	9-3	9-14	9-17	10-3	11-7	$T_{.j}$	$\bar{X}_{.j}$
1	74.2	65.0	56.4	96.4	71.0	68.2	84.4	69.3	93.8	67.0	81.0	826.7	75.0 ± 12.4
2	38.4	36.5	32.0	55.6	70.2	53.0	64.2	58.6	82.3	68.4	59.7	618.9	56.2 ± 15.4
3	27.1	23.8	36.0	51.2	58.9	57.3	64.3	60.8	77.5	75.3	61.4	593.6	54.0 ± 14.3
4	17.3	13.3	19.4	33.3	50.7	50.2	39.4	40.0	61.1	60.6	49.3	434.6	39.5 ± 16.9
5	5.71	7.57	9.45	16.8	38.0	38.9	16.3	23.2	31.3	3.60	10.9	201.0	18.3 ± 12.9
$T_{i.}$	162.7	214.3	153.2	253.3	288.8	267.6	268.6	251.9	346.0	274.9	261.3		
$\bar{X}_j$	32.5	42.8	30.6	70.6	57.7	53.5	53.7	50.3	69.2	54.9	52.2		

Mg./liter BOD determinations for river sampling stations.

Station	Sample Period								Total	Mean
	8-7-64	8-14-64	8-25-64	9-3-64	9-12-64	10-17-64	11-7-64	11-26-64	$T_{.j}$	$\bar{X}_{.j}$
1	3.78	6.64	5.04	2.62	1.38	1.66	3.31	5.97	29.56	3.69±1.39
2	3.18	9.60	5.68	4.02	1.20	2.82	3.76	4.81	42.06	5.25±3.35
3	5.65	4.22	4.80	0.68	1.72	1.82	3.20	5.92	36.38	4.54±2.90
4	2.14	7.00	5.76	5.07	2.44	2.22	3.45	5.00	33.11	4.14±1.94
5	3.98	12.30	6.34	6.49	4.76	15.00	16.30	19.40	84.84	10.60±5.80

Mg./liter ortho-phosphorous for river sampling stations.

Station	Sample Period					Total	Mean
	8-8-64	9-5-64	9-12-64	9-24-64	10-17-64	$T_{.j}$	$\bar{X}_j$
1	0.57	0.37	0.41	0.40	0.07	1.81	0.36 ± 0.17
2	0.45	0.28	0.33	0.41	0.11	1.58	0.31 ± 0.10
3	0.64	0.32	0.36	0.45	0.25	2.02	0.40 ± 0.10
4	0.97	0.32	0.41	0.45	0.52	2.67	0.51 ± 0.24
5	2.10	2.10	2.10	1.20	2.10	9.60	1.12 ± 0.36

Mg./liter total phosphorous for river sampling stations.

	Sample Period							Total	Mean
Station	8-8-24	8-14-64	8-25-64	9-5-64	9-12-64	9-24-64	10-17-64	$T._j$	$\bar{X}_j$
1	0.69	0.29	0.15	0.40	0.44	0.36	0.06	2.39	0.34 ± 0.20
2	0.61	0.50	0.19	0.33	0.53	0.41	0.17	2.73	0.39 ± 0.14
3	0.49	0.78	0.64	0.38	0.40	0.61	0.27	3.57	0.51 ± 0.14
4	1.00	0.49	0.35	0.39	0.42	0.32	0.44	3.41	0.49 ± 0.56
5	2.80	1.35	1.30	2.10	2.10	1.96	2.10	13.71	1.95 ± 0.51

Mg./liter ammonia nitrogen for river sampling stations.

	Sample Period							Total	Mean
Station	8-8-64	8-14-64	8-25-64	9-5-64	9-12-64	9-24-64	10-17-64	$T_{.j}$	$\bar{X}_{.j}$
1	1.20	2.75	2.30	1.57	2.26	2.18	3.16	15.42	2.20 ± 0.31
2	0.98	3.43	2.85	2.55	2.94	3.50	3.67	19.92	2.84 ± 0.29
3	1.96	2.11	2.94	1.29	2.27	1.96	2.96	15.49	2.71 ± 0.18
4	0.98	1.94	1.57	2.35	2.28	2.11	3.43	14.66	2.09 ± 0.23
5	6.86	2.09	1.77	2.65	2.77	1.82	5.01	23.78	3.25 ± 1.35
$T_{i.}$	11.98	13.13	11.43	10.41	12.52	11.57	18.23		

Mg./liter nitrate nitrogen for river sampling stations.

Station	Sample Period							Total	Mean
	8-8-64	8-14-64	8-25-64	9-5-64	9-12-64	9-24-64	10-17-64	$T._j$	$\bar{X}._j$
1	2.75	2.73	2.55	3.13	2.06	2.55	4.66	20.43	2.92 ± 0.82
2	2.35	2.94	3.13	2.65	2.95	2.84	4.90	21.76	3.11 ± 0.82
3	1.76	2.50	1.96	1.96	1.77	2.20	2.94	15.09	2.16 ± 0.42
4	1.96	1.89	2.35	1.87	1.67	2.28	4.13	16.15	2.31 ± 0.82
5	1.76	1.60	5.39	2.12	2.06	2.12	5.88	20.93	2.70 ± 1.82

Mg./liter organic nitrogen for river sampling stations.

