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WATER POLLUTION INVESTIGATION: BUFFALO RIVER

VERSAR INC.

U.S. ENVIRONMENTAL PROTECTION AGENCY
REGION V ENFORCEMENT DIVISION
GREAT LAKES INITIATIVE CONTRACT PROGRAM

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WATER POLLUTION INVESTIGATION:

BUFFALO RIVER

by

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VERSAR, INC.

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This report has been developed under auspices of the Great Lakes Initiative Contract Program. The purpose of the Program is to obtain additional data regarding the present nature and trends in water quality, aquatic life, and waste loadings in areas of the Great Lakes with the worst water pollution problems. The data thus obtained is being used to assist in the development of waste discharge permits under provision of the Federal Water Pollution Control Act Amendments of 1972 and in meeting commitments under the Great Lakes Water Quality Agreement between the U.S. and Canada for accelerated effort to abate and control water pollution in the Great Lakes.

ABSTRACT

The Buffalo River was the subject of a comprehensive evaluation of waste loadings and water quality, performed as part of the U.S. Environmental Protection Agency's committments to abate and control water pollution under the 1972 Great Lakes Water Quality Agreement between the U.S. and Canada.

The Buffalo River, as a result of adverse hydraulic conditions and high waste loadings from industrial discharges and from combined sewer overflows, exhibits a summertime dissolved oxygen concentration of less than one mg/l, a contravention of standards for iron, and evidence of poor water quality in most of the other 24 parameters studied.

Three independent observations confirmed that the industrialized reach of the Buffalo River is a well-mixed body of water. A water quality simulation model was developed, verified, and utilized to predict water quality upon the implementation of Best Practicable Control Technology Currently Available. The projected water quality marginally came within the standards for temperature and for dissolved oxygen, but more stringent waste allocations were recommended for iron. Upon implementation of BPCTCA, the oxygen-demanding waste load of the combined sewer overflows would then become the dominant constraint for achieving good water quality in the Buffalo River.

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1.0 INTRODUCTION

Under the Great Lakes Water Quality Agreement of 1972 between the United States and Canada, the U.S. Environmental Protection Agency is committed to an accelerated effort to abate and control water pollution in the Great Lakes. The Buffalo River in western New York has been identified as one of several concentrated areas of municipal and industrial activity which have poor water quality and contribute to the waste loads of the Great Lakes.

While a number of agencies have gathered much data in a piecemeal fashion, a need existed to comprehensively evaluate the present state and trends of waste loadings and of water quality in the Buffalo River. Consequently, the U.S. Environment Protection Agency contracted with the General Technologies Division of Versar, Incorporated on June 30, 1973, to perform a waste allocation study of the Buffalo River. The objectives of this program were:

(1) To quantify the effect of current industrial, municipal and non-point discharges upon the water quality of the Buffalo River.

(2) To predict the water quality of the Buffalo River upon implementation of Best Practicable Control Technology Currently Available (BPCTCA) for industrial discharges and upon implementation of control and treatment practices for other discharges.

(3) To determine maximum waste loads which must be allocated to satisfy water quality standards for the Buffalo River.

(4) To determine the impact of the Buffalo River upon the water quality of the Niagara River with and without achievement of waste load limitations by discharge into the Buffalo River.

An extensive list of 26 water quality parameters received careful attention in this program in analyzing the stream samples, in documentating the effluent data, and in the modeling and waste allocation tasks.

The parameters were:

Temperature	Sulfate
pH	Cyanide
Total Solids	Arsenic
Total Dissolved Solids	Barium
Suspended Solids	Cadmium
Dissolved Oxygen	Chromium
Ammonia	Copper
Nitrogens	Iron
Total Phosphorus	Lead
Phenols	Mercury
Oil and Grease	Nickel
Chloride	Selenium
Fluoride	Zinc

The waste allocation program methodology consisted of the following elements, each of which is addressed in detail in the body of the report:

(1) An examination of the historical water quality and effluent data base and identification of additional required data.

(2) A field sampling and analysis effort aimed at filling the gaps in the data base.

(3) The correlation of present water quality with present waste loadings (effluents) utilizing simulation modeling techniques.

The simulation modeling task in this program was intended by EPA direction to be "straightforward," i.e., of a limited sophistication. Early in the program, however, it became apparent for a number of reasons (including the atypical hydraulics, the large number of water quality parameters, and the importance of combined sewer overflow waste loads) that extension of existing models was necessary.

(4) To project future waste loadings, based upon control technology appropriate for each discharge.

(5) To project future water quality, utilizing the future waste loadings in conjunction with the developed simulation model.

(6) To compare present and future water quality with water quality criteria and to allocate waste loadings if required in order to satisfy water quality criteria.

(7) To substantiate the accuracy of the results by verifying the simulation model and to substantiate the precision of the results by performing a sensitivity analysis.

(8) To perform an impact analysis of present and projected Buffalo River water quality upon the water quality of the Niagara River.

The program was drastically accelerated by EPA direction so that preliminary waste load allocations would be available by December 31, 1973, in time to affect the implementation by EPA of the NPDES permit program. The acceleration meant that the field sampling and analysis task was started and finished very early and the present and projected waste loads were documented very early. The necessary early expenditure of program funds effectively prevented later revision of these data in an admittedly dynamic pollution abatement situation. Hence, the data and results of this program should be reviewed in the context of the Buffalo River as of July through October 1973.

During this time period there were almost no issued NPDES permits, almost no promulgated Effluent Limitation Guidelines, and the majority of the applicable Draft Development Documents for Effluent Limitation Guidelines were similarly unavailable. Hence, the projected industrial waste loads (which were intended to be consistent with BPCTCA) were in most cases estimates as of October 1973. Promulgated Guidelines, draft Development Documents, and issued NPDES permits, after October, 1973, were therefore not included in this waste allocation program.

This report is organized to guide the reader from an appreciation of the current conditions to a projection of conditions upon the application of abatement technology. The hydraulics of the Buffalo River is discussed in considerable detail in the opening section. The atypical flow behavior has a profound effect upon the subsequent correlations and projections. Next water quality data is presented to give the reader an appreciation of the discrepancies between current status and criteria. The waste loads are then presented, both from the standpoint of current wastes and projected wastes, based upon best practicable control and treatment technology. The correlation of current water quality with current waste loads is presented. This correlation is then utilized to project the water quality consistent with projected waste loads. Waste allocation recommendations are then made for the achievement of the desired water quality. Finally, the current and projected water quality impact of the Buffalo River upon the Niagara River is discussed.

2.0 SUMMARY

Under the Great Lakes Water Quality Agreement of 1972 between the United States and Canada, the U.S. Environmental Protection Agency is committed to an accelerated effort to abate and control water pollution in the Great Lakes. The Buffalo River Basin in western New York, discharging into the eastern end of Lake Erie at the head of the Niagara River, was identified as one of several areas to receive special attention. This report describes a comprehensive evaluation of the present state and trends of waste loadings and of water quality in this area.

The Buffalo River receives the waste loads of its upstream tributaries, very heavy concentration of industrial discharges, and frequent overflows from the combined sewer system. Low water velocities and high water temperatures, combined with high waste loadings, result in a summertime dissolved oxygen concentration of less than one mg/l and an almost total absence of bottom organisms. Of the total of 26 water quality parameters receiving careful attention in this study, most provided evidence of poor water quality. In addition to dissolved oxygen, iron was in clear contravention of water quality standards.

Three independent observations confirmed that the industrialized reach of the Buffalo River is a well-mixed body rather than a free-flowing stream: oscillating flow in the upstream as well as downstream direction (driven by oscillations in the level of Lake Erie); longitudinally homogeneous water quality measurements of virtually every parameter; and a clear choice in successfully matching measured water quality with water quality calculated by a plug-flow vs. a well-mixed simulation model.

The developed and verified model was utilized to predict water quality upon the implementation of Best Practicable Control Technology Currently Available (BPCTCA) loads. The projected water quality, at critical flow conditions, marginally came within the standards for temperature and dissolved oxygen. However, more stringent waste allocations were recommended for iron. Upon implementation of BPCTCA, which would be effective in reducing most waste loads, the oxygen-demanding waste load of the combined sewer overflows would then become the dominant constraint for achieving good water quality in the Buffalo River.

3.0 CONCLUSIONS

(1) Except for the lower reach of Cayuga Creek and for the short Buffalo River itself, most of the Buffalo River watershed (including all of Buffalo Creek and Cazenovia Creek and the upper reaches of Cayuga Creek) is typified by good water quality. This is consistent with an agricultural, wooded, and vacant land use pattern, dotted with small residential communities and scattered park and recreational areas.

(2) The lower 13 kilometers (eight miles) of Cayuga Creek fails to meet water quality standards with respect to dissolved oxygen, ammonia, cyanide, and iron; and has abnormally high levels of oil and grease, phenols, phosphorus, copper, lead, chromium, and selenium. Two of the three primary municipal sewage treatment plants discharging into this reach of Cayuga Creek (which account for 98 per cent of the total effluent from all three plants) are grossly ineffective. The heavy metals and toxic materials are most likely attributable to industrial wastes which are accepted by the municipal sewer system.

(3) Specific contraventions of water quality standards in the industrial reach of the Buffalo River are an average summertime dissolved oxygen concentration of 0.9 mg/l (compared to the minimum allowable of 3.0 mg/l) and an average iron concentration of 3.1 mg/l (compared to the maximum allowable of 0.8 mg/l). Although many of the other parameters, including temperature, are at high levels compared to the natural waters, no other specific water quality contraventions were found.

(4) Chemical analysis of bottom deposits from the industrialized reach of the Buffalo River indicate high levels of oxygen demand, oil, grease, and iron. Biological sampling of these bottom deposits indicate that this reach of river is essentially devoid of bottom organisms; a finding consistent with the measured dissolved oxygen level of less than 1 mg/l.

(5) The Buffalo River is heavily industrialized, with 32 point discharges in eight kilometers (five miles). In addition, frequent overflows, from numerous outfalls, from the combined sanitary/storm sewer system constitute a major waste load. The industrial

waste loads were quantified, and then projected based upon the implementation of Best Practicable Control Technology Currently Available (BPCTCA). The combined sewer overflow waste loads were quantified based upon the consistent results of two separate previous studies. Of all of the BOD waste load (from upstream tributaries, from industrial discharges and from combined sewer overflows), the combined sewer overflow presently constitutes 31 per cent and would constitute 59 per cent upon the projected reductions in the other two waste loads.

(6) The industrialized reach of the Buffalo River is maintained as a shipping channel to a depth of 6.7 meters (22 feet), and has a very low slope, less than 0.2 meters per kilometer. Most of the river's volumetric flow is due to industrial discharges whose intake source is not the River but in the Buffalo Outer Harbor. These industrial flows amount to more than twice the natural discharge at average summertime conditions and to twenty times the natural discharge at critical flow conditions; resulting in a relatively stable total flow rate in summertime. Because of the very large man-made river cross-section, however, the calculated average velocity is very low, less than 0.02 meters per second, and the calculated residence time in this short reach is greater than five days.

(7) Oscillating flow (upstream as well as downstream) of significantly higher velocities than the calculated average, was observed and measured in the industrialized reach of the Buffalo River. Independent sets of time-varying water-level data for Lake Erie at the mouth of the Buffalo River and for the Buffalo River itself also exhibited significant oscillations. A dynamic analysis, which converted observed water level oscillations to flow rate oscillations, resulted in a calculated R.M.S. velocity of 0.096 m/sec, which is in general agreement with the R.M.S. velocity (from direct measurements of velocity) of 0.082 m/sec, and which is five times the calculated time-average downstream velocity of 0.018 m/sec. An extension of the dynamic analysis resulted in a calculated longitudinal movement of water of $\pm$ 200 meters superimposed upon the time-average movement. These observations of the oscillatory flow of the Buffalo River led to the hypothesis that significant longitudinal mixing should result.

(8) Two additional observations, based upon the measurement of water quality at various longitudinal stations in the Buffalo River, supported the above hypothesis of significant longitudinal mixing. First, the water quality near each end of the industrialized reach of the Buffalo River reflected mixing with downstream waters. The Buffalo River near its mouth reflected the better water quality of Lake Erie, and the Buffalo River upstream of industrial discharges reflected the poorer water quality of the

industrialized reach. Second, and of primary significance, the measured water quality of the eight-kilometer (five mile) industrialized reach itself exhibited very convincing longitudinal homogeneity for a wide range of chemical (and thermal) parameters.

(9) A water quality simulation model was constructed with the option to use plug-flow (free-flowing) hydraulics or completely-mixed hydraulics. The model also was constructed to treat the waste loads from combined sewer overflows as a distributed load, with a portion of its oxygen demand exerted as a benthic load. The model also was designed to treat ammonia and phenols as oxidizable (non-conservative) parameter, to treat a very large number of conservative parameters, and to perform a full thermal analysis.

(10) Exercise of the model in both hydraulic modes led to the clear adoption of the well-mixed mode on the basis of matching empirical water quality data with calculated values. This choice was completely consistent with the prior evidence for longitudinal mixing. Furthermore, the well-mixed model, using for the most part constants independently published by others, came very close to matching empirical water quality data for almost all of the parameters. The model was then adequately verified by comparing its water quality predictions with measured wintertime data in a completely different flowrate regime.

(11) The developed simulation model was then utilized to calculate the water quality consistent with the waste loads projected upon implementation of BPCTCA. At critical flow conditions, the projected river temperature (29°C) and dissolved oxygen concentration (3.1 mg/l) were marginally within the water quality criteria. All other parameters, with the exception of iron, were also projected to be within the water quality criteria. The projected iron concentration was 2.7 mg/l at critical flow, compared to the maximum allowable concentration of 0.8 mg/l. It was concluded that waste allocations for iron must be more stringent than those based upon BPCTCA.

(12) With respect to oxygen-demanding wastes, BPCTCA is quite effective in waste abatement. The BOD waste load was reduced by 43 per cent for the upstream tributaries and by 70 per cent for the industrial discharges. However, no reduction of waste loads from combined sewer overflows was projected for the near future. Hypothetically, elimination of all combined sewer overflows could result in a dissolved oxygen concentration in the Buffalo River, at critical flow conditions, of 5.8 mg/l.

(13) The flow rate of the Niagara River is three orders of magnitude greater than the flow rate of the Buffalo River (both at average summertime conditions), making the impact of the Buffalo River upon the water quality of the Niagara River insignificant, both

with present waste loads and with projected waste loads into the Buffalo River. This determination, however, does not take into account any cumulative effects, either temporally or spatially, for which evaluation is beyond the scope of this study.

4.0 RECOMMENDATIONS

(1) The waste load allocations for the following five industrial point-source dischargers should (with the exception of iron) be based upon Best Practicable Control Technology Currently Available:

043 - Mobil Oil Corporation
419 - Allied Chemical Corporation, Industrial Chemicals Division
482 - Allied Chemical Corporation, Specialty Chemicals Division
326 - Republic Steel Corporation
084 - Donner-Hanna Coke Corporation

The specific gross discharge limitations for these five industries, for each chemical constituent (except iron) and heat flux, are tabulated in Appendix E of this report.

(2) The waste load allocations for iron are based upon the water quality criterion rather than upon Best Practicable Control Technology Currently Available. These allocations are:

043 - Mobil Oil	90 kg/day gross	(200 lbs/day)
419 - Allied Chemical ICD	54 kg/day gross	(120 lbs/day)
482 - Allied Chemcial SCD	36 kg/day gross	(80 lbs/day)
326 - Republic Steel	145 kg/day gross	(320 lbs/day)
084 - Donner-Hanna Coke	27 kg/day gross	(60 lbs/day)

(3) The following industries should no longer discharge into the Buffalo River, but should be serviced by new sanitary sewers of the Buffalo Sewer Authority for Katherine Street and Kelley Island. This recommendation is consistent with Best Practicable Control Technology Currently Available and with active plans of cognizant agencies:

569 - Airco Industrial Gases Division, Airco Inc.
191 - Pacific Molasses Company
424 - United States Steel Corporation
271 - International Multifoods Corporation
339 - American Malting Incorporated
056 - Peavey Company

(4) The following industries, although having point discharges into the Buffalo River and into the Buffalo Ship Canal, do not significantly affect the water quality of the Buffalo River because of dilution by Lake Erie waters. Their waste load allocations should be based upon Best Practicable Control Technology Currently Available:

088 - Agway Incorporated
114 - General Mills, Inc.
304 - The Pillsbury Company

(5) Dry-weather discharges into Cayuga Creek from three existing municipal sewage treatment plants should be halted. Incorporation of the sanitary sewage into the Buffalo Sewer Authority system is consistent with recognized control and treatment practices and with active plans of cognizant agencies. The sources of the heavy metals and toxic materials (which have been found in the samples from Cayuga Creek) should be identified and appropriate pretreatment requirements should be imposed. The three sewage treatment plants are:

Village of Depew
Town of Lancaster
Village of Lancaster

(6) Further efforts to improve the water quality of the Buffalo River with respect to dissolved oxygen, beyond the waste allocation recommendations listed above, should be directed at abating the overflows from the combined sewer system. The analyses in this report show this approach to offer the most potential for improved water quality beyond the projections of this report.

(7) Due to significant dilution with waters of Lake Erie, water quality data for the Buffalo River at Stations downstream of the Ohio Street Bridge should not be utilized as a measure of the impact of the Buffalo River upon the Niagara River, nor as a representative measure of the water quality of the industrialized reach of the Buffalo River.

(8) The analysis detailed in this report, and the Conclusions and Recommendations based upon the analysis, should be revised accordingly to reflect newly-promulgated effluent guidelines and water quality criteria.

5.0 HYDRAULICS

5.1 GENERAL DESCRIPTION OF THE STUDY AREA

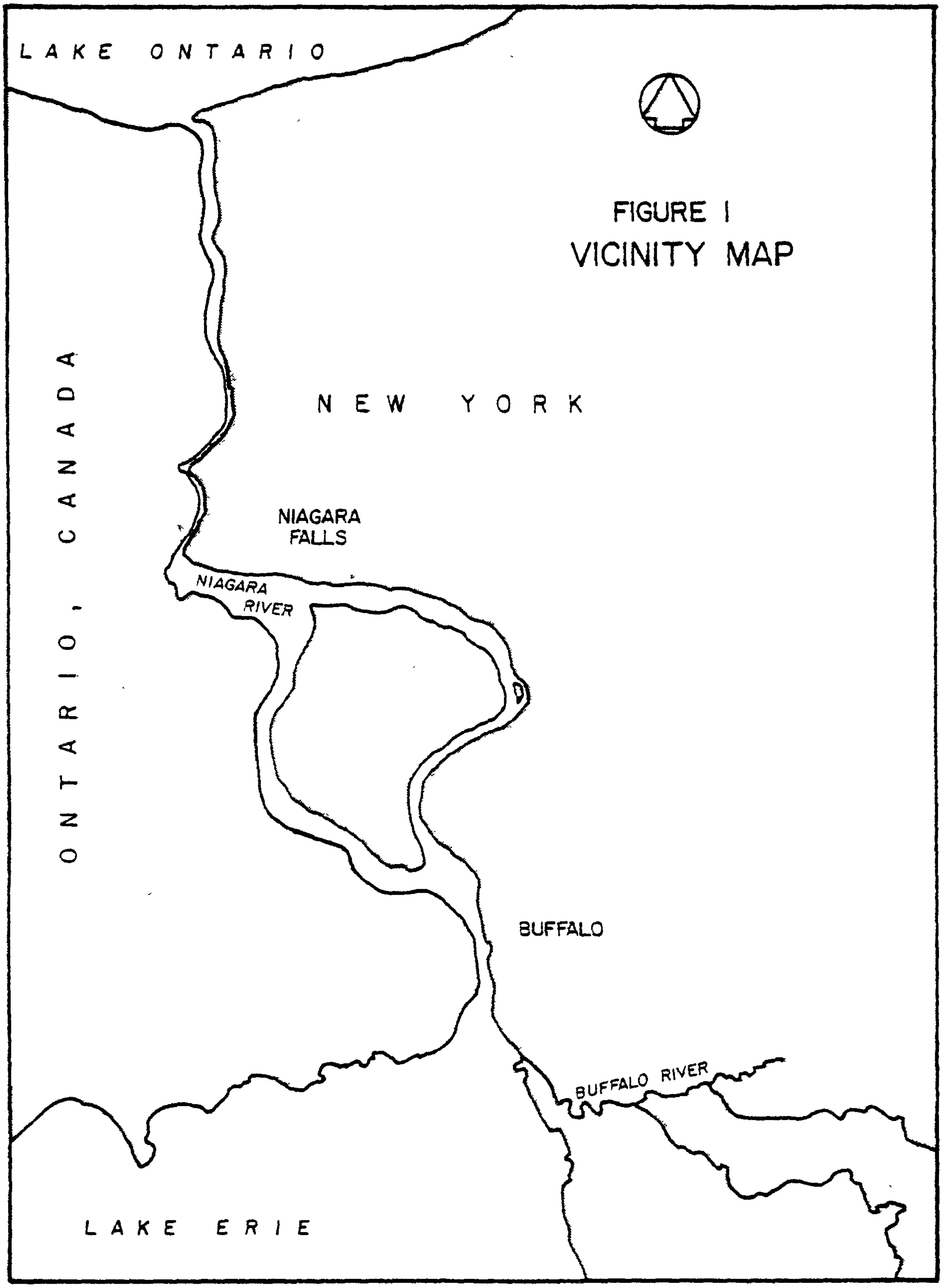
The Buffalo River extends only 13.0 kilometers (8.1 miles) upstream from its mouth. It is an unusually complex body of water with a great many sources of wastes and with historically poor water quality. The Buffalo River is located in the City of Buffalo and surrounding Erie County, in the west central part of New York State. As the vicinity map (Figure 1) shows, the Buffalo River discharges into the easternmost end of Lake Erie, just at the head (southern) end of the Niagara River.

Upstream of the mouth of the Buffalo River, Cazenovia Creek discharges into the Buffalo River at River Kilometer 8.5 (River Mile 5.3). Further upstream, at River Kilometer 13.0 (River Mile 8.1), the head of the Buffalo River is defined by the U.S. Geological Survey as the confluence of Buffalo Creek and Cayuga Creek.

The watershed of the Buffalo River and its three tributaries (Cazenovia Creek, Buffalo Creek, and Cayuga Creek) is roughly triangular in shape as the Basin map (Figure 2) shows, and has a drainage area of about 1,150 square kilometers (446 square miles).[1] The apex of the triangle is the mouth of the Buffalo River at Buffalo, New York; the base of the triangle, about 50 kilometers (30 miles) to the southeast of the apex, is about 40 kilometers (25 miles) long. Buffalo Creek rises in a fan-shaped tributary area in Wyoming County near Java, New York. After the source tributaries join, Buffalo Creek flows generally northwest for 69 kilometers (43 miles) to the confluence with Cayuga Creek.

To the south of Buffalo Creek, Cazenovia Creek flows generally northwesterly for 61 kilometers (38 miles) to its confluence with the Buffalo River. Cazenovia Creek is formed by its East and West Branches, which rise near the southerly corner of the watershed, flow northerly about eight kilometers (five miles) apart and join west of East Aurora.

To the north of Buffalo Creek, Cayuga Creek flows westerly to its confluence with Buffalo Creek (at the head of the Buffalo River), which is 64 kilometers (40 miles) from the source of Cayuga Creek. Little Buffalo Creek, a tributary to Cayuga Creek, joins Cayuga Creek just upstream of Lancaster.


LAKE ONTARIO
FIGURE I
VICINITY MAP
NEW YORK
ONTARIO, CANADA
NIAGARA FALLS
NIAGARA RIVER
BUFFALO
BUFFALO RIVER
LAKE ERIE

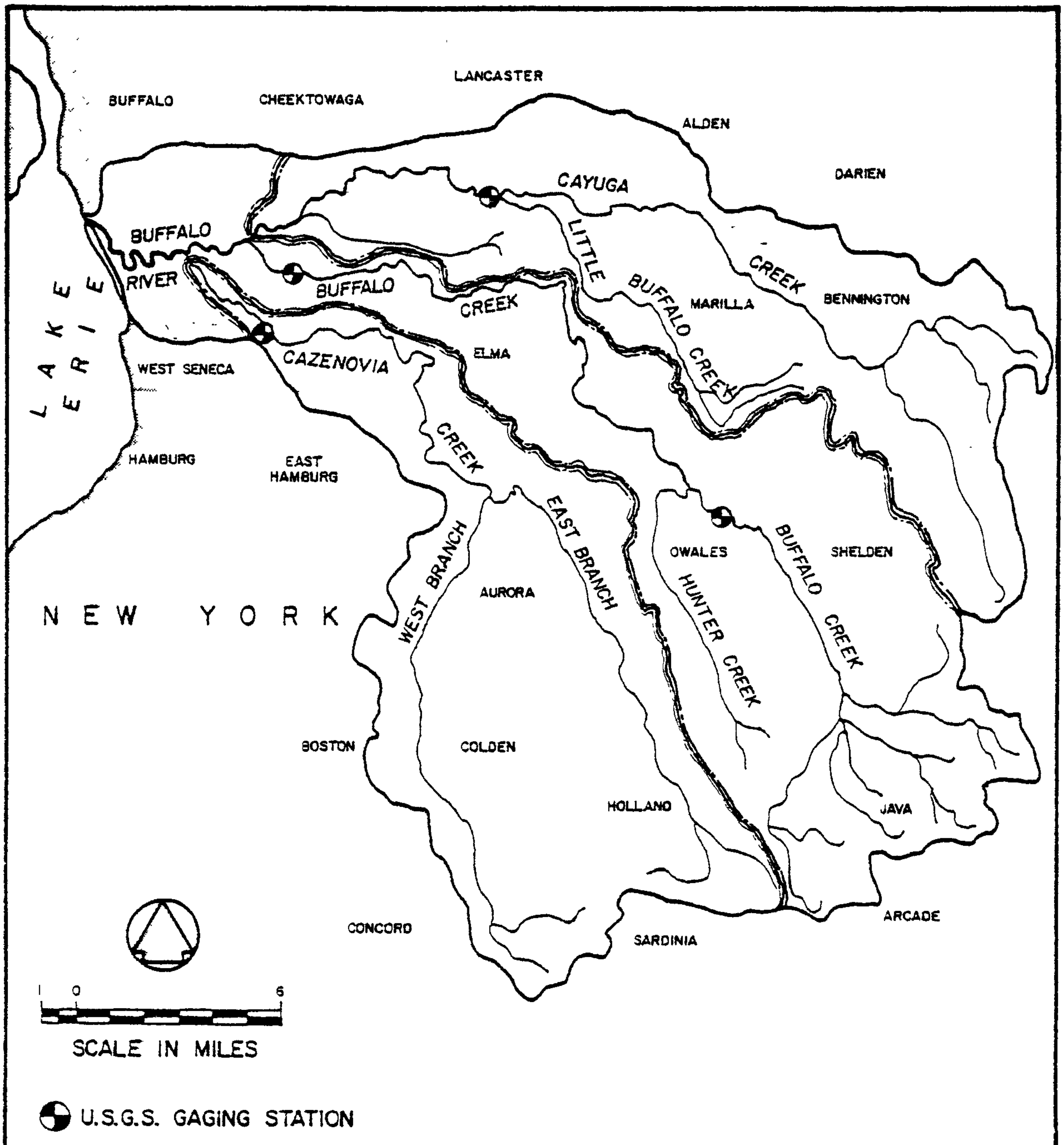


FIGURE 2
BASIN MAP

Except for a few kilometers just above their confluence with the Buffalo River, the tributaries are fast-flowing streams with many rapids and waterfalls.[6] Their drainage areas are generally agricultural. The land adjacent to Buffalo Creek is primarily farmland, woods, and vacant sections. Buffalo Creek does, however, pass through the small communities of Wales Hollow, Wales Center, Porterville, Jerge-Elma, Elma, and Blossom, receiving the corresponding municipal waste loads. There are no major industrial facilities along Buffalo Creek.

Cazenovia Creek similarly is typified by agricultural, wooded and vacant sections of land, with several small residential communities and scattered park and recreational areas. Only a few light industrial facilities discharge directly into Cazenovia Creek.

Cayuga Creek, and its tributary, Little Buffalo Creek, resembles the other two tributaries only in its upper reaches, 16 kilometers (10 miles) and above its confluence with Buffalo Creek. The lower reaches of Cayuga Creek pass through the large urban residential communities of Lancaster and Depew, and bear little resemblance to its upper reaches or to the other two tributaries.

Buffalo River itself (shown in the map of Figure 3) is characterized by heavy industrial development in the midst of a large municipality. Its waste load and water quality problems dominate any such concerns for the entire watershed, and consequently is the dominant area of concern in this waste allocation study. Later sections of this report describe in detail the 43 individual industrial discharges into the Buffalo River, the heavy domestic waste loads into this reach from overflows of the combined storm/sanitary sewer system, the hydraulic character of this reach which aggravate the problems, and the resultant water quality deficiencies which have (until very recently) been typified by the complete absence of aquatic life in this reach.

5.2 HYDROLOGY OF THE BUFFALO RIVER WATERSHED

Table 1 lists topographic data for the entire Buffalo River watershed.[1] The slopes of the tributaries are rather steep, accounting for their free-flowing characteristics. In contrast, the Buffalo River itself has a slope of less than 0.2 m/km (1 ft/mile).

Climatological data for Buffalo is listed in Table 2. Two observations may be made: first, the prevailing wind velocity is high throughout the year and is almost always off Lake Erie (SW). Second, the average monthly precipitation is rather constant throughout the year, ranging from a monthly low of 6.17 cm (2.43 inches) in July to a monthly high of 7.85 cm (3.09 inches) in November.

Figure 4, derived from the data of Harding and Gilbert in ENB-2,[7] shows the duration curves of daily streamflow for the three tributaries, as measured close to the mouth of each tributary. Also shown on Figure 4

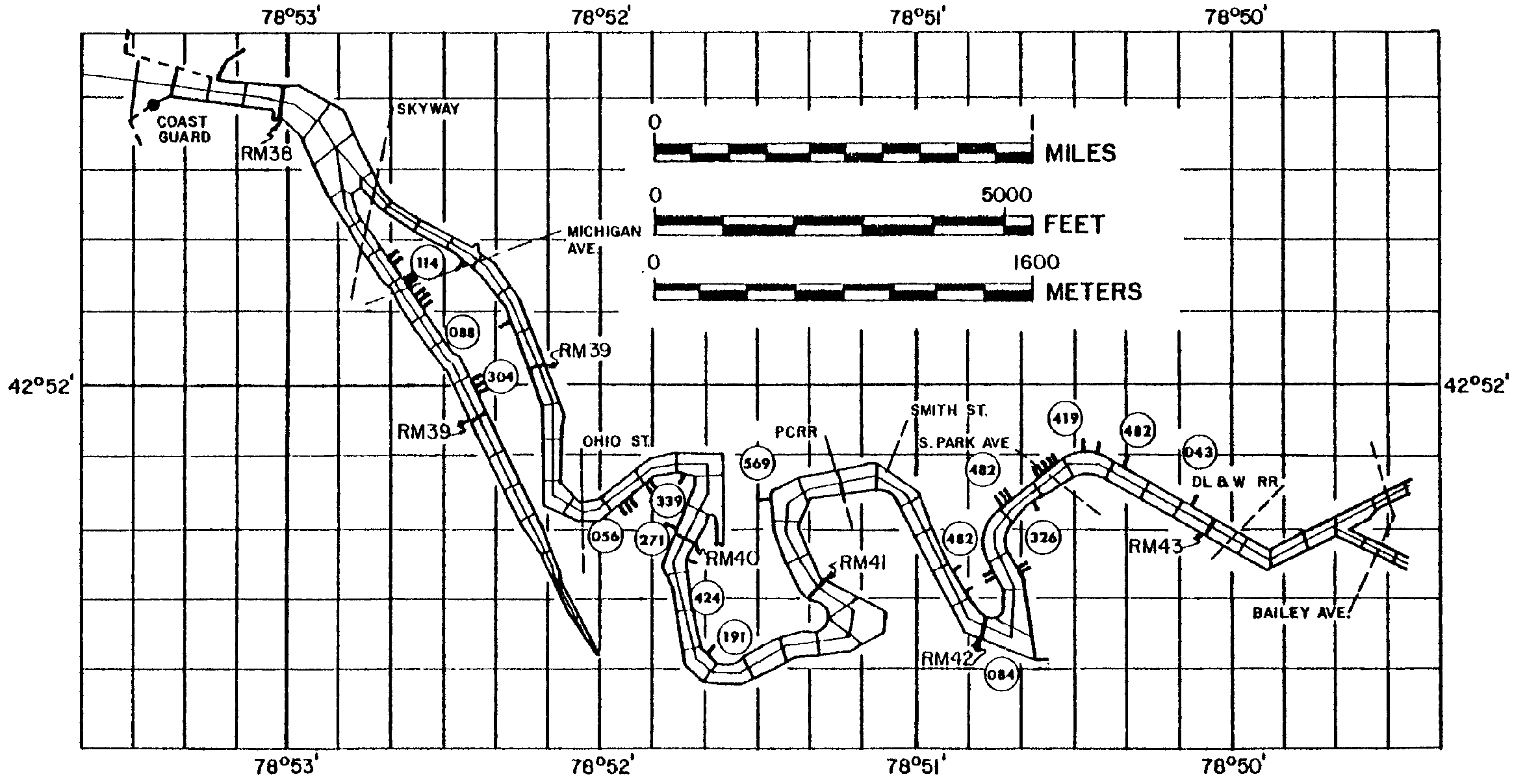


FIGURE 3
DREDGED PORTION OF THE BUFFALO RIVER

Note: Discharger Identification Numbers Refer to Table 8.

is the duration curve for the sum of the three tributaries, which represents the "natural" discharge of the Buffalo River, i.e., the streamflow exclusive of industrial or domestic discharges into the Buffalo River.

Table 3 lists summertime monthly average discharges as measured by the U.S. Geological Survey,[11,12] for Buffalo Creek and for Cazenovia Creek. (The U.S.G.S. gauging station on Cayuga Creek was discontinued after Water Year 1968.) The low-flow period of August and September, represented by the six-year average discharges, is about equivalent to the 70 per cent duration point from Figure 4.

	Buffalo Creek	Cazenovia Creek
Six-year Average Discharge for August and September, m^3/day	68,300	83,200
70 per cent Duration Point, m^3/day	77,100	79,800

Table 4 summarizes the average summer streamflows (i.e., the 70 per cent duration point); and the MA7CD/10 point (the minimum average seven-day critical discharge with a recurrence interval of ten years, approximately equivalent to the 99 per cent duration period) which is specified by the New York State Department of Environment Conservation as critical flow:

Table 4

Average Summer Streamflow and MA7CD/10 Point

	Avg. Summer Flow, m^3/day	MA7CD/10 m^3/day
Buffalo Creek	77,100	10,300
Cazenovia Creek	79,800	11,200
Cayuga Creek	30,300	1,000
Sum of Three Tributaries	187,200	22,500

The U.S. Geological Survey[13] has conducted time-of-travel studies on the tributaries of the Buffalo River; their provisional data is listed in Table 5. The measured stream velocities, over a wide range of volumetric flows, range from 0.05 to 0.36 meters per second (0.15 to 1.2 feet per second).

