UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

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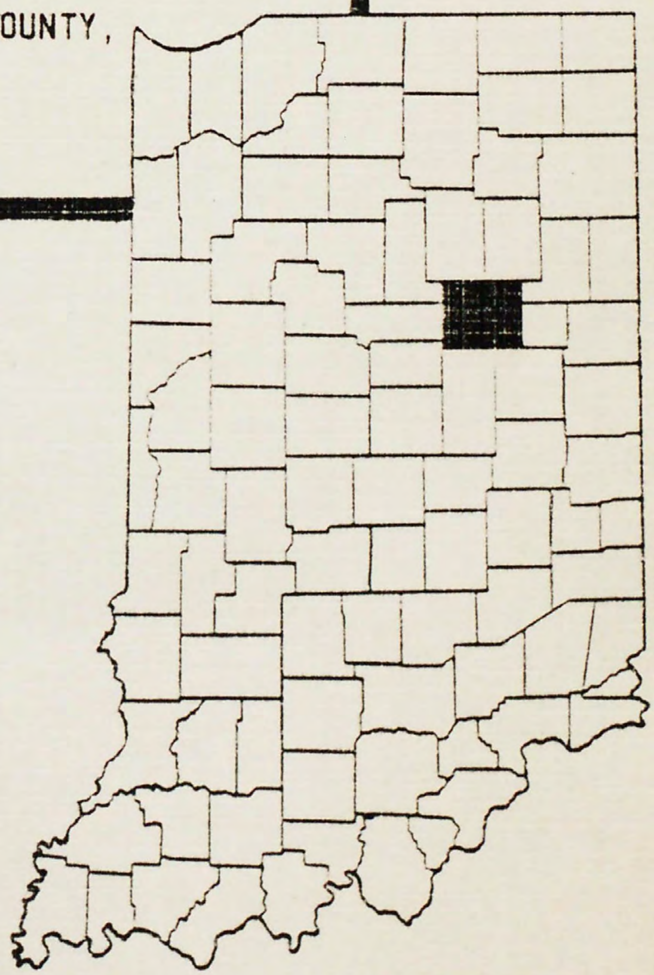

Open-File Report 79-1534

Prepared in cooperation with
Indiana State Board of Health

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By William G. Wilber, Charles G. Crawford, and James G. Peters

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METRIC CONVERSION FACTORS

The inch-pound units used in this report can be converted to the metric system of units as follows:

Multiply inch-pound unit	By	To obtain metric unit
inch (in.)	2.540	centimeter (cm)
foot (ft)	0.3048	meter (m)
square foot (ft^2)	0.0929	square meter (m^2)
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.0283	cubic meter per second (m^3/s)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
million gallons per day (Mgal/d)	3,785	cubic meters per day (m^3/d)

ABBREVIATIONS

Abbreviation	Description
BOD	Biochemical-oxygen demand.
CBOD	Carbonaceous biochemical-oxygen demand.
°C	Degree Celsius.
DO	Dissolved oxygen.
d	Day.
e	Base of the natural logarithm, 2.71828.
ft	Foot.
ft/mi	Foot per mile.
ft^3/s	Cubic foot per second.
$(g/m^2)/d$	Gram per square meter per day.
in.	Inch.
ISBH	Indiana State Board of Health.
K_a	Atmospheric reaeration rate.
K_d	Deoxygenation rate for CBOD.
K_n	First-order kinetics deoxygenation rate for NBOD.
K_r	Stream decay rate for CBOD.
(lb/d)/d	Pound per day per day.
ln	The natural logarithm, base e.
Mgal/d	Million gallons per day.
mg/L	Milligram per liter.
(mg/L)/d	Milligram per liter per day.
mi	Mile.
mi^2	Square mile.
mL	Milliliter.
NBOD	Nitrogenous biochemical-oxygen demand.
NPDES	National Pollution Discharge Elimination System.
$Q_{7,10}$	Average low flow over a 7-day period with a recurrence interval of 10 years.
RM	River mile.
spec. cond.	Specific conductance.
sta. no.	Station number.
temp.	Temperature.
t	Traveltime down the stream.
μmho/cm	Micromho per centimeter.

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ABSTRACT

The Indiana State Board of Health is developing a State water-quality management plan that includes establishing limits for wastewater effluents discharged into Indiana streams. A digital model calibrated to conditions in the Mississinewa River was used to develop alternatives for future waste loadings that would be compatible with Indiana stream water-quality standards defined for two critical hydrologic conditions, summer and winter low flows.

The hydrology of the Mississinewa River downstream from Gas City is controlled primarily by two factors: low slopes, typical of the Tipton Till Plain, and a 10-foot dam at river mile 35.90 in Marion. All point-source waste loads affecting the modeled segment of the Mississinewa River are in the four incorporated municipalities of Fairmount, Jonesboro, Gas City, and Marion, in a primarily agricultural area.

