THE CHARACTERIZATION AND INFLUENCE OF DOMESTIC DRAIN EFFLUENTS ON THE RED CEDAR RIVER

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ABSTRACT

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DOMESTIC DRAIN EFFLUENTS ON THE
RED CEDAR RIVER

By

Arthur Ray Talsma

A study was undertaken to monitor pollutants entering the Red Cedar River of central Michigan, and to determine their effects on the ecosystem. Dissolved oxygen, conductivity, phosphorus, nitrogen, carbon, suspended solids, chlorides and detergents were among the chemical parameters considered. Bioassays, live cars, bottom fauna and coliform analyses were the biological aspects of interest.

Analyses indicated that pollutants were principally of domestic origin, coming from storm drains and combined storm and sanitary drains. Significant differences were found in water quality and river fauna above sources of pollution as compared with below sources. Most parameters showed little or no improvement since 1964.

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Arthur Ray Talsma

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INTRODUCTION

Man has always had an influence on the water systems he uses. In recent years our concern over the pollution problem has grown because the deterioration of water quality can be seen in almost every community. A growing population places increased industrial, recreational, agricultural and domestic demands on its water supplies. Consequently we are compelled to correctly manage the water environment for our own well being.

Defined by the dictionary, pollution is the act of making foul or unclean. Confusion usually arises because there are many kinds of pollutants and each may have various effects on the aquatic system. To the sportsman stream pollution may mean the degradation of aesthetic value or a reduction in game species. To the aquatic biologist stream pollution may involve a change in species diversity or toxicity to aquatic fauna. The bacteriologist would be concerned over a possible increase in bacteria which are harmful to human health. For the purposes of this study water pollution is considered as the impairment of the suitability of water for any of its beneficial uses, actual or potential, by man-caused changes in water quality (Warren, 1971).

A complete log of information concerning the Red Cedar River has been collected over the past years. Aspects of the river climatology, hydrology and biology are described by Meehan (1958), Vannote (1961) and King (1962), respectively. The Michigan State University Institute of Water Research has published much of the information in a series of reports (Brehmer, Ball and Kevern, 1968), (Grzenda, Ball and Kevern, 1968), (Peters, Ball and Kevern, 1968), (Kevern and Ball, 1969), (Brehmer, Ball and Kevern, 1969). A particularly important study of pollution in the area of Michigan State University and East Lansing was conducted by Alvin Jensen (1966). His investigation was concerned with the river water quality as related to urbanization of the surrounding area. He found a significant decrease in water quality as the river flows through the Michigan State University campus. The change was attributed to polluting drain effluents on which some specific analyses were made.

Persons from the university and city have generally surmised that because of a new sewage treatment plant, improved sewerage and advancements in waste treatment made in the communities upstream from East Lansing, the river water quality has improved in recent years. This study was designed to scientifically test this viewpoint and extend our knowledge regarding the Red Cedar River. The investigation began July, 1970, on a 2.63 mile reach of the river flowing through the Michigan State University campus and East Lansing community of Michigan. The three major objectives of the investigation were as follows: to monitor individual drain effluents for pollutants and to determine amounts and sources, to evaluate the effects of the pollutants found on water quality and river life and to determine changes in the river as a follow-up on research done in the past, especially that by Alvin Jensen (1966). Determinations were directed toward domestic sewage and erosional products, including street runoff. These were the most expected forms of pollution as both Michigan State University and East Lansing are highly residential areas with little industry. Most of the upper drainage basin of the river is in an agricultural region.

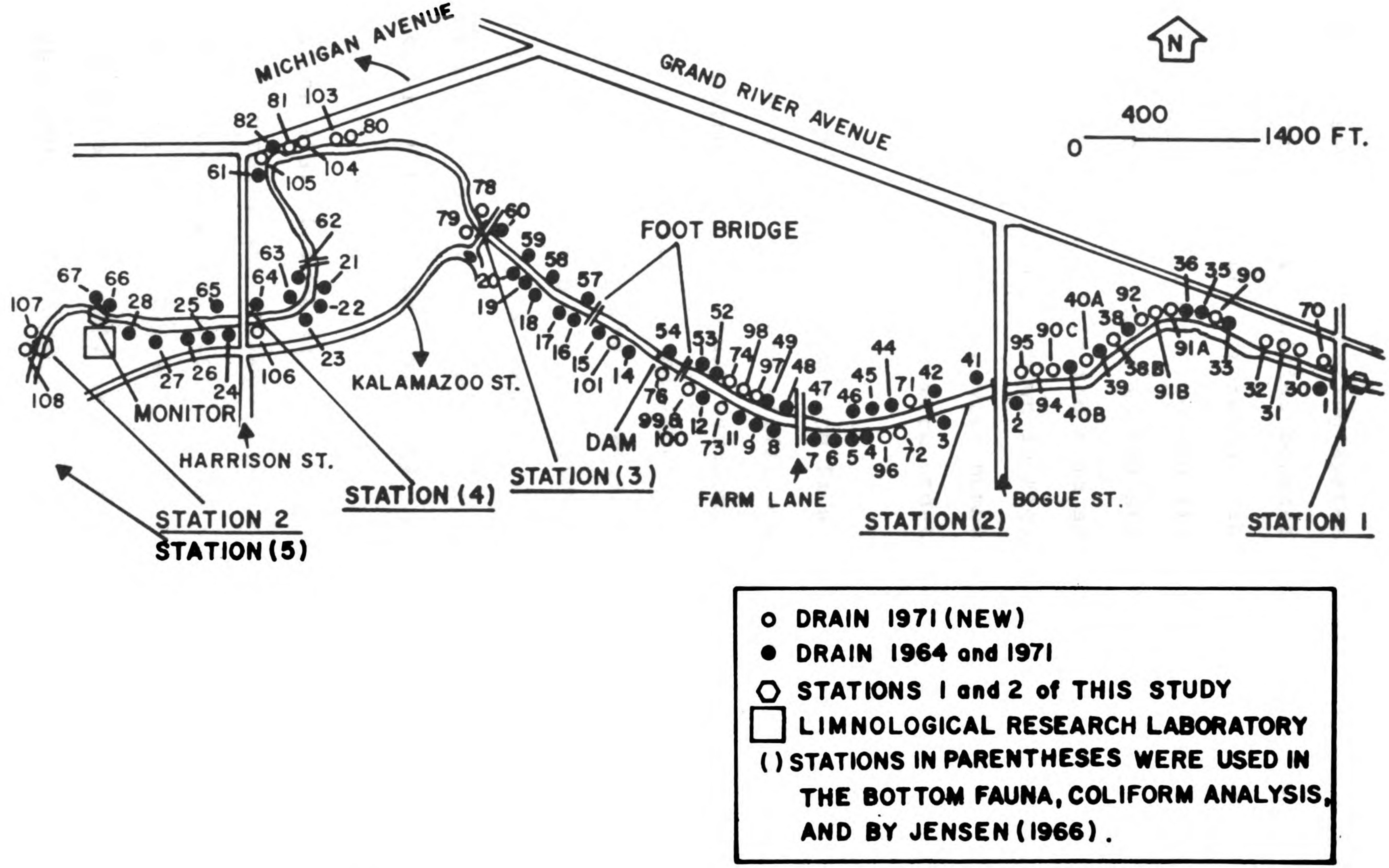
The entry of pollutants into a stream sets off a progressive series of physical, chemical and biological events which may be recognized as dependable criteria of stream conditions (Bartsch, 1967). The parameters selected were those which were felt to best fulfill the objectives of this investigation.

DESCRIPTION OF STUDY AREA

The Red Cedar River is a warm-water stream in southcentral Michigan. It originates as an outflow from Cedar Lake, located in Marion Township, Livingston County, Michigan. The stream flows past the communities of Fowlerville, Webberville, Williamston and Okemos before entering the East Lansing and Michigan State University area. It then connects with the Grand River in Lansing (Ingham County, Michigan).

With the exception of a bottom fauna sampling station at Okemos, the study section was within the boundaries of Michigan State University campus; Hagadorn Road being at the upstream east boundary and East Kalamazoo Street at the downstream west boundary. The study section is 2.63 miles long and the width varies from 25 to 80 feet (Jensen, 1966). At mid-summer in 1970 and 1971 the stream depth varied from less than one foot to approximately six feet in the impoundment formed by a dam located below Farm Lane Bridge (see Figure 1). Along this reach of river approximately 90 drains (all of varying size and significance) enter the river. I

Figure 1. Map of study area. [Locations of stations and drains are shown including information from a study completed by Jensen (1966).]


MICHIGAN AVENUE
GRAND RIVER AVENUE
400
0
1400 FT.
N
FOOT BRIDGE
KALAMAZOO ST.
HARRISON ST.
MONITOR
DAM
FARM LANE
BOGUE ST.
STATION 2
STATION (5)
STATION (4)
STATION (3)
STATION (2)
STATION 1
DRAIN 1971 (NEW)
DRAIN 1964 and 1971
STATIONS 1 and 2 of THIS STUDY
LIMNOLOGICAL RESEARCH LABORATORY
( ) STATIONS IN PARENTHESES WERE USED IN THE BOTTOM FAUNA, COLIFORM ANALYSIS, AND BY JENSEN (1966).

used the same drain numbering system as Jensen (1966) but encountered difficulties because some former drains were no longer present or recognizable; also there have been many new additions. Jensen (1966) had indicated the presence of 68 drains in the study section. I found 90 drain openings within the same section. Therefore, of the first 68 drains shown in Figure 1, most are the same as in 1964 but those with numbers greater than 68 have been newly formed or were undetected by Jensen (1966).

The river is slow moving from Hagadorn Road to the dam after which there are riffle pool areas throughout the remainder of the study section. Above the dam the bottom is principally sand intermixed with rocks. The bottom is covered by one to two inches of silt and detritus. Below the dam the river bed is coarse gravel and sand covered by an inch or less of silt and detritus. Sludge beds have formed below some of the drains. The banks are forested in some areas but much of the river study section runs along parking lots and lawns of Michigan State University.

Figures 2 and 3 illustrate the extreme fluctuation in daily and seasonal flows on the Red Cedar River. As a result of the fluctuation in flow rate, drainage from agricultural areas upstream and rapid runoff from streets and parking lots, the river is often very turbid

Figure 2. Monthly mean discharge near Farm Lane for years 1970 and 1971. [United States Geological Survey at East Lansing, Michigan.]

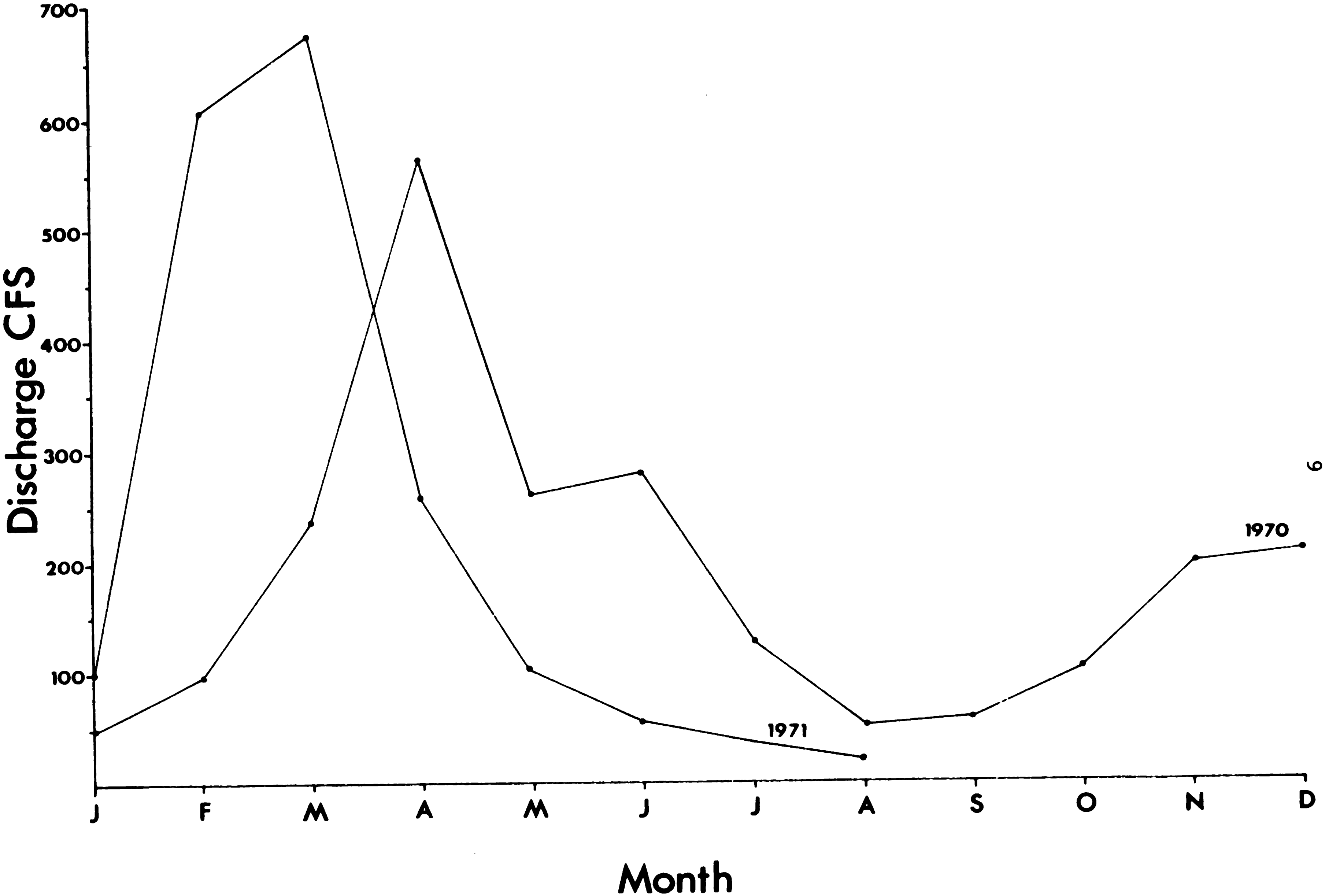
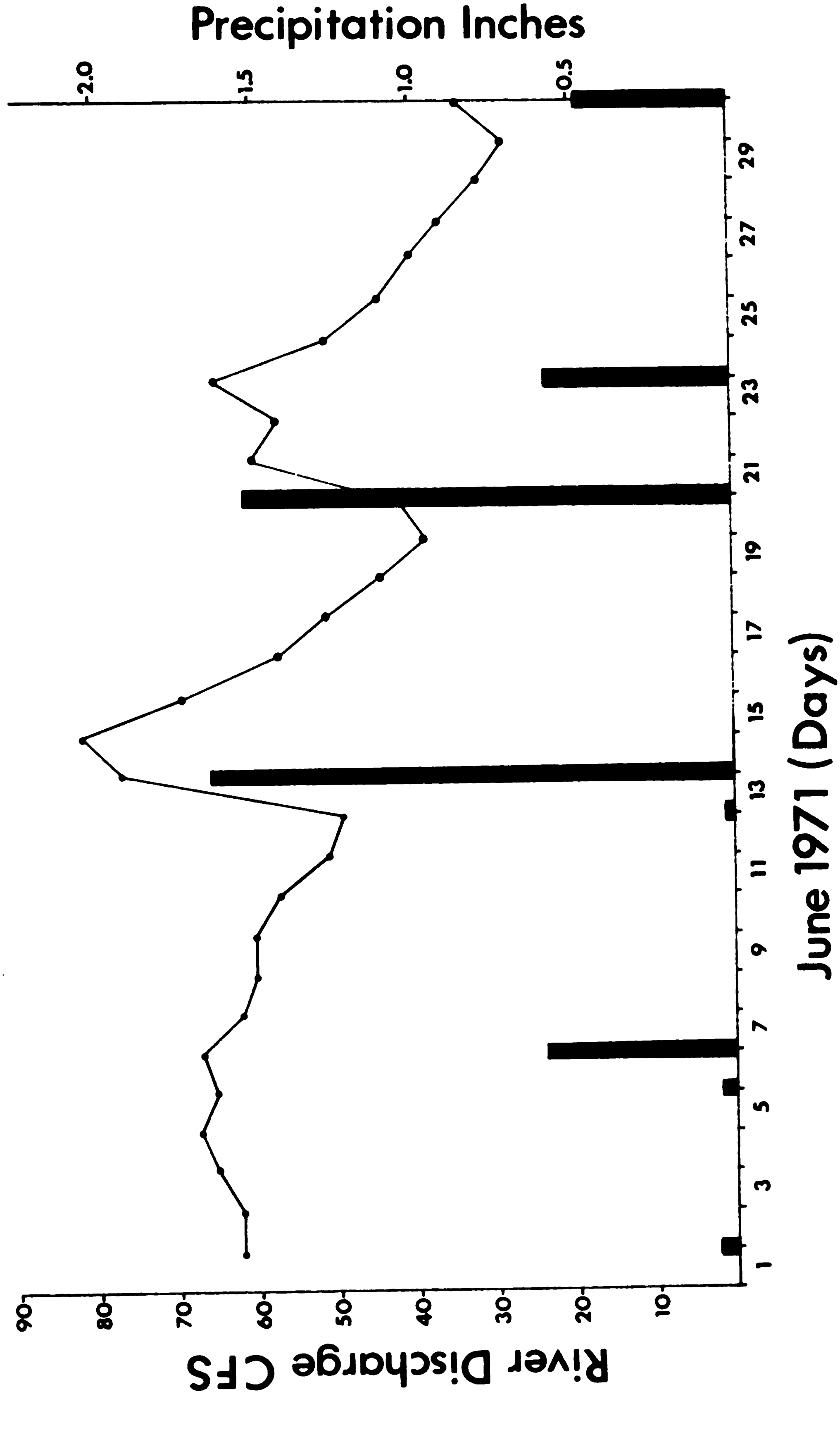

Discharge CFS
700
600
500
400
300
200
100
J
F
M
A
M
J
J
A
S
O
N
D
Month
1970
1971

Figure 3. Precipitation and discharge for June, 1971. Bars represent precipitation. [U.S. Department of Commerce. Local Climatological Data for Lansing, Michigan, and U.S. Geological Survey Station near Farm Lane.]


Precipitation Inches
2.0
1.5
1.0
0.5
River Discharge CFS
90
80
70
60
50
40
30
20
10
June 1971 (Days)
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29

in the lower portions. Because of the turbidity and scouring effect after rain storms, the plant life throughout the study section is restricted even though nutrients are present in excess. Diurnal dissolved oxygen pulses are common with critically low values occurring in the study section during summer and early fall. The aesthetic value of the river and its banks has been lowered by the excessive amount of debris and garbage present.

METHODS

In solving the pollution problem analytical methods for gathering basic data, monitoring, research and treatment control should be continuously upgraded by systematic evaluation and standardization (American Chemical Society Report, 1969). Many authorities including the Federal Environmental Protection Agency recommend the use of Standard Methods (APHA, AWWA, WPCF, 1971) for pollution studies. For this reason, whenever possible, analyses performed for this study were completed using the above reference. Whenever a question arose concerning the reliability of an analysis, replicates were run on the given sample. Standard solutions were used regularly with all analyses in order to check their accuracy.