Table 1. Topographic Data, Buffalo River Watershed (1)

Creek and Locality	Distance Above Mouth of Buffalo River, km (mi)	Elevation Above Sea Level, m (ft)	Slope, m/km (ft/mi)	Drainage Area Above Locality, km^2 (mi^2)
Buffalo Creek				
Source	82 (51)	518 (1,700)	--	--
Cayuga Creek Junction (Mouth)	13 (8)	176 (578)	2.48 (13.1)	388 (150)
Cayuga Creek				
Source	77 (48)	500 (1,640)	--	--
Little Buffalo Creek Junction	34 (21)	206 (675)	3,72 (19.6)	241 (93)
Buffalo Creek Junction (Mouth)	12 (8)	176 (578)	1.12 (5.9)	331 (128)
Little Buffalo Creek				
Source	61 (38)	408 (1,340)	--	--
Cayuga Creek Junction (Mouth)	34 (21)	206 (675)	7.40 (39.1)	60 (23)
Cazenovia Creek				
Source (East Branch)	71 (44)	536 (1,760)	--	--
East Branch at West Branch Junction	37 (23)	245 (805)	3.47 (18.3)	147 (57)
Source (West Branch)	68 (42)	518 (1,700)	--	--
West Branch at East Branch Junction	37 (23)	245 (805)	4.83 (25.5)	158 (61)
Buffalo River Junction (Mouth)	10 (6)	176 (576)	2.31 (12.2)	357 (138)
Buffalo River				
Junction of Buffalo Creek & Cayuga Creek	13 (8)	176 (578)	--	--
Cazenovia Creek Junction	10 (6)	176 (576)	0.19 (1.0)	738 (285)
Mouth	0 (0)	174 (571)	0.15 (0.8	1,154 (446)

Table 2. Climatological Data for Buffalo at Buffalo Airport, Latitude 42°56' N, Longitude 78°44' W (8)

Mouth	Air Temp °C	Air Temp °F	Wind Direction	Wind m/sec	Wind mph	Precipitation cm	Precipitation inches	Rel. Hum. Per Cent
Jan	-3.6	25.5	WSW	7.8	17.4	7.06	2.78	77
Feb	-4.0	24.7	SW	7.3	16.4	6.58	2.59	76
Mar	+0.6	33.0	SW	7.1	15.9	6.91	2.72	74
Apr	+6.5	43.8	SW	6.6	14.8	6.48	2.55	70
May	+13.0	55.4	SW	5.9	13.2	6.27	2.47	70
Jun	+18 6	65.5	SW	5.6	12.5	6.86	2.70	70
Jul	+21.4	70.6	SW	5.4	12.1	6.17	2.43	69
Aug	+20.5	68.9	SW	5.2	11.7	6.45	2.54	71
Sep	+16.9	62.4	S	5.7	12.8	7.63	3.01	73
Oct	+10.7	51.2	S	6.3	14.1	6.33	2.49	74
Nov	+4.4	39.9	S	7.3	16.4	7.85	3.09	74
Dec	-1.7	29.0	WSW	7.6	17.0	7.42	2.92	76
Year	+8.6	47.5	SW	6.5	14.5	82.02	32.29	73

Table 3. Summertime Monthly Average Streamflows (10, 11)

Calendar Year	Buffalo Creek				Cazenovia Creek			
	Jul	Aug	Sep	Oct	Jul	Aug	Sep	Oct
1968	56,300	75,600	56,500	143,200	64,900	87,600	85,600	131,500
1969	242,000	67,800	48,900	97,600	306,000	94,300	72,900	103,700
1970	143,700	52,400	116,900	321,000	163,000	61,400	162,600	389,000
1971	155,000	63,900	61,900	46,500	175,800	84,200	51,200	48,900
1972	255,000	85,000	74,400	277,000	231,000	67,100	130,300	433,000
1973	92,500	66,100	49,900	--	113,700	51,400	49,200	--
6-Year Averages	157,200	68,500	68,000	176,800	175,800	74,400	92,000	221,000

Units: Cubic Meters/Day

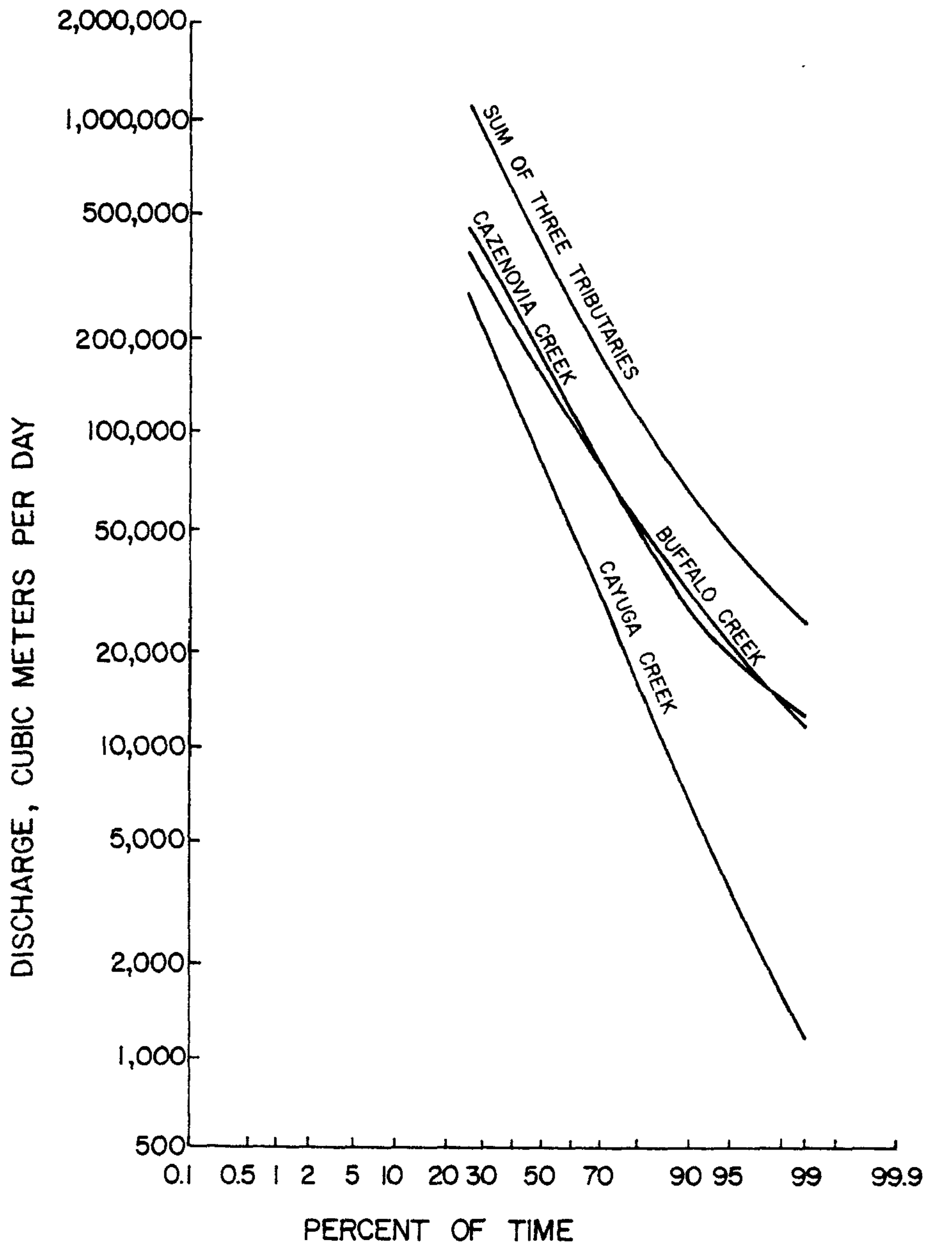


FIGURE 4

DURATION CURVES OF DAILY STREAMFLOW

5.3 HYDROLOGY OF THE DREDGED PORTION OF THE BUFFALO RIVER

The primary subject of this study is the Buffalo River, which is fed by the three tributaries described above, but which is different from the tributaries in several hydrological respects. The lower reach of 8.42 kilometers (5.22 miles) of the Buffalo River is a navigable channel, maintained by the U.S. Army Corps of Engineers to facilitate traffic of lake vessels to the large industries along the river. The channel depth is maintained at 6.7 meters (22 feet) for the entire width of the river, which is a minimum of 51.8 meters (170 feet). As the map of Figure 3 indicates, there are a number of much wider points in the channel, used for turning and maneuvering. In addition, as Figure 3 indicates, the Buffalo Ship Canal (also 6.7 meters deep) is tributary to the Buffalo River very close to the mouth of the Buffalo River. For the purposes of later computations, the dredged portion of the Buffalo River is defined by the longitudinal bounds of River Mile NiBu 43.06 (the upstream interface, at the D.L. and W. railroad bridge, between the dredged and undredged portions of the River); and of River Mile NiBu 37.83. (The mouth of the Buffalo River is located 1.40 km or 0.87 miles downstream from the Michigan Avenue Bridge.)* The length of this dredged reach is therefore 8.415 kilometers (5.23 miles).

To estimate the surface area and volumetric capacity of the dredged portion of the Buffalo River and of the Buffalo Ship Canal, the waterway was longitudinally divided into small segments (shown in Figure 3) on the NOAA-NOS Lake Survey Map 314 (February, 1971 edition) for Buffalo Harbor. Table 6 was derived with the aid of a planimeter, using a constant depth of 6.706 meters (22 feet):

Table 6

Calculated Geometry, Buffalo River and Buffalo Ship Canal

	Buffalo River (Dredged Portion)	Buffalo Ship Canal
Upstream Boundary	RM 43.06	RM 39.33
Downstream Boundary	RM 37.83	RM 38.38
Longitudinal Distance, miles	5.23	0.95
Longitudinal Distance, meters	8,415	1,529
Surface Area, sq. meters	518,900	76,900
Volume, cubic meters	3,480,000	516,000
Average Width, meters	61.66	50.33
Average Cross Section, sq. meters	413.5	337.5

*The hydrological index used throughout this report is expressed as the River Mile measured from the mouth of the Niagara River. When used to locate a station; i.e., purely as an index; the metric equivalent will be omitted. Computations involving distance intervals will however be expressed in metric terms.

Table 5. Stream Velocities[13]

Stream	Date	Discharge, m^3/day	Velocity, m/sec
E. Branch Cazenovia Creek	May 1963	82,800	0.298
	July 1963	8,600	0.073
W. Branch Cazenovia Creek	May 1963	106,200	0.292
	July 1963	8,800	0.070
Cazenovia Creek	May 1963	243,000	0.363
	July 1963	25,900	0.076
	June 1973	154,000	0.046
Cayuga Creek	Aug 1964	16,900	0.055
	Oct 1964	7,800	0.046
	May 1965	66,000	0.148
	June 1973	75,000	0.152
Buffalo Creek	June 1973	168,000	0.360

Another important hydrological characteristic of the Buffalo River (which was mentioned previously) is that the slope is extremely small, only 0.17 meters per kilometer. Hence, the difference in elevation in the dredged reach of 8.4 kilometers is only 1.4 meters.

A third important hydrological characteristic of the Buffalo River is that the volumetric flow of the upstream tributaries is augmented by a comparatively large quantity of industrial discharge water in the dredged portion of the river. In 1967 five major industries jointly formed the Buffalo River Improvement Corporation (BRIC). Intake water from the Outer Harbor on the Lake Erie shoreline is pumped by BRIC to the five industries, which utilize the water for process and cooling purposes and then discharge into the Buffalo River. Hence, this discharge is an addition to the river flow (as opposed to users which withdraw and discharge water from the same waterway). Table 7 shows the five industries and their average discharge rates.

Table 7

BRIC Industries and Discharge Rates

Discharger	Rate, cubic meters per day
Mobil Oil	106,000
Allied Chemical (Specialty Chem. Div.)	62,800
Allied Chemical (Industrial Chem. Div.)	42,800
Republic Steel	172,100
Donner-Hanna Coke	32,100
Total	415,700

This quantity of BRIC flow is more than double the average summer flow from the three upstream tributaries (187,200 cubic meters per day), and is almost twenty times the MA7CD/10 flow from the three tributaries (22,500 cubic meters per day). Moreover, BRIC is obligated to the City of Buffalo to discharge at least 378,500 cubic meters per day (100 million gallons per day) every day; in the summer, the BRIC flow is as much as 454,000 cubic meters per day (120 million gallons per day).

The five industries which utilize and discharge BRIC water are all located within a 1.8 kilometer (1.1 mile) reach of the Buffalo River, from River Mile 42.92 to River Mile 41.82. Table 8 lists the 43 individual industrial discharges into the Buffalo River within the 8.4 kilometer (5.2 mile) dredged reach, and into the Buffalo Ship Canal, along with the discharge flow rates of each. The total industrial discharge is 426,100 cubic meters per day; of this total, 97.5 per cent is accountable to the five industries using BRIC water and discharging in the concentrated 1.8 kilometer reach. A graphic representation of the longitudinal concentration and significance of these five industries is shown in Figure 5, the cumulative flow in the Buffalo River under the conditions of average summer natural flow.

Table 8. Industrial Point Discharges to Buffalo River and Buffalo Ship Canal

Co. No.	Name	Discharge S/N	Bank	River Mile	Flow, MGD	Flow, cu m/day
Buffalo River:						
043	Mobil Oil	001	N	42.92	28.0	106,000
482	Allied, SCD	011	N	42.72	4.75	18,000
419	Allied, ICD	001	N	42.66	4.20	15,900
		002	N	42.64	2.00	7,600
		003	N	42.58	3.70	14,000
		004	N	42.55	1.40	5,300
482	Allied, SCD	010	N	42.54	4.30	16,300
		009	N	42.53	0.002	8
		008	N	42.52	0.03	100
326	Republic Steel	001	S	42.48	8.7	32,900
482	Allied, SCD	007	N	42.43	1.20	4,500
		006	N	42.42	7.50	28,400
		005	N	42.41	0.50	1,900
		004	N	42.27	0.02	80
		003	N	42.26	0.06	200
326	Republic Steel	004	S	42.25	15.6	59,000
		002	S	42.24	8.0	30,300
		003	S	42.06	13.5	51,100
084	Donner Hanna Coke	001	S	42.02	8.5	32,200
482	Allied, SCD	002	N	41.89	0.03	100
		001	N	41.82	0.03	100
569	Airco	001	N	41.25	0.007	30
191	Pacific Molasses	001	N	40.34	0.0004	2
424	U.S. Steel	001	N	40.05	0.14	500
271	International Multifoods	002	S	39.98	0.06	200
		001	S	39.72	0.04	100
339	American Malting	001	S	39.62	0.60	2,300
056	Peavey	003	S	39.56	0.03	100
		002	S	39.55	0.07	300
		001	S	39.54	0.11	400
088	Agway	001	S	38.85	0.05	200
114	General Mills	001	S	38.67	0.39	1,500
Buffalo Ship Canal:						
304	Pillsbury	003	N	38.94	0.002	8
		002	N	38.93	0.041	160
		001	N	38.92	0.010	40
114	General Mills	007	N	38.68	0.02	80
		006	N	38.66	0.02	80
		009	N	38.65	0.04	150
		002	N	38.63	0.16	600
		004	N	38.62	0.04	150
		003	N	38.61	0.02	80
		008	N	38.56	0.01	40
		005	N	38.54	0.01	40

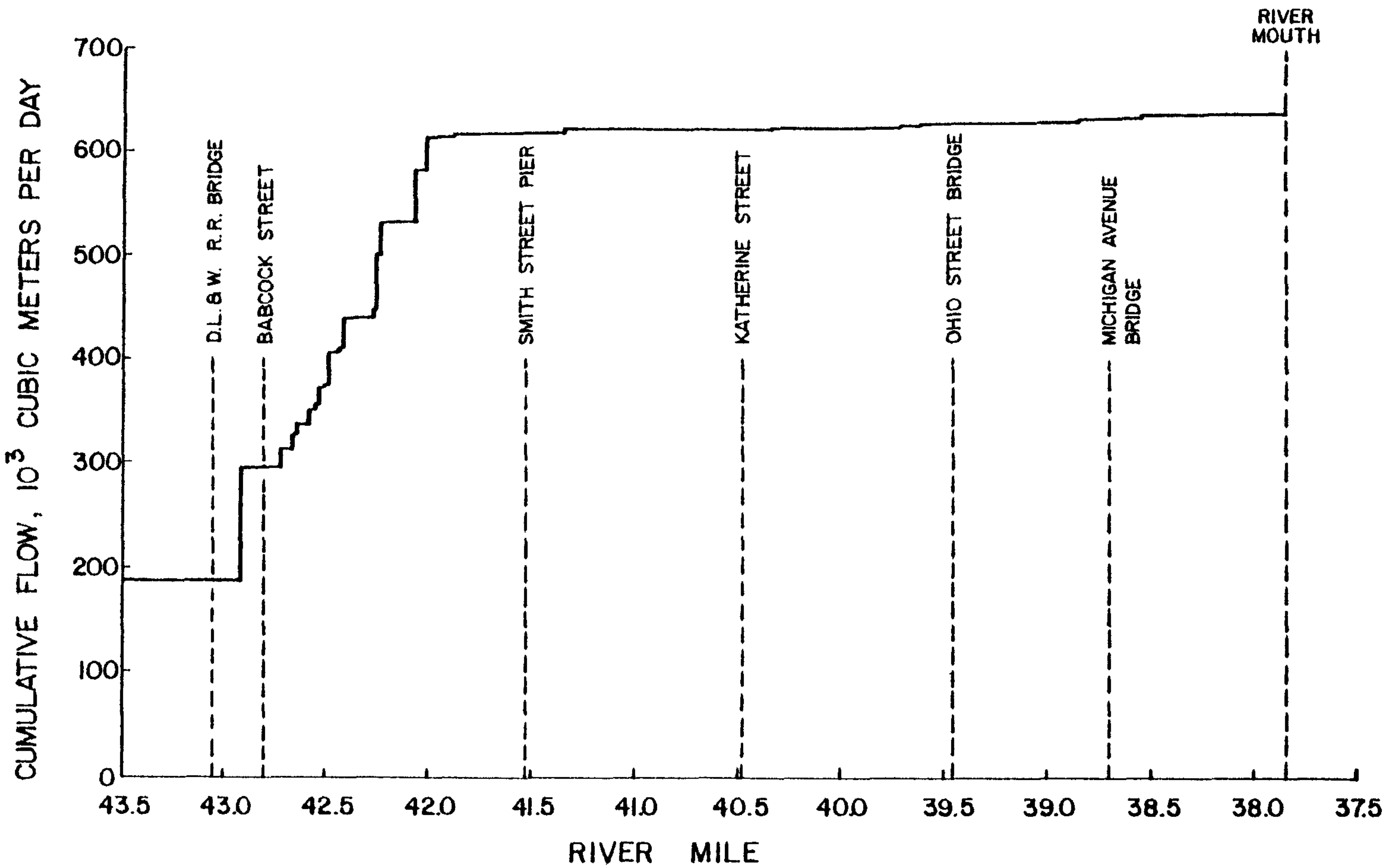


FIGURE 5

CUMULATIVE FLOW IN THE BUFFALO RIVER

UPSTREAM TRIBUTARIES AT 70% DURATION

Included in the cumulative flow in Figure 5, and in total flows in subsequent analyses, is an average daily contribution of 20,300 cubic meters attributable to overflows from the combined sewer system. The derivation of this quantity, and the justification for treating it as distributed both spatially and temporally in the dredged portion of the Buffalo River, will be presented in a later section of this report.

The total flow rate from all three sources (upstream from the tributaries, the industrial discharge, and the overflows from the combined sewer system) is shown in Figure 6 as a function of the natural upstream flow. During the summertime the natural discharge from upstream tributaries is only a minor portion of the total flow rate. In addition, the total flow rate during the summertime is rather constant, not subject to the large day-to-day variations characteristic of more conventional rivers, nor of the extremely low flow rates of dry periods.

Table 9 lists the calculated volumetric flow rates, average velocities, and average residence times in the dredged portion of the Buffalo River for several upstream flow conditions.

Table 9

Calculated Hydraulics of the Buffalo River

Duration Point, Per Cent	Flow, Cubic Meters per Day	Average Velocity, Meters per Second	Residence Time, Days
26	1,574,000	0.0441	2.21
50	858,000	0.0240	4.06
70	634,000	0.0177	5.50
90	513,000	0.0143	6.80
95	491,000	0.0137	7.09
99	471,000	0.0132	7.39

For average summertime conditions (70 per cent duration), the average velocity is extremely small, less than 0.02 m/sec; and the corresponding average residence time is extremely large, greater than five days; owing to the great enlargement of the channel cross-section by the dredging operation. Based upon these calculations, the conclusion may be reached that the dredged portion of the Buffalo River is essentially a stagnant body of water.

5.4 EMPIRICAL HYDRAULIC BEHAVIOR OF THE BUFFALO RIVER

There were reasons to suspect that the calculated average river velocities were not presenting a valid picture of the true hydraulics of the Buffalo River, that superimposed upon the average calculated velocity were distinct local currents and gradients in all three directions (longitudinal, transverse and vertical).

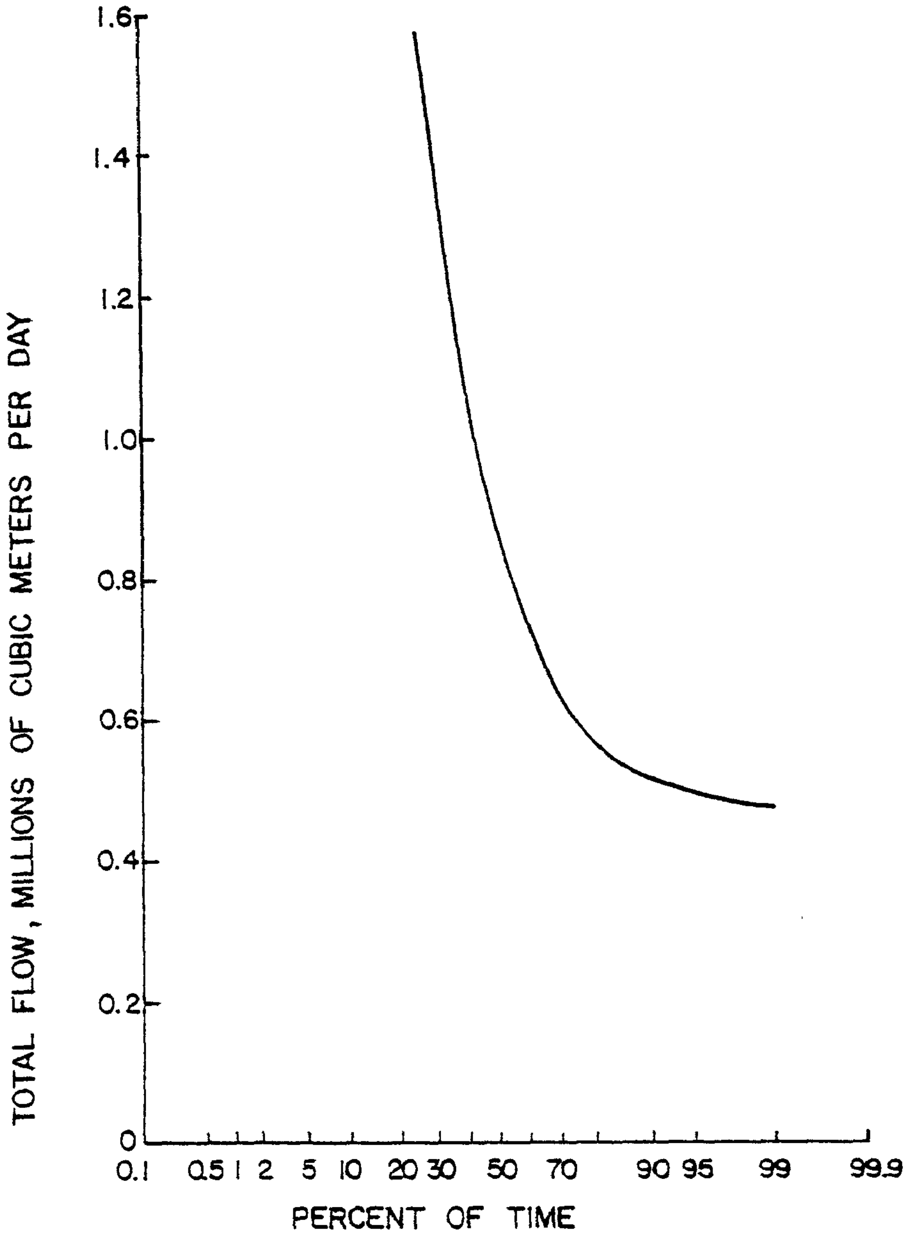


FIGURE 6
DURATION CURVE OF TOTAL FLOW

Blum,[12] in his study of the river hydraulics, found very severe vertical thermal gradients and significant vertical gradients of electrical conductivity, expecially in the heavily industrialized reach from River Mile 43 to River Mile 42. The water at the surface was five degrees (9°F) warmer, and the electrical conductivity was 12 per cent greater, than at a depth of six meters (20 feet). Blum found evidence that an upstream flow of cooler water occurs near the bottom while the warmer surface water flows downstream. Blum's study was made in 1964, prior to the BRIC flow augmentation project, so that these results are not quantitatively valid for the present situation.

Very early in this study, efforts were directed toward shedding some light on the river hydraulics. A cursory inspection along the river revealed the existence of localized currents significantly faster than the very small calculated average velocities, and of instances of reverse (i.e., upstream) flow at several locations. Because of these qualitative indications and because of the potential importance to the waste allocation study, somewhat more definitive data of a semi-quantitative nature were obtained with three types of measurements (Figure 3, a map of the dredged portion of the Buffalo River, may be used to reference the station locations):

(1) Dye injection (Rhodamine B) at the surface, with observations made both visually and by analysis of samples using a fluorometer.

(2) A float to measure velocity of the surface waters. An orange was used as a float; no attempt was made in these early tests to correct for wind effects.

(3) A device to measure velocity as a function of depth, essentially consisting of a float with a weight at an adjustable vertical distance. For the early experiments, the weight was at 4.0 meters (13.2 feet), six-tenths of the depth of the channel.

Dye was injected 54.0 meters (177 feet) downstream of the dredged/undredged interface, near the D.L. and W. railroad bridge, midway across the channel. The measured surface velocity was 0.13 meters per second (0.42 feet per second) upstream. The weighted device, however, travelled 0.0085 m/sec (0.028 ft/sec), also upstream. When the slug of dye reached the dredged/undredged interface, the longitudinal (upstream) movement was halted and the dye dispersed across the stream (vertical dispersion was not measured). Fluorometer analyses of two samples showed that the dye did indeed penetrate the interface and travel upstream:

Sample	Sample Location	Sampling Time After Injection	Dye Conc., ppb
ID1	7.6 m upstream of interface	1,320 sec	7.9
ID2	At interface	1,440 sec	0.0

The measured upstream velocities of 0.13 m/sec at the surface and 0.0085 m/sec at a 4.0 meter depth, combined with a calculated downstream average velocity in the neighborhood of 0.01 m/sec demonstrates a very large velocity gradient in the vertical direction.

A second series of observations were made in the vicinity of the South Park Avenue bridge (R.M. 42.5), approximately 0.8 kilometers (0.5 miles) downstream of the dredged/undredged interface and virtually in the midst of the heavy industrial discharges. The surface velocity, as measured by dye slug travel, was 0.10 m/sec (0.33 ft/sec) downstream; while the velocity at 4.0 meters (13.2 feet) depth was 0.038 m/sec (0.13 ft/sec), also downstream. This compares to a calculated downstream average velocity of approximately 0.02 m/sec; and shows again large velocity gradients and the likelihood of relatively stagnant, cooler water near the bottom.

A third series of observations were made near the Penn Central RR bridge (R.M. 41.4). The surface velocity (measured with the dye) was 0.046 m/sec (0.15 ft/sec). Fluorometer analyses of samples taken 30.5 m downstream of the injection point verified the visual data:

Sample	Sampling Time After Injection	Dye Conc., ppb
ID4	480 sec	11.0
ID5	660 sec	41.7
ID6	840 sec	2.8

In the vicinity of the Ohio Street bridge (R.M. 39.4), the surface velocity was small. Moreover, in the neighborhood of the calculated downstream average velocity, the dye dispersed across the channel (and possibly in a vertical direction) before appreciable longitudinal travel had occurred. Sample ID3, taken a few meters upstream of the injection point after 660 seconds to document any upstream diffusion, proved negative in that the dye concentration was 0.0 ppb.

It is apparent from these first few experiments, despite the lack of regirous quantitative techniques, that the very large vertical velocity gradient in the heavily industrialized reach becomes increasingly dissipated downstream of this reach.

Other early experiments in this field study were aimed at qualitatively measuring any cross-channel velocity gradients at the surface, using an orange as a float. Indeed, such suspicions were confirmed along the entire length of the dredged portion of the river. Channelization was caused by some of the large-volume discharges; and was also a result of the numerous sharp bends in the river. Very high local velocities at the surface approaching one meter per second were observed, compared to the calculated average velocity of approximately 0.02 m/sec.

Later in this study, additional measurements of velocity were made. These data, listed in Table 10, show the existence of large vertical velocity gradients, of up to ten-fold-higher velocities than the calculated time-average velocities, of substantial velocities in the upstream direction, and of velocities which vary considerably with time.

The observations of fluctuating velocities (including substantial upstream flow at times) was independently made by the U.S. Geological Survey in a time-of-travel study on June 19 and 20, 1973.[13] The U.S.G.S. study was conducted in the Buffalo River; dye was injected at South Ogden Street and both gauge heights and dye concentrations were recorded as functions of time at Seneca Street (R.M. 5.9). It should be noted that the U.S.G.S. measurements were made in the shallow portion of the Buffalo River, one kilometer (0.7 miles) upstream of the dredged reach. The provisional results, listed in Table II and shown graphically in Figure 7, verify the oscillating flow of the river as observed in the present study.

A Lake Erie level gauge is maintained at the U.S. Coast Guard Station at the mouth of the Buffalo River. Efforts were made to compare the fluctuations in the Lake level. Representative records of the Lake level, supplied by the National Oceanic and Atmospheric Administration,[14] are shown in Figure 8. It is apparent that several distinct phenomena occur at different times, no doubt the result of wind patterns over Lake Erie. Figure 8a shows very little fluctuation for the period of October 10 through October 13, 1973. For September 30 through October 2, 1973 (Figure 8b), a peak-to-peak amplitude of Lake level of 1.3 meters (0.8 feet) with a regular period of about 14 hours is apparent. For October 13 through October 16, 1973 (Figure 8c), the 14-hour period is again apparent, but the peak-to-peak amplitude is significantly greater, and higher-frequency components are observed.

Figure 8d is the record of Lake Erie level for June 19 and 20, 1973, the same period of time as the upstream river data of Table 11 and Figure 7. The Lake level fluctuations (Figure 8d) for 2 a.m. through 10 a.m. on June 20 are much smaller in amplitude than the river level fluctuations for the same time period (Figure 7), but higher frequencies are apparent in both records and there were larger perturbations in the level of Lake Erie several hours earlier (after noon on June 19th).

A qualitative explanation of the above observations would include the following factors:

(1) The 14-hour period of oscillation of the level of Lake Erie is a characteristic of the seiche of the Lake which has been observed over the years.[14]

(2) Higher-frequency oscillations of the level of Lake Erie at Buffalo were analyzed and presented by Platzman and Rao.[64] Strong and consistent peaks in the spectral density occurred at periods of 14.1 hours, 9.2 hours, 6.0 hours, and 4.1 hours, which correspond to the first four modes of longitudinal free oscillation of the lake.