Model simulations indicate that algal photosynthesis and nitrification are the most significant factors affecting the dissolved-oxygen concentration of the Mississinewa River during summer low flows. Natural reaeration, without photosynthesis, is not sufficient to maintain an average dissolved-oxygen concentration of at least 5 milligrams per liter in the stream, the State's water-quality standard.

Projected carbonaceous and nitrogenous biochemical-oxygen demand loads, from the Indiana State Board of Health, for Owens-Illinois, Inc., and the Gas City and Marion wastewater-treatment facilities will result in violations of the in-stream dissolved-oxygen standard. Fairmount and Jonesboro, because of their distance from the Mississinewa, do not sifnificantly affect the water quality of the modeled segment.

Model simulations also indicate that, during winter low flows, ammonia toxicity, rather than dissolved oxygen, is the limiting water-quality criterion in the Mississinewa River downstream from the Gas City wastewater-treatment facility.

Calculations of the stream's assimilative capacity indicate that future waste discharge in the Mississinewa River basin will probably be limited to the reach downstream from the Marion dam (river mile 35.90).

INTRODUCTION

To meet the goals of section 208 of the Federal Water Pollution Control Act, amendments of 1972, Public Law 92-500, the ISBH (Indiana State Board of Health) is developing a State water-quality-management plan. A key element of the plan is establishing effluent-discharge limits under the NPDES (National Pollution Discharge Elimination System). These limits for Indiana are designed to maintain the following in-stream water-quality standards:

1. Average DO (dissolved-oxygen) concentrations of at least 5.0 mg/L (milligrams per liter) per calendar day and not less than 4.0 mg/L at any time.

2. Maximum ammonia-nitrogen concentrations of 2.5 mg/L for June-August (based on a 96-hour median lethal concentration of 0.05 mg/L unionized ammonia nitrogen) and 4.0 mg/L for November through March.

3. A maximum concentration for toxic substances of one-tenth the 96-hour median lethal concentration for important indigenous aquatic species (Indiana State Board of Health, 1977, p. 6).

In the past, point-source discharge limitations were based on arbitrary assumptions and "best engineering estimates." In the current approach, a digital model is used to link a stream's water quality and effluent discharges. Once calibrated and verified to the specific stream conditions, the model can be used to predict the effect of varying waste load, streamflow, and stream temperature. This capability is essential to proper waste-load allocation.

The objectives of this study were to (1) calibrate and verify a one-dimensional, steady-state, dissolved-oxygen model for the Mississinewa River in Grant County, Ind., and (2) use the calibrated and verified model for determining alternatives for future waste loadings that would ensure that the stream meets Indiana water-quality standards defined for critical summer and winter low-flow conditions. The critical-condition rationale is useful for water-quality planning and management (Hines and others, 1975, p. B5-B6).

BASIN DESCRIPTION

The Mississinewa River drains most of Grant County in east-central Indiana and flows northwest to the Wabash River near Peru (fig. 1). The watershed lies within the Tipton Till Plain and is characterized by nearly flat to gently rolling topography marked by several low morainic ridges (Schneider, 1966, p. 49). Variation in elevation is about 40 ft (feet). Burger and others (1971) indicated that unconsolidated ground and end-moraine deposits overlie limestone, dolomite, and shale of early- and middle-Silurian age. The principal soils of the area consist of the well- to moderately well-drained Morley, the somewhat poorly drained Blount silt loams, and the very poorly drained Pewamo silty clay (Ulrich, 1966, p. 89). Annual precipitation for the area is 36-38 inches (Schaal, 1966, p. 157). The average annual runoff is 11-12 inches (Hoggatt, 1962, p. 9).

The projected land use for Grant County in 1985 is 92 percent agricultural, 2 percent residential, 0.3 percent commercial, 0.4 percent industrial and 5.3 percent open (Schellie Associates, 1968, p. 25). In Grant County, 1,017 acres are devoted to industrial uses. Seventy-six percent of this land is used in mineral extraction, and an addtional 14.2 percent is used in 50 salvage-disposal operations scattered throughout the unincorporated areas of the county.

Virtually all point-source waste loads impacting the modeled segment of the Mississinewa River are in the four incorporated municipalities of Fairmount, Jonesboro, Gas City, and Marion (fig. 1 and table 1). Each of the four communities has a sanitary-sewerage system and secondary waste treatment. Sanitary sewage from industrial plants is discharged to the municipal wastewater-treatment facility, whereas industrial process and cooling waters are discharged directly into streams. Untreated, domestic sewage from a small residential area in Marion is discharged into the Mississinewa River near Indiana Street. Several unincorporated communities as well as a considerable rural population are served by septic systems.