Sampling Design and Statistics

Pollutional evaluation of the river was paramount in this study, so three scientific restrictions were placed on sampling. In general, sampling was conducted when pollutants were thought to be entering the river and at places where pollutants were more likely to be found. Also, it was necessary that the drains be

flowing to enable sampling. Following this design, approximately 45 sampling trips were conducted from July, 1970, to August, 1971. Sampling during the winter months was less frequent. Once samples were collected from the drain effluents, analyses for alkalinity, hardness, chlorides, phosphorus, nitrogen and carbon were regularly completed. At river stations, dissolved oxygen, bottom fauna and coliform determinations were performed in addition to the parameters mentioned above.

The statistics of this study, although principally descriptive summaries, estimate population parameters with the aforementioned restrictions. Common statistics such as means ($\bar{X}$), variances (s_x^2), standard errors (s_x), test of homogeneity and appropriate tests for significant differences between means were performed when needed. Note that in pollutional studies it is often the variance or range (extraordinary value) that one is concerned about rather than a mean.

Sampling Procedures

Water samples were taken in 1000 ml dichromate-rinsed, polyethylene, wide-mouth bottles. To sample the river, bottles were submerged approximately one foot below the surface at midstream. When sampling the drains the bottles were held directly under the effluent except at submerged drains where the samples were taken nearest the opening. All significant drains as well as the two river stations were sampled by canoe or from the bank. The two river sampling stations were at the beginning, Hagadorn Road, and end of the study section, below the Michigan State University Limnological Research Laboratory near East Kalamazoo St. (stations 1 and 2, respectively). These stations were equivalent to stations 1 and 5 in the study made by Jensen (1966). In the case of bottom fauna and coliform examinations, station locations were the same as in Jensen's (1966) study. Samples were labeled when collected, preserved appropriately and refrigerated at 4 C until tests were run. Time, temperature, approximate flow rate, general observations and sample numbers were recorded while at the drain sites. When a drain was not flowing during a sampling trip only the time and flow condition were recorded. When the flow rate of a drain was considered insignificant to warrant sampling or enough samples had previously been taken, only the time, temperature, approximate volume and general observations were recorded.

Chemical Methods

Total Alkalinity, Hardness, and Chlorides

Total alkalinity, hardness and chloride determinations were made by the titrimetric methods described in Standard Methods (APHA, AWWA, WPCF, 1971). The EDTA method was used for hardness determinations and the mercuric nitrate method for chloride analyses.

Detergents

Synthetic detergents (containing surfactants) can cause degradation of water quality by addition of phosphorus and by frothing. Due to lack of time I did not analyze for the presence of detergents in all water samples. Determinations were made on those effluents that were foaming or suspected of containing appreciable amounts of detergents. The methyl green method as described by Hach (1969) was used. The indicator reacts with anionic surfactants such as alkyl benzene sulfonate (ABS) and the more biodegradable linear alkylate sulfonate (LAS). Color intensity was read on a Klett-Summerson colorimeter using a number 54 (green) filter. Values for the samples were read from a standard curve made using standard alkyl benzene sulfonate. Many of the samples from the drains were high in phosphates, chlorides and nitrates, all of which are positive interferences with this method. For this reason caution was taken while making the determinations but little interference was encountered. For example, samples high in phosphorus but with no detergents present showed zero mg/liter detergents. Due to a lack of interferences on the water samples that were analyzed and good reproduction of standard curve values, the method was considered reliable.

Also phosphorus values were complimentary to the detergent values obtained. Often when detergent concentrations were high, phosphorus values were above that normally found in raw sewage.

Phosphorus

Total dissolved and suspended acid-hydrolyzable phosphate determinations were made using the stannous chloride method as described in Standard Methods (APHA, AWWA, WPCF, 1971). Precautions such as using double distilled deionized water, acid-washed glassware and equal timing conditions were employed. The results include dissolved and suspended orthophosphates and hydrolyzable phosphates. The hydrolyzable phosphorus, in turn, includes polyphosphates and some organic phosphorus. The analyses were usually performed within two days after collection, and the results were listed as mg P/liter.

Total Kjeldahl Nitrogen

Total Kjeldahl nitrogen includes free ammonia and organic nitrogen compounds. The Water Research Laboratory at Michigan State University made the determinations for total Kjeldahl nitrogen following the procedure as described in Methods for Chemical Analysis of Water and Wastes (E.P.A., 1971). After collecting, the samples were preserved with 40 mg.$HgCl_2$/liter and stored at 4 C until analyzed. For the determination of ammonia after distillation the Nesslerization method was used. The ammonia-nitrogen was read from a standard curve, and the results were expressed as mg N/liter.

Ammonia-Nitrogen

The distillation method followed by Nesslerization was used for ammonia determinations (APHA, AWWA, WPCF, 1971). Only those samples suspected of having high concentrations of free ammonia or those found to have high concentrations of total Kjeldahl nitrogen were analyzed. Also determinations were made during bioassays when ammonia concentrations were thought to be influential.

Dissolved Organic Carbon

Organic carbon (filterable) determinations were made by the Water Research Laboratory. The instrumental method as described in *Methods for Chemical Analysis of Water and Wastes* (E.P.A., 1971) was used. Samples were preserved and stored at 4 C to prevent oxidation or bacterial decomposition of the organic carbon compounds prior to analysis. Samples were filtered with a 0.45μ Millipore filter, and after acidifying to pH 2.0, the carbonate and bicarbonate carbon was removed by bubbling with nitrogen for five minutes. The samples were then analyzed for organic carbon with a Beckman 915 carbonaceous analyzer. Phthalate standard solutions were used and results recorded as mg C/liter.

Dissolved Oxygen

Dissolved oxygen was measured by polarographic probe and by using the azide modification of the Winkler method as described in Standard Methods (APHA, AWWA, WPCF, 1971). At the Limnological Research Laboratory water is pumped from the river (station 2) into the sensor ports of a continuous flow monitor which was maintained during most of the study period. This instrument monitored the dissolved oxygen with a membrane electrode. Results were recorded as mg DO/liter.

Chromium

Samples from drain effluents suspected of having significant chromium concentrations were analyzed by the Water Research Laboratory. The atomic absorption spectrophotometric method was used, following the procedure in Methods for Chemical Analysis of Water and Wastes (E.P.A., 1971). Results were recorded as mg Cr/liter.

Physical Methods

Temperature, pH, Conductivity

Temperature, pH and conductivity were monitored by the continuous flow monitor at the Limnological Research Laboratory. The accuracy of the monitor was checked at regular intervals. Because the monitor yielded information only on river water from station 2,

measurements of these parameters from station 1 and drain effluents were collected by other means. Temperature was measured with a thermometer while at the river and drain sites. Conductivity and pH measurements were made immediately upon returning to the laboratory with an Industrial Instruments Conductivity Bridge model RC 16B2 and a Beckman Zeromatic II pH meter.

General Observations

While at the drain and river sites general observations were made concerning the severity or intensity of water quality conditions such as: odor, color, gas films, oils, foam, dead aquatic fauna, sludge beds and suspended matter including human feces, sludge and paper. Although these observations were subjective, they were very helpful in choosing further tests, often complemented each other, and were supported by other parameters. For example, a toxic drain effluent with a yellow-green color was analyzed and found to have a high chromium concentration.

Fluorescein Dye Survey

Fluorescein dye was used to help determine sources of pollution. When concerned about an effluent from a specific drain, possible sources were considered by using a map of Michigan State University and East Lansing sewerage system. Speculation as to the contributing

source or sources was made by dropping 15g of fluorescein dye into the sewerage system at points of interest, after which the drain effluent was checked for dye. In all cases the dye was easily visible in the drain effluent and there was no need for fluorometric analysis. Usually only the building from which the effluent may have originated was determined. Errors can be made in a survey procedure of this type and it should be considered as only one method of many which should be used to pinpoint a specific source of pollution.

Biological Methods

Bioassays

Acute toxicity bioassays were used to evaluate effects of drain effluent wastes on fish. Nine static bioassays were run on effluents from five different drains. Bioassay procedures as described by *Standard Methods* (APHA, AWWA, WPCF, 1971) were followed as closely as possible. Because certain procedures and the effluents tested varied between individual bioassays, some of the information concerning methods, materials and results are recorded in Appendix B. The remainder of this section covers factors that were common to all nine bioassays.

The static bioassay, with modification by controlled artificial oxygenation was used because effluents tested often contained excessive biochemical oxygen demands. Dissolved oxygen was maintained by pumping air into the test containers at a rate capable of supplying 4-8 mg/liter. Throughout each bioassay the difference in dissolved oxygen between containers at any one time was minimal; usually testing started with approximately 5 mg/liter in each tank and slowly increased to 7 mg/liter at the end of a 96-hr period. The test containers were 10 gal. rectangular glass aquaria with a depth greater than 15 cm. Test containers were cleaned with detergent and water followed by acid rinsing and final rinsing with distilled water. Green sunfish, Lepomis cyanellus, were used as the experimental fish because they were adaptable to laboratory conditions and common in the Red Cedar River. Fish were taken from a common source other than the river where there was no known prior exposure to unusual conditions. The fish were acclimated to laboratory dilution water (Appendix B) for two weeks before testing. Incidence of disease or mortality was less than 5 percent. Fish were fed daily until two days before testing and not fed during the bioassay. Fish of a uniform size were used. The weight of fish in a test container did not exceed 2 g/liter of test solution. The bioassay test period was 96 hours with the number of dead fish in each test container being observed and recorded at the end of each

24-hr period after introduction of the fish. Fish were considered dead upon cessation of respiratory and other movements and when there was no reaction to mechanical proding. Behavior reactions during the test and symptoms before death were recorded.

The results of the bioassays were expressed in terms of tolerance limits (TL) as described in Standard Methods (APHA, AWWA, WPCF, 1971). A 96-hr TL_{50} of a toxic substance is that concentration in which 50 percent of the fish survive for 96 hours. This value was estimated from a plot of the test data on semilogarithmic coordinate paper with concentrations (percentage by volume) on the logarithimic axis, and percentage survival on the arithmetic axis. The straight-line graphical interpolation was then used to obtain the TL_{50} value.

Bacteriological Methods

Water samples from five river stations (Figure 1) were examined for coliform group bacteria. The coliform group includes all aerobic and faculatative anaerobic, gram-negative, rod-shaped, non spore-forming bacteria which ferment lactose with gas formation within 48 $\mp$ 3hr at 35 C $\pm$ 0.5C. The multiple-tube fermentation technique for members of the coliform group as described in Standard Methods (APHA, AWWA, WPCF, 1971) was used. Samples were taken in sterile sodium thiosulfate-treated glass bottles. Three samples were taken at each station from a bridge by lowering sample bottles through the surface to obtain representative samples. On both sampling dates one sample was taken at midstream, and one approximately equidistant between midstream and each shore. Little time elapsed between collection and examination, where the presumptive test with lauryl tryptose broth was used. The confirmatory test with brilliant green lactose bile broth was run as a check on the first sampling date. The results of the examinations were expressed in terms of the Most Probable Number (MPN).

Bottom Fauna

Bottom fauna (benthic macro-invertebrates) samples were collected with a weighted Petersen dredge. The dredge samples an area of 1.0 square foot to a depth of 2-4 inches. The Petersen dredge was chosen over that of a Surber or Eckman sampler because of the depth of sampling, weak current and coarse bottom. Even with this rugged dredge there was some difficulty sampling so the dredge was lowered repeatedly until an adequate sample was secured. Five "pool" sampling stations were located at the same sites as described by Jensen (1966) and are indicated on Figure 1. Two riffle sampling stations were established, one upstream at Ferguson Park, Okemos and the other 200 feet below the Limnological Research Laboratory. At each station three samples were taken for each sampling date. One sample was taken at midstream and one approximately equidistant between midstream and each shore. Samples were returned to the laboratory in plastic bags and either analyzed immediately or refrigerated. All samples were screened with a standard 30-mesh sieve and organisms picked live by hand with the use of viewer (light and magnifier) and white pan. At downstream stations numbers of chironomids and oligochaetes were so prolific in some cases that only sub-samples were analyzed and appropriate multiplications made. Complete samples were examined for all other organisms. Organisms were preserved in 70 percent ethanol until counted and identified under a binocular dissecting microscope. Keys by Pennak (1953) and Ward and Whipple (1959) were used in identification. Information theory as proposed by Margalef (1956) was used to express species diversity.

Live Car Methods

Live cars were placed above and below specific drains to determine the effects of the effluents upon fish. Four live cars (boxes or cages) were constructed with steel frames and wire mesh, each car having a volume of 2 cubic feet (56.6 liter). They were coated with asphaltum varnish to prevent corrosion and injury to the fish. The effluents of four drains were examined with this technique during separate periods of time. Three live cars were placed in the river for each drain

under study and a major control was kept in the river at the beginning of the study section (Hagadorn Road). Car 1 was approximately 20 yards above the drain studied, where there was no influence of the effluent upon the fish. Car 2 was placed immediately below (3 yards) the drain where water was 50-100 percent effluent. Car 3 was approximately 20 yards below the drain in water which was 0-50 percent effluent. Any difference in mortality between car 1 and 2 could have been the result of a toxic effluent from the drain being studied. A difference between car 2 and 3 would likely be due to dilution, whereas a difference between the major control and car 1 could result from the influence of other drains above the one studied. Ten green sunfish were held in each live car. Fish were acclimated to the temperature of the river before the test period started. Many of the same precautions as followed in the bioassay procedures were repeated in the live car testing. For example, fish of similar size were used and their average weight was recorded for each test. Results are expressed as cumulative percent mortality for each live car.

RESULTS AND DISCUSSION

Drain Effluent Analyses

Similar to Jensen's (1966) study, results of analyses indicated effluents of approximately one-third of the drains located within the bounds of the study area contained materials detrimental to the water quality of the Red Cedar River. One difference is that there are now 90 drains present, whereas, Jensen (1966) reported 68. I would consider approximately nine drains to be major polluters based upon the quantity, frequency of flow and the type of pollutants found in the effluents. Several drain effluents contributed high organic loads with a few containing entirely untreated domestic sewage for days at a time. High chloride concentrations were frequently found in effluents flowing from several of the drains, and a few effluents periodically contained lethal concentrations of chemicals. Gas and oil films were commonly observed, below certain drains. During rains, storm drains often contributed heavy silt loads causing the river to become turbid.

Tables 1 and 2 express measurements of magnitude and dispersion concerning specific pollutants from the

Table 1. Statistical summary of phosphorous and nitrogen analyses for major drain effluents.

Drain Number	Phosphorus mg/liter					Nitrogen mg/liter				
	N	$\overline{X}$	Range	s_x	$s_{\bar{x}}$	N	$\overline{X}$	Range	s_x	$s_{\bar{x}}$
66	20	6.37	10.27-1.63	2.16	0.48	22	41.93	324.00-8.50	77.13	16.45
25	26	1.65	19.56-0.09	3.78	0.74	27	4.35	37.00-0.20	8.87	1.71
82	12	4.12	8.02-1.24	2.17	0.63	12	46.96	392.00-5.00	108.98	31.46
15	14	3.34	28.53-0.23	7.35	1.96	14	1.07	2.45-0.20	0.65	0.17
6	15	0.70	2.20-0.23	0.49	0.13	15	1.05	1.76-0.40	0.42	0.11
62	18	0.70	1.63-0.21	0.38	0.09	17	0.56	1.49-0.02	0.40	0.10
61	5	3.88	11.21-0.81	4.27	1.91	5	8.01	15.40-2.80	5.44	2.43
36	14	0.18	0.78-0.06	0.18	0.05	14	1.34	3.32-0.27	0.91	0.24
Station 1	19	0.16	0.51-0.04	0.10	0.02	19	1.03	1.85-0.67	0.38	0.09

Table 2. Statistical summary of carbon and chloride analyses for major drain effluents.

Drain Number	N	Carbon mg/liter				Chlorides mg/liter			
		$\overline{X}$	Range	s_x	$s_{\bar{x}}$	$\overline{X}$	Range	s_x	$s_{\bar{x}}$
66	22	31.57	61.50-16.00	11.64	2.48	231.86	635.0-60.0	154.3	32.90
25	27	18.13	85.00-1.00	21.03	4.05	1,440	8,350-6.0	2,529	486.70
82	12	34.58	56.50-20.00	10.95	3.16	242.58	2,200-23.5	618.7	178.61
15	14	10.39	24.50-2.00	5.91	1.58	14.79	48.0-0.6	11.1	2.97
6	15	7.88	19.50-4.50	3.70	0.95	23.15	61.0-0.7	16.9	4.37
62	18	6.64	31.50 2.00	7.09	1.67	186.42	1,900-3.0	516.3	121.70
61	5	59.10	112.50-7.50	45.78	20.47	468.20	1,365-16.0	537.3	240.29
36	14	14.00	61.50-4.00	14.49	3.87	1,096	4,650-46.0	1,556	415.93
Station 1	19	9.21	15.50-1.00	3.45	0.79	24.24	37.5-13.5	6.5	1.48

major drains. Values for station 1, representative of the river above the drains, are included for comparison. Additional information is given in Appendices A and D.

Certain factors influenced the statistical values presented and should be considered when studying the tables. Samples contained observations from different seasons. For example, chloride concentrations may be expected to be higher in the winter due to street de-icing practices. Samples contained extraordinary observations. For example, high concentration of pollutants may enter only once a year and are not at all the usual case for a particular drain. Also, one must consider the scientific restrictions placed on the sampling.

To reveal similarities, one can compare the results of certain drain effluent analyses to analyses made on incoming raw sewage at the East Lansing Waste Water Treatment Plant. For the month of June, 1971, analyses made by the plant resulted in the following mean concentrations of chemicals: chlorides, 291 mg/liter; total phosphorus, 6.7 mg/liter; and total Kjeldahl nitrogen, 11.4 mg/liter. The character and amounts of raw sewage escaping from combined-sewer overflows, storm water from separate systems and sewage filth awaiting the scouring effect of storm-water flow are discussed by Weibel (1969).

Drain 66: Drain 66 is a combined-storm and sanitary drain which often flowed raw sewage with a high organic nutrient load. A main sewerage interceptor, comprised of three pipes passing under the river at this point, became blocked at times causing the controlling pressure caps of drain 66 to open and discharge raw sewage into the river. There was evidence also that the pressure caps stayed open at times. This drain was designed to flow only during rain and melting conditions, but because of reasons stated above, this was not the case. Fluorescein dye injected into the main sewerage interceptor below Michigan Avenue on May 5, 1971, flowed from drain 66 several minutes later. During a storm the effluent of this drain was diluted with rain water, but when flowing on a "dry" day long after any rain, the drain effluent was entirely raw sewage discharged to the river instead of being treated by the East Lansing Waste Water Treatment Plant. Values from Tables 1 and 2 show the nutrient load (phosphorus, nitrogen and carbon) to be high. Chloride concentrations were well above those found in the river. One likely source is domestic waste, particularly urine, which increases the amount of chloride in sewage about 15 mg/liter above that of carriage water (Sawyer and McCarty, 1967). Anionic detergent analyses of over 1.5 mg/liter accounted for the foaming seen at times and the increased phosphorus load. Synthetic detergents having polyphosphates as "builder" have been estimated to increase the phosphorus concentration of domestic sewage two to three fold (Sawyer and McCarty, 1967). On the selected days that I analyzed for ammonia nitrogen, results were commonly above 9 mg/liter.