Table 10. Measured Velocities in the Buffalo River (All Data at Mid-Channel; Positive Velocity Indicates Downstream Flow)

Date (1973)	River Mile	Depth, Meters	Velocity, m/sec
8/22	43.06	0.0	-0.130
8/22	43.06	4.0	-0.009
8/22	42.54	0.0	+0.100
8/22	42.54	4.0	+0.038
8/23	41.40	0.0	+0.046
10/17	39.44	5.4	+0.067
10/17	39.44	4.0	+0.143
10/17	39.44	2.7	+0.143
10/17	39.44	1.3	+0.079
10/17	42.54	4.0	-0.116
10/17	41.40	4.0	-0.158
10/18	41.40	1.3	-0 079
10/18	41.40	2.7	-0.049
10/18	41.40	4.0	+0.134
10/18	41.40	5.4	+0.174
10/18	42.54	1.3	+0.052
10/18	42.54	2.7	0.000
10/18	42.54	4.0	-0.043
10/23	39.44	1.3	+0.037
10/23	39.44	2.7	0.000
10/23	39.44	4.0	0.000
10/23	39.44	5.4	-0.015
10/23	41.40	1.3	+0.012
10/23	41.40	2.7	-0.049
10/23	41.40	4.0	-0.049
10/23	42.54	5.4	-0.034
10/23	42.54	4.0	0.000
10/23	42.54	2.7	+0.043
11/2	42.54	1.3	-0.013
11/2	42.54	5.4	+0.068
11/2	42.54	0.0	-0.101

Table 11. Time-of-Travel Measurements in the Buffalo River(13)

Measurements at Seneca Street, R.M. 5.9 Dye Injected 6/19/73 at 19.92 Hours, at South Ogden St., 2.01 Kilometers (1.25 miles) Upstream

Time of Day, 6/20/73 (Hours)	Time After Injection, Hours	Guage Height, Meters	Dye Concentration, μg/liter	Observed Flow Direction*
02.85	6.93	1.58	0.58	+
03.20	7.28	--	0.59	
03.44	7.52	1.74	0.24	-
03.87	7.95	1.89	0.05	-
04.15	8.23	1.80	0.15	+
04.35	8.43	---	0.32	
05.00	9.08	---	0.93	
05.50	9.58	1.86	0.24	-
05.75	9.83	1.84	0.17	+
06.80	10.88	1.72	0.92	+
07.25	11.33	1.82	0.54	-
07.95	12.03	1.76	1.15	+
08.30	12.38	1.68	1.23	+
08.50	12.58	1.68	1.40	+
08.85	12.93	1.74	1.16	-
09.10	13.18	1.80	0.17	-
09.45	13.53	1.77	0.78	+
09.75	13.83	1.76	1.40	+
10.00	14.08	1.70	1 05	+

* + is Downstream
  - is Upstream

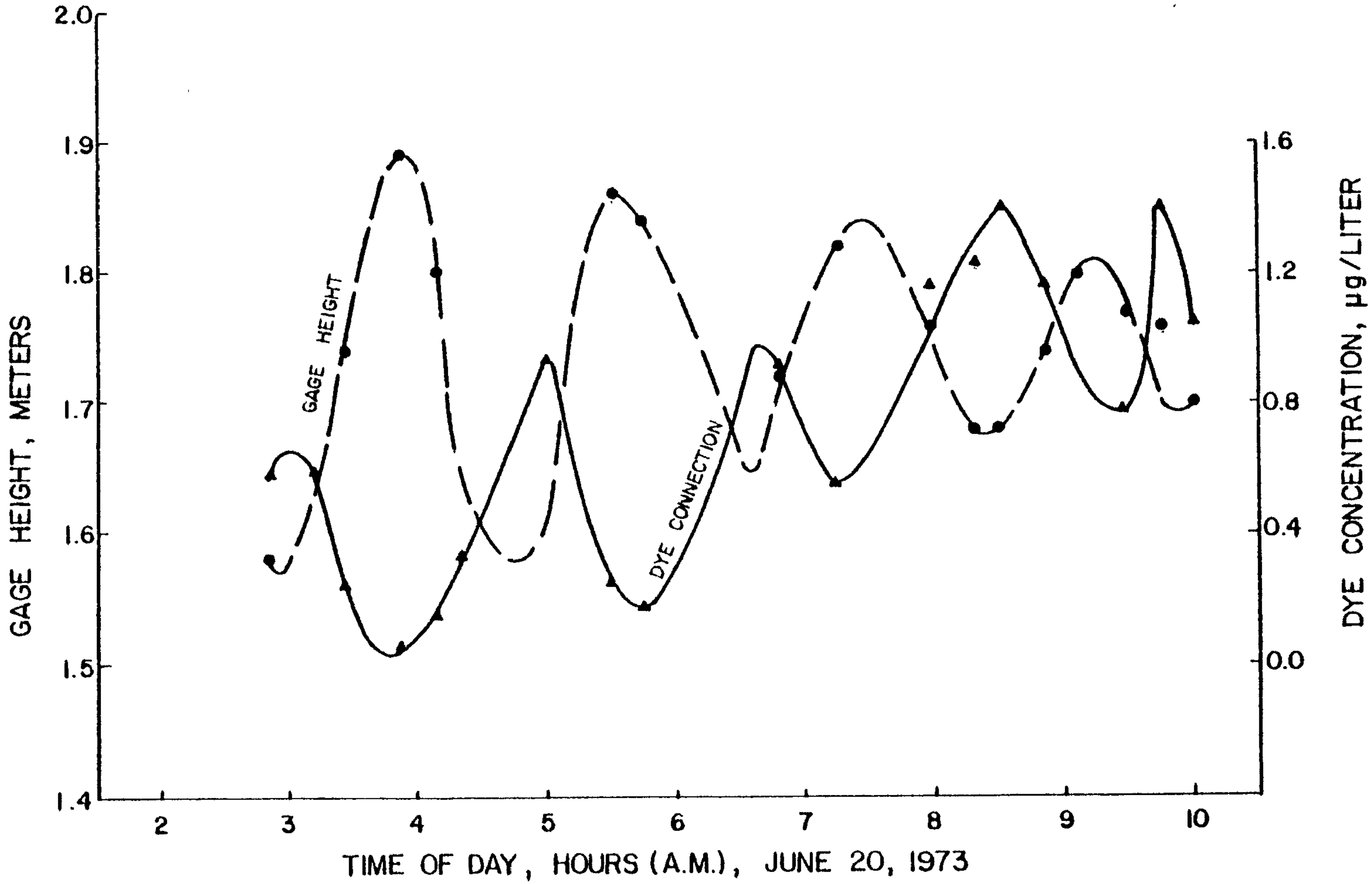


FIGURE 7

FLUCTUATIONS OF THE BUFFALO RIVER AT SENECA STREET(13)

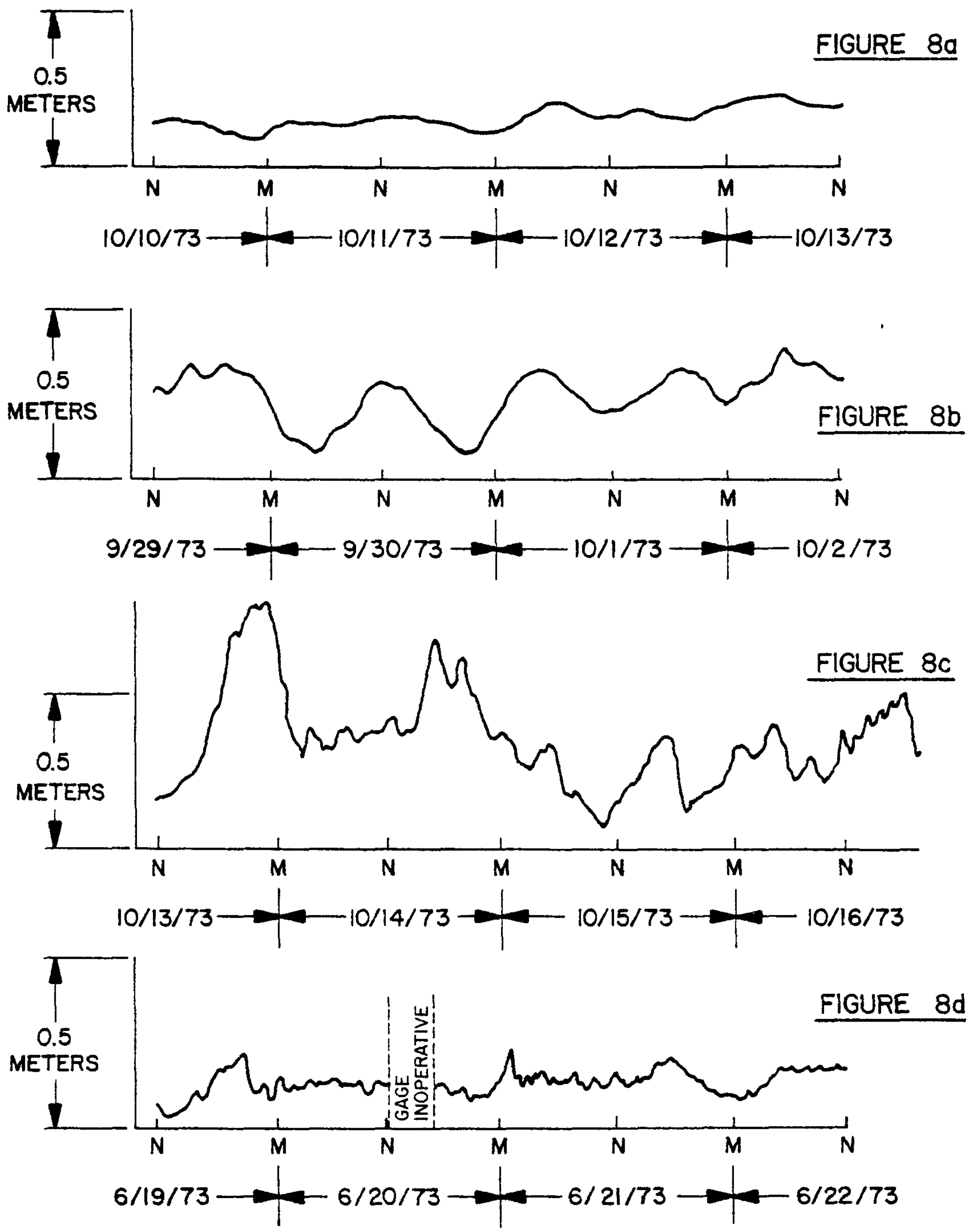


FIGURE 8
LAKE ERIE LEVEL
AT U.S. COAST GUARD STATION[14]

The spectral density at Buffalo at higher frequencies had peaks at 3.7 and 3.3 hours, and the average spectral density for periods of two to three hours was greater at Buffalo than at other stations. At a resolution of 0.05 cycles per day, numerous other peaks became apparent. The oscillations are also significantly affected by geostrophic considerations.

(3) The higher-frequency oscillations observed in Lake Erie at the mouth of the Buffalo River may result from the effect of Pt. Abino, Ontario (see Figure 1), an interfering land mass in Lake Erie just to the west of the mouth of the Buffalo River.

(4) The higher-frequency oscillations observed upstream in the Buffalo River may be evidence of an organ-pipe effect, where the interface between the dredged and undredged segments (at River Mile 43.06) acts as a reflector and where oscillations of a particular frequency may be reinforced.

Although a rigorous quantitative analysis of the observed oscillatory flow characteristics is beyond the scope of this current study, a cursory analysis of the June 20, 1973 U.S.G.S. river level data is presented to translate fluctuating river level into fluctuating volumetric flow rate, longitudinal velocity, and travel distance in the Buffalo River.

The approach used by Feigner and Harris[15] in their dynamic modeling of estuaries was to apply the finite-difference form of the equation of motion to the i^{th} channel in a network:

$$\frac{\Delta Ui}{\Delta t} = -Ui \frac{\Delta Ui}{Xi} - K|Ui|Ui - g \frac{\Delta H}{Xi}$$

and to apply the finite-difference form of the equation of continuity to the j^{th} junction (the nodes, or channel ends) in the network:

$$\frac{\Delta Hj}{\Delta t} = \frac{\Sigma Qj}{A^*j}$$

where Ui = longitudinal velocity in i^{th} channel
t = time
Xi - length of i^{th} channel
Hj = elevation of j^{th} junction
g = acceleration of gravity
K = frictional resistance coefficient
ΣQj = algebraic sum of volumetric flow rate into the j^{th} junction
A^*_n = surface area attributable to the j^{th} junction

The frictional resistance coefficient was evaluated using Manning's equation:

$$K = \frac{gn^2}{2.208\ Rj^{4/3}}$$

where R_i = hydraulic radius of the i^{th} channel
n = Mannings roughness factor, which is about 0.030 $ft^{1/6}$ for dredged-earth channels.[16]

The key to the FWQA numerical analysis of estuaries is that for each time segment, the velocity and elevation are assumed not to vary with distance within a channel. Since good results have been attained by application of this technique,[15,17] using channel lengths of comparable magnitude to the dredged reach of the Buffalo River, this same technique was applied to the Buffalo River. Hence, the equation of continuity may be written for this entire dredged reach of the Buffalo River:

$$Q_T = -24\ As\ \frac{\Delta H}{\Delta t}$$

$$\text{and } U_T = -\frac{1}{3{,}600}\frac{As}{Ax}\frac{\Delta H}{\Delta t}$$

where H = the elevation of the river, meters
t = time, hours
Q_T = transient flowrate downstream (i.e., out of the river), m^3/day
U = transient velocity downstream, m/sec
As = surface area = 518,900 m^2
Ax = cross-sectional area = 413.5 m^2

Hence,

$$Q_T = -12.44 \times 10^6\ \Delta H/{-t},\ m^3/day$$

$$U_T = -0.348\ \Delta H/\Delta t,\ m/sec$$

Table 12 shows the calculations of transient flow rate Q_T and of transient velocity U_T from the U.S.G.S. data of gauge height (H) vs. time (as shown in Figure 7) for June 20, 1973.

The velocity data of Table 12 are summarized in Table 13 and compared to the steady-state values of flow and velocity calculated previously (for 70 per cent duration), and to the actual measured velocities in the River.

Table 12. Calculation of Fluctuating Flows

Time of Day, Hours	Guage Ht. H, meters	$\Delta H/\Delta t$, m/hr	Qt, 10^6 m^3/day	U_t, m/sec	ΔX_t, meters	$\Sigma \Delta X_t$ +200, meters
3.00	1.575	+0 34	-4.2	-0.12	-110	+90
3.25	1.650	+0.52	-6.5	-0.18	-160	-70
3.50	1.780	+0.38	-4.7	-0.13	-120	-190
3.75	1.875	+0.02	-0.2	-0.01	-10	-200
4.00	1.880	-0.72	+8.9	+0.25	+230	+30
4.25	1.700	-0.36	+4.5	+0.13	+120	+150
4.50	1.610	-0.18	+2.2	+0.06	+50	+200
4.75	1.575	+0.16	-2.0	-0.06	-50	+150
5.00	1.615	+0.34	-4.2	-0.12	-110	+40
5.25	1.800	+0.24	-3.0	-0.08	-70	-30
5.50	1.860	-0.08	+1.0	+0.03	+30	0
5.75	1.840	-0.20	+2.5	+0.07	+60	+60
6.00	1.790	-0.26	+3.2	+0.09	+80	+140
6.25	1.725	-0.28	+3.5	+0.10	+90	+230
6.50	1.655	+0.14	-1.7	-0.05	-50	+180
6.75	1.690	+0.32	-4.0	-0.11	-100	+80
7.00	1.770	+0.20	-2.5	-0.07	-60	+20
7.25	1.820	+0.06	-0.7	-0.02	-20	0
7.50	1.835	-0.14	+1.7	+0.05	+50	+50
7.75	1.800	-0.24	+3.0	+0.08	+70	+120
8.00	1.740	-0.24	+3.0	+0.08	+70	+190
8.25	1.680	0.00	0.0	0.00	0	+190
8.50	1.680	+0.16	-2.0	-0.06	-50	+140
8.75	1.720	+0.26	-3.2	-0.09	-80	+60
9.00	1.785	+0.10	-1.2	-0.03	-30	+30
9.25	1.810	-0.16	-2.0	+0.06	+50	+80
9.50	1.770	-0.28	+3.5	+0.10	+90	+170
9.75	1.700	0.0	0.0	0.00	0	+170
10.00	1.700					

Table 13

Summary of Calculated and Measured Velocities

		Velocity, m/sec
Calculated Transient Velocities	(Table 12):	
	High	+0.25
	Low	-0.18
	RMS	0.096
Calculated Steady-State Velocity	(Table 9):	+0.0177
Measured Velocities	(Table 10):	
	High	+0.17
	Low	-0.16
	RMS	0.082

The above data show that the transient velocities calculated from oscillating gauge height measurements correspond very closely to the actual river velocities directly measured in this study. Furthermore, both of these sets of velocity data are an order of magnitude higher than the time-average velocity calculated from steady-state hydraulic inputs to the Buffalo River. Hence the conclusion that the oscillating flows are real phenomena and that they overshadow in magnitude the time-average velocity.

Table 12 also lists the calculated transient longitudinal distance, ΔX_T, that an incremental quantity of river water would move, consistent with the transient velocity:

$$\Delta X_T = 3{,}600 \quad U_T \Delta t$$

and the total transient distance that this incremental quantity of river water moves, relative to some arbitrary point X, is also listed in Table 12. 12.

These data show that the oscillating flow behavior causes transient longitudinal advection of approximately ±200 meters, a significant fraction of the total dredged reach of the Buffalo River. Since diffusive mixing should also be expected (resulting from the oscillatory flow, from the substantial industrial point discharges, and from the numerous bends in the river), considerable mixing is a distinct probability.

6.0 WATER QUALITY

6.1 WATER QUALITY CRITERIA

The water quality criteria applicable to the Buffalo River Basin are those of the New York State Department of Environmental Conservation. Basically, the four water use classes relevant to the Buffalo River Basin are:

Class A - Drinking, culinary, food processing and any other usages

Class B - Bathing and other usages except potable water supply

Class C - Fishing and other usages except bathing and potable water supply

Class D - Agricultural, industrial and other usages except fishing, bathing and potable water supply.

During the period of this study, the N.Y. State Water Quality Standards in effect were those dated November 1967;(18) the waste allocations of this report were based upon these standards. A new set of standards became effective on March 27, 1974, and were revised on October 20, 1974. For the water quality parameters considered in this study, only minor differences exist between the old and new standards. Appendix A contains the relevant portions of the new standards; the relevant specific quantitative criteria are summarized in Table 14 below:

Table 14

The Specific Quantitative Criteria Explicitly Defined for N. Y. State Water Use Classes

		Class A	Class B	Class C	Class D
pH (Range)		6.5-8.5	6.5-8.5	6.5-8.5	6.5-9.5
Phenols, ppb		1	-	-	-
D.O., ppm, trout waters	Daily Avg.	6.0	6.0	6.0	-
	Min.	5.0	5.0	5.0	-
D.O., ppm, non-trout waters	Daily Avg.	5.0	5.0	5.0	-
	Min.	4.0	4.0	4.0	3.0

In addition, all classes require that all other waste constitutents be limited for the protection of fish life; the New York State standards explicitly suggest the following parameters:

Ammonia or Ammonium Compounds	2.0 ppm NH_3
Cyanide	0.1 ppm CN
Ferro- or Ferricyanide	0.4 ppm $Fe(CN)_6$
Copper	0.2 ppm Cu
Zinc	0.3 ppm Zn
Cadmium	0.3 ppm Cd

Although it is not within the scope of this present study to authoritatively translate the "fish life protection" criterion into quantitative limitations on the concentration of chemical constituents (other than those specifically called out in the New York State Standards), some translation was necessary for the performance of this waste allocation study.

The New York State Department of Environmental Conservation has classified all of the Buffalo River as a Class D stream, which imposes a minimum dissolved oxygen criterion of 3.0 mg/l. However, for at least the past twenty years, much of the dredged portion has been septic and devoid of fish life.

The New York State classifications for the rest of the Buffalo River Basin are as follows:

Buffalo Creek, from its confluence with Cayuga Creek (NiBuBu 45.65) to Elma Centennial Park (NiBuBu 60.2), is Class B; and upstream of NiBuBu 60.2, Class A.

Cayuga Creek, from its confluence with Buffalo Creek (NiBuCy 45.65) to Aurora Street in Lancaster (NiBuCy 54.2), is Class C; and upstream of NiBuCy 54.2, Class B.

Cazenovia Creek, from its confluence with the Buffalo River (NiBuCz 43.40) to Cazenovia Street (NiBuCz 44.6), is Class D; and upstream of NiBuCz 44.6 is Class B.

With an assumed projection that the dissolved oxygen level in the Buffalo River would be brought up to the minimum of 3.0 ppm, a study was begun to identify organisms which would then inhabit the river, and to estimate their tolerances to other parameters, with the objective of establishing limits to be utilized in determing water quality contraventions based upon the "fish life" criterion. Two approaches to this study were considered:

(1) a characterization of existing biota in comparable, less polluted streams, and

(2) a species listing based on characterizations of the Buffalo River area when it was less polluted.

A preliminary investigation determined that any stream in the area sufficiently unpolluted to maintain its normal species complement would not be hydrologically comparable to the Buffalo River; therefore the second approach was followed. To obtain data on an essentially unpolluted Buffalo River, one must use 1880 data or earlier. At that time, however, the stream was not channeled and its depth was not maintained by dredging. These alterations so profoundly affected the hydrology of the Buffalo River area that species comparison from this era would be invalid.

A useful compromise between hydrological similarity and relative water purity, for the purposes of this program, is the result of a biological characterization of the Buffalo-Niagara watershed in 1928-1929 by the State of New York Conservation Department,[23,24] which is summarized in Appendix B. Utilizing this species list, the "fish life" criterion of the New York State Standards was translated into the limiting concentrations of chemical constituents of Table 16. This translation was based upon the works of McKee and Wolf[19] and of the Environmental Protection Agency.[20] The column in Table 15 headed "New York State Standards" will serve as the basis in this study for determining water quality contraventions.

More recently, after the above effort was completed, the U.S. Environmental Protection Agency published a similar list[21] in the form of proposed national water quality standards, in compliance with the requirements of Section 304(a) of Public Law 92-500. Table 15 incorporates these EPA proposed criteria for reference purposes only. Any attempt to compare the two lists of limiting concentrations or to rationalize any differences would be highly improper, within the scope of this present study. It is fully recognized that this is a highly complex task, with many instances of parameter interactions.

The "fish life" criterion translation, in addition to concentrations of chemical constituents, must also include a consideration of thermal pollution. The impact of heat addition upon aquatic biota takes several forms (which may also act synergistically):

a) Alteration of the physical properties of water.

b) Alteration of the solubility of dissolved gases. Thermal pollution decreases the dissolved oxygen solubility; not only decreasing the maximum concentration of oxygen, but as important, decreasing the concentration driving force for reaeration of oxygen-deficient waters.

c) Alterations in the reaction rate of chemical and biochemical reactions. In particular, the oxidation of organic wastes is greatly accelerated by elevated temperature, thereby more rapidly depleting available oxygen.

d) If sufficiently-high temperatures are reached, organisms may be directly killed.

Table 15. Maximum Concentrations of Chemical Constituents Necessary for the Protection of Fish Life

Constituents	Maximum Concentration, mg/liter — New York State Standards	Maximum Concentration, mg/liter — EPA Proposed Criteria (Hard Water)
NO_3-N	4	
P-Total	25	
Sulfate	500	
Chloride	250	
Fluoride	1.5	
Oil & Grease	7	
Phenols	0.2	0.1
Arsenic	1.0	
Barium	5.0	
Chromium	0.05	0.05
Iron	0.8	
Lead	0.1	0.03
Mercury	0.006	0.0002
Nickel	0.7	1.0
Selenium	2.5	
Cyanide	0.1*	0.005
Cadmium	0.3*	0.03
Copper	0 2*	0.03
Zinc	0.3*	0.17
Ammonia	2.0*	0.02

*Explicit in New York State Standards

e) Physiological processes such as reproduction, development and metabolism are temperature-dependent.

f) Spatial temperature anomalies can block the passage of anadromous fish, greatly reducing future populations.

The proposed EPA Water Quality Criteria[21] define the maximum weekly average temperature as one-third of the range between the optimum temperature and the ultimate upper incipient lethal temperature for the most sensitive important species (or appropriate life stage) that is normally found at the location at that time. EPA further states that the heated plume temperature be limited to 10°C greater than the ambient temperature and defines other considerations related to the sensitivity of aquatic biota.

The proposed EPA Water Quality Criteria[21] lists, for a number of fish species, the maximum weekly average temperature for growth and the maximum short-term temperature for survival during the summer. These data were based upon a 24-hour median lethal limit minus 2°C and acclimation at the maximum weekly average temperature for summer growth. The data in Table 16 were abstracted from the EPA table, using the species list for the Buffalo River Basin (Appendix B) as the basis for selection:

Table 16

Maximum Temperatures for Selected Fish Species (21)

Species		Maximum Temperature, °C	
Common Name	Scientific Name	Growth	Survival
Carp	Cyprinus carpio	-	34
Channel Catfish	Ictalurus punctatus	33	36
Emerald Shiner	Notropis atherinoides	28	31
Freshwater Drum	Aplodinotus grunniens	-	-
Northern Pike	Esox lucius	28	30
White Crappie	Pomosix annularis	27	32
White Sucker	Catostomus commersonnii	27	29
Yellow Perch	Perca flavesceus	22	29

For the purposes of this program, based upon the discussion above, an upper limit of 29°C should permit short-term survival of the species listed and so will be used as the upper temperature limit.

6.2 ACQUISITION OF WATER QUALITY DATA

Very early in this study, a survey of existing water quality data was made in sufficient detail to identify what additional data would be needed. Many agencies have been active over the years in stream sampling and analysis in the study area, including the U.S. Environmental Protection Agency, the International Joint Commission, the New York State

Department of Environmental Conservation, the U.S. Geological Survey, the U.S. Public Health Service, the Erie County Health Department, and the Great Lakes Laboratory of the State University College at Buffalo.

Although the quantity of water quality data available from other agencies is too voluminous and repetitive to permit reproduction in this report, a great deal of these data were obtained and examined during this study. Table 17 lists averages of some of the more pertinent and recent data reported by other agencies. Note that stream data for the dredged lower reach of the Buffalo River must be recent in order to be useful; the flow augmentation project of the Buffalo River Improvement Corporation in 1967 drastically affected this reach. Moreover, very recent significant reductions in wastes have been made by the industries along this reach.

In Table 17, the River Mile index is based upon the longitudinal distance from the mouth of the Niagara River; for reference purposes, the following are the indices for the junctions in the Buffalo River Basin:

Buffalo River (Mouth)	NiBu	37.83
Buffalo Ship Canal (Mouth)	NiBuSc	38.30
Buffalo River, End of Dredged Reach	NiBu	43.06
Cazenovia Creek (Mouth)	NiBuCz	43.40
Buffalo Creek (Mouth)	NiBuBu	45.65
Cayuga Creek (Mouth)	NiBuCy	45.65

The streams are specified according to the following codes:

Ni	Niagara River
NiBu	Buffalo River
NiBuSc	Buffalo Ship Canal
NiBuBu	Buffalo Creek
NiBuCz	Cazenovia Creek
NiBuCy	Cayuga Creek

The reporting agencies for these water quality data are abbreviated in Table 17 according to the following code, which also specifies the source of the data:

EPA - U.S. Environmental Protection Agency[26]

GLL - Great Lakes Laboratory, State University College at Buffalo[27]

DEC - New York State Department of Environmental Conservation.[28] These data include U.S.G.S. data

RPB - Erie and Niagara Counties Regional Planning Board[5]

The data received from DEC were the results of analysis of individual samples. The averages of DEC data in Table 17 reflect only samples taken during the summer months (July, August, and September) of 1969 through 1972. The GLL data averages similarly reflect only summertime sampling in 1969 and 1970. The EPA (1971) and RPB (1972) data probably

Table 17. Averages of Water Quality Data as Reported by Other Agencies

River	Station	River Mile Index		Reporting Agency	Temp. °C	Alkalinity mg/l	Org-N mg/l	BOD_5 mg/l	D.O. mg/l	Sp. Cond. mhos/cm	pH	TSS mg/l	TDS mg/l	Chloride mg/l	Fluoride mg/l
Niagara	Coast Guard St.	NI	37.66	EPA		95		1.9	11.4		7.9	16	210	27	
	Coast Guard St.	NI	37.66	GLL	23.7	92	2.03		7.7	269	7.56	111	196		
Buffalo River (Dredged)	Skyway	NiBu	38.35	EPA	24.4	111		0.9	2.8		7.7	6		49	
	Michigan Ave.	NiBu	38.70	EPA	23.3	116		2.1	1.8		7.4	16		50	
	Michigan Ave.	NiBu	38.70	GLL	24.7	89	2.18		0.0	334	7.12	72	220		
	Ohio St.	NiBu	39.44	EPA	15.6	109		3.8	4.7	439	6.9	29		52	
	Ohio St.	NiBu	39.44	DEC	25.3	102	1.00	6.4	0.3	482	6.9	33	310	58	
	Hamburg St.	NiBu	39.81	EPA	23.3	114		3.9	2.5		7.5	12		63	
	Smith St.	NiBu	41.53	EPA	25.0	119		7.8	2.3		7.3	15		65	
	N&W RR	NiBu	41.77	GLL	26.0	75	2.63		0.0	385	6.92	154	296		
	S. Park Ave.	NiBu	42.54	EPA	25.0	119		2.5	2.6		7.4	16		56	
	DL&W RR	NiBu	43.06	EPA	26.7	125		3.9	2.4		7.4	88		52	
	DL&W RR	NiBu	43.06	GLL	24.8	101	2.52		0.1	301	7.45	138	217		
Buffalo River	Bailey Ave.	NiBu	43.53	EPA	22.8	136		3.1	4.3		7.4	14		49	
	Seneca St.	NiBu	43.73	RPB				6.8	3.0						
	Harlem Rd.	NiBu	45.65	RPB				2.8	7.2						
Buffalo Ck.	Union Rd.	NiBuBu	48.1	DEC	20.6	110	0.40		8.2	354	8.65	11	234	17.6	0.1
	Union Rd	NiBuBu	48.1	RPB				1.5	9.0						
Cazenovia Ck.	Bailey Ave.	NiBuCz	43.53	EPA	22.8	116		4.9	5.8		7.5	11		58	
	Bailey Ave.	NiBuCz	43.53	RPB				2.0	9.5						
	Seneca St.	NiBuCz	47.5	RPB				2.7	9.4						
Cayuga Ck.	Clinton St.	NiBuCy	45.8	RPB				7.2	5.0						
	Union Rd.	NiBu	48.3	RPB				9.7	6.8						

River	Station	River Mile Index		Reporting Agency	Sulfate mg/l	Phosphate mg/l	NH_3-N mg/l	NO_3-N mg/l	Phenols mg/l	Fe mg/l	F.Coliform MPN/100 ml.	Na mg/l	K mg/l	Ca mg/l	Mg mg/l
Niagara	Coast Guard St.	NI	37.66	EPA	23	0.12				180	2				
	Coast Guard St.	NI	37.66	GLL		0.50	1.55	0.39							
Buffalo River (Dredged)	Skyway	NiBu	38.35	EPA	51						24,000				
	Michigan Ave.	NiBu	38.70	EPA	56				6		4,300				
	Michigan Ave.	NiBu	38.70	GLL		1.27	2.85	0.46							
	Ohio St.	NiBu	39.44	EPA	56	0.18			25	1,600	13,000				
	Ohio St.	NiBu	39.44	DEC	67	0.66	2.57	0.01	16	1,760		34.7	4.5	52	10.6
	Hamburg St.	NiBu	39.81	EPA	68						15,000				
	Smith St.	NiBu	41.53	EPA	71						17,500				
	N&W RR	NiBu	41.77	GLL		1.07	3.69	0.83							
	S. Park Ave.	NiBu	42.54	EPA	69						9,200				
	DL&W RR	NiBu	43.06	EPA	64						13,200				
	DL&W RR	NiBu	43.06	GLL		1.17	2.73	0.47							
Buffalo River	Bailey Ave.	NiBu	43.53	EPA	58						4,300				
	Seneca St.	NiBu	43.73	RPB		1.1					22,000				
	Harlem Rd.	NiBu	45.65	RPB		0.6					1,000				
Buffalo Ck.	Union Rd.	NiBuBu	48.1	DEC	45	0.10	0.09	0.08		17	250	9.7	2.6	45	10.6
	Union Rd	NiBuBu	48.1	RPB		0.03					350				
Cazenovia Ck.	Bailey Ave.	NiBuCz	43.53	EPA	53						2,900				
	Bailey Ave.	NiBuCz	43.53	RPB		0.22					300				
	Seneca St.	NiBuCz	47.5	RPB		0.20					500				
Cayuga Ck.	Clinton St.	NiBuCy	45.8	RPB		2.3					1,800				
	Union Rd.	NiBu	48.3	RPB		3.2					2,200				

reflect some winter data, although most of the stream sampling was accomplished in the summertime.

Data for other water quality parameters, i.e., hardness, color, turbidity, total colifirm, COD, chlorine demand, manganese and silica; were also published by the above agencies, but were not specifically included in this study.

For the purposes of planning the field portion of this study, the following conclusions were reached concerning available historical data:

A considerable amount of attention has been devoted to measuring the following groups of parameters:

Temperature, DO, BOD, COD
pH, Alkalinity, Hardness
TS, TSS, TDS
Turbidity, Conductivity
Bacteria
Phosphates, Nitrogens
Chloride, Sulfate

Some scattered data is available for the following:

Color
Cl_2 Demand
Manganese
Ammonia
Phenols
Iron

Little data is available for the following groups of parameters:

Oil and Grease
Ca, Mg, Na, K
As, Ba, Cd, Cr, Cu, Pb, Hg, Ni, Se, Zn
CN-, F-

Based upon a prior review of the historical stream data and upon an observation early in this program of the unconventional hydraulics of the Buffalo River, a field effort was planned to:

(1) Provide water quality data as a function of depth and of cross-channel position, since strong indications of significant gradients were initially observed.

(2) Provide longitudinal water quality data sufficient to correlate with each of the major discharges.

(3) Provide water quality data for the full range of parameters; since prior data was incomplete with respect to metals, oil and grease, and some toxic

substances; and since these parameters are constituents of the industrial discharges.

Early in this field effort, in recognition of the difficulty in obtaining accurate analyses for heavy metals in the micrograms per liter ranges, the laboratory obtained two reference samples from the Method and Performance Evaluation Laboratory, Environmental Protection Agency (M & PE 1171). The results, listed in Table 18, show excellent reproducibility.

Table 19 is a list of the sampling stations for the field effort in this program.

The individual data points for the field water quality sampling and analysis effort in this study are listed in Appendix C. The averages, for each water quality parameter at each station, are listed in Table 20. The data are based on a stream sampling effort which was conducted in the summer of 1973, from August through early October.

In fulfillment of a contractual requirement, all of the water quality data generated in this study, as well as a great deal of historical stream data previously generated by the Rochester Field Office of Region II, U.S. Environmental Protection Agency, was entered into the STORET system.

The averages of Table 20 include all data at each longitudinal station, regardless of the sampling depth or of the cross-channel position. The vertical and transverse gradients will be separately presented and discussed.

This study was also interested in documenting the water quality of the Buffalo water supply and of the Buffalo River Improvement Corporation supply. The data were extracted from the "intake" sections of the many NPDES permit applications for these industries, from Kopp and Kroner[29] which summarized trace metal analyses, from UC reports,[8] and from a draft Environmental Impact Statement by the Corps of Engineers.[31] This latter reference was particularly valuable for determining the BRIC dissolved oxygen content since water quality was determined in the very locality of the BRIC intake, and since the NPDES system does not include dissolved oxygen data.

Table 21 lists averages of these data, clearly showing that while the city water is of excellent quality, with the intake well out in Lake Erie, the BRIC water is of somewhat lower quality, since the BRIC intake is quite close to the shoreline and is within the Buffalo Outer Harbor.