Station	Sampling Period					Total	Mean
	8-8-64	8-14-64	8-25-64	9-5-64	9-12-64	$T._j$	$\bar{X}_j$
1	5.31	1.96	1.75	2.55	0.00	11.59	2.32 ± 1.92
2	0.00	2.20	2.38	3.14	0.00	7.72	1.54 ± 1.18
3	1.48	0.00	1.96	2.07	2.55	8.06	1.61 ± 0.82
4	3.43	1.53	1.37	0.00	2.20	8.53	1.71 ± 1.25
5	2.45	1.67	1.47	2.06	2.75	10.40	2.08 ± 0.52

River sampling station pH determinations.

Station	Sample Period								Total	Mean
	8-5-64	8-12-64	8-23-64	9-3-64	9-10-64	9-12-64	9-24-64	10-17-64	$T_{\cdot j}$	$\bar{X}_{\cdot j}$
1	7.20	6.20	8.00	7.98	7.40	7.39	7.72	7.88	59.77	7.46±0.59
2	7.60	7.53	7.83	8.04	7.93	7.90	7.55	8.01	62.39	7.79±0.20
3	7.60	8.11	7.69	7.90	8.00	8.00	7.90	7.90	63.10	7.90±0.17
4	7.70	7.79	7.58	7.70	7.80	7.80	7.50	8.09	61.69	7.74±0.14
5	7.51	7.49	7.58	7.70	7.72	7.72	7.55	7.58	60.85	7.16±0.00

Water temperatures at river sampling stations, measured in degrees centigrade.

Day	Station					Total
	1	2	3	4	5	
8-5-64	24.5	27.0	29.0	28.0	25.0	133.50
8-12-64	19.0	19.5	24.8	23.0	19.9	106.20
8-14-64	16.2	20.0	20.0	20.0	20.0	96.20
8-15-64	15.9	18.0	20.0	20.0	18.5	92.40
8-15-64	16.0	20.0	21.0	20.0	20.0	97.00
8-15-64	21.5	21.5	24.0	23.0	21.0	111.00
8-16-64	17.0	18.5	21.0	20.5	19.0	96.00
8-7-64	23.0	24.0	27.5	26.2	26.0	126.70
8-19-64	20.0	26.0	28.0	24.5	24.5	124.00
8-25-64	19.0	19.0	20.5	20.5	20.5	99.50
8-26-64	16.5	17.4	20.1	20.0	19.6	93.60
9-25-64	19.3	22.3	24.0	23.0	22.8	111.40
9-5-64	20.8	23.0	24.0	23.0	21.9	112.70
9-12-64	18.1	20.0	25.0	20.0	19.8	102.90
9-14-64	9.2	19.8	20.0	18.0	18.3	85.30
9-14-64	15.0	18.5	24.0	20.3	20.0	97.80
9-16-64	14.2	15.5	19.5	18.5	17.0	84.70
9-16-64	15.2	18.0	20.0	19.0	18.0	90.20
9-16-64	16.2	18.1	25.0	20.0	20.6	99.90
9-16-64	20.0	23.0	24.0	22.0	20.0	109.00
9-16-64	17.0	19.0	21.0	20.0	20.0	97.00
9-24-64	11.9	13.0	20.0	19.0	18.0	81.90
10-3-64	13.2	13.5	16.0	15.0	14.8	72.50
10-17-64	12.5	13.8	15.5	14.8	17.9	74.50
11-7-64	10.0	10.3	13.0	12.8	14.0	60.10
11-26-64	2.3	1.5	6.0	4.9	7.0	21.70
Total	421.50	480.20	547.75	515.70	504.10	
Average	16.28	18.46	20.99	19.83	19.38	

Grams/liter total residue for sampling stations.

Station	Sampling Period					Total	Mean
	8-12-64	8-25-64	9-5-64	9-12-64	9-24-64	$T._j$	$\bar{X}_j$
1	0.60	1.26	1.25	2.22	3.80	9.13	1.82 ± 1.24
2	3.00	1.73	1.32	0.13	1.46	7.64	1.53 ± 1.02
3	4.40	2.20	2.22	0.93	4.33	14.08	2.81 ± 1.51
4	3.40	3.32	3.00*	0.33	3.86	10.19	2.72 ± 1.62
5	3.10	3.40	1.65	0.39	2.71	11.25	2.25 ± 1.27

*Calculated dummy value.

Turbidity at river sampling stations, measured as Jackson turbidity units.

Station	Sample Period							Total	Mean
	8-7-64	8-14-64	8-25-64	9-5-64	9-12-64	9-24-64	10-17-64	$T._j$	$\bar{X}._j$
1	17	16	17	21	19	22	21	133	19 ± 2.37
2	17	33	60	32	31	29	22	215	31 ± 16.00
3	120	26	59	32	33	26	24	320	43 ± 34.00
4	16	24	45	31	33	24	29	202	29 ± 9.20
5	17	25	44	31	22	25	26	164	23 ± 11.00

Conductance x 10^{-3} measured as Ω^{-1} for river sampling stations.

Station	Sample Period							Total	Mean
	8-7-64	8-14-64	8-24-64	9-5-64	9-12-64	9-24-64	10-17-64	$T._j$	$\bar{X}_j$
1	0.369	0.364	0.338	0.382	0.376	0.490	0.412	2.731	0.390 ± 0.05
2	0.394	0.432	0.528	0.440	0.443	0.534	0.445	3.216	0.460 ± 0.05
3	0.412	0.583	0.522	0.445	0.425	0.610	0.470	3.467	0.494 ± 0.07
4	0.517	0.528	0.522	0.467	0.425	0.574	0.610	3.643	0.520 ± 0.05
5	0.942	0.544	0.349	0.602	0.588	0.642	0.736	4.448	0.635 ± 0.14