Five bioassays (I-V) were performed using effluents from this drain. Bioassay IV is presented in detail in Appendix B, but the others were performed similarly. One difference being that laboratory dilution water was used in bioassays I-III, whereas, river water taken from station 1 was used for dilution in bioassays IV and V. The results of the bioassays, expressed as 96hr TL_{50} values, were as follows: number I = 59.0 percent effluent, number II = 8.1 percent effluent, number III = 25.7 percent effluent, number IV = 35.0 percent effluent and number V = 80 percent effluent. A key observation is that in all five tests some fish died, thus the effluent from drain 66 had a lethal effect on green sunfish.

There is evidence that ammonia and detergents were the toxic agents. The initial ammonia nitrogen concentration for bioassay IV was 15.0 mg/liter. Temperature, oxygen content and pH all affect the toxicity of ammonia (Hynes, 1960). Ammonia is very toxic in warm alkaline water with a low oxygen content. Ellis (1937) states that under average stream conditions with pH value

7.4 and pH 8.5, 2.5 mg/liter NH_3 will be harmful to individuals of the common aquatic species. The initial detergent concentration for bioassay IV was 1.65 mg/liter. Many factors influence the toxicity of detergents such as pH, temperature, type of detergent and dissolved oxygen. For example, as dissolved oxygen content falls detergents become more toxic (Herbert _et_ _al_., 1957). Hokanson (1968) states that in static bioassays, the mean 24-hour TLm values at 25 C in hard water saturated with oxygen was 2.54 mg/liter for L.A.S. detergent. Swisher, O'Rourke and Tomilinson (1964) reported that L.A.S. is relatively toxic to bluegills with the 96hr. TLm value of 3 mg/liter for the C_{12} homolog and 0.6 mg/liter for C_{14} homolog. According to Pickering and Thatcher (1970) the acceptable L.A.S. concentration for fathead minnows is between 0.63 and 1.2 mg/liter based upon chronic toxicity tests. From the evidence presented it seems likely that ammonia nitrogen and detergent concentration of the effluents from drain 66 were responsible in part for the death of green sunfish in bioassays I through V. Other stressing factors that likely added to the toxicity were higher than normal salt content, turbidity, oil film and bacterial populations.

The effect of river dilution on toxicity can be estimated. On sample dates the average dilution ratio

of drain 66 effluent to the river was 1:85 (Appendix A). In bioassay number III the effluent was lethal to one-half the test fish at a ratio of approximately 1:4 (25.7 percent effluent). Therefore, once diluted, effluent from drain 66 is not likely to be acutely toxic to fish. Chronic toxicity to fish and other fauna may, however, result. To have a chronic effect the drain would have to flow frequently or continuously, and fish would have to be somewhat limited in movement.

Applying a factor to the acute toxicity level to estimate a "safe concentration" is difficult and unwise unless a detailed investigation is made. This is especially true when working with sewage, which often contains a mixture of toxic substances. Lloyd (1961) has found that at times toxicities of mixtures of substances are equal to the sum of the toxicities of their components. An excellent discussion of application factors is given by Warren (1971), who reports that the Federal Water Pollution Control Administration has recommended application factors ranging from 0.1 to 0.002 of the acute toxic concentrations depending upon the substance tested and its characteristics. Concentration of materials that are nonpersistent should not exceed 0.1 of the 96hr TLm value at any time. The 24-hour average of the concentration of these materials should not exceed 0.05 of the TLm values after mixing

(FWPCA., 1968). By applying a factor of 0.05 to the 96hr TL_{50} one concludes that the effluent from drain 66 would not chronically effect green sunfish once it has been completely diluted with the river. Above statements were based upon averages and approximations and consider only the effect of poisonous substances. It may be wise to note, however, that on a specific date these statements may be invalid. For example, on June 19, 1971, the dilution ratio of drain 66 effluent to the river was estimated to be 1:38. Certainly, this figure represents a significant difference from the figure of 1:85. Therefore, on the above date, the effluent of drain 66 may well have had a decided effect upon the aquatic life below its opening; especially if one considers additional adverse conditions such as low oxygen or above average temperatures which are common with sewage pollution.

Finally, it is important to report that on three occasions the city sanitation department quickly responded to my request to have this drain checked and corrected. It is unfortunate that unless action is taken by a concerned citizen, a drain can pollute for long periods of time before being corrected.

Drain 25: This drain is a large storm drain which collects runoff from Michigan State University south campus. During a storm it discharges a large volume of water into the river. Usually its effluent is very turbid and dark immediately after a storm but becomes much clearer with dilution once the initial flushing effect is over. Gas and oil films were observed in the effluent, which likely came from tars and fuel emissions washed off the streets. One example of the pollutional effects of this drain was observed during a storm on August 10, 1971. The muddy effluent, having a distinct petroleum odor, spilled into the river causing a definite color change of the entire river below its opening. On this particular date the dilution ratio of drain 25 to the river was estimated to be approximately 1:5, whereas the average dilution ratio was estimated to be 1:170. Although drain 25 was designed to flow during rain and melting conditions, it often flowed at a slow rate (approximately 0.16 cfs) during dry periods. Evidence from a fluorescein dye survey conducted August 6, 1971, indicated that this water was coming from beyond a point where the dye was dropped into the system, north of Michigan State University grounds building.

Results of chemical analyses show that this effluent contains nitrogen, phosphorus and carbon concentrations well above that found in the river. Even though a foam was occasionally observed below this drain, analyses for detergents were very low. On one occasion when a large amount of foam was present (Appendix D), the phosphorus concentration was 19.56 mg/liter, whereas, the detergent analysis showed only 0.05 mg/liter or less active detergent. The causative substance evidently was not methylene green active but was definitely detrimental to the river. Nutrient enrichment and a lowered aesthetic value certainly can be classified as pollution. Table 2 shows the chloride concentrations from this drain were high. On four occasions the concentration of chlorides were above 5,000 mg/liter with resultant conductivities of 15,000 μ mhos cm^{-1}. When this drain discharged high concentrations of chlorides the continuous flow monitor, stationed approximately 200 yards downstream, recorded conductivity peaks (Figure 4). As can be seen by comparing the chloride concentrations of the drain to the river, the effluent is quickly diluted. Twelve such peaks with greater or lesser magnitude were recorded by the monitor throughout the study period. Hardgrove (1969) reported similar results and also noted that the conductivity peaks generally occurred about midday. He stated that while effects of dilution eliminate a hazard in the river, intermittent high chloride values immediately below the drain may be harmful to aquatic life.

A bioassay was conducted on the effluent from drain 25 on July 22, 1971, the same date as in Figure 2. None of the fish died even though the chloride concentration in container 6 was 5,200 mg/liter (Appendix B).

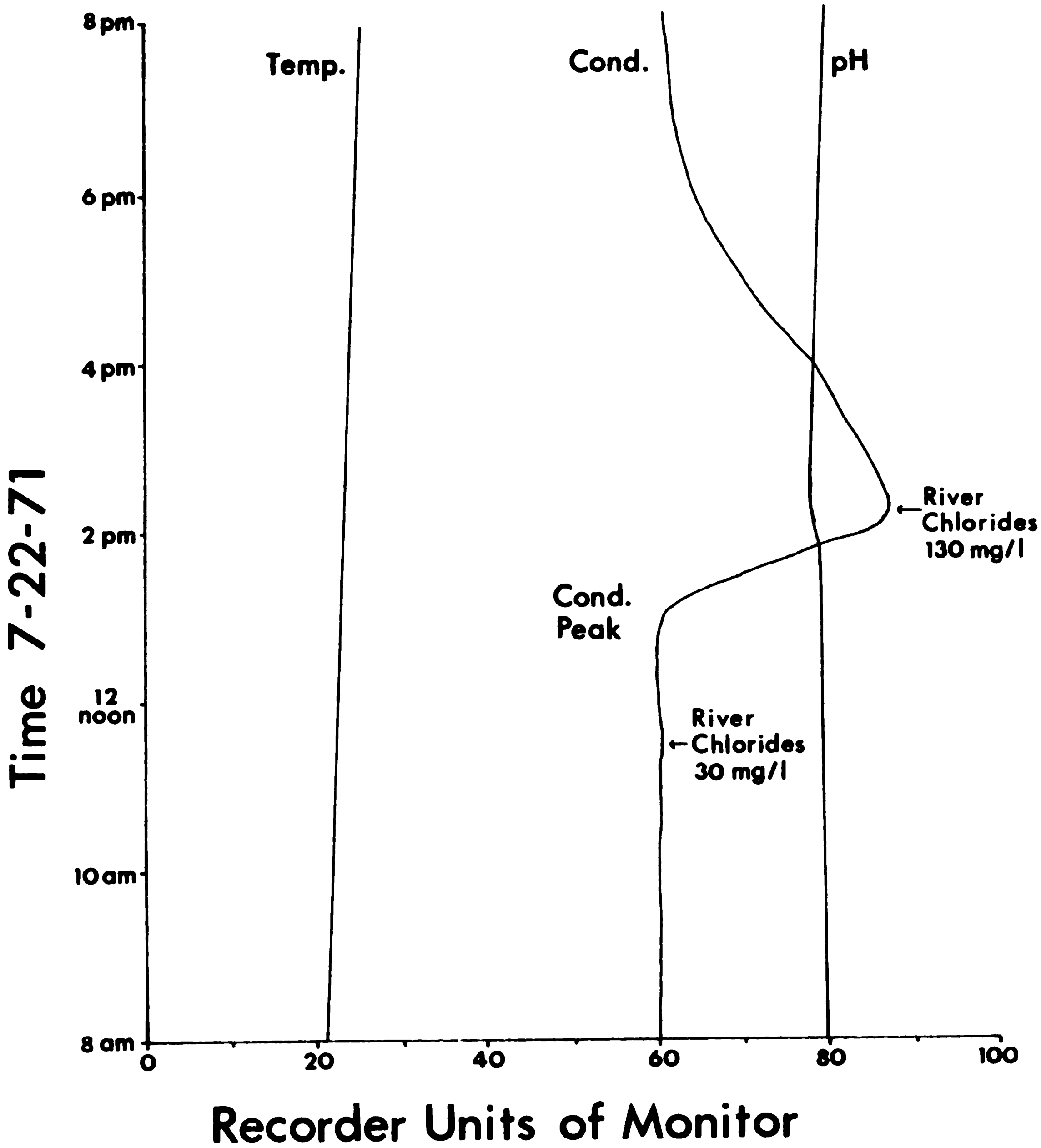


Figure 4. River conductivity peak due to Drain number 25. [Conductivity expressed as μ mhos x 10^1, temperature in degrees centigrade and pH x 10^{-1}. The conductivity of drain number 25 during the peak was 18,932 μ mhos cm^{-1} and had a chloride concentration of 7,600 mg/liter.]

The fish did, however, exhibit stress symptoms such as irregularity of respiration and excitability. Clemens and Jones (1954), using sodium chloride solutions, reported a 96hr TLm of 5,288 mg/liter Cl^- for fathead minnows. Trama (1954) found the 96hr TLm for bluegills to be 7,846 mg/liter Cl^-. Research indicates that common salts (NaCl, $MgCl_2$ and $CaCl_2$) are not very toxic to fish compared with other compounds or even other chlorides like mercuric chloride. The range seems to be between 5,000 and 10,000 mg/liter Cl^- in general. The major reason appears to be that the osmotic pressure of fishes is about six atmospheres or approximately the equivalent of 7,000 mg/liter sodium chloride (Ellis, 1937). Although 80 percent effluent was not lethal to fish during the bioassay, information from a live car test was more revealing. Live cars provide a more realistic test situation because they are placed into the stream where interacting systems of great complexity are present. Warren (1971) concludes that bioassays often cannot yield reliable estimates of safe concentrations of toxic substances and "it is to nature that we must turn finally for the answers we need."

A live car test showed that after a period of continuous exposure to the effluent of drain 25, 60 percent of the test animals died in the live car placed immediately below this drain. Ten percent mortality occurred in a live car placed 20 yards below the drain (Appendix B). It can be concluded that effluents from this drain had a lethal effect on green sunfish when held immobile, but the effect quickly diminished with dilution. One might hypothesize that in the natural environment fish exhibit an avoidance reaction to this drain or that certain invertebrates are limited by its effluent.

High concentrations of chlorides in the effluent of drain 25 during the winter likely occurred as a result of street de-icing practices. Salts used for ice removal at Michigan State University contain approximately 97 percent NaCl with some $CaSO_4$ and $MgSO_4$ and are 98 percent soluble in water. High concentrations in the summer may have been the result of back-washing water softeners, laundry effluents or urine contamination. Several other pollutants also were found in the effluent of drain 25 thus placing it in the category of a major polluting drain.

<u>Drain 82</u>: Drain 82 is a combined storm and sanitary drain which often flowed raw sewage having a high nutrient load (Tables 1 and 2). Its effluent characteristics are very similar to drain 66 which is part of the same sewerage system. The effluent was usually dark gray with particles of feces and paper present. It commonly smelled like sewage or was even septic. Even though the drain opening is almost entirely blocked by stones and

concrete it can easily be found by the unsightly appearance that it leaves on the bank of the river. A sludge bed has developed immediately out from its opening. The effluent was warmer than the river and had an average detergent concentration of 1.33 mg/liter, based on five samples. On one occasion the nitrogen concentration was 392 mg/liter, the highest value recorded from any of the drains. Because this drain's opening is dammed by rocks, it was difficult to estimate its discharge, which was considerable at times. From the sampling data it appears that near the end of the study period, this drain was partially corrected because it flowed less often, usually only during a rain as designed. The city of East Lansing had been notified and supposedly action was taken.

Drain 15: Drain 15 is a storm drain which collects runoff and service water from the Michigan State University power plant, stadium and bus service areas. Effluent temperatures averaged 5 C warmer than the river. Other than high temperature, the effluent was generally of good quality but at specific times contained high concentrations of phosphorus, detergents and chromium. An oily film was characteristic of this drain. A likely source was from the bus service area. Because detergents were high on occasion, a fluorescein dye was dropped into a floor drain of the bus-washing garage, but results were negative. A dye dropped into a storm drain adjacent to the stadium did give positive results. High phosphorus concentrations (Table 1) were possibly due to addition of detergents or sodium phosphate, which is at times used in the power plant to control slatting. On one occasion, when a froth was observed, the concentration of detergents in the effluent was 3.5 mg/liter with a phosphorus concentration of 28.53 mg/liter. Analysis of one of four greenish effluents resulted in a chromium concentration of 3.2 mg/liter. Chromium compounds are often added to cooling water for corrosion control (APHA, AWWA, WPCF, 1971). Doudoroff and Katz (1953) present data showing that fishes of the sunfish family can tolerate in hard water as much as 68 mg/liter Cr for at least 5 days. The same publication reports that a concentration of 1.4 mg/liter Cr as $Cr_2(SO_4)_3$ was lethal to sticklebacks in approximately 96 hours. A bioassay was conducted on this effluent, which also was 36 C and produced an oily film. Results were negative in that 80 percent effluent was not toxic within 96 hours. These results were supported by a live car test in which none of 10 green sunfish died after being held for 13 days immediately below the effluent. Evidence shows that the effluent was neither toxic in the bioassay nor after partial dilution with the river. The average discharge of this drain was 0.15 cfs with an estimated dilution ratio of 1:827 with complete mixing. Even though this drain's effluent may not be lethal to fish, information presented indicates that it is adding to deterioration of water quality in the Red Cedar River.

Drain 6: Drain 6 is a partially submerged drain, so sampling its effluent and estimating its flow was difficult. At times its effluent was sewage-gray in color, becoming even darker immediately after a storm and causing a noticeable color change in the river well below its opening. Oily films were also observed. The effluent averaged 2 C warmer than the river throughout the sampling period. A fluorescein dye survey indicated that most of the flow comes down the storm sewer under Wilson Road with some of the flow coming from the Michigan State University greenhouse area. From Tables 1 and 2 one sees that this drain's effluent on the average is quite similar to the river except in phosphorus concentration, which is somewhat higher. In my opinion these values were low estimates of true effluent parameters because of the difficulty in sampling a submerged drain. It was obvious while sampling that pure effluents were not always obtained but only a mixture of river and drain water.

To determine effects of this drain on fish, a bioassay was run on its effluent of August 13, 1971, which was gray-green in color and produced a slight oily film. The ammonia concentration was 0.24 mg/liter and detergent concentration, zero. Results of the bioassay were negative in that no mortality occurred in 80 percent effluent after 96 hours. Live car test results (Appendix B) show that this drain's effluent was lethal to 90 percent of the fish held immediately below its opening from August 4 to 13. The effluent was lethal to 70 percent of the fish held 20 yards below the drain where there is approximately a 1:1 or greater dilution. It is important to note that mortality began at the same time as a major fish kill occurred further downstream. Toxicity was probably a result of the combined effect of the drain effluent and general low oxygen level in the river. In a second live car test from August 14 to 21, mortality again occurred in the live car placed immediately below the effluent. From information presented it appears that this drain has a detrimental effect on Red Cedar River water quality and likely effects the behavior of some of its aquatic fauna.

Drain 62: Drain 62 is a storm drain receiving service water from Kellogg Center and storm runoff from the surrounding area. This drain is included as a major drain because its effluent, although usually clear, flowed continuously, averaged approximately 5 C warmer than the river and often discharged oily products which produced a thin film on the river. Quite frequently its effluent showed the greenish-yellow hue characteristic of chromium compounds. A dye survey indicated the principal source was from the Kellogg Center, probably from the large air-conditioning unit; this unit would explain the heated effluent and high chromium concentrations. As stated earlier chromate compounds are commonly used to control slate build-up in cooling systems. On one occasion (July 15, 1971) the chromium concentration was 4.8 mg/liter, whereas, the concentration of the river was less than 0.03 mg/liter at station 2. A bioassay was run on the same date; the 96hr TL_{50} value was 86 percent effluent (Appendix B). Having an average dilution ratio of 1:451 it was very unlikely that this drain was directly lethal to aquatic fauna after complete mixing with the river.