6.3 WATER QUALITY IN THE UPSTREAM TRIBUTARIES TO THE BUFFALO RIVER

The water quality of the upper reaches of the three tributaries to the Buffalo River was recently studied by the Erie and Niagara Counties' Regional Planning Board (RPB), with attention focused upon dissolved oxygen, BOD, phosphates, and bacteria.[5] In brief, the conclusions reached by RPB are as follows:

Table 18. Check on Trace Metal Analytical Accuracy
Concentrations in μg/liter

Parameter	Sample X		Sample Y		Limit of Detection
	EPA	Lab	EPA	Lab	
Al	25	<50	1100	1300	50
As	22	<10	278	250	10
Cr	9.2	10	406	440	10
Cu	9.0	<10	314	315	10
Fe	18	< 20	769	810	20
Pb	28	20	350	340	20
Mn	13	< 20	449	450	20
Zn	10	7	367	375	1

Table 19. Sampling Station Locations, Field Stream Study

Waterway	Station No.	River Mile Index		Description of Station
Niagara River	1	Ni	37.70	Buffalo Water Intake
	2	Ni	37.76	South Pier, Coast Guard Station
Ship Canal	3	NiBuSc	38.83	Upstream of Michigan Ave. Bridge
Buffalo River, Dredged Portion	4	NiBu	38.20	Downstream of Skyway Bridge
	5	NiBu	38.70	Michigan Ave. Bridge
	6	NiBu	39.44	Ohio St. Bridge
	7	NiBu	39.65	Alabama St.
	8	NiBu	39.81	Hamburg St.
	9	NiBu	40.20	Downstream of Katherine St.
	10	NiBu	41.40	Penn Central RR Bridge
	11	NiBu	41.53	Smith St. Pier
	12	NiBu	42.16	Downstream of S. Park Ave. Bridge
	13	NiBu	42.33	Downstream of S. Park Ave. Bridge
	14	NiBu	42.47	Downstream of S. Park Ave. Bridge
	15	NiBu	42.54	S. Park Ave. Bridge
	16	NiBu	42.62	Upstream of S. Park Ave. Bridge
	17	NiBu	42.69	Upstream of S. Park Ave. Bridge
	18	NiBu	42.87	Upstream of S. Park Ave. Bridge
	19	NiBu	43.06	DL&W RR Bridge
Buffalo River, Undredged Portion	20	NiBu	43.53	Bailey Ave. Bridge
	21	NiBu	43.73	Seneca St. Bridge
	22	NiBu	45.65	Harlem Rd. Bridge
Buffalo Creek	23	NiBuBu	51.30	Transit Rd. Bridge
Cazenovia Creek	24	NiBuCz	43.53	Bailey Ave. Bridge
	25	NiBuCz	51.40	Transit Rd. Bridge
Cayuga Creek	26	NiBuCy	53.10	Transit Rd. Bridge

Table 20. Averages of Water Quality Data Measured in This Study

Station No.	Stream	R.M. Index	Temp., °C	D.O. mg/l	Sp.Cond. u mhos/cm	pH	TSS mg/l	TDS mg/l	Chloride mg/l	Fluoride mg/l	Sulfate mg/l	Phosphate mg/l	NH_3-N mg/l	Cyanide u g/l	Oil & Grease mg/l
1	Ni	37.70					0	120	25	0.11	29	0.97	0	0	2.5
2	Ni	37.76													
3	NiBuSc	38.83					10	195	46	0.32	48	0.29	0.42	0	1.4
4	NiBu	38.20					19	193	47	0.34	47	0.37	0.70	0	2.5
5	NiBu	38.70													
6	NiBu	39.44	25.4	1.4	449	7.31	23	280	60	0.54	55	0.19	0.81	0	2.1
7	NiBu	39.65					50	231	56	0.46	60	0.52	1.26	0	2.1
8	NiBu	39.81					54	288	52	0.48	60	0.78	1.26	46	0.7
9	NiBu	40.20					45	270	55	0.47	60	0.67	0.98	52	0.1
10	NiBu	41.40	27.3	0.6	477	7.38	34	295	64	0.55	58	0.25	0.78	0	3.3
11	NiBu	41.53	25.8	1.8											
12	NiBu	42.16					78	248	50	0.53	58	0.85	1.12	46	2.7
13	NiBu	42.33					41	260	46	0.53	58	0.44	0.84	33	2.8
14	NiBu	42.47					28	265	48	0.35	62	0.31	0.70	0	5.4
15	NiBu	42.54	28.0	0.8	449	7.14	11	258	59	0.35	57	0.17	0.45	0	2.1
16	NiBu	42.62					17	255	46	0.25	60	0.32	0.42	0	3.5
17	NiBu	42.69					15	254	46	0.25	60	0.22	0.28	0	3.2
18	NiBu	42.87					12	258	51	0.24	61	0.24	0.42	33	5.3
19	NiBu	43.06	24.8	1.1		7.39	10	250	56	0.30	54	0.17	0.48	0	2.4
20	NiBu	43.53	25.9	0.7	427	7.07									
21	NiBu	43.73	27.5	1.2	500										
22	NiBu	45.65	20.2	3.4	570	7.43	24	395	80	0.50	61	2.08	7.56	0	2.1
23	NiBuBu	51.30	18.2	7.5		8.35	8	260	22	0.25	54	0.23	0	0	2.1
24	NiBuCz	43.53	26.0	0.5	410	6.93									
25	NiBuCz	51.40	21.6	8.5		9.00	5	535	57	0.29	74	0.33	0	0	1.5
26	NiBuCy	53.10	17.5	0.4		7.52	38	317	47	0.64	53	2.32	4.45	52	6.0

Table 20. Averages of Water Quality Data Measured in This Study - continued.

Station No.	Stream	R.M. Index	NO_3-N mg/l	Phenols μ g/l	Se μ g/l	As μ g/l	Ba μ g/l	Cd μ g/l	Cr μ g/l	Cu μ g/l	Fe μ g/l	Hg μ g/l	Ni μ g/l	Pb μ g/l	Zn μ g/l
1	Ni	37.70	0.08	6	1	10	100	0	0	0	350	0	0	0	2
2	Ni	37.76													
3	NiBuSc	38.83	0.04	13	2	20	0	0	0	10	1,100	24	20	0	27
4	NiBu	38.20	0.04	8	2	20	0	0	10	20	1,800	25	0	20	31
5	NiBu	38.70													
6	NiBu	39.44	0.10	9	4	0	0	0	6	7	1,130	0	0	74	26
7	NiBu	39.65	0.06	16	1	30	200	0	30	30	4,100	0	0	30	80
8	NiBu	39.81	0.06	11	1	30	0	0	30	30	4,050	10	0	20	81
9	NiBu	40.20	0.05	7	1	20	0	0	30	30	3,450	0	0	20	76
10	NiBu	41.40	0.24	12	4	0	0	0	8	25	2,~~110~~	0	0	92	68
11	NiBu	41.53													
12	NiBu	42.16	0.08	28	3	20	0	0	80	50	5,310	0	0	100	156
13	NiBu	42.33	0.11	29	2	30	0	0	80	40	3,650	0	0	50	106
14	NiBu	42.47	0.09	22	2	20	0	0	70	50	2,900	0	0	90	69
15	NiBu	42.54	0.30	29	2	0	0	0	6	23	1,100	0	0	82	35
16	NiBu	42.62	0.02	18	2	10	0	0	30	20	1,640	17	0	20	39
17	NiBu	42.69	0.04	18	2	10	0	0	20	30	1,480	0	0	0	41
18	NiBu	42.87	0.02	34	2	10	0	0	20	20	1,600	0	0	0	41
19	NiBu	43.06	0.20	70	2				27	13	850	0		20	42
20	NiBu	43.53													
21	NiBu	43.73													
22	NiBu	45.65	0.10	13	4			0	7	13	1,090	0		96	49
23	NiBuBu	51.30	0.13	8	1				0	0	385	0		10	10
24	NiBuCz	43.53													
25	NiBuCz	51.40	0.07	10	2				0	5	180	0		10	6
26	NiBuCy	53.10	0.11	37	12				5	35	985	0	0	17	67

Table 21. Water Quality of Industrial Intake Waters

Parameter	City Water	BRIC Water
pH	8.03	8.03
Sp. Cond., μ mhos/cm	316	294
Alkalinity, mg/l	88	88
BOD5, mg/l	0.9	2.3
TDS, mg/l	207	197
TSS, mg/l	0	8
NH_3-N, mg/l	0.0	0.5
NO_3-N, mg/l	0.07	0.07
Phosphate, mg/l	0.12	1.27
Org-N, mg/l	0.1	2.0
Sulfate, mg/l	27	24
Chloride, mg/l	27	35
Cyanide, mg/l	0.0	0.0
Fluoride, mg/l	0.61	0.61
As, mg/l	0.0	0.0
Ba, mg/l	0.0	0.0
Cd, mg/l	0.0	0.0
Ca, mg/l	37.0	34.3
Cr, mg/l	0.01	0.01
Cu, mg/l	0.017	0.040
Fe, mg/l	0.170	0.847
Pb, mg/l	0.010	0.023
Mg, mg/l	9.8	7.5
Hg, mg/l	0.00	0.00
Ni, mg/l	0.01	0.014
K, mg/l	1.53	1.53
Na, mg/l	9.7	9.7
Zn, mg/l	0.083	0.083
Se, mg/l	0.0	0.0
Oil & Grease, mg/l	1.6	1.6
Phenols, mg/l	0.004	0.008
D. O., mg/l	10.5	8.5
Temperature, °C	21.1	21.1

Buffalo Creek is classified as a "B" stream from its mouth (at its confluence with Cayuga Creek at River Mile 45.7) to River Mile 60.2; and as an "A" stream above River Mile 60.2. No violations of the minimum dissolved oxygen criteria were reported. Some high total phosphorus and fecal coliform levels were reported; probably the result of overland flow from agricultural lands in the upper reaches and of municipal sewage treatment plant effluents (Jerge-Elma and Elma Town) in the lower reaches.

The stream classification for Cazenovia Creek is "D" from its mouth (River Mile 43.4) to one mile upstream of its mouth, and is "B" upstream of River Mile 44.4. No violations of the dissolved oxygen criteria were reported, and the good water quality data reflect a relatively low waste loading to the Cazenovia Creek watershed.

Cayuga Creek has a classification of "C" from its mouth (at River Mile 45.7) to River Mile 54.2, and as "B" upstream of River Mile 54.2. The water quality data indicate low waste loadings in the upper reaches, above River Mile 54. However, below this point, the dissolved oxygen levels fell below the minimum 4.0 mg/l, and the levels of BOD_5, total phosphorus and fecal coliform were all greatly increased, violating the "C" classification for this reach.

Data for the water quality of the lower reaches of each of the three tributaries are listed in Tables 17 and 20. For the purpose of closer examination, these data have been summarized in Table 22. The gross discrepancy in the poor water quality of Cayuga Creek as compared to the good water quality of Buffalo and Cazenovia Creeks is readily apparent. Summarizing the Cayuga Creek parameters associated with domestic wastes,

BOD_5	9.7 mg/l
DO	2.4 mg/l
Total P	2.6 mg/l (as PO_4)
NH_3-N	4.5 mg/l
Fecal Coliform	2,200 MPN/100 ml
Oil and Grease	6.0 mg/l

Three municipal sewage treatment plants (all primary) discharge into Cayuga Creek in Erie County Sanitary District No. 4:

	Flow, m^3/day		Removal Eff., %		Adequate
	Design	Actual	BOD	SS	Chlorination
Depew (Village)	7,500	9,800	28.4	58.4	No
Lancaster (Town)	110	150	72.3	31.0	Yes
Lancaster (Village)	1,900	?	5.8	24.0	No

Table 22. Water Quality of Tributaries

	Buffalo Ck.	Cazenovia Ck.	Cayuga Ck.
Flow @ 70% Dur., m^3/day	77,080	79,770	30,343
Flow @ 99% Dur., m^3/day	11,260	12,480	1,220
Temperature, °C	17.1	21.6	17.5
Dissolved Oxygen, mg/l	8.2	8.8	2.4
BOD_5, mg/l	1.5	2.7	9.7
Total Phosphorus (PO_4), mg/l	0.13	0.28	2.6
NH_3-N, mg/l	0.2	0.1	4.5
Phenols, mg/l	0.008	0.009	0.037
Cyanide, mg/l	0.01	0.01	0.05
Oil & Grease, mg/l	2.1	1.5	6.0
pH	8.1	9.0	7.5
Fecal Coliform, MPN/100 ml.	275	500	2200
Suspended Solids, mg/l	8	5	38
Dissolved Solids, mg/l	238	535	332
Chloride, mg/l	19	57	47
Fluoride, mg/l	0.18	0.29	0.64
Sulfate, mg/l	49	74	53
Nitrate, mg/l	1.6	0.1	0.1
Selenium, mg/l	0.001	0.002	0.012
Iron, mg/l	0.250	0.180	0.985
Zinc, mg/l	0.010	0.006	0.004
Copper, mg/l	0.000	0.010	0.035
Lead, mg/l	0.008	0.010	0.015
Chromium, mg/l	0.000	0.000	0.005
Mercury, mg/l	0.000	0.000	0.000

The Lancaster Village STP is an Imhoff tank built in 1905; its treatment is so ineffective that monthly reports are not even filed with the Erie County Health Department. Erie County plans to phase out all three STP's for dry weather flow. The plans call for incorporation of the sewage into the Buffalo sewer system.

The water quality measurements made in this program revealed other significant data for Cayuga Creek indicating industrial wastes:

Phenols	0.037 mg/l
Cyanide	0.050 mg/l
Selenium	0.012 mg/l
Iron	0.985 mg/l
Copper	0.035 mg/l
Lead	0.015 mg/l
Chromium	0.005 mg/l

The Buffalo Sewer Authority is presently conducting an industrial waste survey[30] to identify the following industrial discharges into the municipal sewers in Erie County Sewer District No. 4 which may have inorganic or toxic constituents:

Dresser Transportation Equipment Co.
Arcata Graphics
Bennett Manufacturing Co.
NL Industries
Ward Hydraulics

Industrial discharges to the municipal sewer systems are eventually discharged by the municipal STP's, probably accounting for the pollution of Cayuga Creek with the above toxic substances. The specific water quality contraventions for Cayuga Creek, as compared to the water quality criteria of Table 15, are for dissolved oxygen, ammonia, cyanide and iron. When the three STP's are phased out, the above water quality problems should no longer affect Cayuga Creek. In any event, compliance with pretreatment standards (as they are promulgated) should be investigated by appropriate agencies.

6.4 WATER QUALITY NEAR THE ENDS OF THE BUFFALO RIVER

The dredged portion of the Buffalo River, a heavily industrialized area, is the principal subject of this study. The very significant oscillating flows of the Buffalo River, discussed in considerable detail earlier in this report, cause two very distinct phenomena at the upper and lower boundaries of the dredged portion of the Buffalo River. First, the data in Tables 17 and 20 show that the water quality upstream of the dredged portion, between River Mile 43.1 (the upstream boundary of the dredged portion) and River Mile 45.7 (the confluence of Buffalo Creek and Cayuga Creek to form the head of the Buffalo River), reflect to a great extent the poor water quality in the downstream dredged portion. The temperature data below shows that this 4.2-kilometer (2.6-mile) reach is influenced as much or more from the downstream waters as it is from the upstream waters:

Upstream	RM 45.7 - Buffalo Ck.	17.1°C
	RM 45.7 - Cayuga Ck.	17.5°C
Mid-Reach of Buffalo River	Rm 45.65 - Harlem Rd.	20.2°C
	RM 43.73 - Seneca St.	27.5°C
	RM 43.53 - Bailey Ave.	25.9°C
Downstream	RM 42.54 - S. Park Ave.	28.0°C

Similarly, the fluctuating flow of the Buffalo River causes water from the shoreline of Lake Erie to travel upstream for a significant longitudinal distance and mix with Buffalo River water close to the mouth of the river.

Downstream of Ohio Street (River Mile 39.44), the water quality changes rapidly and begins to resemble the water quality of the lakeshore. Water quality at these downstream stations, therefore, does not characterize the waste load contribution of the Buffalo River to the Niagara River. Similarly, there is evidence that the Buffalo Ship Canal is periodically flushed out by the rising and falling lake level.

6.5 WATER QUALITY GRADIENTS IN THE DREDGED PORTION OF THE BUFFALO RIVER

The vertical and cross-channel gradients in temperature, dissolved oxygen, and specific conductance were measured at several longitudinal stations over a period of several weeks in the summer of 1973. The individual data are included in Appendix C.

Figures 9 and 10 show the temperature and dissolved oxygen gradients (respectively) in the vertical direction. At the upstream stations, RM 41 and above, both gradients are quite distinct, and with the D.O. level falling to less than one milligram per liter at depths of 3 meters (10 feet) or greater. Further downstream, at RM 39.4 (the Ohio Street Bridge), both the temperature and D.O. vertical gradients are much flatter, consistent with other evidence that upstream travel of lake water affects the water quality of the river near the mouth.

The data of Appendix C show that specific conductance (a measure of dissolved ionic species and used here to indicate concentration gradients for conservation species) does not exhibit the distinct profiles and gradients that are characteristic of temperature and dissolved oxygen. Moreover, the data of Appendix C indicate reasonably good cross-channel homogeneity for all three measured parameters.

The conclusions reached are that:

- Cross-channel gradients are not large.
- The vertical gradients of temperature and dissolved oxygen are important, especially in the upstream

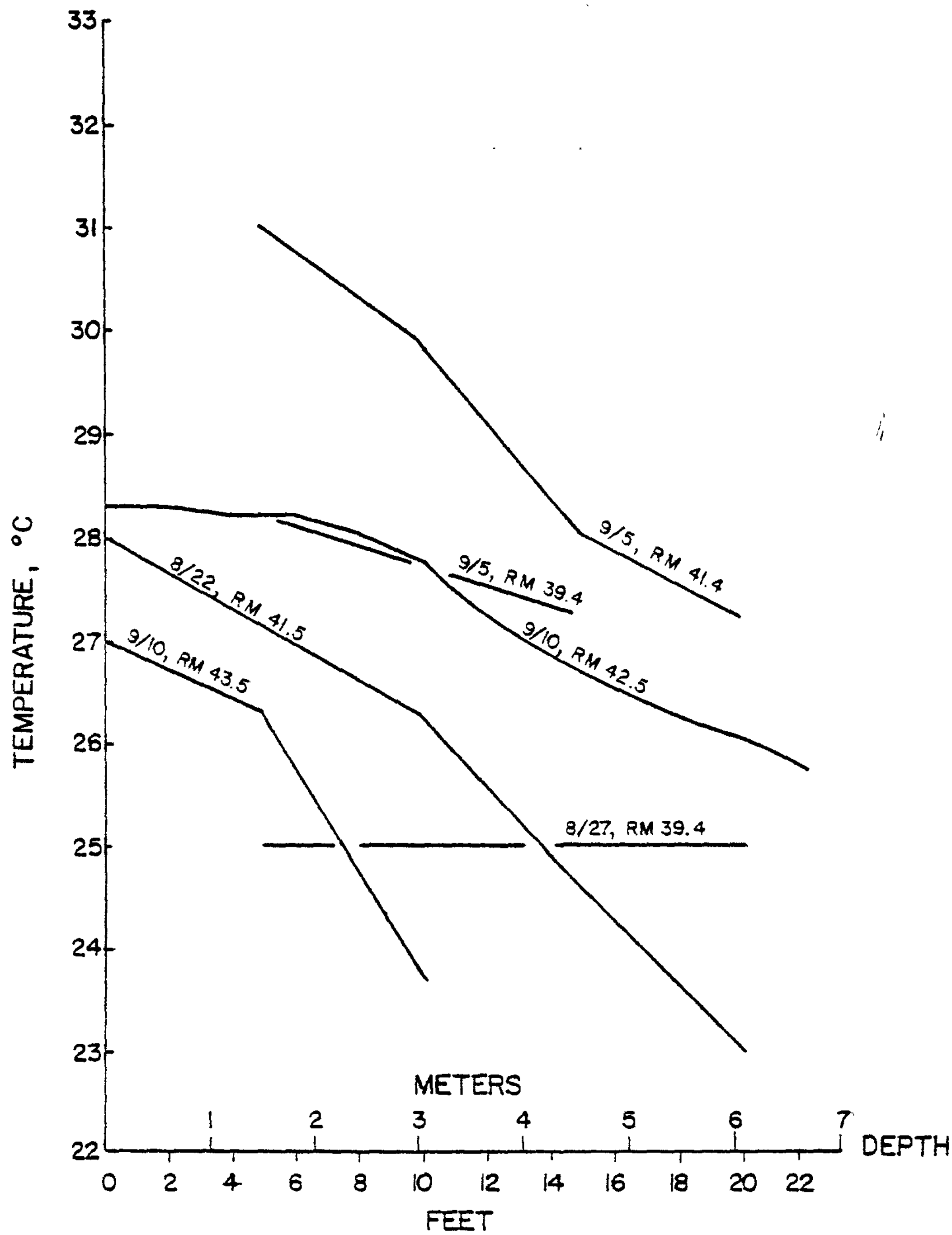


FIGURE 9
VERTICAL TEMPERATURE GRADIENT
MID-STREAM

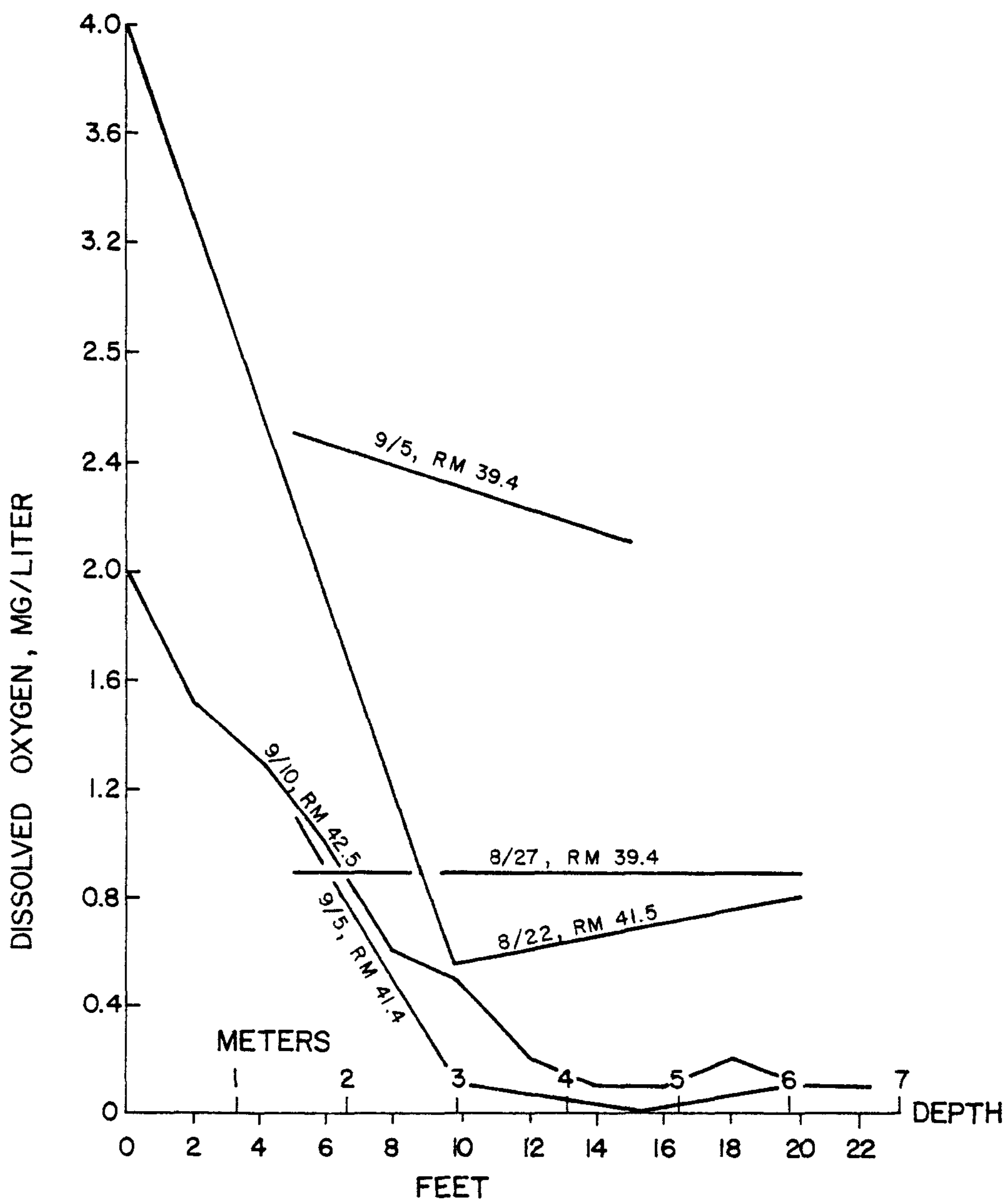


FIGURE 10

VERTICAL D.O. GRADIENT

MID-STREAM

portion of the dredged channel; but that vertical concentration gradients for conservative species are much less significant. Hence, a model of two-layer flow does not appear valid. Rather, it appears that the driving forces for mixing (convection, diffusion, and the eddies of oscillating flow) are sufficient to result in homogeneity for conservative species, but are insufficient to result in vertically-homogeneous temperature and dissolved oxygen.

The earlier discussion of the hydraulics of the dredged portion of the Buffalo River led to the conclusion that extensive longitudinal mixing was probable, caused by the oscillating flow. A cursory analysis of the data in Tables 17 and 20 leads to the empirical verification of the longitudinal well-mixed hypothesis, from River Mile 43.06 (the upstream boundary of the dredged portion) to River Mile 39.44 (the Ohio Street Bridge, where fresh lake water starts to impact the water quality). As one examines Tables 17 and 20, one parameter (column) at a time, the almost complete absence of any significant water quality trends with longitudinal distance in this reach, is readily apparent.

These data in Tables 17 and 20 therefore provide direct experimental support of the hypothesis of no significant longitudinal water quality gradients which was based upon an independent hydraulic analysis. This hypothesis was also tested (extensively discussed later in this report) by applying both a "plug-flow" simulation model and a "well-mixed" simulation model to the river, with the result that the latter model yielded much more valid water quality results as compared to the experimental data.

6.6 WATER QUALITY OF THE DREDGED PORTION OF THE BUFFALO RIVER

Upon acceptance of the hypothesis of longitudinal homogeneity, longitudinal averages of the water quality parameters may be presented and discussed with validity. Table 23 lists these average data, which were derived from the same new data that were used to generate Tables 17 and 20. There was some weighting applied for knowledge of whether or not any winter data influenced reported averages. In general, the DEC and GLL data of Table 17 and the original data of Table 20 were given credence in this weighting, because raw data was more readily available for inspection and critical selection than were the RPB and EPA data of Table 17. An example of data not used was the EPA data for Ohio Street in Table 17; the reported temperature of 15.6°C (10°C lower than the rest of the data in this study) was actually the average of 19 measurements with a range of 1°C to 26°C; the corresponding dissolved oxygen rate was 0.0 mg/l to 12.0 mg/l.[26]

A comparison of the average concentrations in Table 23 with the corresponding water quality criteria (also listed in Table 23) indicates

Table 23. Water Quality, Dredged Portion of the Buffalo River
Concentrations In mg/l

	Water Quality Criteria[a]	Measured Data			
		No. Data Pts.	Max.	Min.	Average
Dissolved Oxygen	3.0*	76	4.0	0.0	0.94
BOD-5	--	41	14.0	0.6	4.22
NH_3-N	2.0*	29	1.26	0.14	0.69
NO_3-N	4	17	0.59	0.0	0.13
Cyanide	0.1*	28	0.05	0.0	0.01
P-Total	25	28	0.85	0.07	0.29
Sulfate	500	33	68	49	57
Chloride	250	33	70	46	57
Fluoride	1.5	17	0.69	0.44	0.53
Oil & Grease	7	29	7.2	0.1	2.6
Phenols	0.2	29	0.266	0.008	0.027
Arsenic	1.0	12	0.03	0.00	0.02
Barium	5.0	11	0.20	0.0	0.0
Cadmium	0.3*	15	0.00	0.00	0.00
Chromium	0.05	27	0.08	0.00	0.02
Copper	0.2*	24	0.06	0.00	0.02
Iron	0.8	10	5.65	0.68	3.11
Lead	0.1	21	0.23	0.00	0.06
Mercury	0.006	27	0.017	0.000	0.001
Nickel	0.7	12	0.00	0.00	0.00
Selenium	2.5	21	0.004	0.001	0.003
Zinc	0.3*	10	0.178	0.024	0.084

(a) Criteria Labelled * are explicit in N. Y. State Standards
Others are implied by "fish survival" criterion.

two clear contraventions of water quality criteria. The average dissolved oxygen concentration of 0.94 mg/l is far short of the minimum for a Class D stream, 3.0 mg/l; and the average iron concentration of 3.11 mg/l is far above the maximum allowable of 0.8 mg/l. All other averages were within the criteria, but some individual data points exceeded the criteria:

	Number of Data Points	
Parameter	Total	Exceeding Criteria
Oil & Grease	29	1
Phenols	29	1
Chromium	27	4
Lead	21	5
Mercury	27	1

The single data points exceeding the criteria for oil and grease, phenols and mercury may very well be anomalies in the data. The existence of multiple data points exceeding the criteria for chromium and lead, however, provide some reasonable indication that occasional contraventions do exist for these metals.

The range of 86 temperature measurements made in the dredged portion of the Buffalo River was 21.5°C to 31.2°C with an overall average of 26.9°C. Hence, the average summertime temperature does not exceed the criterion of 29°C. However, of the 86 points, there were 14 individual measurements which did exceed this criterion, indicating occasional contraventions.

6.7 SEDIMENTATION IN THE BUFFALO RIVER

The industrialized portion of the Buffalo River, and the Buffalo Ship Canal, are periodically dredged for channel maintenance. The quantity of sediment dredged was estimated by the U.S. Army Corps of Engineers.[31]

The quantity of sediment dredged was estimated at 95,500 cubic meters per year (125,000 cubic yards per year), with a spoil density of 740 kg/cu meter (1,250 lbs/cu yard). Based upon an average (of 12 samples) of 34.9 per cent total solids, and assuming that the daily deposition rate is equal to the average daily dredging rate, the daily deposition rate is 68,000 kilograms (150,000 pounds) of dry solids in the dredged portion of the Buffalo River and in the Buffalo Ship Canal.

Table 24 lists the composition (average of 12 sediment analyses, three samples for each of four longitudinal stations) of the sediment, based upon dry solids, and the corresponding daily quantities of each constituent. The composition of the sediment was reported by Sweeney[27] and by the Corps of Engineers.[31]

The sources of the sediment include suspended solids from upstream tributaries as well as discharges into the Buffalo River. Based upon data of Archer and Sala, the total sediment discharged by the three tributaries

Table 24. Dredged Sediment Analyses and Average Daily Quantities Buffalo River (Dredged Portion) and Ship Canal (27,31)

Parameter	Compostion mg/g (Dry Wt.)	Kilograms per day	Pounds per day
TVS	125	8,500	18,750
COD	102	6,900	15,300
BOD	8.5	580	1,275
Cl_2 Demand	13.6	925	2,040
Oil & Grease	7.9	540	1,185
Fe	42	2,860	6,300
Dissolved PO_4	0.039	2.7	5.9
Total PO_4	3.21	220	480
NO_3-N	0.007	0.5	1.0
NH_4-N	0.165	11.2	25
Org-N	1.44	98	216
Total-N	1.57	107	235
Pb	0.0096	0.7	1.4
Zn	0.0247	1.7	3.7

to the Buffalo River is 417,000 kkg per year (460,000 tons per year):[32]

Buffalo Creek	136,000 kkg/yr	(150,000 tons/yr)
Cayuga Creek	100,000 kkg/yr	(110,000 tons/yr)
Cazenovia Creek	181,000 kkg/yr	(200,000 tons/yr)

The daily average is then 1,040,000 kilograms per day (2,520,000 pounds per day), more than enough to account for the quantity dredged from the river.

6.8 BIOLOGICAL DATA IN THE BUFFALO RIVER

A good historical data bank exists for biological data in the dredged portion of the Buffalo River. The 1964 Blum study,[25] conducted before the flow augmentation project was implemented, showed that the dredged portion (but not the river mouth where Lake Erie water travelled upstream) was devoid of demonstrable bottom organisms, consistent with a measured dissolved oxygen level near zero in the same reach. There was no algal growth or plankton growth in the industrialized reach of the river.

More recently, three studies by Sweeney[21] have reported on the biology of the river bottom. The following benthic macroinvertebrates were reported at four stations:

Species Code	Class	Order	Family
A	Oligochaeta	Pleisophora	-
B	Gastropoda	Pulmonata	Physidae
C	Gastropoda	Ctenobranchiata	Valvatidae
D	Pelecypoda	Heterodonta	Sphaeriidae
E	Insecta	Diptera	Chironomidae
F	Tubellaria	Tricladida	Planariidae
G	Hydrozoa	Hydroida	Hydridae
H	Phasmidia	Rhabditat	-

The data for the Coast Guard Station (Ni 37.66) may be regarded as a standard for comparison, since the water quality at this station is much closer to that of Lake Erie than it is to that of the Buffalo River. (Table 17 shows a dissolved oxygen level of 11.4 mg/l at this station). Despite the water quality evidence that fresh lake water partially flushes the river at Michigan Avenue, Table 25 shows a marked decrease in benthic species at this station. Further upstream, in the heart of the industrialized reach, benthic life is very scarce indeed, consistent with the septic nature of the river as demonstrated by water quality data and by sediment analyses.

Table 25. Benthic Macroinvertebrates in the Buffalo River Sources:[27]
Data in Number Per Square Meters (As Reported)

Station	Date	Species A	Species B	Species C	Species D	Species E	Species F	Species G	Species H
Coast Guard Station	6/6/69	2,449.0							
Ni 37.66	7/30/69	18,467.5	31.0	31.0	31.0	821.5			
	9/22/69	4,712.5		108.5		139.5			
	5/13/70	4,805.0		15.5					
	8/13/70	12,508 5		77.5		186.0	31.0	62.0	
	10/27/70	2,501.0			15.5	15.5			15.5
Michigan Avenue,	6/6/69	15.5							
NiBu 38.70	7/30/69	62.0							
	9/22/69	93.0							
	5/13/70	46.5							
	8/13/70	1,891.0		31.0		15.5			
	10/27/70	124.0							
N&W RR	6/6/69								
NiBu 41.77	7/30/69								
	9/22/69								
	5/13/70								
	8/13/70	217.0							
	10/27/70	15.5							
DL&W RR	6/6/69	837.0							
NiBu 43.06	7/30/69	3,689.0							
	9/22/69								
	5/13/70	155.0							
	8/13/70	504.5							
	10.27.70	15.5							

7.0 WASTE LOADS

The discussion in this section covers both the current waste loads into the Buffalo River, and the projected waste loads upon application of best practicable control and treatment technology.

The Buffalo River is subjected to waste loadings from three sources (each discussed in detail in this section):

(1) The upstream discharge of the three tributaries (Buffalo Creek, Cazenovia Creek and Cayuga Creek).

(2) The frequent overflows into the Buffalo River from the combined storm/sanitary sewer system in the City of Buffalo.

(3) The industrial discharges into the Buffalo River.

7.1 UPSTREAM DISCHARGES

The water quality of the upstream tributaries was discussed in the previous section, and summarized in Table 22. The Buffalo Creek and Cazenovia Creek, and the upper reaches of Cayuga Creek were all found to have acceptable water quality, according to New York State criteria. This is consistent with low waste loadings from primarily agricultural and rural lands. The lower reach of Cayuga Creek, however, has poor water quality and severe water quality contraventions, attributable to the discharges from three municipal sewage treatment plants in Erie County Sanitation District No. 4. Some industrial wastes, as well as domestic wastes, are in the influent to those municipal STP's. When Erie County completes its plan to phase out these STP's during the dry weather and incorporate the sewage into the Buffalo sewer system, the lower reach of Cayuga Creek should meet the water quality criteria.

The data from Table 22 were used to generate Table 26, the waste loads into the Buffalo River attributable to the three tributaries. Also listed in Table 26 are the projected waste loads, based upon the incorporation of the Cayuga Creek STP's into the Buffalo sewer system.

Table 26 lists the waste loads under two conditions of flow: the average summertime flow, equivalent to the 70 per cent duration point; and the minimum average seven-day critical discharge with a recurrence interval

Table 26.

Waste Loads to the Buffalo River from the Discharge of the Upstream Tributaries

	70% Dur. "Present"	99% Dur. "Present"	70% Dur. "Projected"	99% Dur. "Projected"
Flow, m^3/day	187,200	22,500	187,200	22,500
Heat Flux, kcal/day x 10^{-6}	0	0	0	0
pH	8.3	8.3	8.6	8.6
Total Solids, kg/day	73,570	8,840	72,450	8,710
Dissolved Solids, kg/day	71,140	8,550	71,140	8,550
Suspended Solids, kg/day	2,434	292.5	1,310	157.5
NH_3-N, kg/day	205.9	24.8	28.8	3.38
Organic-N, kg/day	46.8	5.63	46.8	5.63
BOD-5, kg/day	692.6	83.3	393.1	47.3
Dissolved Oxygen, kg/day	1,348	162.0	1,591	191.2
NO_3-N, kg/day	131.0	15.8	131.0	15.8
Cyanide, kg/day	3.74	0.45	1.87	0.23
P-Total, kg/day	132.9	16.0	37.4	4.50
Sulfate, kg/day	11,230	1,350	11,230	1,350
Chloride, kg/day	7,488	900	7,488	900
Fluoride, kg/day	59.9	7.20	44.9	5.40
Oil & Grease, kg/day	505.4	60.8	337.0	40.5
Phenols, kg/day	2.81	0.34	1.59	0.19
Arsenic, kg/day	0	0	0	0
Barium, kg/day	0	0	0	0
Cadmium, kg/day	0	0	0	0
Chromium, kg/day	0	0	0	0
Copper, kg/day	2.06	0.25	1.87	0.23
Iron, kg/day	70.4	8.46	40.3	4.84
Lead, kg/day	1.87	0.23	1.69	0.20
Mercury, kg/day	0	0	0	0
Nickel, kg/day	0	0	0	0
Selenium, kg/day	0.75	0.09	0.28	0.03
Zinc, kg/day	1.31	0.16	1.50	0.18

of ten years (MA7CD/10), equivalent to the 99 per cent duration point, and specified as critical flow by the New York State Department of Environmental Conservation. The heat flux of the upstream discharge is defined as zero, with the choice of a baseline temperature equivalent to the temperature of this discharge (19.0°C in summer).

7.2 COMBINED SEWER OVERFLOWS

The City of Buffalo is served by a combined sewer system, which was designed to collect and transport both the dry-weather sanitary sewage and most of the wet-weather storm flow. The system was designed to relieve excess wet-weather flow with multiple overflow weirs and outfall sewers into receiving waterways. Although the periodic overflows are predominantly stormwater, raw sanitary sewage is discharged at the same time. Moreover, accumulations of solids (from sanitary sewage) during dry-weather periods are flushed out during subsequent rainstorms.

This combined sewer design is, of course, not applied to new construction, since discharge of untreated sanitary sewage into waterways is in direct violation of all water quality standards. The City of Buffalo sewer system, like many other systems across the country, is quite old. Sixty per cent of the Buffalo sewers were built prior to 1910, and 92 per cent prior to 1940.[35] The overflows from the combined sewer system of the Buffalo Sewer Authority (BSA) discharge into three waterways, of which one is the dredged portion of the Buffalo River. Of the approximately 70 BSA outfall sewers, Table 27 lists the major points of discharge into the Buffalo River.

Two recent studies were used to quantify the waste load from the combined sewer system into the Buffalo River. One was published by Greeley and Hansen in 1968[33] for Erie County; the other was published by L.S. Wegman in 1973 for the Buffalo Sewer Authority.[35]

The Greeley and Hansen study emphasized that (in the 1968 time period) no reliable estimates of overflow quantities could be derived from the records of the Buffalo Sewer Authority (BSA). Although BSA maintained records of the number of overflows at several of the larger interceptors and records of the maximum water height at the overflow weir; data of height vs. time during overflows was not collected.

The estimated overflow quantities were derived in the Greeley and Hansen study by an analysis of rainfall records, assumptions regarding ground wetting and runoff, and an assumption regarding the hydraulic capacity of the interceptors. The conclusions were that:

(1) The average number of overflow occurences was 74 per year, or approximately one every five days. (Note: precipitation is quite evenly distributed over the year, with an average monthly precipitation

Table 27.

Major Combined Sewer Discharge Points into the Buffalo River

Hamburg Street Sewer	NiBu	38.12
Main Street Sewer		38.35
Washington Street		38.42
Indiana Street		38.46
Illinois Street		38.52
Michigan Avenue		38.70
Mackinaw and Ohio		38.82
Ohio Street Storm		39.08
Ganson Street Sewer		39.37
Louisiana Street		39.37
Hamburg and South Streets		39.72
Smith Street		41.32
South Park and Lee Street		42.32
Maurice Street		42.52
Babcock Street		42.62
Abbott Road		42.94
Bailey Avenue		43.32

of 2.69 inches, a maximum (in November) of 3.09 inches, and a minimum (in July) of 2.43 inches).[8] On the average, precipitation occurred 119 times per year; so that combined sewer overflows resulted from 62 per cent of the storms.

(2) The total volume of the overflows in the City of Buffalo (drainage are of 8,960 hectares) was 18.5 million cubic meters per year. On the average, 2.19 per cent of the BSA raw sewage is in the overflow, and the total overflow on a unit drainage area basis is 2,070 cubic meters per year per hectare.

The drainage area served by the combined sewer in the Buffalo River Basin is 3,610 hectares. Using the factor developed above, the estimated total overflow into the Buffalo River is 7.45 million cubic meters per year, or an average of 20,300 cubic meters per day. This waste load was assumed to be evenly distributed in time for the purposes of this study, because of the relatively uniform rainfall pattern, the relatively high frequency of overflows, and the relatively high retention time of the dredged portion of the Buffalo River. Moreover, because of the multiplicity of overflow points and the mixing phenomena in the Buffalo River, this waste load was assumed to be spatially distributed. The waste concentrations of combined sewer overflows are extremely variable, of course. These overflows are a combination of stormwater, street washings, raw sewage, and sewer flushings; and the accumulated (from dry weather) solids in streets and sewers which are flushed by stormwater make the waste loads of the overflows large and make these waste loads vary considerably not only from storm-to-storm but also during any particular storm, both spatially and temporally. Very little historical data was available for the Buffalo River Basin overflows; however, one such set of data (in the EPA/Rochester Field Office records) illustrates this variability:

Table 28

Measurements of Overflows from the Combined Sewer System

Date	Rainfall	Sampling Location	Volatile Solids	Fixed Solids	Total Suspended Solids
July 31, 1961	Heavy	Smith St.	125 mg/l	285 mg/l	410 mg/l
July 31, 1961	Heavy	Commercial St.	333 mg/l	1,144 mg/l	1,477 mg/l
August 2, 1961	Moderate	Smith St.	22 mg/l	28 mg/l	50 mg/l
August 2, 1961	Moderate	Michigan Ave.	25 mg/l	10 mg/l	35 mg/l

These data also point out that because of street and sewer flushings, combined sewer overflows cannot be assumed a simple mixture of stormwater and average raw sewage. (The average waste concentrations for Buffalo Sewer Authority raw sewage influent to the treatment plant in 1966 was 94 mg/l BOD and 143 mg/l suspended solids).

Although a systematic study of combined sewer overflows was not available for Buffalo, one such study was performed at Bucyrus, Ohio, in the Sandusky River Basin.[34] Table 29 lists the results of many overflow sample analyses; the average concentrations from this study were adopted as the waste concentration for this study.

The results (for just BOD and suspended solids) were as follows for the entire City of Buffalo:

Avg. Overflow Vol.,	m^3/day	50,600
BOD_5	mg/l	106
	kg/day	5,360
SS	mg/l	382
	kg/day	19,300

The more recent Wegman study consisted of a similar hydraulic analysis of rainfall/runoff and a similar assumption about the hydraulic capacity of the interceptors; however, the storm water flows were rigorously calculated by more recently-developed methods, using actual storm events over a two-year period. The Wegman finding was that the average overflow volume attributable to City of Buffalo storm water drainage was 50,700 cubic meters per day, virtually identical to the Greeley-Hansen result of 50,600 cubic meters per day.

However, Wegman used pollutional concentrations from another (non-Buffalo) source[36] to calculate waste loads in the combined sewer overflow:

Avg. Overflow Vol.,	m^3/day	50,700
BOD_5	mg/l	74
	kg/day	3,760
SS	mg/l	255
	kg/day	12,910

This is equivalent to an average 1.3 per cent of the BSA raw sewage in the combined sewer overflow, a low figure (as admitted by Wegman) compared to other systems. It is possible, however, using the data in the Wegman report to independently calculate the pollutional loads of combined sewer overflows, without use of non-Buffalo pollutional concentrations. The sum of dry-weather flows and the calculated storm runoff flows is the total input to the sewer system (on a time-integrated basis over two years of study). This sum, less the measured influent flow at the BSA Sewage Treatment Plant, must be the loss due to combined sewer overflows:

	Flow, m^3/day	BOD_5, kg/day	SS, lg/day
Dry Weather Flow*	546,700	99,800	75,500
Storm Water Runoff*	155,000	1,100	19,700
Total Input	701,700	100,900	95,200
STP Influent*	651,000	95,200	78,000
Combined Sewer Overflow	50,700	5,700	17,200

*Independently-estimated or calculated in the Wegman Study.

Table 29.

Waste Concentration of Combined Sewer Overflows, Bucyrus, Ohio

Parameter	Median Values of Multiple Samples: Location 1	Location 2	Location 3	Average of Median Values
BOD_5, mg/l	140	100	78	106
COD, mg/l	394	40	355	396
SS, mg/l	360	400	385	382
VSS, mg/l	180	160	200	180
TS, mg/l	1,260	780	830	957
NO_3-N, mg/l	3.2	3.1	2.4	2.93
NH_3-N, mg/l	1.1	1.1	1.8	1.33
Org-N, mg/l	5.6	6.7	5.9	6.06
PO_4, mg/l	8.8	7.7	7.5	8.00
Total Coliform/ 100 ml	3.6×10^6	7.5×10^6	3.6×10^6	4.90×10^6
Fecal Coliform/ 100 ml	2.4×10^6	0.4×10^6	0.3×10^6	1.03×10^6
Fecal Strep/100 ml	0.5×10^6	0.02×10^6	0.04×10^6	0.19×10^6

Table 30.

Waste Loads to the Buffalo River from Combined Sewer Overflows

Flow, m^3/day	20,300
Total Solids, kg/day	19,430
Dissolved Solids, kg/day	11,670
Suspended Solids, kg/day	7,755
NH_3-N, kg/day	27.0
Organic-N, kg/day	123.0
BOD-5, kg/day	2,152
Dissolved Oxygen, kg/day	189.8
NO_3-N, kg/day	41.2
P-Total, kg/day	53.0

The following table summarizes the three sets of data:

		Greeley-Hansen plus Burgess-Niple	Wegman plus USWPC Research Data	Material Balance Using Wegman Data
Avg. Overflow Vol.,	m^3/day	50,600	50,700	50,700
BOD_5	mg/l	106	74	112
	kg/day	5,360	3,760	5,700
SS	mg/l	382	255	339
	kg/l	19,300	12,910	17,200

For the practical purposes of this program, it is concluded that the Wegman study verifies the combined sewer overflow waste loads calculated from the Greely and Hansen study. For use in this waste allocation program for the Buffalo River, the above waste loads are multiplied by the drainage area ratio of 0.402 (Buffalo River Drainage Basin of 3,610 hectares and total City of Buffalo Drainage area of 8,960 hectares). The Wegman report shed no new light on the quantification of the overflows from each of the more than 250 BSA overflow chambers or from each of the 70 BSA overflow outfalls.

Based upon an average overflow rate into the Buffalo River of 20,300 cubic meters per day, and upon the waste concentrations from Table 29, the waste loads into the Buffalo River from the combined sewer overflows are presented in Table 30.

Although several recommendations for abatement of this pollution load were made in both the Greeley and Hansen and Wegman studies, there is at present no known approved plan for implementing any of these recommendations. Hence, for the purposes of this waste allocation study, the projected waste loads into the near future will be unchanged from the current combined sewer overflow waste loads.

7.3 PRESENT INDUSTRIAL WASTE LOADS

As of July 1973, there were 32 industrial point discharges to the dredged portion of the Buffalo River. A total of 13 different NPDES permit applications (i.e., companies) were on file with Region II of the U.S. Environmental Protection Agency, so that many of the companies had more than one point discharge. Table 31 lists the point discharges in the order of River Mile, starting with the discharge furthest upstream. The "company number" in Table 31 corresponds to the NPDES application identification number assigned by EPA. The volumetric flow rate for each discharge is also listed in Table 31.

The waste loads for each point discharge were calculated directly from the NPDES permit applications, and are listed in Appendix D. One parameter, however, the dissolved oxygen content of the industrial effluents, was not included in the NPDES permit applications. Discussions with

Table 31.

Industrial Discharges to the Buffalo River

Co. No.	Name	Discharge S/N	Bank	River Mile	Flow, m^3/day
043	Mobil Oil	001	N	42.92	105,980
482	Allied, Buffalo Dye	011	N	42.72	17,979
419	Allied, ICD	001	N	42.66	15,897
		002	N	42.64	7,570
		003	N	42.58	14,005
		004	N	42.55	5,299
482	Allied, Buffalo Dye	010	N	42.54	16,276
		009	N	42.53	8
		008	N	42.52	95
326	Republic Steel	001	S	42.48	32,930
482	Allied, Buffalo Dye	007	N	42.43	4,542
		006	N	42.42	28,388
		005	N	42.41	1,893
		004	N	42.27	76
		003	N	42.26	208
326	Republic Steel	004	S	42.25	59,046
		002	S	42.24	30,356
		003	S	42.06	49,773
084	Donner Hanna Coke	001	S	42.02	32,135
482	Allied, Buffalo Dye	002	N	41.89	95
		001	N	41.82	114
569	Airco	001	N	41.25	27
191	Pacific Molasses	001	N	40.34	2
424	U.S. Steel	001	N	40.05	545
271	International Multi-foods	002	S	39.98	23
		001	S	39.72	170
339	American Malting	001	S	39.62	265
		002	S	39.61	1,893
056	Peavey	003	S	39.56	11
		002	S	39.55	64
		001	S	39.54	397
088	Agway	001	S	38.85	19
114	General Mills	001	S	38.67	1,476

quantities of raw materials, products, and process water use; to enable the direct use of guidance or guideline documents in generating waste loadings.

(2) The Levels B and A guidance documents only cover selected industries; several of the major dischargers in this study were not covered.

(3) The Level I and Level II guideline documents were, in October 1973, in a state of development and review. Some industries were covered in Phase I of Group I, with the contractors' reports published June 30, 1973, but not all of these were then published in the Federal Register. Other industries were being studied in Phase II of Group I, and the contractors' development documents were expected by the end of FY 1973. Still other industries were to be studied in Group II; the development documents were not expected before the end of FY 1974 (too late to be useful in this study).

To overcome these difficulties so that recommended waste allocations could be made available to EPA by December 31, 1973, EPA and Versar mutually agreed that the projected industrial discharges would be based upon full compliance with either issued NPDES permits or with EPA Region II Permit Summary Tables as of October 1973. By that date, only Allied SCD had been issued a permit,and Permit Summary Tables had been prepared for Mobil Oil, Allied ICD, and Republic Steel. In addition, the application of best practicable control technology to the Donner-Hanna Coke plant (as then defined by Interim Effluent Guidance documents and by the then-pending development document for Effluent Guidelines) resulted in the following projection:

BOD_5	15.1 kg/day net (89.1 kg/day gross)
Phenols	0.335 kg/day net (0.60 kg/day gross)

All other parameters, same as "present"

The remaining eight industrial dischargers account for only 1.5 per cent of the total industrial discharge in the dredged portion of the Buffalo River. For the purposes of this waste allocation program, the volume of these eight discharges is not critically important to the results. Their relatively small volumetric flowrate also makes their utilization of the municipal sewer system a reasonable projection, which would be the equivalent (for the purposes of this analysis) of a projection of complete elimination of water-borne waste discharges into the Buffalo River. Hence, the projection is effective elimination of these discharges. In verification of this projection, it was learned that the Buffalo Sewer Authority has plans to provide a sanitary sewer on Katherine Street to accomodate Airco, Pacific Molasses, and U.S. Steel. A sanitary sewer for Kelley Island (Ganson Street) is under active development, to accomodate International Multifoods, American Malting, and Peavey.

Elimination of some of the present point discharges and waste abatement in many of the others, according to the application of best practicable control and treatment technology, resulted in the projected individual waste loads listed in Appendix E and in the total projected industrial waste load listed in Table 32.

7.5 COMPARISON OF WASTE LOADS

A cursory comparison of the various waste loads (at average summer flow) is shown below, using BOD_5 as the parameter of comparison:

	BOD_5 Load, kg/day	
	Present	Projected
Upstream Tributaries	693	393
Combined Sewer Overflows	2,152	2,152
Industrial Point Sources	4,096	1,221
Totals	6,941	3,766

On this basis of BOD_5 waste load, the combined sewer overflow constitutes 31 per cent of the present waste load, a very significant fraction. Upon realization of the projected reductions in the other waste loads, however, these combined sewer overflows would constitute 59 per cent of the total; and would thus become the predominant source of wastes into the Buffalo River.

The data above also show, with respect to BOD_5, that the application of best practicable control technology would result in very large reductions in the waste loads from the upstream tributaries (43 per cent) and from the industrial point sources (70 per cent). Despite the projection of no abatement in the near future of the combined sewer overflow wastes, the total projected BOD_5 waste loads would signify a 46 per cent reduction from the present total.

8.0 SIMULATION MODEL

The data describing the present water quality of the industrialized reach of the Buffalo River, and data describing the present waste loads into this reach, have been separately presented in prior sections of this report. The purpose of this section is to describe a simulation model that can adequately correlate these two sets of data, i.e., to calculate a set of water quality data (from empirical waste load data) that matches the set of empirical water quality data. Once such a correlation of present data is achieved, the model will be used to project future water quality from projected waste loads.

8.1 CHOICE OF MODELING APPROACHES

The simulation models in general use may be categorized into three groups: the relatively simple steady-state uniform flow stream models which are essentially computerized versions of the Streeter-Phelps analysis for the BOD-DO relationship; the models which have been created to simulate water bodies significantly different from the classical one-dimensional free-flowing stream; and the models which have been created to analyze some water quality parameters of special interest.

Many rudimentary models are being used by water quality planners of the first type, the computerized Streeter-Phelps relationships. Among those better known are STREM, developed by Hydroscience, Inc., for the Delaware River Basin Commission;[37] and DOSAG, originally developed by the FWPCA and later modified and documented by the Texas Water Development Board.[38] Some of these models have been expanded to include the diurnal photosynthetic effect upon the dissolved oxygen deficit.[39,40]

Many of the models of the first type are limited in the water quality parameters they include or are limited to the very simplest physical applications of point sources of wastes to a constant-temperature, non-dispersive, free-flowing stream. The requirements of this study dictate attention to a great many water quality parameters. Furthermore, the investigation of the hydraulics of the Buffalo River provided considerable evidence that a free-flowing (i.e., plug-flow) simulation would not be appropriate.

The second type of simulation model addresses the problems of water bodies not falling into the class of free-flowing streams. Two specific physical situations have received attention. First are the impoundment models describing lakes and reservoirs. The Water Resources

Engineers, Inc., model,[39] the Washington University model,[41] the Clemson model,[42] the MIT model[43] and the Wisconsin University model[44] fall into this category. Second are the estuary models with necessary time-variation, typified by the Texas A & M efforts,[45] the Water Resources Engineers, Inc., efforts,[39,48] the O'Connor and Thomann efforts,[46,47] the Tracor efforts,[49] the Chesapeake Bay Institute efforts,[50] the MIT efforts,[51] the Texas University efforts,[52,53] and EPA efforts.[54]

This type of simulation model appears to be applicable to the physical situation of the Buffalo River. Evidence for a well-mixed condition has been presented, both from an analysis of the hydraulics and from the longitudinal homogeneity of the water quality data, so that the lake-and-reservoir modeling approach should have some applicability. Although evidence for fluctuating flows in the Buffalo River was presented, no attempt has been made to systematically acquire time-varying water quality data (and no persuasive evidence has been uncovered to deem this necessary), so that estuary models would not add a useful dimension to this study.

The third type of simulation model is aimed at a specific pollution parameter. Thermal pollution has received significant attention,[43,55,58] as has acid mine drainage.[56,57] Clearly, this present study is too broad in scope to concentrate on such specifics, but the techniques for modeling thermal pollution could be utilized in this study.

Several types of existing models therefore would be adaptable to the needs of this program, but no single computerized model was found which had all of the desired features. Moreover, the task of abstracting portions of computerized versions of several models and then combining them for the purposes of this study appeared a formidable one. It was decided, then, to abstract the mathematical techniques of several existing models, to augment these techniques as required, and to then program the result.

Program VERWAQ was thus created as a simulation model for water quality prediction, which extends the capabilities of other models in the following ways:

(1) A stream may be treated either by a plug-flow approach (no longitudinal dispersion) or by a completely-mixed approach (complete dispersion of all constituents including heat). The same computer program is used for both; the desired approach is selected with an input key word.

(2) The model and computer program may simultaneously handle an unlimited number of water quality parameters,

both conservative and non-conservative. At present, 57 parameters can be treated, including all 27 required by the Great Lakes list of pollution parameters. Independent flexibility for listing the output is built into the program, to select and permute the parameters according to the user's interests.

(3) Thermal analysis of a stream includes the heat flux from discharges and tributaries, convection and conduction between the stream and the ambient air, and solar radiation to the stream. Two additional program options (selected by input key words) are to include or neglect heat transfer and radiation, and to include or neglect heat additions from discharges and tributaries.

(4) The reaeration coefficient is determined in each river segment in two ways: as determined by stream velocity, and as determined by wind velocity. The program selects the larger of the two coefficients for each reach.

(5) The combined sewer overflows were treated as distributed (non-point) wastes. For the plug-flow model, the Streeter-Phelps differential equations were augmented by a distributed waste model and re-integrated. Benthal oxygen demand was also treated as a distributed waste load, and was treated primarily as a function of sedimentation of combined sewer overflow solids.

(6) The model and program have been constructed so that the following features may be expeditiously added to the calculations:

a) Precipitation of slightly-soluble salts, to account for in-stream reactions among ionic constituents of different waste streams. Calculated ionic concentration products will then not exceed established solubility constants. This effort is increasingly important as various water quality criteria become more quantitatively explicit with respect to small concentrations of many chemical species.

b) Sedimentation of Suspended Solids. This effort is important to effectively simulate suspended solids and sedimented solids, and to provide a feedback for calculating benthic loads.

c) Bacteria die-off.

As the earlier discussion hinted, two independent and convincing arguments exist for a completely-mixed model; the results of an analysis of the hydraulics and the longitudinal homogeneity of water quality data.

For these reasons, a completely-mixed simulation model was to be tested. The modeling effort, however, also included the testing of a plug-flow model (as normally applied to free-flowing streams); the objective was to permit the better modeling approach to emerge on its own merits. As the succeeding discussion shows, the completely-mixed model turned out to be the better choice, thereby providing a third independent verification for the assumed hydraulic character of the Buffalo River.

In the presentation of water quality data, observations were made of transverse as well as longitudinal homogeneity, and of vertical homogeneity for conservative parameters. Distinct vertical gradients, however, were observed for temperature and dissolved oxygen. While the importance of these gradients should not be discounted, the time and budgetary constraints of this study dictated that the modeling effort should be limited to the simulation of averaged data.

The following sections describe highlights of the VERWAQ model in some mathematical detail. The first sections are devoted to some of the features of the plug-flow option which makes it unique with respect to other plug-flow simulation models. The mathematical basis for completely-mixed option is then described. Finally, the application of these models to arrive at an adequate simulation model for the Buffalo River is discussed.

8.2 FEATURES OF THE VERWAQ PLUG-FLOW MODEL

A. Thermal Analysis with Distributed Load and Heat Transfer. The steady-state balance in a river at a point-source addition of either a wastewater discharge or a tributary flow is straightforward:

$$\theta_1 = \frac{Q_o\theta_o + Q_d\theta_d}{Q_o + Q_d}$$

where Q_o = upstream river flow rate, m³/day

Q_d = discharge or tributary flow rate, m³/day

θ_o = upstream temperature, °C

θ_d = discharge or tributary temperature, °C

θ_1 = downstream temperature, °C

The steady-state heat balance around a differential segment of the river (between point-source additions), with inclusion of heat transfer and of a non-point-source (distributed) waste load, is composed of the following terms, each in Kcal/day:

$$\text{Upstream Heat Flux} = C_p\, Q_o\, (\theta_o - \theta^*)$$

$$\text{Non-Point-Source Heat Flux} = C_p(\theta_{NP} - \theta^*) \left(\frac{Q_{NP}}{R_{NP}} \right) dx$$

$$\text{Heat Transfer Heat Flux} = W(RAD + CONV)\ dx$$

$$\text{Downstream Heat Flux} = -C_p \left(Q_o + \frac{Q_{NP}}{R_{NP}} dx\right) (\theta_o - \theta^* + d\theta_o)$$

where θ^* = Reference Temperature, °C

Q_{NP} = Non-Point-Source (Distributed) total flow rate, m^3/day

R_{NP} = Longitudinal distance (reach), meters, over which Q_{NP} is evenly distributed

x = Longitudinal distance from start of river segment, meters

W = Width of river, meters

RAD = Net daily solar radiation, kcal/m^2, day

CONV = Heat transfer rate from the atmosphere to the river, kcal/m^2, day

C_p = Heat capacity for water = 10 Kcal/m^3, °C

Setting the sum of the above four terms equal to zero (for steady-state) and integrating over a longitudinal river distance X (meters) yields:

$$\theta_1 = \theta_o + \frac{X}{Q_o} \left[10^{-3} W(RAD + CONV) + \frac{Q_{NP}}{R_{NP}} (\theta_{NP} - \theta_o) \right]$$

where θ_1 = Temperature, °C, at the downstream end of X.

The heat transfer rate from the atmosphere to the river may be found by the following empirical relation:[62]

$$CONV = (93.7 + 41.9\ WIND)\ (\theta_a - \theta)$$

where WIND = wind speed, m/sec

θ_a = Air temperature, °C

θ = River temperature, °C

B. Waste Oxidation with a Distributed Load. The steady-state carbonaceous BOD balance around a differential segment of the river (between point-source additions), with inclusion of a non-point-source (distributed) waste load, is composed of the following terms, each in Kg/day of BOD (ultimate):

Upstream waste input - $C^*L_oQ_o$

Non-Point-Source waste input = $C^*L_{NP}\dfrac{Q_{NP}}{R_{NP}}\ dx$

Reaction Loss = $- C^*K_RL_oWH\ dx$

Downstream Output = $- C^*(Q_o + \dfrac{Q_{NP}}{R_{NP}}dx)\ (L_o + dL_o)$

where L_o = Upstream carbonaceous BOD concentration, mg/l

L_{NP} = Non-Point-Source carbonaceous BOD concentration, mg/l

C^* = Conversion Factor = 10^{-3} Kg-l/mg-m^3

H = Depth of river, meters

K_R = River carbonaceous BOD removal coefficient, 1/day

and where the other symbols are as previously defined.

Setting the sum of the above four terms equal to zero (for steady-state) and integrating over a longitudinal river distance X (meters) yields:

$$L_1 = L_o\ e^{\phi_R X} - \frac{L_{NP}\ Q_{NP}}{\phi_R\ Q_o X}\ (1 - e^{\phi_R X})$$

$$\phi_R = - K_R\frac{WH}{Q_o} + \frac{Q_{NP}}{Q_o X}$$

where L_1 = Carbonaceous BOD concentration, mg/l, at the downstream end of X.

Similarly, for the nitrogenous BOD,

$$N_1 = N_o\ e^{\phi_N X} - \frac{N_{NP}\ Q_{NP}}{\phi_N\ Q_o X}\ (1 - e^{\phi_N X})$$

$$\phi_N = - K_N\ \frac{WH}{Q_o} + \frac{Q_{NP}}{Q_o X}$$

where N_o = Upstream nitrogenous BOD concentration, mg/l

N_1 = Downstream nitrogenous BOD concentration, mg/l

N_{NP} = Non-point-source nitrogenous BOD concentration, mg/l

K_N = Oxidation coefficient of nitrogenous BOD, 1/day

C. Deoxygenation with a Distributed Load. The steady-state balance around a differential segment of the river (between point-source additions), with inclusion of a non-point-source (distributed) waste load, is:

$$\frac{Q_o}{WH}\frac{dD}{dx} = -K_A D + K_D L + K_N N + B$$

where D = C_s-C = oxygen deficit in the river, mg/l

C = Dissolved oxygen concentration, mg/l

C_S = Saturation limit for dissolved oxygen concentration (at temperature θ), mg/l

K_D = Oxidation coefficient of carbonaceous BOD, 1/day

K_A = Atmospheric reaeration coefficient, 1/day

B = Benthal oxygen demand, mg/l, day

and where the other symbols are as previously defined.

The reaeration coefficient, K_A, may be calculated in two ways:

(a) Based upon stream velocity for free-flowing rivers,[37,39]

$$(K_A)_1 = 86{,}400 \frac{(D_L U)^{1/2}}{H^{3/2}}$$

where D_L = molecular diffusivity of oxygen in water, 2.09×10^{-9} m^2/sec at 20°C

U = longitudinal stream velocity, m/sec

H = depth of river, meters

(b) Based upon wind velocity for reservoirs,[39]

$$(K_A)_2 = \frac{3.62}{H(4-\sqrt{WIND})}$$

where WIND = Wind velocity, m/sec.

VERWAQ calculates both $(K_A)_1$ and $(K_A)_2$, and chooses the larger value as representing the controlling mechanism for reaeration. The chosen value, K_A^{20} is then temperature-corrected according to:[37]

$$K_A = K_A^{20} \, [1.024]^{(\theta - 20)}$$

Substituting for L and N according to the results of the previous section, and integrating, yields:

$$D_1 = -\frac{C_1}{J_A}(1 - e^{J_A X}) + \frac{C_2}{J_A - \phi_R}(e^{\phi_R X} - e^{J_A X})$$

$$+ \frac{C_3}{J_A - \phi_N}(e^{\phi_N X} - e^{J_A X}) + D_o e^{J_A X}$$

where D_o and D_1 are (respectively), the upstream and downstream oxygen deficits, mg/l;

where

$$J_A = -\frac{K_A WH}{Q_o}$$

$$J_D = -\frac{K_D WH}{Q_o}$$

$$J_N = -\frac{K_N WH}{Q_o}$$

and where

$$C_1 = \frac{WH}{Q_o} + \frac{J_D Q_{NP} L_{NP}}{\phi_R Q_o X} + \frac{J_N Q_{NP} N_{NP}}{\phi_N Q_o X}$$

$$C_2 = J_D L_o + \frac{J_D Q_{NP} L_{NP}}{\phi_R Q_o X}$$

$$C_3 = J_N N_o + \frac{J_N Q_{NP} N_{NP}}{\phi_N Q_o X}$$

D. Combined Sewer Overflow Waste Loads. VERWAQ treats combined sewer overflows as a distributed waste load in the longitudinal direction. For almost all water quality parameters, this means that at any longitudinal station, the wastes associated with the incremental flow from combined sewers becomes instantaneously mixed with the river water at that station in both the transverse and vertical directions. However, three facts are independently known:

(1) A large proportion of the carbonaceous BOD exerted by combined sewer overflows is due to the volatile suspended solids in the overflows.

(2) In deep channels with relatively low linear velocities, a significant fraction of these suspended solids will settle to the bottom of the channel.

(3) Analyses of channel-bottom sediments revealed significant benthal oxygen demand.

To accommodate these facts, the carbonaceous BOD waste load from combined sewer overflows is partitioned. Some fraction W_B of this BOD waste load is exerted as a benthal oxygen demand, with the remainder $1-W_B$ exerted homogeneously in the river water.

Hence, in the analysis above, the non-point-source carbonaceous BOD concentration L_{NP} actually refers to the homogeneous fraction of the total concentration L'_{NP}:

$$L_{NP} = L'_{NP} (1-W_B)$$

The benthal oxygen demand may be calculated according to the following empirical relation:[59]

$$B = 3.14 \times 10^{-5} \frac{YZ}{H} \sqrt{T_a} \left[\frac{5 + 160 Z}{1 + 160 Z} \right]$$

where Y = grams BOD_5 per Kg of volatile matter in bottom deposits

Z = deposition rate of volatile solids, Kg/m^2, day

T_a = time, days (up to 365) for accumulation of bottom deposits

Then, since 10^{-3} YZ = Kg of BOD_5 deposited/m^2, day

$$10^{-3} YZ = \frac{10^{-3} W_B L'_{NP} Q_{NP}}{R_{NP} W}$$

and

$$B = 3.14 \times 10^{-5} \frac{W_B L'_{NP} Q_{NP}}{R_{NP} WH} \left[\frac{5 + 160\ Z}{1 + 160\ Z}\right] \sqrt{T_a}$$

E. The Special Case of Zero Non-Point-Source Waste Loads. For the case where there is zero non-point-source waste loads, $Q_{NP} = 0$, and the equations of the previous sections reduce to those of other simulation programs (i.e., the Streeter-Phelps solutions):

$$\theta_1 = \theta_o + \frac{X}{Q_o} [\ 10^{-3}\ W(RAD + CONV)\ ]$$

$$\phi_R = J_R = - \frac{K_R WH}{Q_o}$$

$$\phi_N = J_N$$

$$L_1 = L_o\ e^{J_R X}$$

$$N_1 = N_o\ e^{J_N X}$$

$$D_1 = \frac{B}{J_A} (1 - e^{J_A X}) + \frac{J_D L_o}{J_A - J_R} (e^{J_R X} - e^{J_A X}) + \frac{J_N N_o}{J_A - J_N} (e^{J_N X} - e^{J_A X}) + D_o\ e^{J_A X}$$

F. Mode of Computer Operation. In the plug-flow optional mode of VERWAQ, the computations are performed in a stepwise manner similar to other simulation models. Starting at the upstream point, the river is modeled either until a significant change in the river characteristics (i.e., W, H, or the rate coefficients) justifies their alteration; or until a point source addition (i.e., a tributary or an industrial or domestic discharge) is made. In either case, the water quality and the quantities of heat and the various constituents just upstream of the new conditions become the initial state for the next river segment.

The various rate coefficients are, of course, temperature-corrected (by conventional means) in VERWAQ.

8.3 MODEL FOR COMPLETE MIXING AND DISPERSION

In a completely-mixed body of water at steady state, the concentrations of the various parameters (and the temperature) are the same for the water leaving the body as for the body of water itself. In addition, there is no distinction by longitudinal position of the waste loads into the water body, nor is there a distinction between point sources and non-point sources.

A. The heat balance around such a completely-mixed body of water is composed of the following terms, each in Kcal/day:

Upstream and Waste Load Heat Flux = $C_p \sum Q_i (\theta_i - \theta^*)$

Heat Transfer Heat Flux = WX(RAD + CONV)

Downstream Heat Flux = $- C_p \sum Q_i (\theta_e - \theta^*)$

where the symbols are as previously defined, with the subscript i referring to the i-th source (the upstream flow, a point source, or a non-point source), and the subscript e referring to both downstream and the equilibrium in the completely-stirred body of water.

Summing the above terms and equating to zero (for steady state),

$$\theta_e = \frac{\sum Q_i \theta_i + 10^{-3}\ WX\ (RAD + CONV)}{\sum Q_i}$$

B. For each conservative parameter (i.e., where the constituent is neither generated, destroyed, or transferred to the water body's environment),

$$P_{e,j} = \frac{\sum Q_i\ P_{i,j}}{\sum Q_i}$$

where $P_{i,j}$ = concentration, mg/l, of the j-th constituent in the i-th source

$P_{e,j}$ = concentration, mg/l, of the j-th constituent in the body of water and in the downstream flow

The analysis for conservative parameters is the same whether a plug-flow model or a completely mixed model is used.