Drain 61: This drain is a 72-inch combined storm and sanitary drain which is controlled by a large pressure cap; consequently it flowed only during melting conditions or a rain. Despite its less frequent flow the drain's detrimental effect.was great because of the character and volume of discharge. The effluent was usually gray-black, contained a large amount of suspended material (sewage), smelled septic and noticably changed the quality of the river for several hundred yards below its opening. Tables 1 and 2 show that the nutrient level and chlorides were much higher than in the river. On one occasion results of detergent and ammonia analyses were 1.05 mg/liter and 10.0 mg/liter, respectively. The ammonia concentration may be explained by the fact that when sewage sets in a sewer during low flow (no rain), pockets of water may become totally deoxygenated; anaerobic bacteria reduce nitrates to ammonia and sulphates to sulphides. Therefore, a mass of water is formed which is not only deoxygenated but contains poisons and has a heavy oxygen deficit (Hynes, 1960). Hynes (1960) also states that a further complication is introduced by the presence of oil or detergents which affect uptake of oxygen at the waters surface. On August 10, 1971, the evening before a fish kill the entire river changed from a muddy-brown color to gray-black directly out from drains 61, 82 and 105, which were all flowing. The average dilution ratio of drain 61 to the river was 1:34. Considering information presented, it seems apparent that this drain contributed to the deterioration of Red Cedar River water quality.

Drain 36: Drain 36 is a partially submerged storm drain thus sampling its effluent and estimating its flow was difficult. By using a dye and entering the drain through a manhole, I determined that water comes down a storm sewer under Michigan Avenue. Because the drain discharges a considerable amount of water even during "dry" periods there must be some source other than storm runoff. With evidence such as a cloudy-gray color, higher than normal chlorides and frothing, it appeared that, at times, this drain's effluent was contaminated by sewage. A detergent level of 2.2 mg/liter was found on April 4, 1971. During a rain its effluent became very turbid and gray-brown in color. There was often a distinct sulphur-like odor and rusty appearance at the drain opening under dry conditions. In addition iron-like deposits were noticed in the storm sewer. Iron and sulfur bacteria can produce precipitates of ferric hydrate from ferrous compounds (Starkey, 1967). Tables 1 and 2 indicate that this drain does not significantly add to organic-nutrients. Again, obtaining representative samples from a submerged drain was difficult.

A live car test continuing from September 4 through September 19 proved to be negative, therefore, no data were collected to suggest toxicity to aquatic fauna. On occasion a few dead crayfish and amphibians were observed at the mouth of this drain. More information should be collected before judging this drain's complete influence upon the river. It is apparent, however, to a canoeist that drain 36 is adding to the destruction of the river's recreational quality.

River Quality and General Effects of Pollution

Two objectives are met in this section. First, it is illustrated that water quality of the Red Cedar River changes from Hagadorn Road to East Kalamazoo Street as a result of an accumulation of pollutants from the many drains. The effects of pollution on a receiving stream often become confused, because additional sources of pollution may enter the environment before the receiving water has been able to assimilate the entire effects of an initial source. When this occurs the effects of subsequent introductions become superimposed on those of the initial source, and the total effect may confine large reaches of the stream (FWPCA, 1969). Second, when possible, a comparison was made of present water quality parameters with those of the past.

Individual parameters are discussed after which I have simply listed significant contributing drains based on individual observations and the discussion of the previous section. One or more effects of pollution may be characteristic of any one effluent. Hynes (1960) has divided the effects of pollution into five categories: addition of poisonous substances, addition of suspended solids, de-oxygenation, addition of non-toxic salts and heating. Other less subtle effects should be considered, such as the gradual eutrophication of the river which may result in changes in fauna or usefulness to mankind.

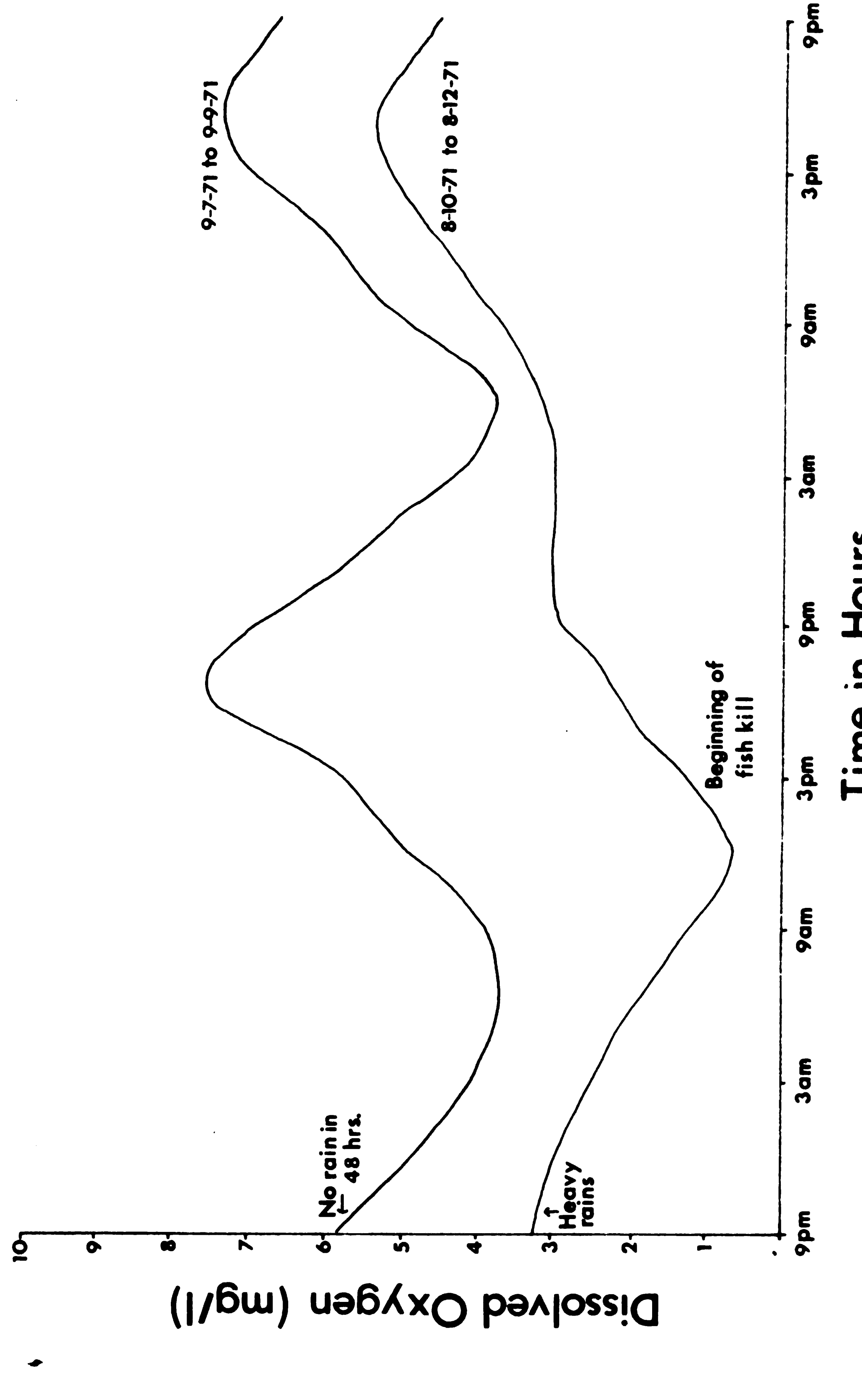
Linton (1967) in a study of low-level chronic effects of pollution on rock bass in the river, found that the annual potential instantaneous rate of natural increase for rock bass was negative (population dying) in the "polluted zone" from Farm Lane bridge to Okemos Road. In contrast, values of a "clean zone" were all positive. He concluded that with respect to environmental observations, differences in success of the rock bass populations can probably be attributed to pollutants.

Dissolved Oxygen and Fish Kills

One very destructive kind of pollution occurs when relatively large amounts of putrescible organic materials are introduced into waters causing an oxygen depletion (Warren, 1971). Evidence indicates that this type of destruction has and will continue to occur in the Red Cedar River unless corrective action is taken.

Water Quality Standards for Michigan Intrastate Waters (Mich. Water Resources Comm., 1968) state that for tolerant fish (carp, bullheads) the average daily D.O. should not be less than 4 mg/liter nor shall any single value be less than 3 mg/liter. However, Tarzwell (1957) pointed out that generally under polluted conditions a fish will require more oxygen. One major and two minor fish kills were observed primarily in the lower half of the study section. Figure 5 shows the diurnal oxygen curve of station 2 during the major fish

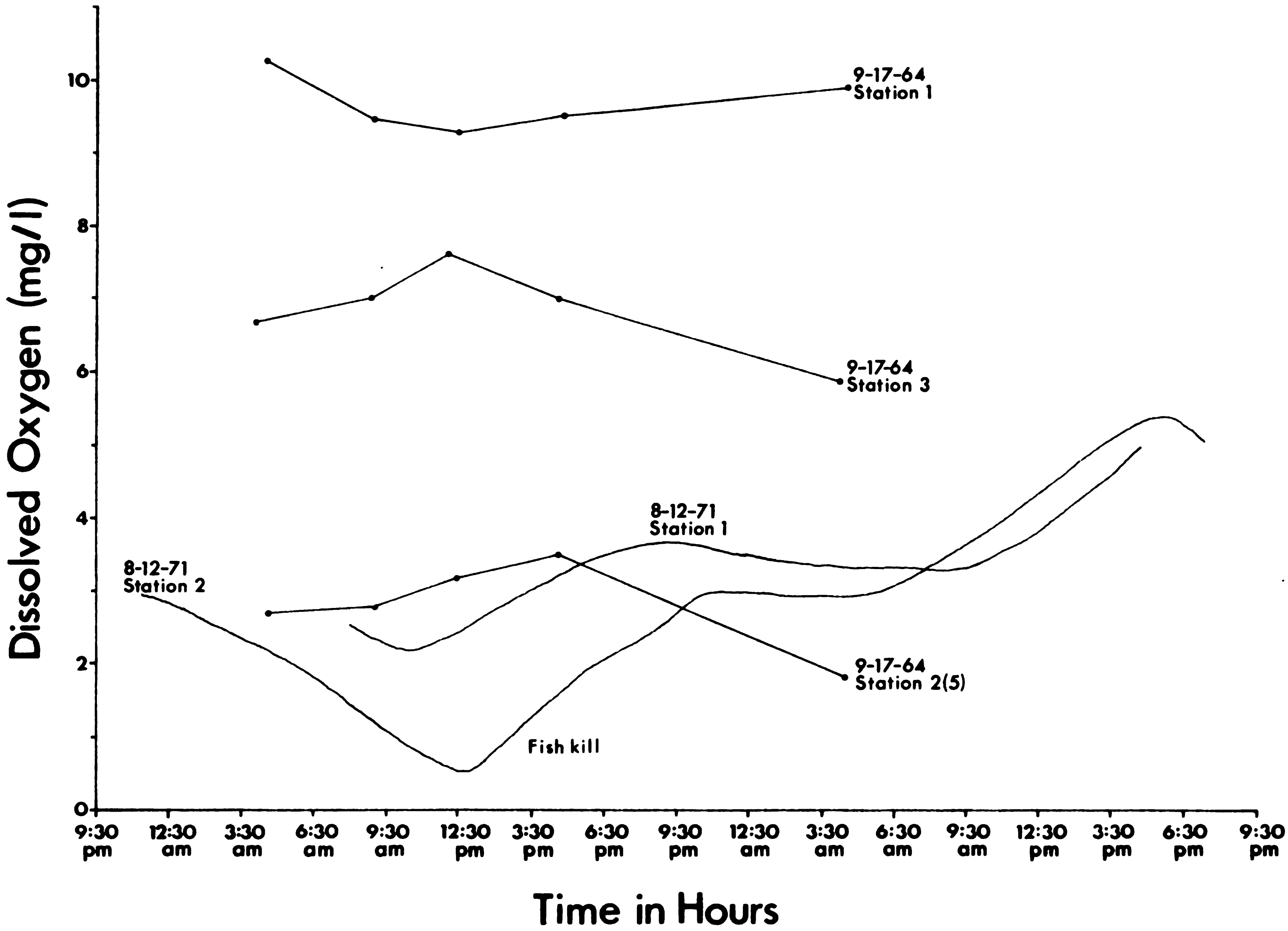
Figure 5. "Typical" late summer diurnal oxygen curve compared to one during a fish kill. [Values were taken from the monitor and checked with Winkler determinations. A 48-hour cycle at station 2.]


Dissolved Oxygen (mg/l)
10
9
8
7
6
5
4
3
2
1
9pm
3am
9am
3pm
9pm
3am
9am
3pm
9pm
Time in Hours
No rain in 48 hrs.
Heavy rains
Beginning of fish kill
9-7-71 to 9-9-71
8-10-71 to 8-12-71

kill of August 11, 1971. During the evening of August 10, 1971, a sudden storm caused several drains to discharge a large amount of organic matter into the river (see drain 61 and list below) which, when oxidized by micro-organisms, caused an oxygen deficit. The action of a sudden rain also will cause the release of reducing substances from the disturbed muds (Bamforth, 1962). In addition oxygen production by primary producers in the river is reduced by scouring and turbidity. Besides being affected by low oxygen, fish were likely stressed by higher than normal ammonia (station 2 = 1.0 mg/liter NH_3) and sulphides which increase during anaerobic decomposition. Over 1,000 fish of many species, such as white sucker, spotted sucker, rock bass, green sunfish, northern pike and various cyprinids died throughout the river below the Michigan State University dam. Two minor kills of approximately 50 fish (mainly white suckers) also occurred.

Considering Figures 5 and 6, sudden rainstorms usually result in an oxygen depletion, especially during low-flow periods. Hardgrove (1969) presented four illustrations of heavy runoff resulting in an oxygen drop, although none were as severe as the one presented in Figure 5. Oxygen concentrations were generally greater upstream than downstream. Jensen (1966) reported that oxygen saturation decreased linearly from

Figure 6. Difference in diurnal oxygen curves between stations 1 and 2. [Note, three of the curves are from Jensen's (1966) study of which each value is the mean of three observations.]


Dissolved Oxygen (mg/l)
0
2
4
6
8
10
9-17-64 Station 1
9-17-64 Station 3
9-17-64 Station 2(5)
8-12-71 Station 1
8-12-71 Station 2
Fish kill
9:30 pm
12:30 am
3:30 am
6:30 am
9:30 am
12:30 pm
3:30 pm
6:30 pm
9:30 pm
12:30 am
3:30 am
6:30 am
9:30 am
12:30 pm
3:30 pm
6:30 pm
9:30 pm
Time in Hours

a mean value of 75 percent at station 1 to a mean value of 18 percent at station 2 (5). The dissolved oxygen as shown in Figure 6 was greater at station 1 than 2 in both the curves taken from Jensen's study (1966) and in those taken during this study. The location of station 3, which is between station 1 and 2, is shown on Figure 1. The difference in oxygen content is much greater than one would expect with normal stream succession; therefore, given the information from the drain effluents, it seems apparent that oxygen reduction is the result of incoming pollution. Jensen (1966) concluded, by correlating increasing phosphorus, nitrogen and BOD values with decreasing oxygen concentration, that sewage entering the river is the factor most responsible for observed oxygen concentrations. It appears that there has been some improvement in oxygen quality near station 2 (5) since 1964. The continuous monitor and Winkler tests, in this study and as used by Hardgrove (1969), revealed the normal diurnal oxygen flux to be similar to the curve presented in Figure 5 (top). A continuum of diurnal oxygen curves taken from the monitor revealed the average daily value was between 5 and 6 mg/liter with the fluctuation dependent upon such factors as season, rainfall, cloud cover and plant growth. Hardgrove (1969) indicated that September through October and April through May exhibited the greatest degree of development of diurnal oxygen curves. Data indicates that oxygen levels at station 2 have increased in recent years; compare the "typical" diurnal oxygen curve of Figure 5 to the 1964 curve in Figure 6. At first it may seem invalid to compare just two oxygen curves taken at different times, during different years and at slightly different points. But, the curve in Figure 5 is a representative curve, and Jensen (1966) also presented other similar curves to the ones shown in Figure 6; therefore, it appears that the average daily oxygen concentration near station 2 (5) has increased from approximately 3 mg/liter in 1964 to between 5 and 6 mg/liter in 1971. This change in the lower reach of the river is likely due to the closing of the East Kalamazoo Street Sewage Treatment Plant.

Data indicate that the following drains have discharged effluents which were capable of contributing significantly to oxygen depletion in the river: 61, 82, 25, 66, 33, 36, 6, 47, 58, 103 and 64.

Chlorides

Sodium chloride, a universal constituent of sewage, is reduced in concentration only by dilution. In fact, before the development of bacteriological tests, chloride determinations served as a basis for detecting contamination of ground-waters by sewage (Sawyer and McCarty, 1967).

Table 3 shows that the mean chloride concentration of the river increased significantly from station 1 to station 2. Data indicate that drain effluents are responsible for the increased chloride concentration (see discussion of drain 25). Throughout the study period 12 drains discharged effluents with chloride concentrations greater than 1,000 mg/liter, 4 drains greater than 5,000 mg/liter and 2 drains greater than 20,000 mg/liter. Also, there seems to be little reason for a significant increase in chlorides due to purely "natural" stream succession.

Most ecologists are of the opinion that common salts have little effect on our aquatic systems because, generally, toxicity to aquatic fauna does not occur at concentrations under 1,000 mg/liter. The highest level found in the river at station 2 was 230 mg/liter. However, freshwater organisms are adapted to living in waters of low salt content. Thus, an increase in salts changing the osmotic pressure may directly or indirectly affect some stage in the life history of freshwater animals in ways decreasing their distribution, abundance and value to man (Warren, 1971). Anderson (1950) found that Daphinia magna were least resistant to chlorides during the molt stage of their life. Because we are looking at low, non-toxic levels in the river, concern over the indirect influences of salts might be more appropriate.

Table 3. Summary of water parameters for river stations 1 and 2.

Water Parameter and Station	N	$\overline{X}$	Mg/liter			$\alpha = .1$ Homogeneity of Variance	$\alpha = .1$ t Test $\mu 1 = \mu_2$	$\alpha = .1$ Approx. t Test $\mu 1 = \mu_2$
			Range	s_x^2	$s_{\bar{x}}$			
Chlorides 1	19	24.24	13.5-37.5	41.70	1.48	Reject H_o		Reject H_o
Chlorides 2	28	51.04	20.0-230.0	1.972	8.39			
Carbon 1	19	9.21	1.0-15.5	11.90	0.79	Accept H_o	Reject H_o	
Carbon 2	28	11.80	5.5-31.0	26.17	0.97			
Nitrogen 1	19	1.03	0.51-1.85	0.144	0.09	Reject H_o		Reject H_o
Nitrogen 2	28	3.50	0.45-18.80	16.914	0.78			
Phosphorus 1	19	0.158	0.04-0.51	0.009	0.02	Accept H_o	Accept H_o	
Phosphorus 2	27	0.196	0.03-0.49	0.014	0.02			

Chlorides influence the density of water. Judd (1970) found that salts entering a lake caused an increase in density of bottom waters and as a result, there was incomplete spring overturn. The lake received runoff from adjacent streets and expressways with chloride concentrations of over 10,000 mg/liter during periods of deicing. Although in this study we are not directly concerned with a lake, salts introduced into the Red Cedar River will eventually flow into Lake Michigan. Ownbey and Willeke (1965) predicted that by the year 2020, Lake Michigan would contain 12 mg/liter Cl^- over the present 7 mg/liter because of salt increases in adjoining rivers. They considered this to have no overall harmful effect on the lake, but felt as do I, that much of the salt input could be eliminated.