C. In the case of carbonaceous BOD,

$$\text{Upstream and Waste Load Input} = C^*\sum Q_i L_i$$
$$\text{Downstream Output} = -\ C^* L_e \sum Q_i$$
$$\text{Reaction Loss} = -\ C^*\ K_R\ L_e\ V_B$$

where V_B = volume of the body of water, m^3. Hence,

$$L_e = \frac{\sum Q_i\ L_i}{\sum Q_i + K_R V_B}$$

Similarly, for nitrogenous BOD,

$$N_e = \frac{\sum Q_i\ N_i}{\sum Q_i + K_N V_B}$$

D. The oxygen balance in the river then may be evaluated:

$$\text{Upstream and Waste Load Input} = C^*\sum Q_i C_i$$
$$\text{Downstream Output} = -\ C^* C_e \sum Q_i = -\ C^*(C_{S,e} - D_e) \sum Q_i$$
$$\text{Carbonaceous Deoxygenation Loss} = -\ C^*\sum Q_i L_i + C^* L_e \sum Q_i$$
$$\text{Nitrogenous Deoxygenation Loss} = -\ C^*\sum Q_i N_i + C^*\ N_e \sum Q_i$$
$$\text{Benthic Oxygen Demand} = -\ C^*\ B\ V_B$$
$$\text{Reaeration Input} = C^*\ K_A\ D_e\ V_B$$

Summing the above terms and equating to zero (for steady state) yields:

$$D_e = \frac{1}{\sum Q_i + K_A V_B}\ [\ BV_B + C_{S,e}\sum Q_i - \sum Q_i C_i + \sum Q_i L_i - L_e \sum Q_i + \sum Q_i N_i - N_e \sum Q_i\ ]$$

where L_e and N_e are evaluated from previously-developed relations, and where

D_e = Oxygen deficit, mg/l (both equilibrium and downstream)

$C_{S,e}$ = Saturation limit for dissolved oxygen, mg/l (at temperature θ_e)

8.4 APPLICATION OF THE PLUG-FLOW MODEL (FOR DISSOLVED OXYGEN)

The plug-flow model was applied extensively to the dredged portions of the Buffalo River, using various values and combinations of values for the constants. The "present" waste load inputs were as described in the previous section of this report, and the upstream flow was at the average summer value (70 per cent duration point).

Satisfactory simulation of the empirically-determined non-conservative water quality parameters was not achieved using the plug-flow model. A typical attempt (Run 013) is described below. For this particular attempt, a constant temperature of 26.9 °C (the empirical average temperature) was imposed upon the river.

The input constants for this attempt, all based upon independent data, estimates and rationale, are as follows:

(1) Average summertime Solar Radiation Constant, RAD = 5,500 $Kcal/m^2/day$. This value is commonly found in the literature.[8,59,60,61]

(2) Average summertime Wind Speed, WIND = 5.4 m/sec.[8]

(3) Average summertime Air Temperature, θ_a = 20.6 °C

(4) Deoxygenation and BOD removal coefficients (base e), $K_R = K_D = K_N = 0.23\ [1.040]^{(\theta - 20)}$, $days^{-1}$.[37,39,45,59,63]

(5) Benthic Oxygen Demand

From Table 30, $Y = \frac{BOD_5}{VSS} = \frac{160}{180} \times 10^3 = 589\ \frac{\text{gms } BOD_5}{\text{Kg VSS}}$.

After applying a temperature-correction factor,[37] the actual waste loads, and using T_a = 365/2, the benthic oxygen demand is

$$B = 0.3831\ W_B \left[\frac{3.037 + W_B}{0.607 + W_B}\right] [1.080]^{(\theta - 20)}\ \frac{mg}{l,day}$$

For this particular calculation W_B was arbitrarily chosen as 0.574 (the fraction of the carbonaceous BOD waste load, of the combined sewer overflow, that is exerted as a benthic oxygen demand).

$$B = 0.672 \, [1.080]^{(\theta - 20)} \, \frac{mg}{l, day}$$

This value for W_B of 0.574 is reasonable, when compared to a physically similar situation, i.e., a BOD removal efficiency in primary treatment in a sewage treatment plant.

Figure 11 shows the calculated dissolved oxygen profile for this attempt, as well as the empirical data from Tables 17 and 20. While the experimentally-determined dissolved oxygen content is uniformly low (0.0 to 1.8 mg/l) throughout this reach, the profile calculated with the plug-flow model is distinctly different. A boundary condition of the plug-flow model is a value of 7.2 mg/l at River Mile 43.1 (upstream of any significant waste load); hence, the form of the calculated profile is dictated by this boundary condition. The calculated profile of Figure 11 shows a very rapid drop in dissolved oxygen, from 7.2 mg/l at River Mile 43.1 to 0.0 mg/l at River Mile 40.4; and a value close to 0.0 mg/l from this point to the river mouth. Note, however, that the average calculated dissolved oxygen concentration in this reach, 1.4 mg/l, is not very different from the average measured value, 0.94 mg/l.

The rapid drop in the calculated dissolved oxygen is attributable to the high value of the calculated deoxygenation coefficients, 0.30 $days^{-1}$, at the river temperature of 26.9°C. Even with a high calculated value for the reaeration coefficient at this temperature, 0.38 $days^{-1}$, the waste loads are too great in comparison to the self-purification capability of this reach of the river.

Other calculation attempts with other sets of reasonable constants for the plug-flow model yielded very similar dissolved oxygen profiles, although the longitudinal point where the calculated dissolved oxygen concentration became zero varied somewhat. It was concluded, therefore, that the plug-flow simulation model is not applicable to the Buffalo River. This result confirms the prior conclusions based upon the river hydraulics and upon the empirical water quality data.

8.5 APPLICATION OF THE COMPLETELY-MIXED MODEL (FOR TEMPERATURE)

The average of measured temperatures under average summertime conditions in the dredged portion of the Buffalo River was 26.9°C

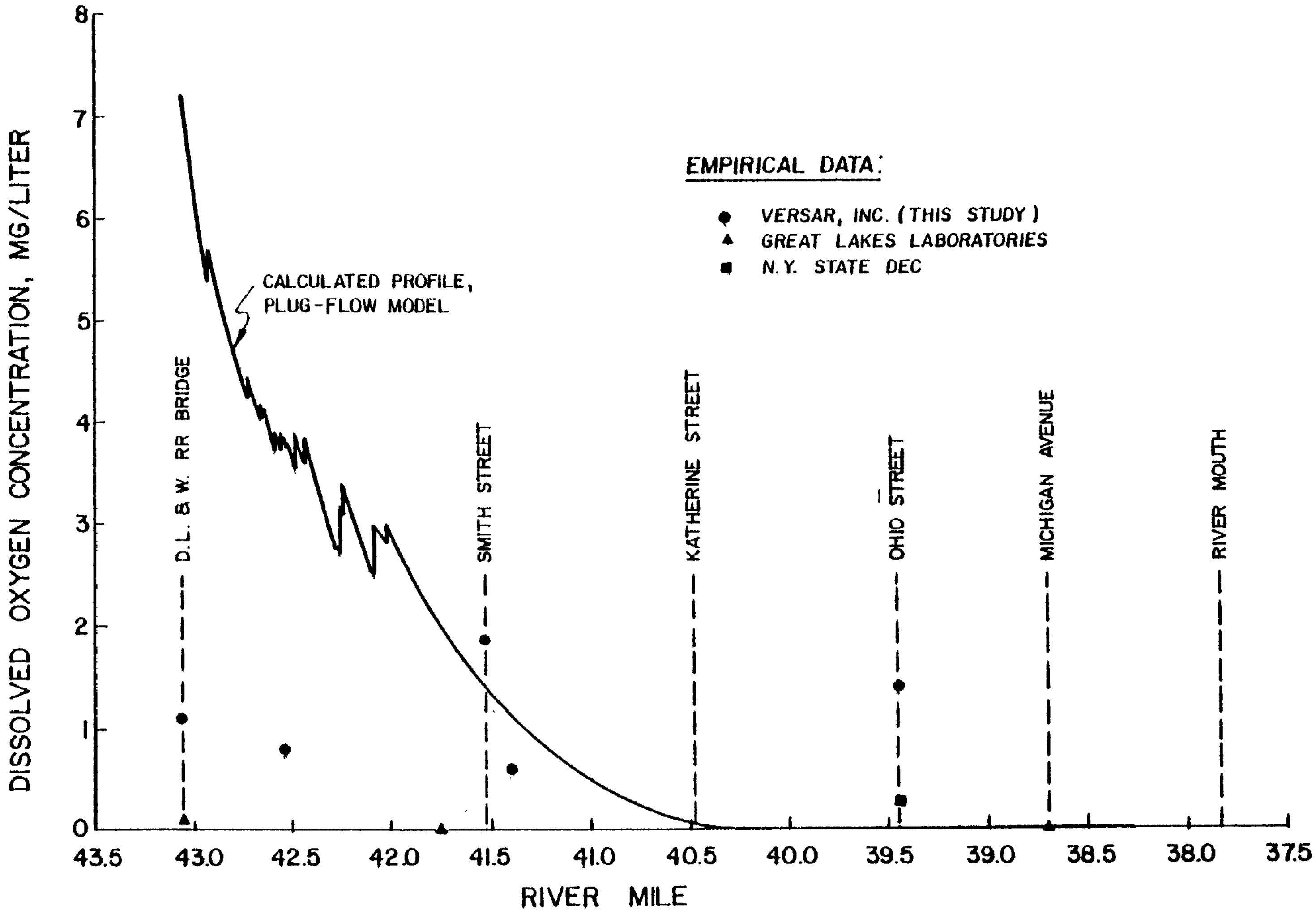


FIGURE 11

LONGITUDINAL DISSOLVED OXYGEN PROFILE

(Table 21). The heat load from hot discharges into the Buffalo River, at "present" industrial waste loads, was calculated as 4,474 x 10^6 kcal/day. The calculated heat flux due to convection (at an average wind speed of 5.4 m/sec and at an average air temperature of 20.6°C) was -1,046 x 10^6 kcal/day. For the calculated temperature to match the experimental average (using 19.0°C as an average temperature for the upstream tributaries), the solar radiation intensity must be 3,039 kcal/m^2, day instead of the value found in the literature of 5,500 kcal/m^2, day. This implies that 45 per cent of the total solar radiation is blocked (due to shadows) from impinging upon the surface of the water. A qualitative inspection of the river revealed banks, piers and industrial buildings which could be responsible for such shading.

The solar radiation constant of 3,039 kcal/m^2, day was therefore adopted, so that the calculated river temperature would be in agreement with the measured temperature.

8.6 APPLICATION FOR THE COMPLETELY-MIXED MODEL (FOR DISSOLVED OXYGEN AND FOR NON-CONSERVATIVE PARAMETERS)

The completely-mixed modeling option of VERWAQ was applied to the dredged portion of the Buffalo River, from the upstream boundary of the dredged reach at River Mile 43.06 to the Ohio Street Bridge at River Mile 39.44 (since water quality data strongly indicated that fresh lake water mixes significantly with river water downstream of this station).

Calculation Run 015 was made utilizing the completely-mixed modeling option, average summer upstream flow, "present" waste loads, and the same set of input constants that were used for Run 013 (and that were presented in the previous discussion in this report), except for the revised solar radiation constant. The results of the calculations for non-conservative species are presented below together with the averages of empirical data (from Table 23):

	No. of Data Points	Avg. of Measured Values, mg/l	Calculated Value, mg/l
Phenols	29	0.03	0.02
BOD_5	41	4.22	4.22
NH_3-N	29	0.69	0.69
Dissolved Oxygen	76	0.94	1.03

The excellent agreement between the experimentally-determined data and the values calculated using the completely-mixed model, with respect to both the equilibrium dissolved oxygen concentration and the equilibrium concentrations of oxygen-demanding species, justifies the adoption of this modeling approach and confirms the hypothesis of a well-mixed river made previously from an hydraulic analysis and from the homogeneity of measured water quality data.

8.7 VERIFICATION OF THE COMPLETELY-MIXED MODEL (FOR DISSOLVED OXYGEN)

The comparison made above justified the selection of the simulation model. In order to verify this selection, the completely-mixed model, including the same input constants, was tested under intentionally different conditions of river flow and temperature. Table 33 lists some recent measured water quality data reported by the New York State Department of Environmental Conservation[28] for the sampling station in the dredged portion of the Buffalo River at Ohio Street (River Mile 39.44). The data for Table 33 were intentionally selected to be wintertime data, and are a priori different from the summertime data presented earlier in Table 17.

Also listed in Table 33 are volumetric flow rates for the upstream tributaries, for the dates corresponding to the NYSDEC water quality measurements at Ohio Street. Flow data were available from the U. S. Geological Survey[10] only for Buffalo Creek and Cazenovia Creek; the flowrate for Cayuga Creek (and so the sum of the tributary flowrate) was estimated from the other two stream discharges, assuming the same duration point on any given day. Figure 12 was the flowrate correlation used to generate total upstream flows for Table 33. The data in Table 33 were limited to those points whose flows were less than the 20 per cent duration point (approximately 1.5 million cubic meters per day from all three tributaries) for two reasons. First, inappropriate extrapolation of the correlation of Figure 12 would have been necessary. Second, and more important, the completely-mixed hydraulic model developed for summertime conditions may no longer be appropriate at very high upstream flows (i.e., the dredged portion of the Buffalo River may act more like a free-flowing stream under these flow conditions).

The data selected for Table 33 were also limited to the four months of December, January, February, and March, when wintertime water temperatures were relatively stable (as they are in the selected summer months used for the model development). During the spring (April and May) and fall (October and November) months, the NYSDEC data for Buffalo Creek[28] indicate relatively rapid changes in the water temperature:

Month	Average Temperature, °C
October	9
November	5
December	1
January	0

Month	Average Temperature, °C
February	0
March	2
April	9
May	17
June	18
July	22
August	20
September	18

Moreover, the relatively rapid changes in upstream water temperature (and in air temperature) would be expected to result in rather steep vertical temperature gradients in the dredged portion of the Buffalo River. Since it is beyond the scope of this study to investigate such non-steady-state conditions in the spring and fall, the data of Table 33 were limited to the four cold months.

The measured data in Table 33 shows that wintertime upstream flows, as expected, are very much greater than the corresponding average summertime upstream flow of 187,200 cubic meters per day. The direct results of very high upstream flows (lower residence time for deoxygenation and greater dissolved oxygen input to the industrialized reach) and of very much lower temperatures (higher dissolved oxygen concentrations at saturation and lower deoxygenation reaction rates) may be observed in the consistently high measured dissolved oxygen concentration at Ohio Street. Even within these limited data, some effect of upstream flow may be seen from Table 33, with the lowest value of dissolved oxygen corresponding with the lowest flowrate.

The completely-stirred model developed for summertime conditions was exercised under each of the flow and temperature conditions in Table 33, and the resulting calculated dissolved oxygen concentrations are included in Table 33 and in Figure 13 for direct comparison with the measured values. While the calculated values are in general slightly lower than the measured values, reasonably good agreement exists. Furthermore, the sensitivity of the calculated dissolved oxygen to upstream flowrate is comparable to the sensitivity of the measured dissolved oxygen, as is shown in Figure 13.

This satisfactory agreement between measured and calculated wintertime data, using a completely-mixed model based upon a different hydraulic regime (i.e., upstream flowrates almost an order of magnitude lower than in wintertime), is interpreted as adequate verification of the model. After all, the intended use of the model is prediction of summertime water quality (at varying waste loads), not extrapolation of the model to different hydraulic regimes.

Table 33

Wintertime Water Quality Data

Buffalo River at Ohio Street

Date	Tributary Flow* m^3/day	Temp., °C	Dissolved Oxygen, mg/l Measured	Calculated
121768	997,000	1	12.0	9.8
010869	862,000	1	10.8	9.7
021769	535,000	3	9.2	8.5
030469	587,000	4	9.2	8.5
031769	397,000	3	7.4	7.7
121669	1,293,000	3	10.4	10.0
020970	1,271,000	4	12.0	10.0
022570	1,135,000	1	11.8	10.2
030970	1,341,000	2	12.2	10.0
022072	861,000	1	10.6	9.7

* Tributary Flow Calculated From USGS Data

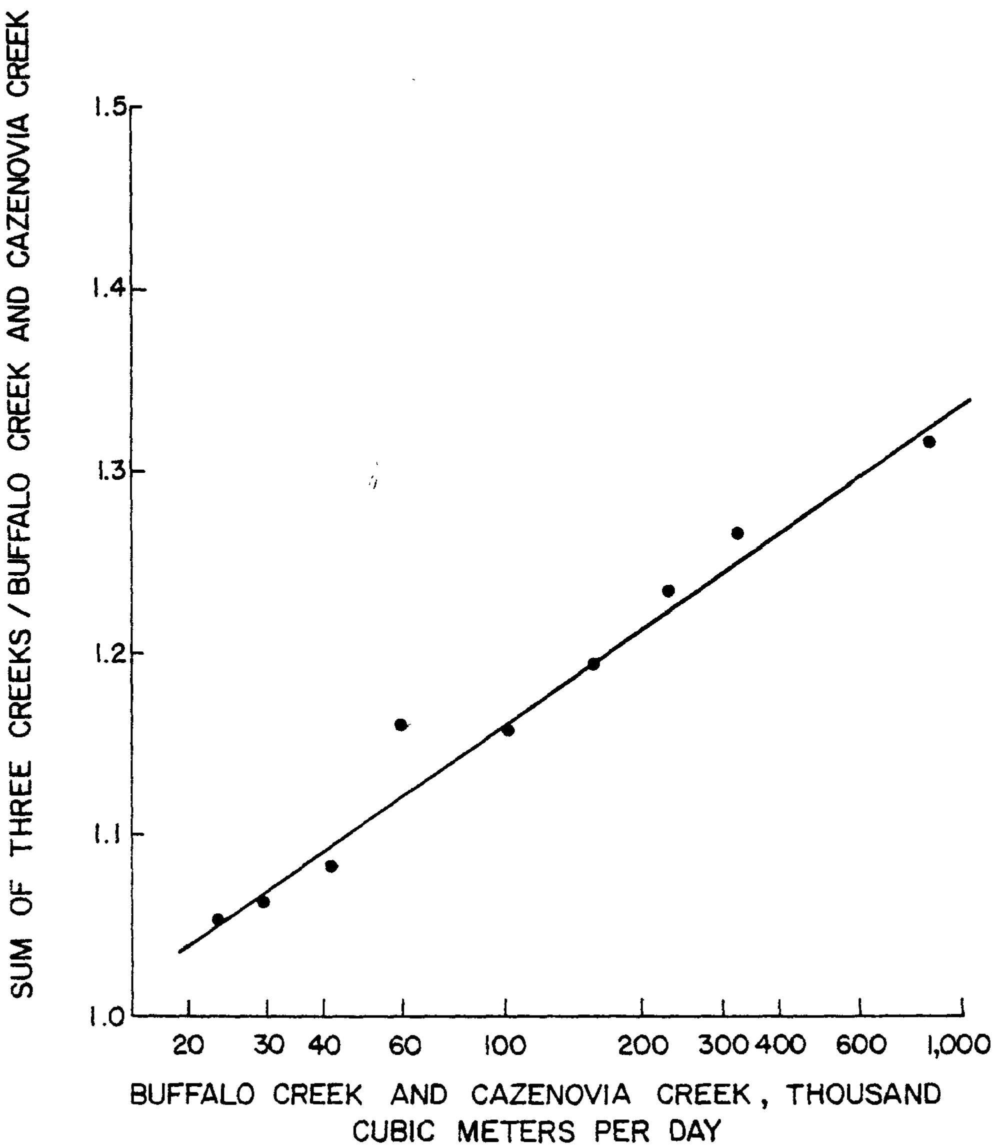


FIGURE 12

TOTAL UPSTREAM DISCHARGE
VS.
DISCHARGE OF TWO CREEKS(7)

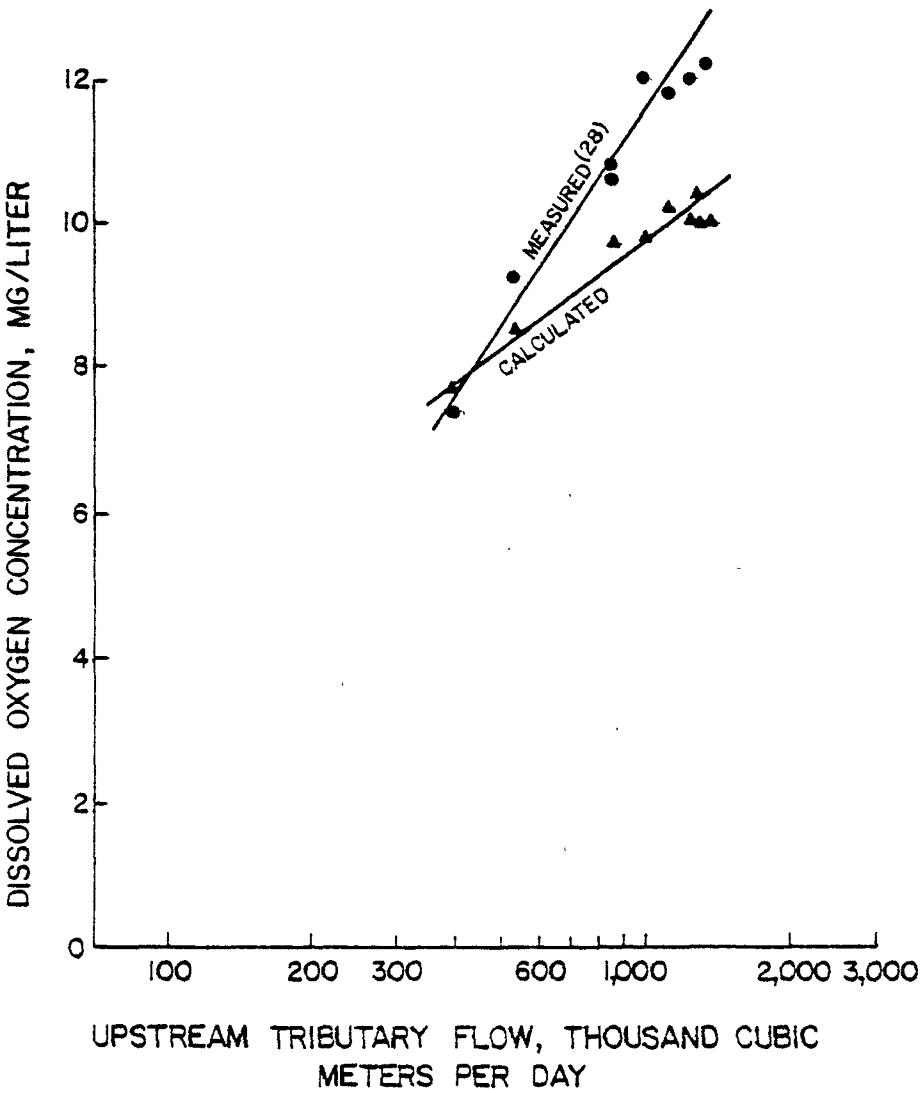


FIGURE 13

WINTERTIME DISSOLVED OXYGEN LEVELS

8.8 APPLICATION OF THE COMPLETELY-MIXED MODEL (FOR CONSERVATIVE PARAMETERS)

Equilibrium values for the concentrations of conservative species were calculated, using the completely-mixed simulation model, for the "present" waste loads and at average summertime conditions (70 per cent duration point for the flow from upstream tributaries). These data are listed in Table 34, along with the averages of comparable measured data (from Table 23).

For the great majority of the parameters, the calculated values were very close to the average of measured values and well within the measurement precision (Table 23 lists the range of the measured data). This close agreement validates the calculation procedure. The two exceptions, both cases where measured data were lower than calculated data, were for fluoride and nickel.

An effort was made to evaluate the potential for precipitation of slightly-soluble salts, whose ions may have originated from different industrial discharges. Table 35 compares some solubility products based upon the calculated concentrations of ionic species in Table 34, with actual (reference) solubility products. Apparently several species actually do exceed their solubilities, and precipitation of these species would be expected.

8.9 MODEL LIMITATIONS

Throughout this study, a number of unique characteristics were observed in the dredged portion of the Buffalo River. Significant vertical gradients in temperature, dissolved oxygen, and velocity have been discussed in previous sections of this report. Stage fluctuations and current reversals of both a periodic (due to Lake Erie seiche activity) and a random nature were also discussed. The water quality data near each end of the dredged portion (and upstream of the dredged portion) provided evidence of some longitudinal gradients in these two areas. The analysis of wintertime data (Figure 13) indicates the emerging importance of plug flow as upstream flows become higher.

All of the above observations bring attention to the limitations of the completely-mixed model in accurately simulating the water quality of the Buffalo River; by seemingly indicating the need for a multi-dimensional analysis, a time-variable analysis, and an analysis which covers the complete spectrum of upstream flows.

While the complexities of the system are fully appreciated, the guidelines for this study precluded the development of correspondingly complex water quality simulation models. The criterion applied

Table 34

Measured and Calculated Conservative Parameters

Concentrations in mg/l

	Measured Data			Calculated Data
	Max.	Min.	Average	
NO_3-N	0.59	0.0	0.13	0.42
Cyanide	0.05	0.0	0.01	0.034
P-Total	0.85	0.07	0.29	0.60
Sulfate	68	49	57	60.5
Chloride	70	46	57	51.7
Fluoride	0.69	0.44	0.53	1.14
Oil & Grease	7.2	0.1	2.6	3.89
Arsenic	0.03	0.00	0.02	0.011
Barium	0.20	0.0	0.0	0.001
Cadmium	0.00	0.00	0.00	0.004
Chromium	0.08	0.00	0.02	0.057
Copper	0.06	0.00	0.02	0.034
Iron	5.65	0.68	3.11	3.066
Lead	0.23	0.00	0.06	0.071
Mercury	0.017	0.000	0.001	0.001
Nickel	0.00	0.00	0.00	0.027
Selenium	0.004	0.001	0.003	0.000
Zinc	0.178	0.024	0.084	0.098

TABLE 35 Selected Solubility Products
(Note: E-XX means $X10^{-xx}$)

Compound	Calculated Ksp	Actual (Reference) Ksp	Precipitation
$Ca_3(PO_4)_2$	9.3 E-20	1.2 E-19	
$CaSO_4$	5.5 E-7	2.0 E-4	
$FePO_4$	7.7 E-10	1.3 E-22	*
CaF_2	5.2 E-12	3.4 E-11	
$AlPO_4$	2.2 E-10	6.3 E-19	*
AlF_3	8.5 E-18	5.3 E-4	
$Ca(OH)_2$	5.8 E-17	6.2 E-5	
$Fe(OH)_3$	1.1 E-24	1.1 E-36	*
$Al(OH)_3$	3.1 E-25	1.1 E-15	
$CaCO_3$	1.2 E-6	1.0 E-8	*
$Zn(OH)_2$	1.3 E-19	1.8 E-14	
$ZnCO_3$	2.6 E-9	2.0 E-11	*
$Zn_3(PO_4)_2$	9.3 E-28	1.0 E-32	*
$Pb(OH)_2$	2.8 E-20	1.0 E-9	
$PbCO_3$	5.8 E-10	3.3 E-14	*
$Pb_3(PO_4)_2$	1.0 E-29	1.7 E-32	*
NiF_2	2.7 E-15	2.0 E-2	
$Ni(OH)_2$	2.9 E-20	1.7 E-9	
$NiCO_3$	6.0 E-10	6.1 E-7	

to the model in this study was the adequacy of simulating the empirical water quality data under summertime low-flow conditions. Tables 17 and 20, which list the empirical summertime water quality data, in fact show no significant longitudinal water quality gradients from River Mile 43.06 to River Mile 34.44 for any of the water quality parameters including temperature, dissolved oxygen, and the metals. The application of the completely-mixed model for temperature, for dissolved oxygen, and for the metals yielded calculated concentrations very close to measured values. For these two reasons, then, it is concluded that the test of adequacy is satisfied for the completely-mixed model; and that the accuracy of model projections is reasonable within the study constraints and the level of sophistication of the modeling techniques utilized.

9.0 WATER QUALITY PROJECTIONS

The previous sections of this report describe efforts to quantify the hydraulics, the water quality, and the waste loads into the Buffalo River, and then to generate a simulation model to correlate these data. The primary purpose of this work was to create a tool for projecting the effects of waste load reductions upon water quality. These water quality projections are presented in this section of the report, along with the recommended waste load allocations needed to achieve the required water quality. Finally, this section projects the impact of the Buffalo River upon the Niagara River.

9.1 PROJECTED WASTE LOADS

In the Waste Load section of this report, both "present" and "projected" waste loads were quantified. The projections made, based upon implementation of best practical control technology for industrial discharges and upon implementation of control and treatment practices for other discharges, are summarized in Table 36 for easy reference in this section. For the waste loads from the upstream tributaries, two columns are included in Table 36. The first is at average summertime flow (equivalent to the 70 per cent duration point). The other is at the minimum average seven-day critical discharge with a recurrence interval of ten years (equivalent to the 99 per cent duration point), specified by the New York State Department of Environmental Conservation as critical flow for the purpose of determining whether or not water quality contraventions exist.

The previous section of this report outlined the development of a simulation model, which was constructed to calculate water quality in the Buffalo River from a set of hydraulic and waste load inputs. This model was then exercised, utilizing the projected waste loads of Table 36, to generate a projected water quality. The following sections document the results of these calculations.

9.2 PROJECTED WATER QUALITY (TEMPERATURE)

The heat input from hot discharges into the Buffalo River (from Table 36), is 4,441 x 10^6 kcal/day, and the heat input from solar radiation is 1,577 x 10^6 kcal/day. Assuming the same summertime values as before for wind velocity (5.4 m/sec) and air temperature (20.6°C), the heat input to the river from convection is $(166.0 \times 10^6)(20.6-\Theta)$ kcal/day, where Θ is the river water temperature. Hence, the total heat input is $(9{,}438-166.0\Theta) \times 10^6$ kcal/day.

Table 36. Projected Waste Loads Into The Buffalo River

	Upstream Tributaries			
	Avg. Summer 70% Dur.	MATCD/10 99% Dur.	Industrial	Combined Sewer Overflow
Flow, m^3/day	187,200	22,500	419,100	20,300
Heat Flux, kcal/day x 10	0	0	4,441	0
pH	8.6	8.6	--	--
Total Solids, kg/day	72,450	8,710	107,990	19,430
Dissolved Solids, kg/day	71,140	8,550	98,050	11,670
Suspended Solids, kg/day	1,310	157.5	9,937	7,755
NH_3-N, kg/day	28.8	3.38	246.4	27.0
Organic-N, kg/day	46.8	5.63	160.4	123.0
BOD-5, kg/day	393.1	47.3	1,798	2,152
Dissolved Oxygen, kg/day	1,591	191.2	2,953	189.8
NO_3-N, kg/day	131.0	15.8	70.6	41.2
Cyanide, kg/day	1.87	0.23	17.31	--
P-Total, kg/day	37.4	4.50	192.8	53.0
Sulfate, kg/day	11,230	1,350	25,480	--
Chloride, kg/day	7,488	900	19,550	--
Fluoride, kg/day	44.9	5.40	639	--
Oil & Grease, kg/day	337.0	40.5	1,061	--
Phenols, kg/day	1.59	0.19	12.15	--
Arsenic, kg/day	0	0	6.43	--
Barium, kg/day	0	0	0	--
Cadmium, kg/day	0	0	0.67	--
Chromium, kg/day	0	0	9.37	--
Copper, kg/day	1.87	0.23	16.97	--
Iron, kg/day	40.3	4.84	1246.5	--
Lead, kg/day	1.69	0.20	21.66	--
Mercury, kg/day	0	0	0.22	--
Nickel, kg/day	0	0	16.56	--
Selenium, kg/day	0.28	0.03	0	--
Zinc, kg/day	1.50	0.18	53.22	--

At a total flow of Q cubic meters per day, the heat content of the river water above the baseline temperature (i.e., upstream temperature) of 19.0°C is $(Q \times 10^3)(\Theta-19.0)$ kcal/day. Equating heat input to heat content:

1. At average summertime flow,
   $Q = 626{,}600\ m^3/day$
   $\Theta = 26.9°C$
2. At critical flow,
   $Q = 458{,}500\ m^3/day$
   $\Theta = 29.1°C$

The projected temperature at average summertime flow, 26.9°C, is the same as the measured value for present conditions, since no significant changes in heat input from industrial discharges was projected. The projected average river water temperature at critical flow, 29.1°C, is right at the maximum value of the water quality criteria (within the calculation precision) right at the maximum value previously established for the protection of fish life.

It must be recognized that the prediction is for average temperature while the standards relate to maximum temperatures. Under both flow conditions, and especially at critical flows, the actual river temperature is subject to the prevailing conditions (as opposed to average summer conditions) of solar flux, air temperature, and wind velocity. Several instances of excessive river temperatures (as compared to the criterion) were experimentally observed, and it is reasonable to expect that adverse combinations of prevailing weather conditions would result in occasional contraventions of the thermal water quality standard.

One possible regulatory posture would be the monitoring of the actual average river water temperature. In the event of excessive river temperature, each of the discharging industries could be required to either reduce their heat input proportionately or to compensate by increasing their discharge flow rate at a constant heat flux. A more usual regulatory posture is to oblige dischargers to perform these reductions year-round, which would result in compliance at the low flow proscribed by the standards.

These regulatory postures, however, are not deemed necessary as a formal recommended waste allocation. The water quality criterion for thermal pollution already contains a maximum-survival-temperature safety factor; and the MA7CD/10 criterion already accounts for extreme low-flow conditions. The application of both safety factors to the projections results in a "borderline" case, where the projected average temperature is just equal to the maximum allowable temperature. In view of the inclusion of two safety factors, a third to protect against extreme weather conditions would be unjustified. Hence, there is no fundamental contravention of the thermal water quality standard.

9.3 PROJECTED WATER QUALITY (DISSOLVED OXYGEN AND NON-CONSERVATIVE PARAMETERS)

The completely-mixed simulation model, using the same constants as in the matching of present water quality (in the previous section), was utilized to project the equilibrium concentrations of dissolved oxygen, biological oxygen demand, ammonia, and organic nitrogen consistent with the projected waste loads of Table 36. Table 37 lists the total flow rate, the overall waste load, and the resulting calculated water quality; for both the condition of average summertime upstream flow rate (Case 1) and the condition of critical upstream flow rate (Case 2). At average summertime flow (70 per cent duration), the projected dissolved oxygen concentration is 3.8 mg/l, above the minimum standard of 3.0 mg/l. This value is well above the "present" value of 1.0 mg/l, attesting to the effectiveness of reducing the waste loads from the industrial discharges and from the municipal sewage treatment plants on Cayuga Creek (i.e., the implementation of best practicable control technology currently available). The projected dissolved oxygen concentration at critical flow (99 per cent duration) is 3.1 mg/l, barely above the minimum standard, but still meeting the water quality standard.

Again, as was the case with thermal pollution, the projection just barely meets the standard. It is recognized that the projection is in terms of average concentrations, whereas the standards are for temporal and spatial minima (in the case of dissolved oxygen). The same argument applies here that applied in the thermal pollution case; i.e., that a safety factor has already been used in formulating the standard in terms of MA7CD/10, the critical low flow criterion, to ostensibly make the comparison more conservative from the viewpoint of environmental adequacy. Another safety factor to account for transient deviations from the projected average is therefore not justified. It is therefore judged that the implementation of best practicable control technology currently available would be sufficient to satisfy the dissolved oxygen water quality standard.

Table 37 lists the results of three additional calculations for hypothetical (not practicable) waste loads. Cases 3, 4, and 5 were all at critical flow conditions and have been included to show the relative potential benefits from any further reductions of waste loads.

Case 3 illustrates the effect of a hypothetical total elimination of net oxygen-demanding waste loads from the industries discharging into the Buffalo River. The "ideal" industrial discharge of Case 3 is defined as the same discharge flow rate and thermal waste as the "projected" industrial discharge, but with zero net discharge of oxygen-demanding wastes (i.e., the industrial discharge would simply be heated B.R.I.C. water). As Table 37 indicates, the predicted dissolved oxygen concentration would be 3.4 mg/l, not very much greater than the 3.1 mg/l predicted for Case 2. This is true because the best practicable control technology currently available would be quite effective from the standpoint of net oxygen-demanding waste load reduction. Also the "ideal" industrial wastes would still be sizeable on a gross basis, the B.R.I.C. intake is in the relatively polluted Outer Harbor rather than in the body of Lake Erie (see Table 21). A secondary effect should be noted: as all wastes are reduced (including those of dischargers into the Buffalo River, those industrial dischargers south of the Buffalo River at Lackawanna, and the non-industrial discharges), the Outer Harbor should become less polluted and so the B.R.I.C.

Table 37. Projected Water Quality, Non-Conservative Parameters

	Case 1	Case 2	Case 3	Case 4	Case 5
Upstream Flow, % Duration	70	99	99	99	99
Industrial Discharges	Projected	Projected	Ideal	Projected	Ideal
Combined Sewer Overflow	Projected	Projected	Projected	Absent	Absent
Total Flow, m^3/day	623,000	459,000	459,000	438,000	438,000
Total BOD_5 Waste Load, kg/day	3,770	3,420	3,160	1,270	1,000
Total Nitrogens Waste Load, kg/day	620	550	450	400	300
Calculated BOD_5, mg/l	1.89	1.73	1.52	1.02	0.81
Calculated NH_3-N, mg/l	0.22	0.21	0.18	0.19	0.61
Calculated Org-N, mg/l	0.25	0.23	0.18	0.13	0.09
Calculated D. O., mg/l	3.79	3.06	3.44	5.80	6.19

intake should become less polluted. The quantitative evaluation of this effect is beyond the scope of this present study.

Case 4 illustrates the effect of a hypothetical complete elimination of combined sewer overflows, but with the "projected" industrial and upstream waste loads. The predicted dissolved oxygen concentration is 5.8 mg/l, a substantial increase from the 3.1 mg/l of Case 2. This calculation demonstrates that upon the implementation of practicable control and treatment technology for the industrial discharges and for the Cayuga Creek sewage plants, the predominant source of oxygen-demanding wastes is the overflow from the combined sewer system. The larger potential for improvement therefore lies in reducing these overflow waste loads rather than in further reductions in other waste loads.

Case 5 is a hypothetical combination of Cases 3 and 4; i.e., the "ideal" industrial discharge of zero net oxygen-demanding wastes, plus the complete elimination of combined sewer overflows. The calculated dissolved oxygen concentration is 6.2 mg/l, not very much greater than the 5.8 mg/l value of Case 4. This comparison supports the conclusion above that the large further potential for improvement is in the realm of combined sewer overflows.

9.4 PROJECTED WATER QUALITY (CONSERVATIVE PARAMETERS)

Table 38 summarizes the predicted concentrations for the conservative parameters in the industrialized reach of the Buffalo River, derived from the completely-mixed simulation model with the "projected" waste loads of Table 36. The predicted concentrations for both average summertime flow and critical flow are compared in Table 38 against the water quality criteria (which are either explicit or implied by the fish survival criterion).

The single conservative parameter for which the predicted concentration exceeds the criterion is iron. For this metal, therefore, the reductions in waste loads associated with the implementation of best practicable control and treatment technology are inadequate. The present, "Projected", and "Idealized" sources if iron are shown in Table 39 (in kg/day, gross), where "Idealized" is equivalent to B.R.I.C. intake water.

Table 39

Sources of Iron

	Present	Projected	Idealized
Upstream	9	5	5
043 - Mobil Oil	116	116	90
482 - Allied SCD	140	91	54
419 - Allied ICD	14	46	36
326 - Republic	1,513	965	145
084 - Donner-Hanna	32	32	27
Total	1,823	1,255	357

Table 38. Projected Water Quality, Conservative Parameters

	Water Quality Criteria[a]	Projected Concentrations, mg/l	
		Avg. Summer Flow	Critical Flow
NO -N	4	0.39	0.28
Cyanide	0.1*	0.03	0.038
P-Total	25	0.45	0.55
Sulfate	500	58.6	58.6
Chloride	250	43.2	44.6
Fluoride	1.5	1.09	1.40
Oil & Grease	7	2.23	2.40
Phenols	0.2	0.010	0.013
Arsenic	1.0	0.010	0.014
Barium	5.0	0.0	0.0
Cadmium	0.3*	0.001	0.001
Chromium	0.05	0.015	0.020
Copper	0.2*	0.030	0.037
Iron	0.8	2.054	2.729
Lead	0.1	0.037	0.048
Mercury	0.006	0.000	0.000
Nickel	0.7	0.026	0.036
Selenium	2.5	0.000	0.000
Zinc	0.3*	0.087	0.116

(a) Criteria Labelled * are explicit in New York State Standards. Others are implied by "fish survival" criterion.

The total iron in the "idealized" case, 357 kg/day, is coincidentally the precise quantity required to limit the iron concentration in the Buffalo River to 0.8 mg/l. The reason is that B.R.I.C. intake water already has an iron concentration of 0.85 mg/l (compared to 0.17 mg/l in the open lake). The recommended waste allocations for iron, therefore, are the quantities listed above for the Idealized case, and are in terms of maximum gross daily discharges.

9.5 SUMMARY OF WASTE LOAD ALLOCATIONS

The following waste load allocations are recommended as a result of the analysis in this report:

(1) For all parameters except iron, the maximum daily gross discharge from each industry on the Buffalo River should be the quantities listed in Appendix E (i.e., the "projected" industrial waste loads).

(2) For iron, the maximum daily gross discharge from each industry should be the following:

043, Mobil Oil	90 kg/day	(200 lbs/day)
482, Allied SCD	54 kg/day	(120 lbs/day)
419, Allied ICD	36 kg/day	(80 lbs/day)
326, Republic Steel	145 kg/day	(320 lbs/day)
084, Donner-Hanna	27 kg/day	(60 lbs/day)
All others	0 kg/day	(0 lbs/day)

(3) There should be no dry-weather effluents from these existing municipal sewage treatment plants into Cayuga Creek:

Village of Depew
Town of Lancaster
Village of Lancaster

9.6 IMPACT UPON THE NIAGARA RIVER

Table 40 lists the mean monthly flow rate for the Niagara River during the summer months;[10] the average flow rate is 536,000,000 cubic meters per day. This huge discharge is 855 times the average summertime Buffalo River discharge of 627,000 cubic meters per day.

Table 40
Mean Monthly Flow Rates of the Niagara River in Summertime[10]
Flow Rate Data in Million Cubic Meters per Day

Year	July	August	September	3-Month Average
1968	524	509	504	509
1969	570	656	546	560
1970	531	517	517	522
1971	527	518	513	519
1972	580	567	556	568
Average	546	535	527	536

Table 21 listed the water quality at the Buffalo city water intake, which is at River Mile Ni 37.7, at the upper (southern) end of the Niagara River where Lake Erie empties into the Niagara River. The data of Table 21 were converted to daily quantities of each chemical species (using the above volumetric flow rate), which are listed in Table 41. Also listed in Table 41 are the daily quantities discharged from the Buffalo River, both for present waste load conditions and for the projected waste load conditions (at average summertime flow rates), consistent with the water quality of Tables 23, 37, and 38. Any minor discrepencies between the present and projected waste loads from the Buffalo River are because the former are empirically determined while the latter are the results of modeling.

The concentration data of Table 41 show that because of the large difference in flow rates (the Niagara discharge is three orders of magnitude greater than the Buffalo discharge in summertime), there is no significant impact of the Buffalo River upon the water quality of the Niagara River. This statement is valid for both the present and projected conditions in the Buffalo River, and is true for all parameters (thermal, non-conservative and conservative). This statement, however, does not take into account three factors for which quantitative evaluation is beyond the scope of this study:

(1) The effects of any chemical species discharged from the Buffalo River which, despite relatively small instantaneous quantities, tend to accumulate with time in the Niagara River or in Lake Ontario.

(2) The effects of any chemical species which are not only discharged from the Buffalo River but which are also discharged from other river systems tributary to the Great Lakes. While the relative quantities of such species from the Buffalo River may be small, the spatially-cumulative effect upon the Great Lakes may not be small.

(3) The effects of a Buffalo River plume hugging the Niagara River bank, prior to complete mixing. This is complicated, of course, by industrial and combined sewer discharges directly into the Niagara River and into the Black Rock Canal.

Table 41. Daily Quantities of Chemical Species, Niagara and Buffalo Rivers

Parameter	Daily Quantity			Total Daily Quantity		Concentration		
	Niagara Present	Buffalo Present	Buffalo Projected	Present	Projected	Niagara Present	Total Present	Total Projected
Flow, 10^6 mg^3/day	536	0.627	0.627	536.6	536.6	--	--	--
Temperature, °C	21.1	26.9	26.9	--	--	21.1	21.1	21.1
Heat Flux, 10^9 kcal/day	1,126	4.47	4.44	1,130	1,130	--	--	--
Dissolved Oxygen	5,630,000	589	2,375	5,630,000	5,630,000	10.5	10.5	10.5
BOD_5	480,000	2,644	1,184	480,000	480,000	0.9	0.9	0.9
NH_3-N	0	432	138	432	138	0.0	0.0	0.0
Organic-N	54,000	--	157	--	54,000	0.1	--	0.1
NO_3-N	38,000	81	243	38,000	33,000	0.07	0.07	0.07
P-Total	16,000	182	283	16,000	16,000	0.03	0.03	0.03
Sulfate	14,500,000	35,700	36,700	14,500,000	14,500,000	27	27	27
Chloride	14,500,000	35,700	27,000	14,500,000	14,500,000	27	27	27
Oil and Grease	860,000	1,629	1,398	860,000	860,000	1.6	1.6	1.6
Phenols	2,100	16.9	13.7	2,100	2,100	0.004	0.004	0.004
Cyanide	0	6.3	19.2	6.3	19.2	0.0	0.0	0.0
Fluoride	327,000	332	684	327,000	328,000	0.61	0.61	0.61
Arsenic	0	12.5	6.4	12.5	6.4	0.0	0.0	0.0
Barium	0	0	0	0	0	0.0	0.0	0.0
Cadmium	0	0	0.67	0	0.67	0.0	0.0	0.0
Chromium	5,400	12.5	9.37	5,400	5,400	0.01	0.01	0.01
Copper	9,100	12.5	18.84	9.100	9,100	0.017	0.017	0.017
Iron	91,000	1,949	1,287	93,100	92,400	0.170	0.173	0.172
Lead	5,400	37.6	23.35	5,400	5,400	0.010	0.010	0.010
Mercury	0	0.63	0.22	0.63	0.22	0.00	0.00	0.00
Nickel	5,400	0	16.56	5,400	5,400	0.01	0.01	0.01
Selenium	0	1.9	0.28	1.9	0.28	0.0	0.0	0.0
Zinc	44,500	53	54.72	44,500	44,500	0.083	0.083	0.083

Note: For Chemical Species, Quantities are in kg/day, Concentrations are in mg/liter. Heat Flux is with respect to a baseline temperature of 19.0 C.

APPENDICES

APPENDIX A, APPLICABLE N.Y.S. WATER QUALITY STANDARDS (10/20/74)

Section 701.4 CLASSES AND STANDARDS FOR FRESH SURFACE WATERS

The following items and specifications shall be the standards applicable to all New York fresh waters which are assigned the classification of AA, A, B, C, or D, in addition to the specific standards which are found in this Part under the heading of each such classification.

Quality Standards for Fresh Surface Waters

Items	Specifications
1. Turbidity	No increase except from natural sources that will cause a substantial visible contrast to natural conditions. In cases of naturally turbid waters, the contrast will be due to increased turbidity.
2. Color	None from man-made sources that will be detrimental to anticipated best usage of waters.
3. Suspended, colloidal or settleable solids.	None from sewage, industrial wastes or other wastes which will cause deposition or be deleterious for any best usage determined for the specific waters which are assigned to each class.
4. Oil and floating substances.	No residue attributable to sewage, industrial wastes or other wastes nor visible oil film nor globules of grease.
5. Taste and odor-producing substances, toxic wastes and deleterious substances.	None in amounts that will be injurious to fishlife or which in any manner shall adversely affect the flavor, color or odor thereof, or impair the waters for any best usage as determined for the specific waters which are assigned to each class.
6. Thermal discharges	(See PART 704 of this Title.)

CLASS "A"

Best Usage of waters. Source of water supply for drinking, culinary or food processing purposes and any other usages.

Conditions related to best usage of waters. The waters, if subjected to approved treatment equal to coagulation, sedimentation, filtration and disinfection, with additional treatment if necessary to reduce naturally present impurities will meet New York State Department of Health drinking water standards and will be considered safe and satisfactory for drinking water purposes.

Quality Standards for Class "A" Waters

Items	Specifications
1. Coliform	The monthly median coliform value for one hundred ml of sample shall not exceed five thousand from a minimum of five examinations and provided that not more than twenty percent of the samples shall exceed a coliform value of twenty thousand for one hundred ml of sample and the monthly geometric mean fecal coliform value for one hundred ml of sample shall not exceed two hundred (200) from a minimum of five examinations.
2. pH	Shall be between 6.5 and 8.5.
3. Total Dissolved Solids	Shall be kept as low as practicable to maintain the best usage of waters, but in no case shall it exceed 500 milligrams per liter.
4. Dissolved Oxygen	For cold waters suitable for trout spawning, the DO concentration shall not be less than 7.0 mg/l from other than natural conditions. For trout waters, the minimum daily average shall not be less than 6.0 mg/l. At no time shall the DO concentration be less than 5.0 mg/l. For non-trout waters, the minimum daily average shall not be less than 5.0 mg/l. At no time shall the DO concentration be less than 4.0 mg/l.
5. Phenolic Compounds	Shall not be greater than 0.005 milligrams per liter (Phenol).

6. Radioactivity

Items	Specifications
a. Gross Beta	Shall not exceed 1,000 picocuries per liter in the absence of Sr^{90} and alpha emitters.
b. Radium 226	Shall not exceed 3 picocuries per liter.
c. Strontium 90	Shall not exceed 10 picocuries per liter.

Note 1: Refer to note 1 under Class "AA" which is also applicable to Class "A" standards.

CLASS "B"

Best usage of waters. Primary contact recreation and any other uses except as a source of water supply for drinking, culinary or food processing purposes.

Quality Standards for Class "B" Waters

Items	Specifications
1. Coliform	The monthly median coliform value for one hundred ml of sample shall not exceed two thousand four hundred from a minimum of five examinations and provided that not more than twenty percent of the samples shall exceed a coliform value of five thousand for one hundred ml of sample and the monthly geometric mean fecal coliform value for one hundred ml of sample shall not exceed two hundred (200) from a minimum of five examinations. This standard shall be met during all periods when disinfection is practiced.
2. pH	Shall be between 6.5 and 8.5
3. Total Dissolved Solids	None at concentrations which will be detrimental to the growth and propagation of aquatic life. Waters having present levels less than 500 milligrams per liter shall be kept below this limit.

4. Dissolved Oxygen	For cold waters suitable for trout spawning, the DO concentration shall not be less than 7.0 mg/l from other than natural conditions. For trout waters, the minimum daily average shall not be less than 6.0 mg/l. At no time shall the DO concentration be less than 5.0 mg/l. For non-trout waters, the minimum daily average shall not be less than 5.0 mg/l. At no time shall the DO concentration be less than 4.0 mg/l.

Note 1: Refer to note 1 under Class "AA" which is also applicable to Class "B" standards.

CLASS "C"

Best usage of waters. Suitable for fishing and all other uses except as a source of water supply for drinking, culinary or food processing purposes and primary contact recreation.

Quality Standards for Class "C" Waters

Items	Specifications
1. Coliform	The monthly geometric mean total coliform value for one hundred ml of sample shall not exceed ten thousand and the monthly geometric mean fecal coliform value for one hundred ml of sample shall not exceed two thousand from a minimum of five examinations. This standard shall be met during all periods when disinfection is practiced.
2. pH	Shall be between 6.5 and 8.5.
3. Total Dissolved Solids	None at concentrations which will be detrimental to the growth and propagation of aquatic life. Waters having present levels less than 500 milligrams per liter shall be kept below this limit.
4. Dissolved Oxygen	For cold waters suitable for trout spawning, the DO concentration shall not be less than 7.0 mg/l from other than natural conditions. For trout waters, the minimum daily average shall not be less than 6.0 mg/l. At no time shall the DO concentration be less than 5.0 mg/l. For non-trout waters, the minimum daily average shall not be less than 5.0 mg/l. At no time shall the DO concentration be less than 4.0 mg/l.

Note 1: Refer to note 1 under Class "AA" which is also applicable to Class "C" standards.

CLASS "D"

Best usage of waters. These waters are suitable for secondary contact recreation, but due to such natural conditions as intermittency of flow, water conditions not conducive to propagation of game fishery or stream bed conditions, the waters will not support the propagation of fish.

Conditions related to best usage of waters. The waters must be suitable for fish survival.

Quality Standards for Class "D" Waters

Items	Specifications
1. pH	Shall be between 6.0 and 9.5.
2. Dissolved Oxygen	Shall not be less than 3 milligrams per liter at any time.

Note: Refer to note 1 under Class "AA" which is also applicable to Class "D" standards.

Note 1: With reference to certain toxic substances affecting fishlife, the establishment of any single numerical standard for waters of New York State would be too restrictive. There are many waters, which because of poor buffering capacity and composition will require special study to determine safe concentrations of toxic substances. However, most of the non-trout waters near industrial areas in this state will have an alkalinity of 80 milligrams per liter or above. Without considering increased or decreased toxicity from possible combinations, the following may be considered as safe stream concentrations for certain substances to comply with the above standard for this type of water. Waters of lower alkalinity must be specifically considered since the toxic effect of most pollutants will be greatly increased.

Ammonia or Ammonium Compounds	Not greater than 2.0 milligrams per liter expressed as NH_3 at pH of 8.0 or above.
Cyanide	Not greater than 0.1 milligrams per liter expressed as CN.
Ferro-or Ferricyanide	Not greater than 0.4 milligrams per liter expressed as $Fe(CN)_6$.
Copper	Not greater than 0.2 milligrams per liter expressed as Cu.
Zinc	Not greater than 0.3 milligrams per liter expressed as Zn.
Cadmium	Not greater than 0.3 milligrams per liter expressed as Cd.

Appendix B, Species Characterization of Lake Erie-Niagara River Watershed, 1928-1929

MICROPLANKTON

ISOKONTAE

Chlamydomonas
Cladophora glomerata
Closterium acerosum
Closternum aciculare
Closterium Venus
Coelastrum microporum
Cosmarium cycicum
Cosmarium reniforme
Crucigenia rectangularis
Dictyosphaerium pulchellum
Endorina elegans
Elaktothrix gelatinosa
Gonatozygon monotaenium
Kirchnierella lunaris
Kirchnierella obesa
Micractinium pusillum
Mougeotia
Nephrocytium agardhianum
Oocystis crassa
Oocystis elliptica
Oocystis Borgei
Oocystis parva
Oocystis lacustris
Oocystis solitaria
Pandorina morum
Pediastrum simplex
Pediastrum duplex
Pediastrum Boryanum
Quadrigula pfitzeri
Quadrigula Chodata
Quadrigula lacustris
Scenedesmus bijugatus
Scenedesmus quadricauda
Sphaerocystis Schroeteri
Spirogyra
Spirogyra tenuissima
Staurastrum longiradiatum
Stigeoclonium tenue
Tetraspora lacustris
Westella botryoides

MICROPLANKTON (continued)

HETEROKONTAE

Botryococcus Braunii

CHRYSOPHYCEAE

Dinobryon divergens
Dinobryon stipitatum
Mallomonas
Synura uvella

BACILLARIALES

Asterionella formosa
Cocconeis placentula
Cymatopleura solea
Diatoma elongatum
Encyonema
Fragilaria crotonensis
Fragilaria virescens
Gyrosigma attenuatum
Melosira granulata
Navicula
Nitzxchia
Stephanodiscus niagara
Surirella ovalis
Synedra
Tabellaria fenestrata
Tabellaria flocculosa

DINOPHYCEAE

Ceratium hirundinella
Peridinium

MYXOPHYCEAE

Anabaena flos-aquae
Anabaena Lemmermanni
Aphanocapsa
Aphanizomenon flos-aquae
Aphanothece
Coelosphaerium Naegelianum
Lyngbya aeruginea-caerulea
Merismopedia elegans
Microcystis aeruginosa
Nostoc

Appendix B, Species Characterization of Lake Erie-Niagara River Watershed, 1928-1929 - continued

MICROPLANKTON (continued)

PROTOZOLA
- Amoeba
- Difflugia
- Vorticella

ROTIFERA
- Anapus ovalis
- Anuraea aculeata
- Anuraea chochlearis
- Asplanchna
- Asplanchnopus multiceps
- Conochilus unicornis
- Gastropus
- Harringia eupoda
- Monostyla cornuta
- Monostyla quadridentata
- Nothoica longispina
- Ploesoma truncatum
- Ploesoma Hudsoni
- Polyarthra platyptera
- Synchaeta stylata
- Trochosphaera

AQUATIC PLANTS

EQUISETACEAE
- Equisetum limosum

TYPHACEAE
- Typha angustifolia
- Typha latifolia

SPARGANIACEAE
- Sparganium eurocarpum

NAJADACEAE
- Potamogeton amphifolius
- Potamogeton americanus
- Potamogeton angustifolius
- Potamogeton bupleuroides
- Potamogeton compressus

AQUATIC PLANTS (continued)

NAJADACEAE (continued)
- Potamogeton filiformis
- Potamogeton foliosus
- Potamogeton gramineus
- Potamogeton lucens
- Potamogeton natans
- Potamogeton pectinatus
- Potamogeton pusillus
- Potamogeton vaginatus
- Potamogeton Richardsonii
- Najasflexilis
- Zannichellia

ALISMACEAE
- Sagittaria heterophylla
- Sagittaria latifolia
- Sagittaria latifolia

HYDROCHARITACEAE
- Elodea canadensis
- Vallisneria americana

CYPERACEAE
- Scirpus americanus
- Seirpus validus
- Scirpus acutus
- Eleocharis palustris
- Eleocharis palustris

LEMNACEAE
- Lemna minor
- Spirodela polyrhiza

PONTEDERIACEAE
- Pontederia cordata
- Heteranthera dubia

JUNCACEAE
- Juncus brachycephalus

CERATOPHYLLACEAE
- Ceratophyllum demersum

Appendix B, Species Characterization of Lake Erie-Niagara River Watershed, 1928-1929 — Continued

AQUATIC PLANTS (continued)

NYMPHAECEAE
- Nymphozanthus advena

RANUNCULACEAE
- Ranunculus longirostris

HALORAGIDACEAE
- Myriophyllum exalbescens

CRUSTACEANS

COPEPODA
- Achtheres amblophitis
- Canthocamptus illinoiensis
- Canthocamptus staphylinoides
- Canthocamptus staphylinus
- Cyclops bicuspidatus
- Cyclops robustus
- Cyclops vulgaris
- Diaptomus ashlandi
- Diaptomus oregonensis
- Diaptomus sicilis
- Epischura lacustris
- Ergasilus centrarchidarum
- Eucyclops agilis
- Limnocalanus macrurus
- Macrocyclops annulicornis
- Macrocyclops signatus
- Mesocyclops obsoletus
- Paracyclops phateratus
- Platycyclops fimbriatus

CLADOCERA
- Acroperus harpae
- Alona rectangula
- Bosmina longirostris
- Bosmina longispina
- Camptocerus rectirostris

CRUSTACEANS (continued)

CLADOCERA (continued)
- Ceriodaphnia pulchella
- Ceriodaphnia reticulata
- Chydorus gibbus
- Chydorus sphaericus
- Daphnia longispina galeata
- Daphnia longispina mendotae
- Daphnia longispina typica
- Daphnia pulex
- Daphnia retrocurva
- Eurycercus lamellatus
- Holopedium gibberum
- Hyacryptus sordidus
- Hyocryptus spinifer
- Latona setifera
- Leptodora kindtii
- Leydigia quadrangularis
- Macrothrix latricornis
- Moina rectirostris
- Pleuroxus aduncus
- Pleuroxus denticulatus
- Pleuroxus striatus
- Sida crystallina
- Simocephalus serrulatus
- Simocephalus vetulus

OTHER CRUSTACEA
- Mysis relicta
- Pantoporeia hoyi

FISHES

PETROMYZONIDAE
- Ichthyomyzon concolor
- Ichthyomyzon unicolor
- Petromyzon marinus Linnacus
- Entosphenus appendix

Appendix B, Species Characterization of Lake Erie-Niagara River Watershed, 1928-1929 — Continued

FISHES (continued)

POLYODONTIDAE
- Polyodon spatula

ACIPENSERIDAE
- Acipenser fulvescens

CYPRINIDAE
- Cyprinus carpio
- Carassium auratus
- Nocomis biguttatus
- Nocomis micropogon
- Erimystax dissimilis
- Erinemus storerianus
- Erinemus hyalinus
- Rhinichthys atronasus lunatus
- Rhinichthys cataractae
- Semotilus atromaculatus atromaculatus
- Margariscus margarita
- Clinostomus elongatus
- Opsopoeodus emiliae
- Notropis heteradon
- Notropis heterolepis
- Notropis volucellus volucellus
- Notropis deliciosus stramineus
- Notropis dorsalis
- Notropis hudsonius
- Notropis whipplii spilopterus
- Notropis atherinoides Rafinesque
- Notropis rubrifrons
- Notropis corntus chrysocephalus
- Notropis cornutus frontalis
- Notropis umbratilis syanocephalus
- Notemigonus crysoleucas crysoleucas
- Hybognathus hankinsoni
- Chrosomus erythrogaster
- Hyborhynchus notatus
- Pimephales promelas promelas
- Campostama anomalum

FISHES (continued)

AMEIURIDAE
- Ictalurus punctatus
- Villarius lacustris
- Ameiurus melas
- Ameiurus nebulosus
- Ameiurus natalis
- Leptops olivaris
- Naturus flavus
- Schilbeodes gyrinus
- Schilbeodes miurus

LEPISOSTEIDAE
- Lepisosteus platostomus
- Lepisosteus osseus

AMIIDAE
- Amia calva

HIODONTIDAE
- Hiodon tergisus

CLUPEIDAE
- Pomolobus chrysochlorus
- Pomolobus pseudo-harengus
- Dorosoma cepedianum

COREGONIDAE
- Leucichthys artedi artedi
- Leucichthys artedi albus
- Coregonus clupeaformis

SALMONIDAE
- Salmo fario
- Salmo irideus
- Salmo irideus shasta
- Cristivomer namayeush namayeush
- Salvelinus fontinalis fontinalis

Appendix B, Species Characterization of Lake Erie-Niagara River Watershed, 1928-1929 - Continued

FISHES (continued)

CATOSTOMIDAE
- Megastomatobus cyprinella
- Carpiodes cyprinus
- Catostomus commersonnii
- Catostomus catostomus
- Hypentelium nigricans
- Erimyzon sucetta
- Minytrema melanops
- Moxostoma aureolum
- Moxostoma anisurum
- Moxostoma lesueurii
- Moxostroma duquesnii
- Placopharynx carinafus

UMBRIDAE
- Umbra limi

ESOCIDAE
- Esox americanus
- Esox niger
- Esox lucious
- Esox masquinongy

ANGUILLIDAE
- Anguilla rostrata

CYPRINODONTIDAE
- Fundulus diaphanus menona

PERCOPSIDAE
- Percopsis omiscomaycus

APHREDODERIDAE
- Aphredoderus sayanus

SERRANIDAE
- Lepibema chrysops

FISHES (continued)

PERCIDAE
- Perca flavesccus
- Stizostedion canadense griseum
- Stizostedion glasusum
- Hadropterus maculastus
- Percina caprodes zebra
- Rheocrypta copelandi
- Imostoma shumardi
- Ammocrypta pellucida
- Boleosoma nigrum nigrum
- Poecilichthys coeruleus coeruleus
- Poecilichthys exilis
- Catonotus flabellaris
- Etheostroma belennioides

CENTRARCHIDAE
- Micropterus dolomieu
- Aplites salmoides
- Chaenobryttus gulosus
- Helioperca incisor
- Xenotis megalotis
- Eupomotis gibbosus
- Ambloplites rupestris
- Pomaxis annularis
- Pomaxis sparoides

ATHERINIDAE
- Labidesthes sicculus

SCIAENIDAE
- Aplodinotus grunniens

COTTIDAE
- Triglopsis thompsonii
- Cottus bairdii bairdii
- Cottus bairdii kumlieni
- Cottus cognatus
- Cottus ricei

FISHES (continued)

GASTEROSTEIDAE

Eucalia inconstans
Gasterosteus aculeatus

GADIDAE

Lota maculosa

APPENDIX C - WATER QUALITY DATA, INDIVIDUAL MEASUREMENTS

Sample No.	112	113	114	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216
Date (1973)	822	822	822	827	827	827	827	827	827	827	827	827	827	827	827	827	827	829	829
Station No.	11	11	11	6	6	6	6	6	6	10	10	10	10	15	15	15	15	22	21
Depth, m.	0	3.0	6.1	1.5	1.5	3.0	4.6	6.1	1.5	1.5	1.5	4.6	1.5	1.5	1.5	4.6	1.5	0	1.5
X-Channel Pos.	M	M	M	N	M	M	M	M	S	N	M	M	S	N	M	M	S	M	M
Temp, °C	28.0	26.5	23.0	25.2	25.0	25.0	25.0	25.0	25.0	26.7	26.3	26.6	26.5	28.8	28.2	27.5	28.2	25.5	27.5
D.O., mg/l	4,0	0.5	0.8	0.8	0.9	0.9	0.9	0.9	1.1	0.4	0.4	0.2	0.4	0.7	0.6	0.2	0.8	1.9	1.2
Sp.Cond, µm/cm				450	440	460	450	450	450	490	520	490	460	520	450	460	430	630	500
pH																			
TSS, mg/l																			
TDS, mg/l																			
Chloride, mg/l																			
Fluoride, mg/l																			
Sulfate, mg/l																			
PO_4, mg/l																			
NH_3-N, mg/l																			
NO_3-N, mg/l																			
Oil&Grease, mg/l																			
Cyanide, µg/l																			
Phenols, µg/l																			
Se, µg/l																			
As, µg/l																			
Ba, µg/l																			
Cd, µg/l																			
Cr, µg/l																			
Cu, µg/l																			
Fe, µg/l																			
Hg, µg/l																			
Ni, µg/l																			
Pb, µg/l																			
Zn, µg/l																			

Appendix C (cont.)

Sample No.	217	218	219	220	221	222	223	224	225	226	301	302	303	304	305	306	307	308	309
Date (1973)	829	829	829	829	829	829	829	829	829	829	905	905	905	905	905	905	905	905	905
Station No.	15	15	15	15	15	15	10	10	10	10	22	22	15	15	15	15	15	15	15
Depth, m.	1.5	4.6	1.5	4.6	1.5	4.6	1.5	1.5	4.6	1.5	0	0	1.5	4.6	1.5	3.0	4.6	1.5	4.6
X-Channel Pos.	N	N	M	M	S	S	N	M	M	S	N	S	N	N	M	M	M	S	S
Temp, °C	29.8	28.2	29.2	28.0	29.8	27.9	29.4	29.2	28.0	28.8	26.8	27.0	31.0	29.0	30.8	30.0	29.0	31.0	29.6
D.O., mg/l	1.3	0.4	1.0	0.4	1.2	0.4	1.3	1.2	0.3	0.9	2.8	2.7	0.6	0.1	0.4	0.1	0.1	0.4	0.1
Sp.Cond, μm/cm	450	460	460	440	430	420	440	440	460	460	630	450	390	470	500	470	480	460	490
pH																			
TSS, mg/l																			
TDS, mg/l																			
Chloride, mg/l																			
Fluoride, mg/l																			
Sulfate, mg/l																			
PO_4, mg/l																			
NH_3-N, mg/l																			
NO_3-N, mg/l																			
Oil&Grease, mg/l																			
Cyanide, μg/l																			
Phenols, μg/l																			
Se, μg/l																			
As, μg/l																			
Ba, μg/l																			
Cd, μg/l											L16	L16			L16				
Cr, μg/l											L80	L80			L80				
Cu, μg/l																			
Fe, μg/l											970	970			970				
Hg, μg/l											L0.1	L0.1			L0.1				
Ni, μg/l																			
Pb, μg/l											230	230			230				
Zn, μg/l																			

Appendix C (cont.)

Sample No.	310	311	312	313	314	315	316	317	318	319	320	321	322	401	402	403	404	405	406
Date (1973)	905	905	905	905	905	905	905	905	905	905	905	905	905	910	910	910	910	910	910
Station No.	10	10	10	10	10	10	6	6	6	6	6	6	6	20	20	20	20	20	24
Depth, m.	1.5	1.5	3.0	4.6	6.1	1.5	1.5	4.6	1.5	3.0	4.6	1.5	4.6	0	0	1.5	3.0	1.5	1.5
X-Channel Pos.	N	M	M	M	M	S	N	N	M	M	M	S	S	N	M	M	M	S	N
Temp, °C	31.2	31.0	29.9	28.0	27.2	30.4	28.4	27.8	28.2	27.7	27.2	28.2	27.8	26.9	27.0	26.3	23.8	25.3	26.2
D.O., mg/l	0.8	1.1	0.1	0.0	0.1	0.8	2.7	1.9	2.5	2.3	2.1	1.9	1.5	1.0	1.0	0.7	0.4	0.5	0.4
Sp.Cond, μm/cm	490	520	470	450	490	500	480	480	420	470	380	480	420		450	430	400		
pH															7.3	7.0	6.9		
TSS, mg/l																			
TDS, mg/l																			
Chloride, mg/l																			
Fluoride, mg/l																			
Sulfate, mg/l																			
PO_4, mg/l																			
NH_3-N, mg/l																			
NO_3-N, mg/l																			
Oil&Grease, mg/l																			
Cyanide, μg/l																			
Phenols, μg/l																			
Se, μg/l																			
As, μg/l																			
Ba, μg/l																			
Cd, μg/l		L16							L16										
Cr, μg/l		L80							L80										
Cu, μg/l																			
Fe, μg/l		970							620										
Hg, μg/l		L0.1							L0.1										
Ni, μg/l																			
Pb, μg/l		230							230										
Zn, μg/l																			

Appendix C (cont.)