Other likely influences of an increase in salt content are the synergistic effects with other toxicants (Brown, Shurben and Farwell, 1967); the detrimental effect on plants if used for irrigation water (Peterson, 1968); or the unsuitability of the water for industrial purposes. Cleary (1967) states that salinities of 50-175 mg/liter are considered "doubtful" by some for industrial use. This level is below the Federal drinking water standard of 250 mg/liter chlorides.

Drains which contributed effluents having high chloride concentrations were: 25, 1, 2, 80, 67, 66, 82, 36, 62, 22, 64, 61 and 63.

Suspended Solids

Figure 7 indicates that there was an increase in suspended solids from Dobie Road, which is above the communities of East Lansing and Okemos, to station 2. See Appendix D for the location of Dobie Road relative to stations 1 and 2.

Suspended solids can effect a lotic environment in many ways. Jensen (1966) states that turbidity, a measure of the suspended matter interfering with light passage, and siltation prevent abundant nitrogen and phosphorus from supporting large blooms of aquatic vegetation in the Red Cedar River. Brehmer (1958) concluded that turbid water conditions limited periphyton production in the river. Suspended solids also can effect sight feeding fish and destroy spawning habitat; a probable factor in the population limitation of rock bass, especially in the lower portion of the study section.

In stream pollution control work, Sawyer and McCarty (1967) consider all suspended solids to be potential settleable solids, as time is not a limiting factor. Hynes (1960) states that deposits of solids smother algal growth, kill rooted plants and limit cryptic animals by altering the nature of the substratum.

As a rule hardness and conductance increase with an increase in suspended solids (Sawyer and McCarty, 1967).

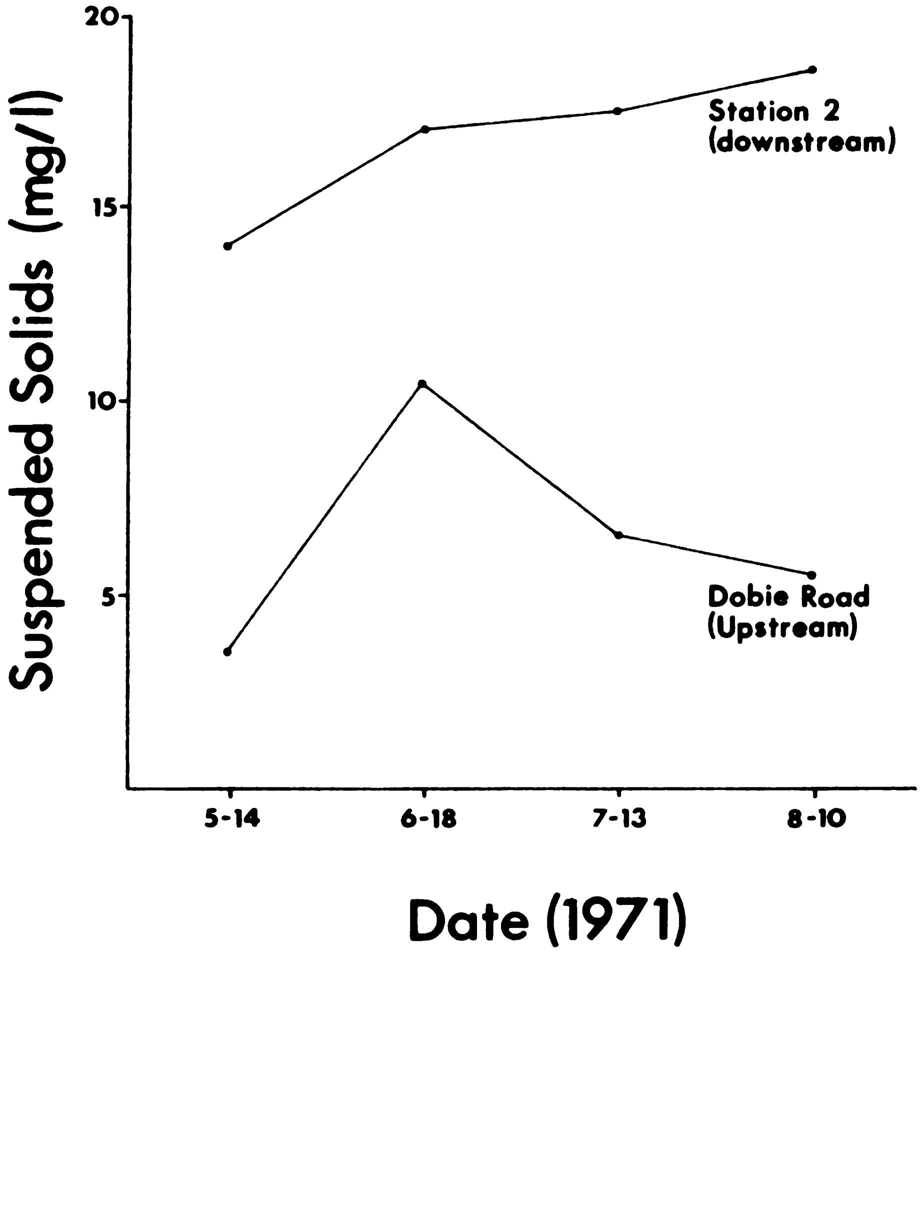


Figure 7. Suspended solids (unpublished data). [Each value is the average of two determinations.]

As can be seen from Table 4 both these parameters increased from station 1 to 2 and therefore support the suspended solids data.

Drains which at times appeared to discharge a high content of suspended solids (silt) were 25, 66, 82, 36, 1, 6, 61 and 8. The three major sources of increased suspended solids were initial street runoff, sewage contamination and construction causing soil erosion.

Phosphorus

Phosphorus is considered by aquatic ecologists as an important nutrient because it often limits or controls production of aquatic systems. The role of phosphorus in the Red Cedar River has been discussed in some detail by Brehmer (1958 and 1956), Grzenda (1960) and Jensen (1966) as well as others.

Table 3 shows the relative magnitude of the phosphorus values and the increase from station 1 to 2. Data from this and past studies show a general range in phosphorus concentration of 0.1 mg/liter to 0.2 mg/liter. Working with laboratory cultures Chu (1943) found that optimum growth of all organisms studied in cultures can be obtained in phosphorus concentrations from 0.09 to 1.8 mg/liter and phosphorus concentration from 0.009 mg/liter downward are limiting. Sawyer (1965) reported that nuisance conditions can be expected when the concentration of inorganic phosphorus exceeds

Table 4. Summary of five water parameters for river stations 1 and 2.

Water Parameter and Station	N	$\overline{X}$	Mg/liter Range	s_x^2	$s_{\bar{x}}$	Homogeneity of Variance	t Test $\mu_1 = \mu_2$	Approx. t Test $\mu_1 = \mu_2$
M.O. Alk. 1	19	258.70	186.0-284.0	846.76	6.68	Accept H_o	Accept H_0	
M.O. Alk. 2	27	250.40	126.0-290.0	1,590.8	7.68			
Hardness 1	19	317.60	258.0-364.0	741.59	6.25	Reject H_o		Accept H_o
Hardness 2	28	327.20	162.0-418.0	2,604.3	9.64			
pH 1	19	8.00	7.30-8.50	0.071	0.06	Accept H_o	Accept H_o	
pH 2	27	7.93	6.80-8.55	0.135	0.07			
Conductivity 1	18	518.03	442.0-569.0	1,123.1	7.90	Reject H_o		Reject H_o
Conductivity 2	21	561.80	328.0-834.0	12,404.9	24.30			
Temperature 1	16	19.31c						
Temperature 2	16	19.62c						

0.01 mg/liter. As a guide line, the Federal Water Pollution Control Administration (1968) reported that the concentration of total phosphorus should not be increased to levels exceeding 0.10 mg/liter in flowing streams or 0.05 mg/liter where streams enter lakes or reservoirs. From information presented one sees that phosphorus as a plant nutrient is not "limiting" but is present in excessive amounts in the Red Cedar River.

Increase in mean phosphorus concentration from station 1 to 2 is principally the result of drains discharging phosphorus-rich effluents. This is especially true of effluents containing raw sewage or detergents. Jensen (1966) working with ortho-phosphorus reported a similar increase and concluded that large quantities of phosphorus were being loaded into the river at the East Lansing Kalamazoo Street Sewage Treatment Plant which is no longer in operation. Some enrichment from leaf litter does occur throughout the study section, but it probably is less than the amount which enters the river upstream in heavily forested areas. Above statements are supported by Brehmer (1958) who reported that physical and chemical characteristics of the river indicate that municipal drains and sewage treatment plant outfalls are the most important sources of phosphorus. Those drains which discharged significant amounts of phosphorus into the river were: 66, 61, 82, 25, 15, 6 and 103; the latter no longer flows. Often these drains contributed their highest phosphorus concentrations during storms.

Nitrogen

As with phosphorus, nitrogen is an important component of stream eutrophication. Evidence suggests that in specific situations nitrogen may be a more important limiting factor than phosphorus. Sawyer (1965) reported that nitrogen may be the more critical factor limiting algal production in natural waters since phosphorus is stored in algal cells in excess. However, current thinking seems to indicate that phosphorus usually is the controlling nutrient. Brehmer (1958) concluded that nitrogen, rather than phosphorus, was the nutrient limiting plant productivity in the river. Results here and Jensen's (1966) study indicate neither phosphorus nor nitrogen is limiting, but rather that productivity is limited by turbidity and siltation. Table 3 shows the magnitude of the mean nitrogen concentrations and changes from one station to another. A comparison with past studies is made more difficult because only total Kjeldahl nitrogen was measured regularly.

The level of 3.5 mg N/liter at station 2 seems relatively high when compared with the average total Kjeldahl nitrogen of raw sewage, which was 11.4 mg/liter at the East Lansing Waste Water Treatment Plant for

June, 1971. Jensen (1966) reported that nitrogen levels at all stations were above levels commonly found in unpolluted streams. Müller (1953) concluded that excessive growths of plants and algae in polluted waters can be avoided if the concentration of total nitrogen is not allowed to rise much above 0.6 mg/liter. The increase from station 1 to station 2, again can best be explained by the addition of effluents with high nitrogen concentrations.

Although ammonia is generally kept at a low level because it is almost immediately converted to nitrites and nitrates or utilized by the aquatic flora, it did on occasion reach high levels. The ammonia concentration during a fish kill reached 1.00 mg/liter in the lower river just after a sudden storm; a concentration considered as pollutional by Reid (1961). Jensen (1966) found there was a gradual downstream increase of ammonia throughout the study section.

Data indicate that as a plant nutrient nitrogen is present in excess just as with phosphorus. Abundant growths of algae were observed during the summer and fall only when the river was not turbid. Primary production was not measured in this study.

Carbon

Organic substrate concentration was determined by measuring the actual amount of organic carbon present in a sample. Although BOD and COD determinations have become accepted standards of measurement in water pollution control work they are essentially ineffective for several reasons. FWPCA (1969) considers BOD procedures as inherently nonreproducible, and the unpredictable nature of test results make their interpretation difficult. There are also limitations on COD analyses such as the degree of oxidation of a compound tends to depend upon its structure. Stenger and Van Hall (1968) provide a more complete discussion of the methods used to estimate organic substrates. With the introduction of the carbonaceous analyzer by Van Hall, Safranko and Stenger (1963), researchers are tending toward the more direct analysis. The carbonaceous analyzer measures the amount of carbon present which can be reduced to carbon dioxide.

Table 3 shows that the mean carbon concentration increased from 9.21 mg/liter at station 1 to 11.80 mg/liter at station 2. The increase likely is the result of drain effluents with high carbon concentrations. A drain such as 66 which often flowed raw sewage had a mean carbon concentration of 31.6 mg/liter. For comparison, organic carbon can be correlated with B.O.D. values (Ford, 1968). Jensen (1966) found that B.O.D. values increased from 3.69 at station 1 to 10.60 at station 2. He reported that waters having a B.O.D.

of 3 are of poor quality, and those with a B.O.D. of 4 are bad quality. Those drains which discharged a significant amount of dissolved organic carbon into the river were 25, 66, 82, 103, 8, 64, 61 and, on one occasion, drain 54 discharged a very dark effluent with 1,400 mg C/liter for a short period of time.

Bottom Fauna

This section deals with the macro-invertebrate community structure, emphasizing indicator organisms and community diversity as biological indices of environmental change. Because of habitat preference and low motility, bottom organisms are directly affected by substances that enter the environment (Whilm and Dorris, 1966). The addition of domestic sewage and initial storm runoff to a river increases available energy through added organic matter and also contributes to turbidity, siltation, toxic materials and low dissolved oxygen. These factors generally lead to low diversity of species, with only tolerant ones present, but support large populations because of the energy-rich ecosystem. Thus we might expect a significant change in the bottom fauna from station 1 to 2 considering the data presented in past sections.

As was true of Jensen's (1966) study, bottom samples indicated productivity was high but diversity was extremely low. Figures 8 and 9 show an increase in

Figure 8. Number of Oligochaeta per square foot at river sampling stations. [Open bars are those of Jensen (1966). Distances on abscissia are proportional to distances between stations.]

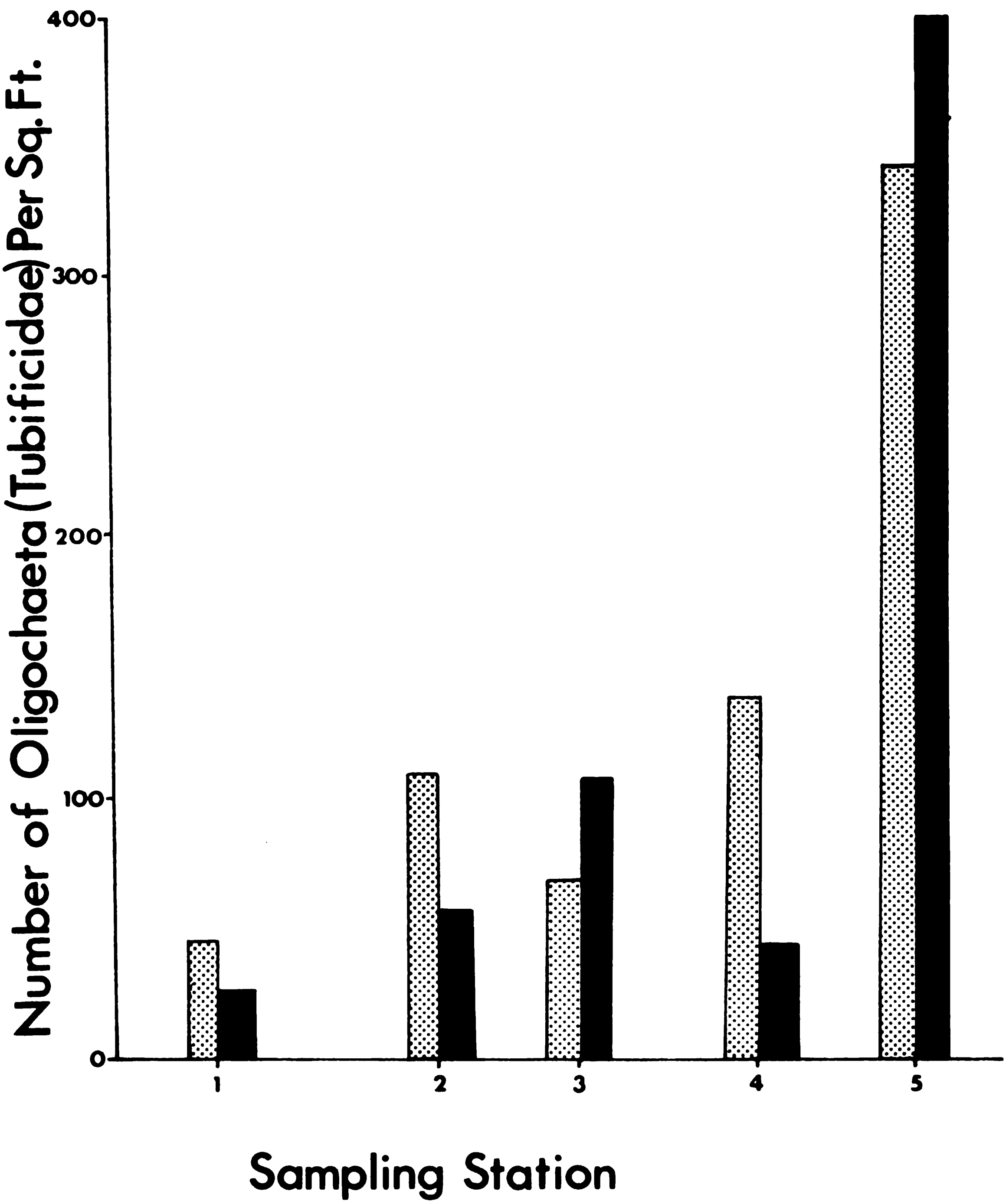
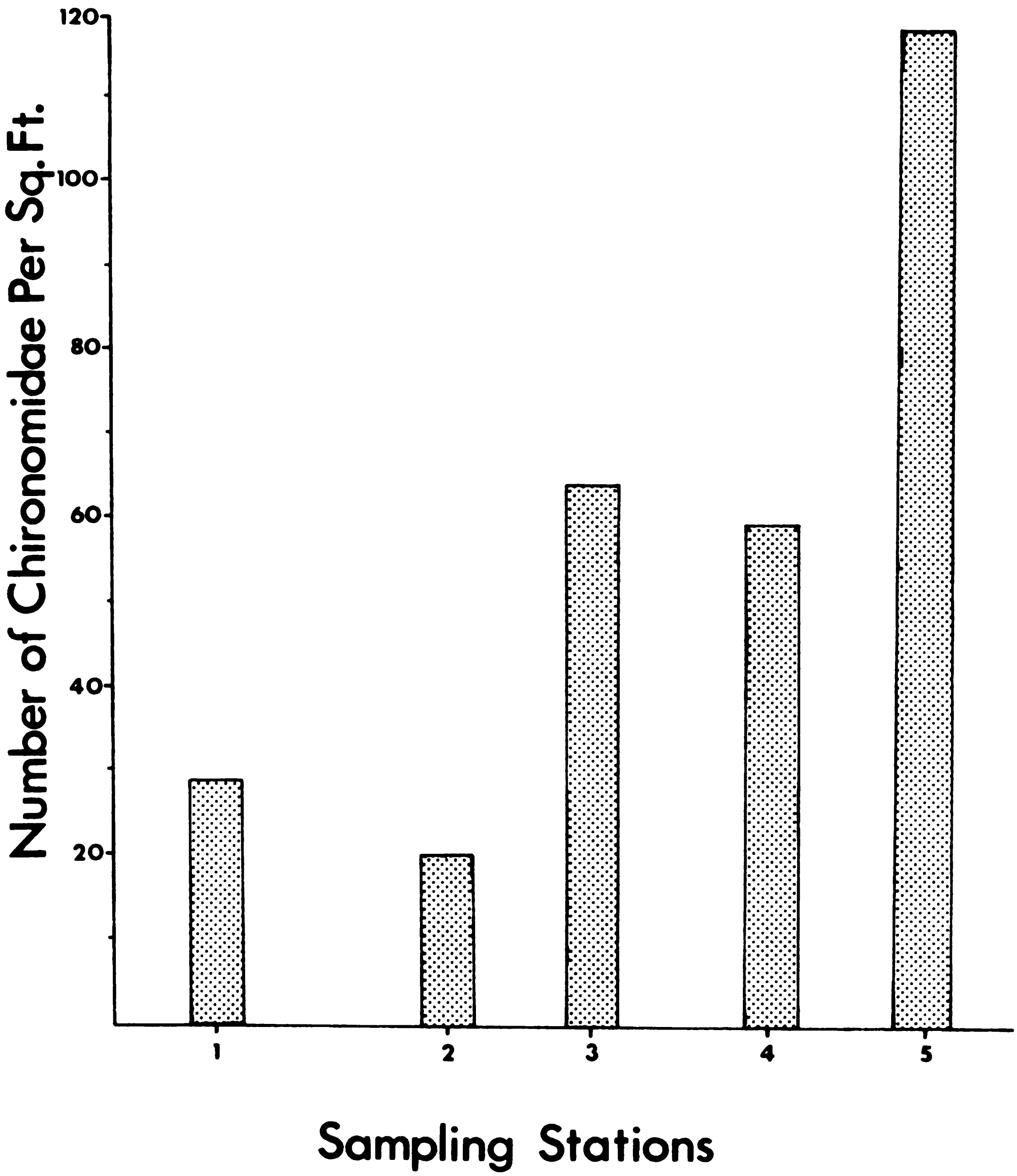

Number of Oligochaeta (Tubificidae) Per Sq. Ft.
400
300
200
100
0
1
2
3
4
5
Sampling Station

Figure 9. Number of Chironomidae per square foot at river sampling stations. [Distances on abscissa are proportional to distances between stations.]



Number of Chironomidae Per Sq. Ft.
120
100
80
60
40
20
1
2
3
4
5
Sampling Stations

Oligochaeta and Chironomidae as one goes downstream from Hagadorn Road to East Kalamazoo Street. Of the oligochaetes, tubificids are found in concentrated populations in streams and rivers that are polluted with sewage (Pennak, 1953). Although Tubificidae were by far the most common of the Oligochaeta, other families, such as the enchytraeids, were probably represented in the samples. In fact, subsamples showed that the majority of the oligochaetes were the cosmopolitan *Tubifex tubifex*, which is tolerant of organic pollution. Chironomidae, which were present in high numbers, are typical of streams rich in organic matter and can live in relatively low oxygen concentrations. Of course the presence of oligochaetes and chironomids does not necessarily mean that the oxygen level in the river is low. Hynes (1963) has stated that if a river is reasonably well oxygenated oligochaetes may still be dominant in accumulated organic matter, although accompanied by chironomids and usually some clean-water animals (Table 5). All five stations of Figures 8 and 9 were slow moving "pool" areas with sand and silt bottom for the most part.

In another phase of collecting bottom fauna data, two riffle sampling stations were established. One at Ferguson Park, Okemos, above all the drains mentioned in this study, and the other 200 feet below the Limnological Research Laboratory. A list of organisms

Table 5. Summary of "pool" bottom fauna expressed as mean number per square foot.

Organism	Station				
	1	2	3	4	5
Oligochaeta	23	58	104	44	398
Chironomidae	29	20	64	59	118
Elmidae	8	6	1	3	1
Pelecypoda	4	7	4	7	11
Gastropoda	1	1	3	2	-
Baetidae	-	1	-	-	-
Rhagionidae	-	1	-	-	-
Planaria	-	-	-	-	1
Hirudinae	-	-	-	-	2

encountered and numbers of individuals per square foot is given in Table 6.

Some investigators have classified bottom organisms according to pollution tolerance, but this is difficult and there is lack of agreement. One can be reasonably correct, though, if he is quite general as is Beak (1965) who lists three groups as follows:

Group 1	Group 2	Group 3
Oligochaeta	Chironomidae	Odonata
	Hirudinea	Trichoptera
	Pelecypoda	Megaloptera
	Gastropoda	Ephemeroptera
	Amphipoda	Plecoptera

Group 1 includes the most tolerant. Group 2, which are facultative with regard to pollution, and Group 3 are generally sensitive to water pollution. This classification seems to apply quite well to the Red Cedar River. Oligochaeta were found with 100 percent frequency both upstream and down, but it is interesting to note that the density downstream below the drains is approximately a 100-fold increase over that of the • upstream station.

The occurrence of Hirudinea in downstream samples is probably related to the increase of available food (oligochaetes and chironomids). Leeches are commonly carnivorous and feed on snails, oligochaetes and other small invertebrates, but others are scavengers which

Table 6. Riffle bottom fauna--organisms and number per square foot.

Organism	Number of Individuals Per Square Foot for Each Sample*											
	Upstream 8/6/70			Upstream 8/15/70			Downstream 8/6/70			Downstream 8/15/70		
Gastropoda												
1 Amnicolidae	5	3	6	3	3	2	-	1	-	-	-	-
2 Pleuroceridae	4	1	1	-	-	1	-	-	-	-	-	-
3 Ancylidae	-	-	-	9	1	-	-	-	-	-	-	-
Pelecypoda												
4 species M	2	1	3	1	2	1	-	1	2	12	86	-
5 species N	1	-	-	-	-	1	-	-	-	-	-	-
Turbellaria												
6 Planariidae	1	1	1	11	-	-	19	29	24	2	255	1
7 Oligochaeta	19	12	6	25	2	11	2800	3660	2040	4040	1485	1170
Hirudinae												
8 species A	-	-	-	-	-	-	2	2	2	-	3	-
9 species B	-	-	-	-	-	-	-	1	1	-	-	-
10 species C	-	-	-	-	-	-	-	1	1	5	-	-
Decapoda												
Astacidae												
11 *Orconectes* sp.	-	-	-	-	-	-	1	-	-	-	-	-
Amphipoda												
Gammaridae												
12 *Gammarus* sp.	-	-	-	2	1	1	-	-	-	-	-	-
Insecta												
Ephemeroptera												
13 *Ephemerella* sp.	-	-	-	-	-	1	-	-	-	-	-	-
14 *Caenis* sp.	1	5	6	18	3	15	-	3	-	-	1	-
15 *Baetis* sp.	-	1	-	1	-	-	-	-	-	1	5	1
16 *Brachycercus* sp.	-	-	1	-	-	-	-	-	-	-	-	-
17 *Hexagenia* sp.	8	-	3	2	-	-	1	-	-	-	-	-

Table 6. Continued.

Organism	Number of Individuals Per Square Foot for Each Sample*											
	Upstream 8/6/70			Upstream 8/15/70			Downstream 8/6/70			Downstream 8/15/70		
Psychomyiidae												
31 *Polycentropus* sp.	1	-	1	5	-	-	-	-	-	-	-	-
Diptera												
32 species Y	-	-	-	1	-	-	-	-	-	-	-	-
33 species Z	-	-	-	-	1	-	-	-	-	-	-	-
Chironomidae												
34 *Chironomus* sp.	1	-	-	-			140	480	200	100	195	-
35 all others	28	8	2	80	26	97	240	700	740	440	2565	210
36 species R	6	7	10	3	7		140	200	60	40	60	-
37 Tabanidae	1	-	-	-	-	-	-	-	-	-	-	-
Tipulidae												
38 *Antocha* sp.	-	1	1	2	-	-	-	-	-	-	-	-
39 *Tipula* sp.	-	-	-	-	-	4	-	-	-	-	-	-
Simuliidae												
40 *Cnephia mutata*	-	-	-	7	-	-	-	-	-	-	7	-
41 Heleidae	-	-	-	-	2	5	-	-	-	-	-	-
42 Empididae	-	-	-	-	-	-	-	-	-	-	2	-
18 *Baetisca* sp.	-	-	-	-	-	1	-	-	-	-	-	-
19 *Stenonema* sp.	1	-	-	1	-	-	-	-	-	-	-	-
Hemiptera												
20 Corixidae	-	1	-	-	-	-	-	-	-	-	-	-
Odonata												
21 Gomphidae	1	-	-	-	-	-	-	-	-	-	-	-
Plecoptera												
22 *Phasganophora* sp.	-	-	-	-	1	-	-	-	-	-	-	-

Table 6. Continued.

Organism	Number of Individuals Per Square Foot for Each Sample*											
	Upstream 8/6/70			Upstream 8/15/70			Downstream 8/6/70			Downstream 8/15/70		
Coleoptera												
Elmidae												
23 long-tail sp.	8	1	1	13	2	-	-	-	1	5	1	-
24 short-tail sp.	-	-	-	2	7	9	-	-	-	-	-	-
Psephenidae												
25 *Ectopria* sp.	-	-	-	1	-	-	-	-	-	-	-	-
Gyrinidae												
26 *Gyrinus* sp.	-	-	-	7	-	-	-	-	-	-	-	-
Megaloptera												
Sialidae												
27 *Sialis* sp.	-	4	3	-	-	-	-	-	-	-	-	-
Trichoptera												
28 species X	-	-	2	-	-	1	-	-	-	-	-	-
Hydropsychidae												
29 *Hydropsyche* sp.	-	-	-	3	-	2	-	-	-	-	1	-
30 *Cheumatopsyche* sp.	-	-	-	7	-	-	-	-	-	-	2	-

*Three samples were taken at each station on both dates.

feed on dead animal matter (Pennak, 1953). Hynes (1963) notes leeches are found in polluted water, but they persist even after a river has recovered.

At Okemos the total number of chironomids per square foot was less than 100, whereas, downstream their numbers always exceeded 500. Chironomidae, being typical of streams rich in organic matter, are chiefly herbivorous, feeding on algae, higher aquatic plants and detritus (Pennak, 1953).

Megaloptera, Trichoptera and Ephemeroptera were all much more abundant in upstream samples than those from near the Limnological Research Laboratory. The caddisfly and mayfly are shown by Odum (1959) to be part of the community of a clear and fresh stream. Pennak (1953) lists these orders as typical of freshwater habitats wherever there is an adequate supply of oxygen. The presence of these three orders does not necessarily indicate that the river at Okemos is a clear, fresh stream, because midges and aquatic worms were still predominant. It does indicate, though, that the river is well oxygenated and fairly pollution free (at Okemos) for a warm-water river. It also shows that there is a "better" balance of organisms (herbivore, carnivore, predator, prey) upstream above the drains mentioned than below. This type of habitat is supportive of game fish also. Neither presence nor absence of a species alone can be taken as reliable evidence of the existence of the particular range of conditions man chooses to consider pollutional. The question of abundance of a particular species needs consideration, as does abundance of other species with which it is associated (Warren, 1971).

Margalef as quoted from Wilhm and Dorris (1966) "proposed analysis of natural communities by methods derived from information theory. Diversity and information may be considered equal for practical purposes and can be calculated directly from the sample. Unlike many expressions for describing community structure, Margalef's index of diversity includes numbers of individuals representing each species. Maximum diversity exists if each individual belongs to separate species." Thus this diversity index which is based on formulas of Shannon-Wiener accounts for relative abundance of the different species. Information theory has distinct advantages because it is not dependent upon constant sample size and number when making comparisons and only total number of recognizable species in a unit area is needed.

The formula

$$\overline{H} = - \sum_{i}^{m} \frac{n_i}{N} \log_2 \frac{n_i}{N}$$

is used where

m = number of species,

n_i = number of individuals of a particular species, and

n_i/N = probability of encountering that particular species in a sample.

Upstream at Okemos, above the drains, $\bar{H}$ was equal to 4.13. Downstream at station 2, $\bar{H}$ was equal to 1.35.

The adequacy of six samples is expressed in Figures 13 and 14 of Appendix C. Wilhm and Dorris (1968) claim the information value stabilizes by the fourth sample in a stream environment. They have summarized the question of sampling by stating that because several species may be super-abundant in a stream receiving organic wastes, a large probability exists that an individual observed during sampling belongs to a species previously recognized. The high redundancy is reflected in a low index of diversity. Only a few samples would be necessary to describe this low-information system, and additional samples would be superfluous. Clean-water areas are characterized by smaller numbers of individuals and larger numbers of species. There is less repetition of information per individual and thus more samples are needed to describe this system adequately. This may be true of the upstream station (Okemos), although, new species encountered would likely be rare; $\bar{H}$ would increase showing an even greater difference from that downstream.

Two points should be noted concerning the information values found. First, the relative difference between the two values and secondly their comparison to values of similar studies.

Longitudinal succession is evident in all streams and rivers (Odum, 1959). In most streams the gradient decreases, and temperature, organic drift, volume of flow and general productivity increase as one advances toward the mouth. River bed sustrate usually changes too, going from rock and rubble to silt and clay. With these changes the community structure also changes and therefore it is natural for the bottom fauna of some rivers to go from mayfly and caddisfly to bloodworms and oligochaetes near the mouth. This change may be quite rapid in nature, but, for the approximately six-mile reach of river between Okemos and station 2 all indications show that the change in numbers and species, as reflected by ($\bar{H}$) and the past discussion, is far too great. The velocity of flow and natural bottom were approximately the same at both stations, although there was more intermixed silt at station 2. Supported by information of previous sections it can be said that the change in macro-invertebrate community structure is due largely to the great number of drains that enter the river between the two stations.

Information values found in this study are in agreement with other studies. A complete table is given by Wilhm and Dorris (1968) where values range from approximately 3.5 in unpolluted zones to 1.3 near sources of pollution.

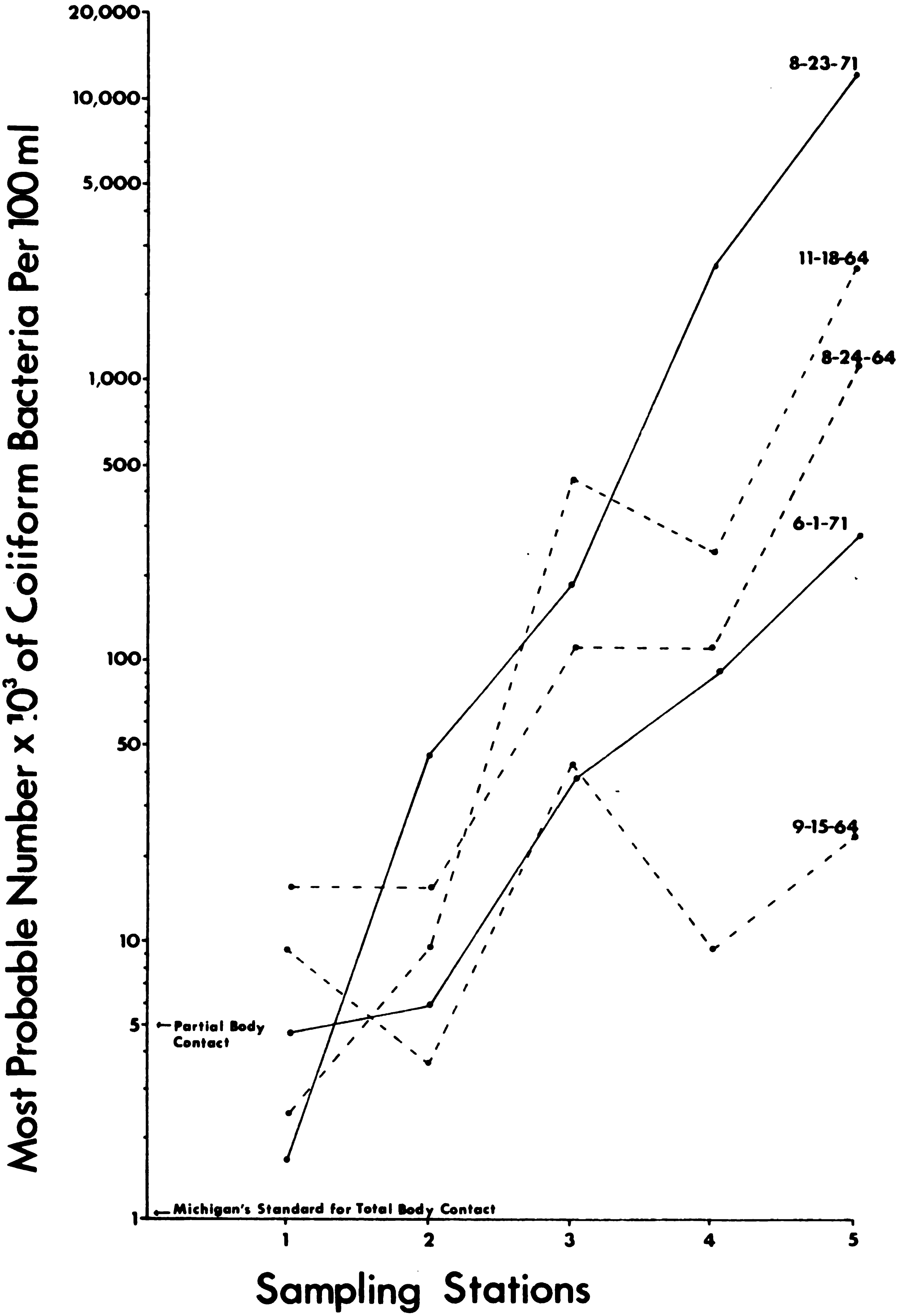
In conclusion, the increase in pollution tolerant organisms from station 1 to 2, the presence of certain indicator organisms and the difference in diversity from Okemos to station 2 all are evidence of a significant change in the macro-invertebrate community. The change within the river section investigated is greater than "natural succession" would allow and therefore coupled with previous data it seems apparent that the drain effluents have brought about the change.

Coliform Bacteria

The coliform bacteria analysis is a unit of measurement used for determining the human safety of water. Diseases of intestinal origin, such as typhoid, dysentery, cholera and infectious hepatitis can be transmitted by polluted water. Because specific pathogenic organisms are very difficult to isolate, coliform organisms are used as indicators of the disease potential of water. Of the three main groups of bacteria present in the intestinal tract of man, coliform organisms are the most closely related to intestinal pathogens. Experience has established the significance of coliform bacteria densities as criteria of the degree of pollution and thus of the sanitary quality of water (APHA, AWWA, WPCF, 1971). Coliforms are found in soil as well as in the intestinal wastes of both man and animals, thus, surface runoff can add coliform bacteria to streams (Frobisher, 1957). Usually soil runoff accounts for densities of less than 1000 organisms/100ml (MPN). High numbers of coliforms indicate that raw sewage has entered the river. It should be realized that the results reported as MPN are merely an index of the number of coliform bacteria which, more probably than any other number, would give the results shown by the laboratory examination.

Jensen (1966) found that as the river flows through the Michigan State University campus, MPN of coliforms increases exponentially on logarithmic graph paper, indicating several sources of domestic sewage enter the river throughout the study section. Figure 10, which includes Jensen's (1966) results, illustrates the same situation was true during the summer of 1971. In fact values for August 23, 1971, indicate an even worse situation. It should be reported, however, that this analysis took place during a rain which caused several drains to discharge raw sewage. As might be expected a

Figure 10. Most probable number (MPN) for coliform bacteria per 100ml of river water at sampling stations 1-5. [Broken lines are values of 1964 from Jensen (1966).]