Sample No.	407	408	409	410	411	412A	412B	412C	412D	412E	412F	412G	412H	412I	412J	412K	412L	413	414
Date (1973)	910	910	910	910	910	910	910	910	910	910	910	910	910	910	910	910	910	910	910
Station No.	24	24	24	24	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
Depth, m.	0	1.5	3.0	1.5	1.5	0	0.6	1.2	1.8	2.4	3.0	3.7	4.3	4.9	5.5	6.1	6.7	1.5	4.6
X-Channel Pos.	M	M	M	S	N	M	M	M	M	M	M	M	M	M	M	M	M	M	M
Temp, °C	27.2	26.5	23.6	26.5	27.9	28.3	28.3	28.2	28.2	28.0	27.7	27.2	26.8	26.5	26.2	26.0	25.7		
D.O., mg/l	1.2	0.3	0.3	0.3	0.9	2.0	1.5	1.3	1.0	0.6	0.5	0.2	0.1	0.1	0.2	0.1	0.1		
Sp.Cond, μm/cm	390	420	420		470	400												420	390
pH	6.9	6.9	7.0		7.0	7.0												7.0	7.0
TSS, mg/l																			
TDS, mg/l																			
Chloride, mg/l																			
Fluoride, mg/l																			
Sulfate, mg/l																			
PO_4, mg/l																			
NH_3-N, mg/l																			
NO_3-N, mg/l																			
Oil&Grease, mg/l																			
Cyanide, μg/l																			
Phenols, μg/l																			
Se, μg/l																			
As, μg/l																			
Ba, μg/l																			
Cd, μg/l																			
Cr, μg/l																			
Cu, μg/l																			
Fe, μg/l																			
Hg, μg/l																			
Ni, μg/l																			
Pb, μg/l																			
Zn, μg/l																			

Appendix C (cont.)

Sample No.	415	416	417	418	419	501	502	503	504	505	506	507	508	509	510	601	602	603	604
Date (1973)	910	912	912	912	912	918	918	918	918	918	920	920	920	920	920	925	925	925	925
Station No.	15	19	15	10	6	22	19	15	10	6	22	19	15	10	6	22	19	15	10
Depth, m.	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
X-Channel Pos.	S	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
Temp, °C	27.6	26.2	26.0	25.0	23.9						14.0	24.0	24.2	22.5	21.5	15.2	23.8	24.8	23.8
D.O., mg/l	1.0	0.9	1.1	0.3	1.4						0.4	0.1	0.1	0.1	0.8	9.75	2.00	3.75	1.50
Sp.Cond, µm/cm	410																		
pH	7.0										7.35	7.35	7.21	7.36	7.27	7.42	7.35	7.38	7.38
TSS, mg/l		8.0	14.0	21	20	9	2	4	3	5	66	22	11	59	63	19	2	8	9
TDS, mg/l		265	271	295	286	385	260	255	285	268	475	247	251	262	270	356	246	238	320
Chloride, mg/l		54	55	62	61	85	65	65	70	62	122	62.5	62	69	66	47.2	49.7	51.2	63.8
Fluoride, mg/l		0.36	0.42	0.52	0.46	0.68	0.28	0.28	0.50	0.58	0.64	0.33	0.38	0.50	0.59	0.30	0.21	0.32	0.55
Sulfate, mg/l		60	60	57	48	56	51	51	60	58	71	55	58	57	59	54	49	54	60
PO_4, mg/l		0.04	0.07	0.15	0.12	5.6	0.15	0.17	0.13	0.07	0.92	0.13		0.19	0.15	0.86	0.16	0.14	0.18
NH_3-N, mg/l		0.42	0.42	0.84	0.70	10.36	0.14	0.28	0.42	0.70	9.24	0.42	0.42	0.56	0.84	4.48	0.56	0.56	1.12
NO_3-N, mg/l																0.10	0.30	L0.10	0.20
Oil&Grease, mg/l		3.4	2.9	1.4	0.7	3.3	3.0	2.2	7.2	3.7	0.5	0.9	1.2	3.3	2.5	3.8	4.5	3.6	3.3
Cyanide, µg/l		L26	L26	L26	L26	L26	L26	L26	L26	L26	L26	L26	L26	L26	L26	L26	L26	L26	L26
Phenols, µg/l		8	12	12	10	11	22	21	8	12	16	38	23	14	10	13	18	13	9
Se, µg/l		2	2	4	3	4	2	3	3	4	4	1	1	4	4				
As, µg/l																			
Ba, µg/l																			
Cd, µg/l																			
Cr, µg/l						10	10	L10	10	L10						L10	60	L10	10
Cu, µg/l						10	20	30	90	20						10	L10	40	20
Fe, µg/l						1240	880	860	1220	680						920	760	1310	1450
Hg, µg/l						L1	L1	L1	L1	L1						L1	L1	L1	L1
Ni, µg/l																			
Pb, µg/l						20	20	L20	L20	L20						L20	20	L20	60
Zn, µg/l						45	31	27	45	24						28	43	42	36

Sample No.	605	606	607	608	609	610	701	702	703	704	705	706	707	708	801	802	803	1001	1002
Date (1973)	925	927	927	927	927	927	1002	1002	1002	1002	1002	1004	1004	1004	1011	1011	1011	1025	1025
Station No.	6	22	19	15	10	6	22	19	15	10	6	26	23	25	26	23	25	1	4
Depth, m.	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	0	0	0	0	0	0	1.5	1.5
X-Channel Pos.	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	-	M
Temp, °C	22.0	17.0	25.3	25.4	23.8	21.7	16.2	24.8	25.5	24.0	21.9	18.7	9.9	22.2	16.2	16.4	20.9		
D.O., mg/l	0.50	3.0	1.2	1.7	1.0	1.0						0.2	6.4	8.4	0.6	8.5	8.5		
Sp.Cond, µm/cm																			
pH	7.22	7.52	7.46	7.53	7.41	7.43						7.52	8.31	8.72	7.52	8.39	9.27		
TSS, mg/l	16	4	19	18	44	15	24	5	10	67	20	63	11	9	12	5	1	0	19
TDS, mg/l	359	433	259	260	337	235	325	220	272	272	261	297	264	563	336	256	506	120	193
Chloride, mg/l	60.2	90.4	50.2	60.7	57.7	59.7	58	54	59	58	52	46	23	50	47	21	64	25	47
Fluoride, mg/l	0.48	0.42	0.20	0.22	0.44	0.44	0.45	0.39	0.48	0.76	0.69	0.71	0.24	0.27	0.56	0.26	0.30	0.11	0.34
Sulfate, mg/l	54	60	52	52	54	56	65	59	68	57	56	46	47	74	60	60	74	29	47
PO_4, mg/l	0.34						0.95	0.37	0.28	0.59	0.28	2.66	0.12	0.23	1.98	0.34	0.42	0.97	0.37
NH_3-N, mg/l	0.98	6.16	0.84	0.56	0.98	0.84						4.2	L0.14	L0.14	4.7	L0.14	L0.14	L0.14	0.70
NO_3-N, mg/l	L0.10	0.09	0.10	0.59	0.28	0.20						0.05	0.13	0.03	0.16	0.13	0.11	0.08	0.04
Oil&Grease, mg/l	3.2	0.9	0.2	0.5	1.2	0.2						8.0	2.4	1.6	4.0	1.8	1.4	2.5	2.5
Cyanide, µg/l	L26	L26	L26	L26	L26	L26						73	L26	L26	31	L26	L26	L26	L26
Phenols, µg/l	12	13	266	74	15	L4						52	7	8	22	8	11	6	8
Se, µg/l												16	1	2	8	1	1	1	2
As, µg/l																		10	20
Ba, µg/l																		100	L50
Cd, µg/l																		L20	L20
Cr, µg/l	10						10	10	20	20	L10	L10	L10	L10	10	L10	L10	L10	10
Cu, µg/l	L10						20	20	20	60	L10	20	L10	10	50	L10	L10	L10	20
Fe, µg/l	1660						1340	900	1260	5650	2000	990	480	170	980	290	190	350	1800
Hg, µg/l	L1						L1	L1	L1	L1	L1	L1	L1	L1	L1	L1	L1	L1	25
Ni, µg/l																		L20	L20
Pb, µg/l	L20						L20	20	30	80	L20	L20	L20	20	30	20	L20	L20	20
Zn, µg/l	22						74	51	40	178	41	4	13	4	67	7	8	2	31

Appendix C (cont.)

Sample No.	1003	1004	1005	1006	1007	1008	1009	1010	1011	1012
Date (1973)	1025	1025	1025	1025	1025	1025	1025	1025	1025	1025
Station No.	3	7	8	9	12	13	14	17	16	18
Depth, m.	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
X-Channel Pos.	M	M	M	M	M	M	M	M	M	M
Temp, °C										
D.O., mg/l										
Sp.Cond, µm/cm										
pH										
TSS, mg/l	10	50	54	45	78	41	28	15	17	12
TDS, mg/l	195	231	288	270	248	260	265	254	255	248
Chloride, mg/l	46	56	52	55	50	46	48	46	46	51
Fluoride, mg/l	0.32	0.46	0.48	0.47	0.53	0.53	0.35	0.25	0.25	0.24
Sulfate, mg/l	48	60	60	60	58	58	62	60	60	61
PO_4, mg/l	0.29	0.52	0.78	0.67	0.85	0.44	0.31	0.22	0.32	0.24
NH_3-N, mg/l	0.42	1.26	1.26	0.98	1.12	0.84	0.70	0.28	0.42	0.42
NO_3-N, mg/l	0.04	0.06	0.06	0.05	0.08	0.11	0.09	0.04	0.02	0.02
Oil&Grease, mg/l	1.4	2.1	0.7	0.1	2.7	2.8	5.4	3.2	3.5	5.3
Cyanide, µg/l	L26	L26	46	52	46	33	L26	L26	L26	33
Phenols, µg/l	13	16	11	7	28	29	22	18	18	34
Se, µg/l	2	1	1	1	3	2	2	2	2	2
As, µg/l	20	30	30	20	20	30	20	10	10	10
Ba, µg/l	L50	200	L50	L50	L50	L50	L50	L50	L50	L50
Cd, µg/l	L20	L20	L20	L20	L20	L20	L20	L20	L20	L20
Cr, µg/l	L10	30	30	30	80	80	70	20	30	20
Cu, µg/l	10	30	30	30	50	40	50	30	20	20
Fe, µg/l	1100	4100	4050	3450	5310	3650	2900	1480	1640	1600
Hg, µg/l	24	L1	10	L1	L1	L1	L1	L1	17	L1
Ni, µg/l	20	L20	L20	L20	L20	L20	L20	L20	L20	L20
Pb, µg/l	L20	30	20	20	100	50	90	L20	20	L20
Zn, µg/l	27	80	81	76	156	106	69	41	39	41

APPENDIX D, PRESENT INDUSTRIAL WASTE LOADS

Discharge I.D.	04301	48211	41901	41902	41903	41904	48210	48209
FLOW RATE	105480	17979	15897	7570	14005	5299	16276	7
HEAT FLUX	1928834	37755	112868	40877	53218	31793	74869	30
ALKALIN	7525.	3955.	1335.	499.6	1260.	476.9	0.0	0.9841
ACIDITY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T-HARD	0.1070E 05	0.0	2083.	984.1	1821.	688.9	0.0	0.0
T-SOLIDS	0.2575E 05	3596.	3911.	0.2362E 05	3193.	1240.	6755.	2.332
TDS	0.2427E 05	3200.	3720.	0.2332E 05	3081.	1145.	5973.	1.915
TSS	1378.	35.96	190.8	30.28	112.0	95.38	32.55	0.1514
NH3-N	63.59	0.3596	22.26	10.60	26.01	4.239	195.3	0.1514E-03
ORG-N	42.39	0.0	4.769	2.271	4.201	1.590	0.0	0.7570E-03
BOD-5	635.9	719.2	30.20	11.35	50.42	2.649	48.83	0.6283
ULT-OD	1431.	1080.	166.9	74.94	220.6	30.20	952.1	0.9466
DIS-OXY	656.2	145.2	117.4	57.71	109.8	39.97	125.8	0.5914E-01
NO3-N	8.478	1.978	2.385	1.135	2.801	1.325	3.581	0.3785E-02
CYANIDE	2.120	1.798	0.3179	0.1514	0.2801	0.1590	1.628	0.7570E-03
P-TOTAL	52.99	0.5394	0.1590	0.3028	2.101	0.1060	4.069	0.1514E-03
SULFATE	0.1166E 05	467.5	715.4	302.8	616.2	196.1	1432.	0.3558
SULFIDE	0.0	17.98	6.359	3.028	5.602	2.120	16.28	0.7570E-02
SULFITE	635.9	0.0	15.90	7.570	0.0	0.0	0.0	0.0
CHLORIDE	5193.	1043.	476.9	234.7	406.1	164.3	195.3	0.3785
FLUORIDE	498.1	2.697	3.179	1.514	4.201	1.060	4.883	0.6207E-02
OIL+GR	296.7	62.93	0.0	0.0	655.4	0.0	50.46	0.0
PHENOLS	7.948	0.8989E-01	0.6359E-01	0.7570E-01	0.5602E-01	0.2120E-01	0.3906	0.0
SURFACT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AL	2.120	0.0	20.67	9.841	18.21	6.889	0.0	0.6056E-03
SB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AS	3.179	0.1798	0.1590	0.7570E-01	0.0	0.5299E-01	0.1628	0.0
BA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CD	0.1060	0.1798E-01	0.6359	0.3028	0.5602	0.4239	0.6510E-01	0.7570E-05
CA	3497.	575.3	540.5	295.2	567.2	212.0	122.1	0.5677
CR	21.20	0.8989E-01	2.385	1.135	2.101	0.7948	0.5371	0.1514E-04
CO	0.0	0.0	0.0	0.0	2.801	0.0	0.0	0.1514E-03
CU	6.253	0.1978	0.0	0.0	1.400	0.0	0.2116	0.6056E-04
FE	115.5	6.832	5.087	1.968	5.182	1.696	21.16	0.6434E-03
PB	3.709	0.3236	7.948	3.785	7.002	2.649	0.6510	0.1514E-03
MG	0.0	0.0	0.0	0.0	123.2	0.0	0.0	0.7570E-01
MN	0.0	0.6832	0.0	0.0	1.400	0.0	0.8464	0.1135E-03
HG	0.0	0.1079E-01	0.5564E-01	0.2649E-01	0.4902E-01	0.1855E-01	0.1790E-01	0.1514E-05
MO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NI	5.299	0.0	0.0	0.0	0.0	0.0	0.0	0.0
K	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NA	1166.	341.6	190.8	90.84	140.0	60.94	309.2	0.9841E-01
SE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SN	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TI	0.0	0.0	31.79	15.14	0.0	10.60	0.0	0.2271E-03
V	30.73	0.3236	0.4769	0.3028	0.4201	0.1590	0.0	0.2120E-03

NOTES: Flow Rate, cubic meters per day
Heat Flux, kkg-cal per day
Chemical Wastes, kg per day

APPENDIX D, PRESENT INDUSTRIAL WASTE LOADS (CONTINUED)

Discharge I.D.	48208	32601	48207	48206	48205	48204	48203	32604
FLOW RATE	94	32930	4542	28388	1893	75	208	59046
HEAT FLUX	6451	95496	14534	113551	9275	666	728	779406
ALKALIN	10.22	1548.	6604.	7125.	1615.	9.084	24.57	5019.
ACIDITY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T-HARD	0.0	4643.	0.0	0.0	0.0	0.0	0.0	7735.
T-SOLIDS	66.79	8825.	8121.	0.1022E 05	6364.	39.97	74.95	0.1281E 05
TDS	66.50	5697.	8130.	1374.	6294.	38.08	73.08	0.1021E 05
TSS	0.2838	0.1778E 05	345.2	397.4	49.22	2.195	4.580	644.5
NH3-N	0.1324E-01	1.976	235.3	32.93	8.329	0.1514	1.686	5.905
ORG-N	0.0	9.220	0.0	22.71	15.33	0.0	0.0	27.75
BOD-5	0.9460E-01	88.91	454.2	369.0	227.2	9.084	34.98	89.75
ULT-OD	0.2015	183.7	1740.	893.9	447.2	14.31	60.06	286.1
DIS-OXY	0.1601	262.2	35.97	231.8	14.56	0.5416	1.641	392.2
NO3-N	0.4730E-02	2.305	0.4542	5.678	0.1136	0.6813E-02	0.3664	2.952
CYANIDE	0.0	0.3293	0.4542	2.839	0.1893	0.7570E-02	0.2082E-01	0.5905
P-TOTAL	0.3122E-01	3.293	0.2271	8.516	0.7572E-01	0.1363E-01	0.3748E-01	44.87
SULFATE	4.446	3688.	399.7	681.3	75.72	3.028	3.123	1417.
SULFIDE	0.0	0.6586	4.542	28.39	1.893	0.7570E-01	0.2082	1.181
SULFITE	0.0	0.0	0.0	0.0	62.47	0.0	0.0	0.0
CHLORIDE	32.16	1021.	1640.	1917.	3027.	5.299	10.41	1771.
FLUORIDE	0.7757E-01	10.21	1.317	5.678	0.0	0.0	0.0	13.58
OIL+GR	0.0	171.2	19.53	167.5	15.52	0.5299E-01	1.041	59.05
PHENOLS	0.0	0.6586E-01	2.067	0.5394	0.1893E-02	0.2271E-02	0.3123E-02	0.0
SURFACT	0.0	0.0	0.0	0.0	1.136	8.327	11.24	0.0
AL	0.7568E-02	10.54	0.8630	5.394	0.7061	0.0	0.0	19.13
SB	0.0	1.646	0.0	0.0	0.2272	0.0	0.0	2.952
AS	0.0	0.6586	0.4542E-01	0.5678	0.1893E-01	0.0	0.0	0.5905
BA	0.0	0.0	0.0	0.0	0.5679	0.0	0.0	0.0
CD	0.9460E-04	0.6586E-01	0.1363E-01	0.1136	0.1136E-01	0.0	0.0	0.1181
CA	7.095	1291.	0.4542	2.839	66.25	2.195	6.454	2096.
CR	0.1892E-03	2.766	0.4633	0.8516	0.1693E-01	0.0	0.0	0.8266
CO	0.1892E-02	0.0	0.1862	1.164	0.4354E-01	0.0	0.0	0.0
CU	0.7568E-03	1.317	0.2725	2.441	1.704	0.0	0.0	2.716
FE	0.8041E-02	971.4	46.78	63.02	1.988	0.0	0.0	53.79
PB	0.1892E-02	1.877	0.4542	3.066	0.2272	0.0	0.0	1.299
MG	0.9460	230.5	131.7	823.1	15.14	0.0	0.0	413.3
MN	0.1419E-02	7.936	0.5587	1.703	0.7004E-01	0.0	0.0	1.535
HG	0.1892E-04	0.3293E-01	0.1817E-02	0.1414E-01	0.3407E-02	0.0	0.0	0.5905E-01
MO	0.0	0.0	0.0	0.0	0.5300	0.0	0.0	0.0
NI	0.0	0.8562	0.0	0.0	0.1609	0.0	0.0	0.8266
K	0.0	46.10	0.0	0.0	6.058	0.0	0.0	76.17
NA	1.230	493.9	0.2839E 05	1703.	2414.	7.343	14.16	708.6
SE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SN	0.0	1.646	0.0	0.0	3.881	0.0	0.0	2.952
TI	0.2838E-02	0.0	0.2271	1.419	0.9465E-01	0.0	0.0	0.0
ZN	0.2460E-02	2.437	5.587	3.066	0.1950	0.0	0.0	2.775

UNITS: Flow Rate, cubic meters per day
Heat Flux, kkg-cal per day
Chemical Wastes, kg per day

APPENDIX D, PRESENT INDUSTRIAL WASTE LOADS (CONTINUED)

Discharge I.D.	32602	32603	08401	48202	48201	56901	19101	42401
FLOW RATE	30356	49773	32135	94	113	27	1	545.
HEAT FLUX	115352	313569	719823	378	1283	185	137	8556
ALKALIN	2003.	4181.	3213.	9.933	13.06	1.529	0.0	0.1154E 05
ACIDITY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.995
T-HARD	7285.	6371.	4499.	0.0	0.0	7.753	0.0	0.0
T-SOLIDS	7619.	0.1219E 05	0.1070E 05	18.92	107.9	19.38	0.0	1351.
TDS	6041.	9059.	0.1003E 05	15.70	98.15	18.95	0.0	496.5
TSS	720.5	1145.	674.8	0.4730	6.134	0.4368	0.0	854.0
NH3-N	24.89	4.480	38.56	0.1892E-02	0.2272	0.8190E-02	0.0	1.155
ORG-N	0.3036	21.90	22.49	0.0	0.0	0.8190E-02	0.0	0.8011
BOD-5	109.3	94.57	321.3	17.03	20.45	0.8190E-01	0.0	5.995
ULT-OD	277.3	260.6	756.8	25.55	31.69	0.1966	0.0	17.80
DIS-OXY	238.0	373.2	186.8	0.7390	0.7761	0.2028	0.0	3.497
NO3-N	2.125	3.982	21.85	0.1041E-01	0.1136E-01	0.4368E-02	0.0	6.758
CYANIDE	5.161	0.4977	0.3213	0.9460E-02	0.1136E-01	0.0	0.0	0.0
P-TOTAL	12.14	21.90	1.285	0.2838E-02	0.6816E-01	0.0	0.0	2.997
SULFATE	850.0	1294.	1703.	2.460	15.34	2.621	0.0	391.3
SULFIDE	0.6071	0.9955	0.0	0.9460E-01	0.1136	0.0	0.0	0.0
SULFITE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CHLORIDE	1670.	1493.	3663.	3.784	14.77	2.675	0.0	40.87
FLUORIDE	51.30	19.91	24.42	0.0	0.0	0.0	0.0	0.0
OIL+GR	48.57	99.55	22.17	2.781	0.1477	0.0	0.0	0.5450E-01
PHENOLS	2.064	0.1493	8.034	0.0	0.6816E-03	0.1201E-03	0.0	0.1090E-02
SURFACT	0.0	0.0	0.0	0.5676	36.35	0.0	0.0	0.0
AL	133.7	16.92	0.0	0.0	0.0	0.0	0.0	0.0
SB	1.518	2.489	0.0	0.0	0.0	0.0	0.0	0.0
AS	0.3036	0.4977	0.0	0.0	0.0	0.0	0.0	0.0
BA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CD	0.6071E-01	0.9955E-01	0.0	0.0	0.0	0.0	0.0	0.0
CA	1955.	1866.	2532.	4.825	3.862	7.753	0.0	0.0
CR	0.5768	0.9457	0.0	0.0	0.0	0.2310	0.0	0.0
CO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CU	1.305	0.8461	0.0	0.0	0.0	0.0	0.0	0.0
FE	256.0	231.8	32.13	0.0	0.0	0.0	0.0	0.0
PB	6.314	2.738	0.0	0.0	0.0	0.0	0.0	0.0
MG	333.9	348.4	0.0	0.0	0.0	0.0	0.0	0.0
MN	9.714	3.185	0.0	0.0	0.0	0.0	0.0	0.0
HG	0.3036E-01	0.4977E-01	0.0	0.0	0.0	0.0	0.0	0.0
MO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NI	0.5464	0.9955	8.034	0.0	0.0	0.0	0.0	0.0
K	152.7	80.13	106.0	0.0	0.0	0.0	0.0	0.0
NA	455.3	696.8	437.0	1.514	21.58	0.0	0.0	0.0
SE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SN	1.518	2.489	96.40	0.0	0.0	0.0	0.0	0.0
TI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZN	5.646	3.589	3.213	0.0	0.0	0.6006E-01	0.0	0.0

UNITS: Flow Rate, cubic meters per day
Heat Flux, kkg-cal per day
Chemical Wastes, kg per day

APPENDIX D, PRESENT INDUSTRIAL WASTE LOADS (CONTINUED)

Discharge I.D.	27102	27101	33901	33902	05603	05602	05601	08801	11401
FLOW RATE	22	170	265	1693	11	64	397	18	1476
HEAT FLUX	249	3951	1007	8139	23	135	833	642	11217
ALKALIN	2.043	15.33	125.6	170.4	3.635	56.58	1.985	0.9034E-01	115.1
ACIDITY	0.0	0.0	0.0	0.0	0.0	0.0	21.12	0.0	0.0
T-HARD	0.0	22.14	0.0	246.1	0.0	0.0	0.0	0.0	0.0
T-SOLIDS	16.75	33.21	551.2	369.1	11.47	7.009	8026.	5.311	1317.
TDS	13.30	33.21	643.9	369.1	9.145	2.379	4173.	4.950	1221.
TSS	3.450	0.0	10.12	0.0	2.329	4.630	3853.	0.3213	95.94
NH3-N	0.3178	0.0	0.5035	0.0	0.3408	0.6430E-01	11.51	0.0	0.4428
ORG-N	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7469
BOD-5	1.362	0.0	389.5	0.0	2.102	29.13	332.3	0.3780E-01	761.6
ULT-OD	3.473	0.0	586.6	0.0	4.686	43.98	550.2	0.5670E-01	1148.
DIS-OXY	0.1559	0.9779	2.077	14.71	0.9175E-01	0.5193	3.206	0.9015E-01	10.80
NO3-N	0.1021	0.1703E-01	0.4505	0.0	0.9048E-02	0.5144E-02	1.866	0.0	2.494
CYANIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P-TOTAL	0.2270	0.3406E-02	7.446	0.0	0.7384	0.1286	23.82	0.5670	1.018
SULFATE	0.0	4.428	0.0	49.22	0.0	0.0	0.0	0.0	0.0
SULFIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SULFITE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CHLORIDE	0.0	4.939	8.480	54.90	2.488	2.765	97.26	0.0	56.09
FLUORIDE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OIL+GR	0.3178	0.0	0.0	0.0	7.293	22.27	24.30	0.0	159.4
PHENOLS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SURFACT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MG	0.0	1.873	0.0	20.82	0.0	0.0	0.0	0.0	0.0
MN	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HG	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
K	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NA	0.0	1.533	0.0	17.04	0.0	0.0	0.0	0.0	0.0
SE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SN	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZN	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

UNITS: Flow Rate, cubic meters per day
Heat Flux, kkg-cal per day
Chemical Wastes, kg per day

APPENDIX E, PROJECTED INDUSTRIAL WASTE LOADS

Discharge I.D.	04301	48211	41901	41902	41903	41904	48210
FLOW RATE	105980	17979	15897	7570	14005	5299	16276
HEAT FLUX	1928834	37755	112868	40877	53218	31793	74869
ALKALIN	7525.	3955.	1335.	499.6	1260.	476.9	0.0
ACIDITY	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T-HARD	0.1070E 05	0.0	2089.	984.1	1821.	688.9	0.0
T-SOLIDS	0.2448E 05	3344.	3625.	1726.	3193.	1208.	6103.
TDS	0.2427E 05	3200.	3466.	1650.	3053.	1155.	5973.
TSS	932.6	151.6	170.1	81.00	149.9	56.70	137.2
NH3-N	63.59	13.57	16.66	7.933	14.68	5.553	12.29
ORG-N	42.39	0.0	4.769	2.271	4.201	1.590	0.0
BOD-5	307.3	77.13	46.58	22.18	41.03	15.53	69.82
ULT-OD	937.9	176.8	166.3	79.19	146.5	55.43	160.0
DIS-OXY	656.2	145.2	117.4	57.71	109.8	39.97	125.8
NO3-N	8.478	1.978	3.148	1.499	2.773	1.049	3.581
CYANIDE	2.120	1.748	0.3179	0.1514	0.2801	0.1590	1.628
P-TOTAL	52.99	0.5394	7.154	3.406	6.302	2.365	4.069
SULFATE	0.1166E 05	467.5	715.4	302.8	616.2	196.1	1432.
SULFIDE	0.7419	17.98	6.359	3.028	5.602	2.120	16.28
SULFITE	635.9	0.0	15.90	7.570	0.0	0.0	0.0
CHLORIDE	5193.	1043.	476.9	234.7	406.1	164.3	195.3
FLUORIDE	498.1	2.697	3.179	1.514	4.201	1.060	4.883
OIL+GR	296.7	28.77	25.44	12.11	22.41	8.478	26.04
PHENOLS	1.261	0.5394	0.6359E-01	0.7570E-01	0.5602E-01	0.2120E-01	0.4883
SURFACT	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AL	2.120	0.0	20.67	9.841	18.21	6.889	0.0
SB	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AS	3.179	0.1798	0.1590	0.7570E-01	0.0	0.5299E-01	0.1628
BA	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CD	0.1060	0.1798E-01	0.1017E-01	0.4845E-02	0.8963E-02	0.3391E-02	0.6510E-01
CA	3497.	575.3	540.5	295.2	567.2	212.0	1221.
CR	2.056	0.8989E-01	0.1828	0.8705E-01	0.1611	0.6094E-01	0.5371
CO	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CU	6.253	0.1978	0.6359	0.3028	0.5602	0.2120	0.2116
FE	115.5	6.832	17.23	8.206	15.18	5.744	21.16
PB	3.709	0.3236	0.6359	0.3028	0.5602	0.2120	0.6510
MG	0.0	0.0	119.2	56.77	105.0	39.74	0.0
MN	0.0	0.6832	0.5087	0.2422	0.4482	0.1696	0.8464
HG	0.0	0.1079E-01	0.0	0.0	0.0	0.0	0.1790E-01
MO	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NI	5.299	0.0	0.0	0.0	0.0	0.0	0.0
K	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NA	1166.	341.6	190.8	90.84	140.0	60.94	309.2
SE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TI	0.0	0.0	31.79	15.14	0.0	10.60	0.0
ZN	30.73	0.3236	0.4769	0.3028	0.4201	0.1590	0.0

UNITS: Flow Rate, cubic meters per day
Heat Flux, kkg-cal per day
Chemical Wastes, kg per day

APPENDIX E, PROJECTED INDUSTRIAL WASTE LOADS (CONTINUED)

Discharge I.D.	32601	48206	32604	32602	32603	08401	48201
FLOW RATE	32930	28388	59046	30356	49773	32135	113
HEAT FLUX	95496	113551	779406	115352	313569	719823	1283
ALKALIN	1548.	7125.	5019.	2003.	4181.	3213.	13.06
ACIDITY	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T-HARD	4643.	0.0	7735.	7285.	6371.	4499.	0.0
T-SOLIDS	6059.	8602.	0.1281E 05	6648.	0.1219E 05	0.1070E 05	99.06
TDS	5697.	8374.	0.1021E 05	6041.	9059.	0.1003E 05	98.15
TSS	363.5	239.3	649.5	592.9	1145.	674.8	0.9576
NH3-N	1.976	21.43	5.995	47.17	4.480	38.56	0.8577E-01
ORG-N	9.220	22.71	27.75	0.3036	21.90	22.49	0.0
BOD-5	88.91	121.8	89.75	109.3	94.57	321.3	0.4873
ULT-OD	183.7	381.3	286.1	377.6	260.6	756.8	1.117
DIS-OXY	262.2	221.8	392.2	238.0	373.2	186.8	0.7761
NO3-N	2.305	5.678	2.952	2.125	3.982	21.85	0.1136E-01
CYANIDE	0.3293	2.839	0.5975	6.496	0.4977	0.3213	0.1136E-01
P-TOTAL	3.293	8.516	44.87	12.14	21.90	1.285	0.6816E-01
SULFATE	3688.	681.3	1417.	850.0	1294.	1703.	15.34
SULFIDE	0.6586	28.39	1.181	0.6071	0.9955	0.0	0.1136
SULFITE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CHLORIDE	1021.	1987.	1771.	1670.	1493.	3663.	14.77
FLUORIDE	10.21	5.678	13.58	51.30	19.91	24.42	0.0
OIL+GR	152.8	45.42	59.05	228.6	99.55	22.17	0.1818
PHENOLS	0.6586E-01	0.8516	0.0	0.6921	0.1493	8.034	0.3408E-02
SURFACT	0.0	0.0	0.0	0.0	0.0	0.0	36.35
AL	10.54	5.394	19.13	133.7	16.92	0.0	0.0
SB	1.646	0.0	2.952	1.518	2.489	0.0	0.0
AS	0.6586	0.5678	0.5905	0.3036	0.4977	0.0	0.0
BA	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CD	0.6586E-01	0.1136	0.1181	0.6071E-01	0.9955E-01	0.0	0.0
CA	1291.	2.839	2096.	1555.	1866.	2532.	3.862
CR	2.766	0.8516	0.8266	0.5768	0.9457	0.0	0.0
CO	0.0	1.164	0.0	0.0	0.0	0.0	0.0
CU	1.317	2.441	2.716	1.305	0.8461	0.0	0.0
FE	428.3	63.02	53.79	256.0	227.3	32.13	0.0
PB	1.877	3.066	1.299	6.314	2.738	0.0	0.0
MG	230.5	823.3	413.3	333.9	348.4	0.0	0.0
MN	7.936	1.703	1.535	5.714	3.185	0.0	0.0
HG	0.3293E-01	0.1419E-01	0.5905E-01	0.3036E-01	0.4977E-01	0.0	0.0
MO	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NI	0.8562	0.0	0.8266	0.5464	0.9955	8.034	0.0
K	46.10	0.0	76.17	152.7	80.13	106.0	0.0
NA	493.9	1703.	798.6	455.3	696.8	437.0	21.58
SE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SN	1.646	0.0	2.952	1.518	2.489	96.40	0.0
TI	0.0	1.419	0.0	0.0	0.0	0.0	0.0
ZN	2.437	3.066	2.775	5.646	3.584	3.213	0.0

UNITS: Flow Rate, cubic meters per day
Heat Flux, kkg-cal per day
Chemical Wastes, kg per day

APPENDIX F

Metric Units Conversion Table

Multiply (Metric Units)	By	To Obtain (English Units)
Cubic Meters per Day	0.0002642	Million Gallons per Day
Cubic Meters per Day	0.0004087	Cubic Feet per Second
Kilometers	0.62137	Miles
Meters	3.2808	Feet
Square Kilometers	0.3861	Square Miles
Square Meters	10.7639	Square Feet
Hectares	2.4710	Acres
Kilograms	2.2046	Pounds
Meters per Second	2.2369	Miles per Hour
Centimeters	0.3937	Inches
Kilogram Calories	3.9685	Btu
Liters	0.2642	Gallons
Metric Tons (kkg)	1.1023	Short Tons

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16. Abstracts

The Buffalo River was the subject of a comprehensive evaluation of waste loadings and water quality, performed as part of the U.S. Environmental Protection Agency's commitments to abate and control water pollution under the 1972 Great Lakes Water Quality Agreement between the U.S. and Canada.

The Buffalo River, as a result of adverse hydraulic conditions and high waste loadings from industrial discharges and from combined sewer overflows, exhibits a summertime dissolved oxygen concentration of less than one mg/l, a contravention of standards for iron, and evidence of poor water quality in most of the other 24 parameters studies.

(continued on next page)

17. Key Words and Document Analysis. 17a. Descriptors

Water pollution
Stream pollution
Water quality, mathematical models
Combined sewers, water pollution
Industrial wastes, water pollution
New York
Lake Erie

17b. Identifiers/Open-Ended Terms

Water Quality Data, Buffalo (New York)
Buffalo River Basin
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Three independent observations confirmed that the industrialized reach of the Buffalo River is a well-mixed body of water. A water quality simulation model was developed, verified, and utilized to predict water quality upon the implementation of Best Practicable Control Technology Currently Available. The projected water quality marginally came within the standards for temperature and for dissolved oxygen, but more stringent waste allocations were recommended for iron. Upon implementation of BPCTCA, the oxygen-demanding waste load of the combined sewer overflows would then become the dominant constraint for achieving good water quality in the Buffalo River.