20,000
10,000
5,000
1,000
500
100
50
10
5
1
Most Probable Number x 10³ of Coliform Bacteria Per 100 ml
8-23-71
11-18-64
8-24-64
6-1-71
9-15-64
Partial Body Contact
Michigan's Standard for Total Body Contact
1
2
3
4
5
Sampling Stations

sudden summer storm causing a large input of sewage in proportion to the dilution offered would result in extremely high coliform densities. Considering Michigan intrastate water quality standards (Figure 10), portions of the Red Cedar River are unsafe for total or partial body contact; for example, canoeing and fishing.

SUMMARY

1. Analyses indicated effluents of approximately one-third of the 90 drains located within the bounds of the study area contained materials detrimental to the water quality of the Red Cedar River.

2. Untreated domestic sewage, high concentrations of chlorides, oily products, detergents and heavy silt loads were discharged into the river by specific drains.

3. Drain 66, 25, 6 and 62 were found to have a lethal effect on green sunfish either in bioassays or by live car tests.

4. Data suggest that sudden summer rain storms were the underlying cause of the major input of pollution having detrimental effects on river fauna.

5. Low dissolved oxygen resulted in a major fish kill in the lower portion of the study section during the summer of 1971.

6. Although on occasion dissolved oxygen levels became critically low, data indicate that there has been

some improvement in the average daily dissolved oxygen near the Limnological Research Laboratory (station 2) since 1964.

7. Results of this and Jensen's (1966) study indicate neither phosphorus nor nitrogen is limiting, but rather that productivity is limited by turbidity and siltation.

8. An increase in pollution-tolerant organisms from station 1 to 2, the presence of certain indicator organisms, and a difference in diversity from Okemos to station 2 all are evidence of a significant change in the macro-invertebrate community.

9. Coliform bacteria increase exponentially as one goes downstream from Hagadorn Road to East Kalamazoo Street where levels are well above safe standards.

10. When one considers the chemical parameters as well as coliform numbers and bottom fauna there seems to be little improvement in the river since 1964.

11. The cumulative effect of several drain effluents have caused a significant change in the water quality of the river from Hagadorn Road to East Kalamazoo Street. The effect is illustrated by an increase in carbon, nitrogen, phosphorus, chlorides, coliform bacteria and pollution-tolerant bottom organisms as one goes downstream.

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LITERATURE CITED

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APPENDICES

APPENDIX A

INFORMATION CONCERNING DRAINS

APPENDIX A

Description of Drains

August 1971

Drains on South Side of River

Drain Number	Approx. Dia. in Inches	Description*
1	72	Opening is covered with wire gates. --Flowed often at low levels and during rains the effluent was muddy. On one occasion the chloride concentration was above 25,000 mg/liter.
2	24	Drain with a cement retaining wall located 100 feet upstream from Bogue Street.--Effluent generally clear with low flow. At times the chloride concentration was above 5,000 mg/liter.
3	12	A concrete drain located 180 yards downstream from Bogue Street.--Flowed infrequently and is considered insignificant.
72	18	A concrete drain which is usually one-half submerged and hidden by bushes.--Flowed infrequently and is considered insignificant.
96	10	Concrete drain with a retaining wall which is usually 1 foot above the river level.--No discharge ever recorded even during extended rains.

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*Comments also include information concerning the effluents based upon general observations and chemical analyses. Melting conditions gave the same results as periods of rain. Each drain was visited at least 20 times.

Drains on South Side of River--Continued

Drain Number	Approx. Dia. in Inches	Description
4	18	This drain has a retaining wall and generally is one-half submerged.--Flow was recorded only once during a heavy rain.
5	8	Drain has a small retaining wall.--Never observed flowing even during a rain.
6	36	A concrete pipe located 75 feet upstream from Farm Lane. Opening is usually three-fourths below the water.--Considered a major drain.
7	6	A steel pipe located 20 feet upstream from Farm Lane.--Drain flowed a small amount of clear heated effluent. Because temperatures were commonly above 50 C the discharge may be the result of a leak in a hot water line.
8	28	This drain has a cement retaining wall surrounded by broken brick.--This drain discharges a considerable amount of dark dirty water during a storm. A froth and oily film were observed at times.
9	12	Flowed during rains and on occasion during dry periods, but effluent was generally clear with low nutrients and salts.
11	12	This drain is low on the bank with a cement retaining wall.--Drain was never observed flowing and seemed to be partially filled with soil.
73	28	The drain is hidden back into the bank of the river. The drain is partially filled with gravel and cement blocks.--Flow was low, clear and considered insignificant.

Drains on South Side of River--Continued

Drain Number	Approx. Dia. in Inches	Description
12	12	Located across and downstream from the U.S.G.S. survey station. This drain has a small cement retaining wall and is hidden by bushes.--Flowed only during rains and was considered insignificant.
99	12	A tile within a small cement retaining wall and located 25 yards upstream from first foot bridge.--Flowed only during heavy rains and was considered insignificant.
100	4	Located 20 feet upstream from first foot bridge.--Never observed flowing.
13	6	Located 20 feet downstream from first foot bridge.--Never observed flowing.
14	12	High on the bank 28 yards downstream from the dam.--Never observed flowing.
101	4	Located 40 yards below dam and has a cement retaining wall.--Never observed flowing.
15	27	Concrete pipe with large retaining wall located 20 feet upstream from second foot bridge.--Considered a major drain.
16	16	This drain has a large cement retaining wall.--Flowed infrequently and was considered insignificant.
17	8	Located 10 feet downstream from above drain.--Never observed flowing.
18	36	Drain with no retaining wall located across from M.S.U. botanical gardens.--Oily films, sewage gray color, and high turbidity observed infrequently.
19	15	Concrete pipe located approximately 75 yards below drain 18. This drain seems to be different than the one described by Jensen (1966).--During a rain the initial effluent was dark and turbid.

Drains on South Side of River--Continued

Drain Number	Approx. Dia. in Inches	Description
20	6	Located across from the M.S.U. women's gym. Consists of a steel pipe low on the bank.--Never observed flowing.
79	12	Tile drain located 20 yards below East Kalamazoo Street on M.S.U. campus.--Never observed flowing.
21	18	Located 60 yards downstream from third foot bridge. Outfall slants toward the river.--Flowed infrequently at a slow rate and was clear.
22	24	Located 200 feet downstream from Jenison Fieldhouse. This is a cement drain with no retaining wall.--Flowed often at a slow rate and was generally clear. Froth, oily films and muddy effluents were observed at times, especially during a rain.
23	24	Located one foot below above drain.--Drain no longer flows and is filled in.
106	16	Cement pipe high on the bank 15 yards upstream from Harrison Street.--Flowed only during heavy rains and was considered insignificant.
24	12	Located under Harrison Street Bridge. This is a metal pipe high on the bank.--Never observed flowing.
25	72	Located 60 yards downstream from Harrison Street. Drain is oval and blocked by wire gates. Considered a major drain.
26	12	Metal drain one foot from the drain described by Jensen (1966) which is now rusted and does not flow. This drain is high on the bank and has caused considerable bank errosion.--Appears to be a storm drain which discharges turbid water during rains.

Drains on South Side of River--Continued

Drain Number	Approx. Dia. in Inches	Description
27	24	Metal drain low on the bank across from Brody parking lot.--Flowed infrequently and at a slow rate but was a dark sewage color and smelled as such. High carbon, nitrogen and phosphorus concentrations present when sampled.
28	12	Concrete pipe located out from the Limnological Research Laboratory.--Flowed only during heavy rains and was considered insignificant.
		Drains on North Side of River
70	12	Steel pipe located high on the embankment of Hagadorn Road.--Storm drain which discharges runoff from Hagadorn Road during a heavy rain.
30	4	Metal pipe below what appears to be a water tank.--Flowed infrequently and was considered insignificant.
31	12	Tile drain located 100 yards downstream Hagadorn Road behind Cedar View Apartments.--Flowed only during a rain and was considered insignificant.
32	4	Located 30 feet downstream from above drain. Pipe extends below water. Appears to be a septic drain.--No evidence of flow.
33	72	Located 75 yards upstream from Riverside East Apartments. This drain has a large cement retaining wall.--Appears to be a combined storm and sanitary drain which discharged sewage during a rain. Analyses showed high phosphorus, nitrogen and carbon to be present.
90	6	Black tile high on the bank behind Riverside East Apartments.--Never observed flowing.

Drains on North Side of River--Continued

Drain Number	Approx. Dia. in Inches	Description
35	12	Located below parking lot of Riverside East Apartments. This drain is a corrugated steel pipe protruding from the bank but hidden by bushes.--Flowed only during rain and was considered insignificant.
36	72	Located adjacent to west side of Riverside East Apartments. This drain is one-half submerged and has a large cement retaining wall.--Considered a major drain.
91	8	Tile drain high on the bank 70 yards below drain 36.--Flowed only during heavy rains.
91_B	6	Tile drain high on the bank next to a wooden fence and 100 yards downstream from drain 36.--Flowed only during rains and was considered insignificant.
92	6	Steel pipe protruding from bank approximately five feet.--Flowed only during rains and was considered insignificant.
38	10	Cement drain with no retaining wall low on the bank behind broken blocks.--Insignificant.
38_B	6	Steel pipe behind brick and red steel apartments.--Insignificant.
39	6	Located near east end of Eaton Rock Apartments parking lot. Steel pipe with wire cover located low on the bank.--Flowed infrequently and was considered insignificant.
40_A	42	Located 200 yards upstream from Bogue Street. Combined storm and sanitary drain with a steel pressure cap.--Discharged turbid water with high nutrient loads during heavy storms.

Drains on North Side of River--Continued

Drain Number	Approx. Dia. in Inches	Description
40_B	72	Located within the same retaining wall as drain 40A. Drain has a large steel pressure cap which only opened a few inches during heavy rains.
40_C	12	Steel drain next to 40B.--Never observed flowing.
94	16	Cement drain located low on the bank 100 yards upstream from Bogue Street.--Flowed only during rains and seems to come from a parking ramp.
95	16	Cement drain located 75 yards upstream from Bogue Street.--Same as above drain.
41	12	Located 50 feet downstream from Bogue Street.--Flowed infrequently at a slow rate.
42	30	Concrete pipe behind the M.S.U. Alumni Chapel. This drain appears as a large cement retaining wall because opening is not visible.--Flowed infrequently at a slow rate.
71	10	Drain is low on the bank with a small metal retaining wall.--Insignificant.
44	8	Located behind Kresge about 10 yards downstream from drain 71. No retaining wall and is low on the bank.--Insignificant.
45		Drain appears as a large cement retaining wall behind Kresge. Could not find an opening.--Insignificant because filled in.
46	12	Located 150 yards upstream from Farm Lane. Drain has a large retaining wall and is one-half submerged.--Slight discharge during a rain.

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

Drain Number	Approx. Dia. in Inches	Description
47	36	Located 40 feet upstream from Farm Lane. Drain is beneath the water and a sidewalk goes up to the retaining wall.--Seems to be a combined storm and sanitary drain which discharges a large amount of dark oily effluent during a rain storm. Effluent is nutrient rich.
48	24	Located 10 yards downstream from Farm Lane. Drain is three-fourths below water and has no retaining wall.--At times water flows into this drain, but during rains it discharged some sewage into the river. When sampled the effluent was nutrient rich. On one occasion, 12/4/70, drain 48 flowed raw sewage for several hours while the city sanitation department was repairing the sewerage system.
49	15	Concrete pipe with a retaining wall located a few yards upstream from the M.S.U. canoe shelter.--Flowed infrequently and was usually clear. A greenish effluent was observed on occasion during dry periods.
97	12	Located behind parking Ramp #2 (M.S.U.). Appears to be a newly constructed drain with a retaining wall. Drain is commonly one-half submerged.--Slight discharge during rains.
98	6	Tile with broken walk surrounding it. Located just upstream from the U.S.G.S. survey station.--Insignificant.
74	26	Located several yards downstream from the U.S.G.S. survey station. Drain has a newly constructed cement retaining wall.--Infrequently discharges a dark gray effluent at a slow rate.

Drains on North Side of River—Continued

Drain Number	Approx. Dia. in Inches	Description
52	10	Concrete drain with retaining wall located behind the Computer Center. The end section of this drain is broken off. Flowed infrequently and considered insignificant.
53	12	Located 10 yards upstream from the first foot bridge. Cement retaining wall and screen cover. This drain's description is somewhat different than that given by Jensen (1966). The drain was likely reconstructed, since the new M.S.U. Administration building was built. Several other former drains are missing in this area.--Infrequently discharged a dark turbid effluent at a slow rate after a rain storm.
54	20	Located immediately above dam. Drain is built into the side walls of the dam. Drain may be different than in 1964.--Flowed infrequently. On one occasion the effluent was rusty, turbid, had a foul odor and a carbon concentration of 1,400 mg/liter.
57	12	Located 20 yards downstream from the second foot bridge. Drain has a small retaining wall and generally is three-fourths submerged.--Insignificant.
58	60	A rectangular concrete conduit below the water. Drain 58 seems to be a combined storm and sanitary drain of the East Lansing sewerage system.--Discharged a large volume of sewage gray effluent into the river during rain storms. The effluents were nutrient rich and often smelled septic and formed oily films.
59	24	Located behind M.S.U. Women's Gym. This drain has a large cement retaining wall surrounded by broken concrete.--Infrequently flowed raw sewage and also discharged an effluent with a gray-white precipitate on occasion.

Drains on North Side of River--Continued

Drain Number	Approx. Dia. in Inches	Description
60	30	Located 10 feet upstream from East Kalamazoo Street on M.S.U. campus. This drain is low on the bank and has a retaining wall.--Effluent was generally clear with a oily film present.
78	12	Located 20 yards below East Kalamazoo Street on M.S.U. campus. Tile drain with no retaining wall.--Insignificant.
80	36	Cement drain with the two end segments broken off. Bank has erroded and a sludge bed has formed out from the drain.--Effluent is very dark and turbid during a rain. On occasion it discharges water with high chloride and nutrient concentrations.
103	10	Steel pipe extending below the water. Located 10 feet below drain 80.--Prior to repair in November 1970 this drain discharged raw sewage into the river. The effluent had a high nutrient content due to the feces, paper and food particles present. Evidently the city took action after I reported the situation.
104	12	This drain has a cement retaining wall that is broken off and tilted.--Discharged dark turbid water during storms.
81	40	Cement drain with retaining wall located 20 feet below drain 104.--Slight flow during rains.
82	24	Corrugate metal drain located at the corner of Harrison Street and Michigan Ave. This drain is part of the East Lansing combined storm and sanitary sewerage system.--Considered a major drain.

Drains on North Side of River--Continued

Drain Number	Approx. Dia. in Inches	Description
105	36	Located 20 yards below 82 and is covered with a cement box-like retaining wall. Also hidden by bushes.--This drain discharged a dark sewage rich effluent during heavy rain storms. Flow seemed to subside immediately after a rain.
61	72	Located 10 yards below above drain. Drain has a large cement retaining wall and a pressure cap.--Considered a major drain.
63	20	Located below Kellogg Center parking lot. Drain has a cement retaining wall.--Discharged dark turbid water during a rainstorm.
64	24	Located adjacent to Harrison Street bridge and has no retaining wall.--During the winter of 1970-71 this drain discharged sewage into the river which formed a sludge bed. During this time the effluent had very high nutrient and chloride levels. It appeared that this drain was corrected at the end of April 1971, after which it no longer discharged sewage.
65	15	Located across from drain 25 and has a cement retaining wall.--Flowed infrequently and was considered insignificant.
66	36	Located across from the Limnological Research Laboratory. This drain has a cement retaining wall.--Considered a major drain.
67	12	Located 10 feet downstream from above drain and has a cement retaining wall. This drain discharges water for short periods of time during dry conditions as well as flowing during rains.--The effluent was generally clear but produced an oily film on the river. Nitrogen, carbon, chloride and phosphorus concentrations were considerably higher than the river on occasion.

Drains on North Side of River--Continued

Drain Number	Approx. Dia. in Inches	Description
107	27	Located 80 yards downstream from drain 67. Cement retaining wall present.--Dark turbid effluent immediately after a storm began but soon became clear with dilution.
108	36	Corrugated steel pipe embedded in loosely poured cement next to M.S.U. property line fence.--Flowed during rains and was considered insignificant.

Table 7. Formulas for estimating average discharge and dilution ratio.

$$AS = D^2 \cdot a \text{ from the quotient } (h/D)$$

where:

AS = area of segment in square inches.

D = diameter of drain in inches.

a = area corresponding to the quotient (h/D) in Table 9b of Chemical Engineer's Handbook (Perry, 1950).

h = average height of segment in inches (depth of effluent in the drain, measured while sampling).

$$X = AS \cdot K_1 \cdot K_2$$

where:

X = discharge in cubic feet per second (cfs).

K_1 = conversion of inches to feet (144 in^2/ft^2).

K_2 = estimated rate of flow (2 ft/sec).

The average dilution ratio of the drain to river can then be calculated by reducing the fraction X/C.

where:

C = average discharge of the river on sampling dates (124 cfs).

APPENDIX B

INFORMATION CONCERNING TOXICITY TEST

Table 8. Characteristics of laboratory dilution water.

Parameter*	8/19/71	9/13/71
pH	7.82	7.86
Total Alkalinity	320	346
Hardness	322	336
Chlorides	2.50	2.50
D.O.	8.10	8.20

*Values are in mg/liter, except pH.

Information Concerning Bioassay IV

Table 9a. Experimental data for bioassay IV.

Container	and % Concentration	C Temp.	D.O.	pH	Mg/liter NH_3	Numbers of Survivors	C Temp.	D.O.	pH	Mg/liter NH_3	Numbers of Survivors	C Temp.	D.O.	pH	Mg/liter NH_3
		Initial					48 Hours					96 Hours			
1	0	15.5	6.4	7.7	-	10	21.0	8.0	8.4	0.48	10	22.0	7.3	8.5	0.92
2	20	15.2	6.5	7.9	-	10	21.0	7.1	8.4	5.70	7	22.0	6.4	8.5	5.05
3	33	15.5	5.9	7.9	-	7	21.0	6.7	8.3	8.90	6	22.0	7.0	8.5	5.45
4	47	15.0	5.0	7.9	-	4	19.0	6.0	8.3	12.30	0	20.5	-	-	-
5	66	15.5	4.7	7.85	-	0	19.0	5.9	8.3	17.30	0	-	-	-	-
6	80	16.0	5.9	8.0	15.00	0	19.0	4.3	8.1	-	0	-	-	-	-

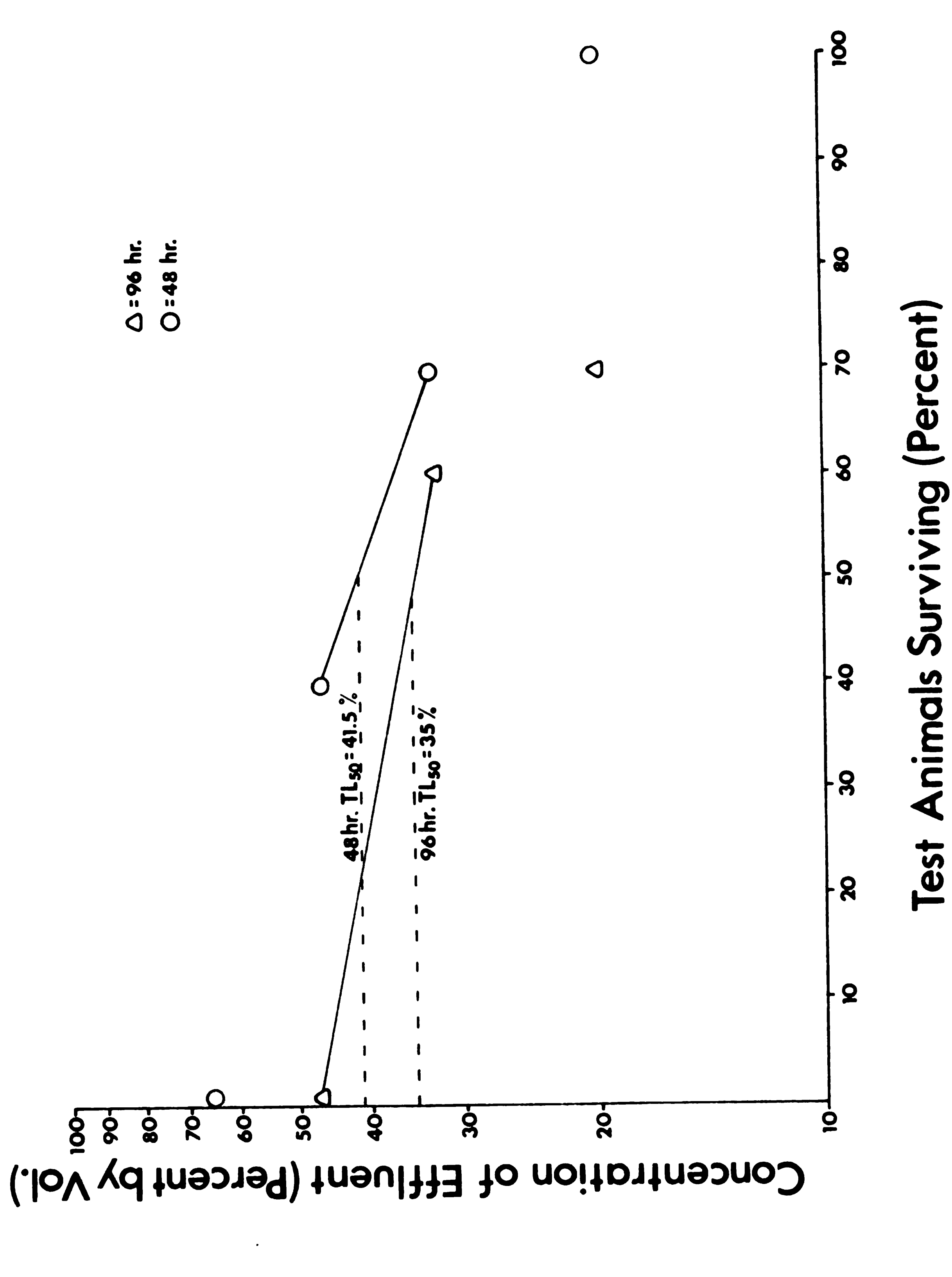
Table 9b. Effluent characteristics for bioassay IV.

Drain 66	Hardness = 298 mg/liter
Date = 5/13/71	P = 7.3 mg/liter, N = 23.9 mg/liter
pH = 7.9	Carbon = 23.0 mg/liter
Conductivity = 1,196 µmhos	Detergents = 1.65 mg/liter
M.O. Alkalinity = 468 mg/liter	NH_3 = 15.0 mg/liter

Table 9c. Bioassay IV procedures.

Volume = 30 liters
Laboratory dilution water
Ten green sunfish, acclimated to 18 C
Average weight = 4.2 gm

Figure 11. Estimation of 50 percent tolerance limits by straight-line graphical interpolation for bioassay IV.



Concentration of Effluent (Percent by Vol.)
100
90
80
70
60
50
40
30
20
10
Test Animals Surviving (Percent)
10
20
30
40
50
60
70
80
90
100
△ = 96 hr.
○ = 48 hr.
48 hr. TL_{50} = 41.5 %
96 hr. TL_{50} = 35 %

Information Concerning Bioassay VI

Table 10a. Experimental data for bioassay VI.

Container and % Concentration of Effluent		C Temp.	D.O.	pH	Number of Survivors	C Temp.	D.O.	pH	Number of Survivors	C Temp.	D.O.	pH
		Initial				48 Hours				96 Hours		
1	0	22.0	7.0	7.8	10	23.0	7.8	8.3	10	24.0	6.9	8.5
2	20	22.0	7.6	7.8	10	23.0	7.7	8.2	10	24.0	7.1	8.3
3	33	22.0	7.6	8.0	10	23.0	8.0	8.4	10	24.0	7.1	8.5
4	50	23.0	7.7	7.9	10	22.0	8.1	8.2	9	23.0	7.2	8.2
5	66	23.0	5.9	7.9	8	22.0	8.2	8.0	8	23.0	8.0	8.1
6	80	24.0	7.0	8.0	8	22.0	8.1	7.9	7	23.0	7.7	8.0
7	100	24.0	7.0	7.9	2	22.0	7.0	8.3	1	23.0	7.0	8.4

Table 10b. Effluent characteristics for bioassay VI.

Drain 62	M.O. Alk. = 184 mg/liter, Cr. = 4.8 mg/liter
Date = 7/19/71	Hardness = 154 mg/liter, Carbon = 8.0 mg/liter
pH = 7.9	P = 0.59 mg/liter, N = .44 mg/liter
Conductivity = 1035 μmhos	NH_3 = 0.36 mg/liter

Table 10c. Bioassay VI procedures.

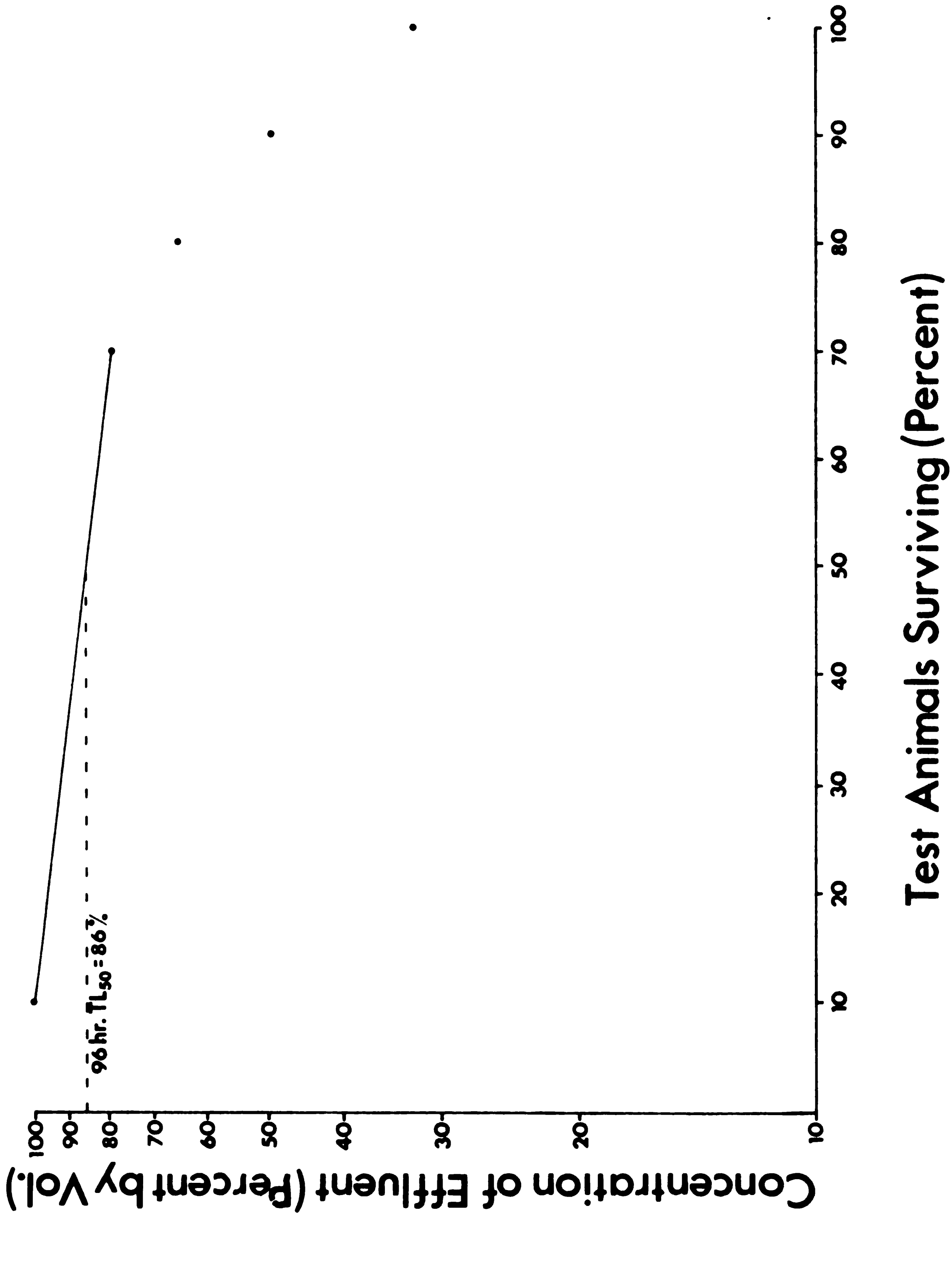
Volume = 30 liters

Laboratory dilution water

Ten green sunfish, acclimated

to 22 C. Aver. wt. = 5.6 gm.

Figure 12. Estimation of 50 percent tolerance limits by straight-line graphical interpolation for bioassay VI.



Concentration of Effluent (Percent by Vol.)
100
90
80
70
60
50
40
30
20
10
96 hr. TL50 = 86%
10
20
30
40
50
60
70
80
90
100
Test Animals Surviving (Percent)

Table 11. Live car test on drain 25 effluent.

Date	Cumulative percent mortality of test animals*			
	Major Control 0% Effluent	Car 1 0% Effluent	Car 2 50-100% Effluent	Car 3 0-50% Effluent
7/16/71	0	0	0	0
7/18/71	0	0	0	0
7/19/71	0	0	0	0
7/20/71	0	0	40	0
7/21/71	0	0	40	0
7/22/71**	0	0	40	0
7/23/71	0	0	50	10
7/24/71	0	0	60	10
7/25/71	0	0	60	10
7/26/71	0	10	60	10

*Test began 7/14/71 with ten green sunfish acclimated to the temperature of the river and/or effluent (25 C). Average weight = 4.2 gm.

**Two conductivity peaks occurred at station 2 as recorded by the monitor. Also a bioassay was conducted of which the 96 hr TL_{50} was greater than 80 percent effluent.

Table 12. Live car test on drain 6 effluent.

Date	Cumulative percent mortality of test animals*			
	Major Control 0% Effluent	Car 1 0% Effluent	Car 2 50-100% Effluent	Car 3 0-50% Effluent
		Test A		
8/4/71	0	0	0	0
8/5/71	0	0	0	0
8/6/71	0	0	0	0
8/8/71	0	0	0	0
8/9/71	0	0	0	0
8/10/71	0	0	0	0
8/11/71**	0	0	30	0
8/12/71	0	0	90	70
8/13/71	0	0	90	70
		Test B		
8/14/71	0	0	10	0
8/15/71	0	0	10	0
8/16/71	0	0	10	0
8/17/71	0	0	10	0
8/18/71	0	0	10	0
8/20/71	0	0	30	0
8/21/71	0	0	40	0

*Test A began 8/3/71 and test B began 8/13/71 with 10 green sunfish acclimated to the temperature of the river and/or effluent (22 C). Average weight--test A = 4.2 gm, test B = 5 gm.

**A major fish kill occurred downstream--D.O. was low.

APPENDIX C

INFORMATION CONCERNING BOTTOM FAUNA

Table 13. Summary of "pool" bottom fauna expressed as number per square foot. Sample date July 28, 1971.

Station	North 1/4	Midstream	South 1/4	Mean
		Oligochaeta		
1	12	8	48	23
2	76	60	39	58
3	124	96	92	104
4	60	60	12	44
5	552	458	185	398
		Chironomidae		
1	20	28	40	29
2	20	20	21	20
3	32	88	72	64
4	68	12	98	59
5	282	40	32	118
		Elmidae		
1	8	4	12	8
2	4	10	3	6
3	-	4	-	1
4	-	4	4	3
5	2	-	1	1

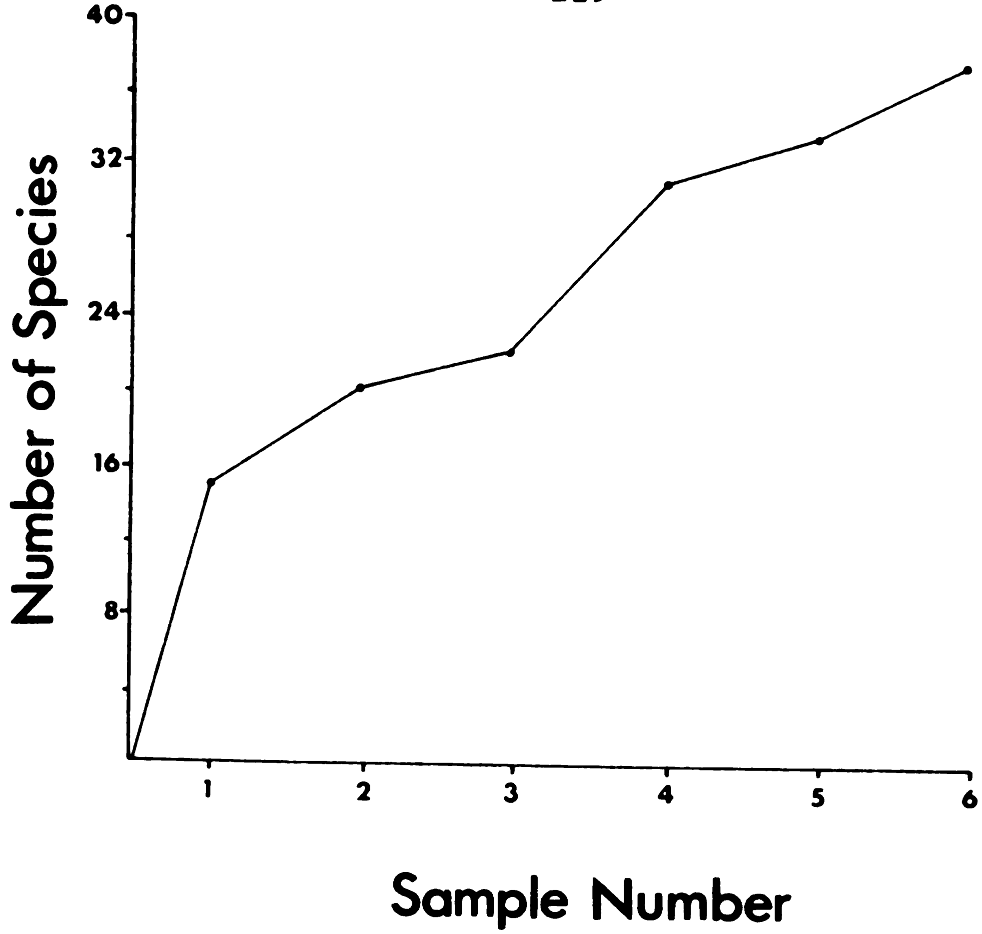


Figure 13. Test of sampling adequacy upstream.

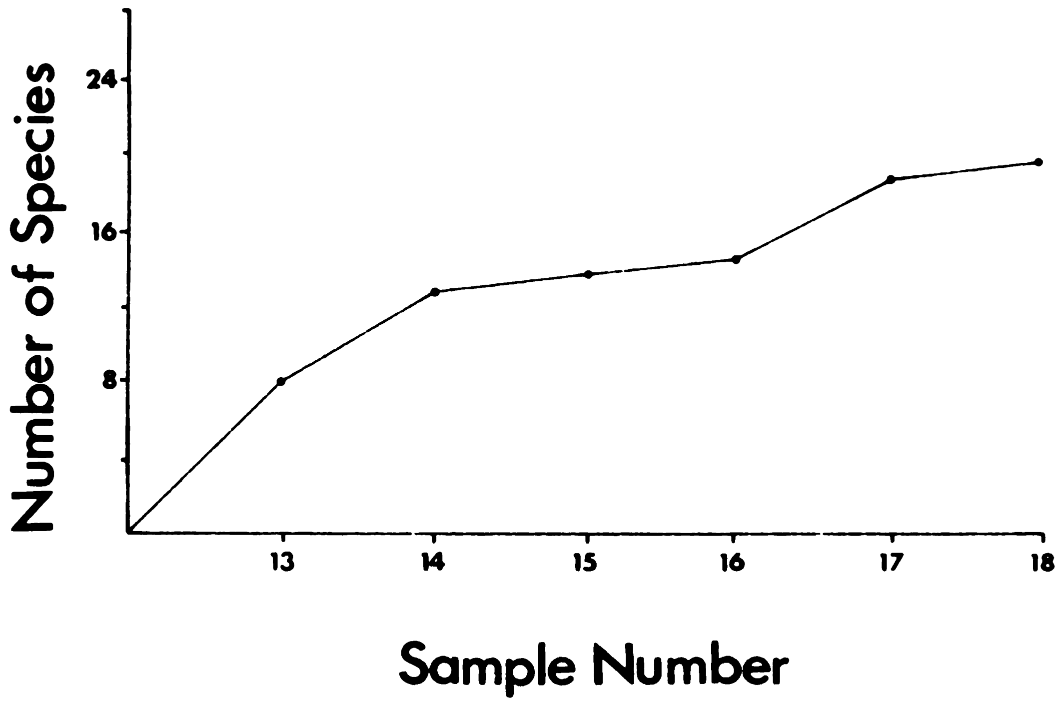


Figure 14. Test of sampling adequacy downstream.

APPENDIX D

GENERAL INFORMATION

Figure 15. A. Photograph of drain 66 discharging sewage.

B. Photograph of drain 82 discharging sewage.

C. Major fish kill of August 11, 1971 [shopping cart with dead fish].

D. Photograph of effluent from drain 25.

A

B

C

D

Figure 16. Map of the Red Cedar River.

Figure 17. Map showing sewerage system of Michigan State University.* [As of Sept. 1971.]

*Survey of drains entering the Red Cedar River within the boundaries of Michigan State University. Engineering Services Dept., Mich. State Univ., 1965.