The Gas City-Jonesboro sewerage system is to be regionalized in 1980 or 81. As part of this plan, the Jonesboro facility will be phased out, and wastewater presently treated at Jonesboro will then be treated at Gas City. Advanced waste treatment is to be added to the Gas City and Marion wastewater-treatment facilities in 1981.

Public and semiprivate water supplies in the basin are exclusively from ground water.

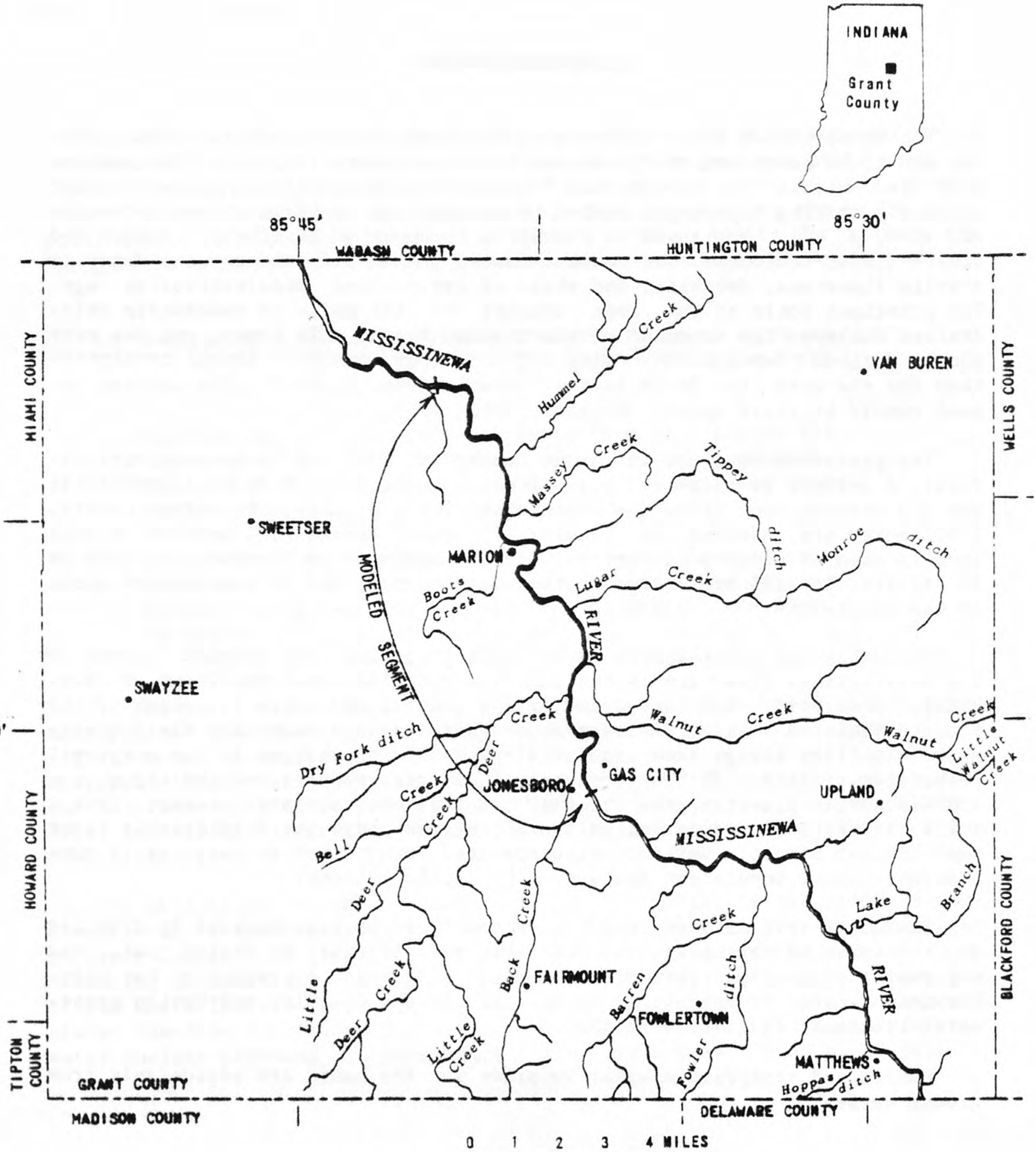

Figure 1.— Location of modeled segment on the Mississinewa River, Grant County, Ind.

Table 1.--NPDES restrictions for municipalities and industries in the Mississinewa River basin, Grant County, Ind.

[Source of data, Indiana State Board of Health, 1978]

Discharger	Receiving stream	Flow (Mgal/d)	Five-day BOD (mg/L)	Suspended solids (mg/L)	Oil and grease (mg/L)	pH[1]
Active Products Corp.	Mississinewa River	----	------	[2]30/30	[2]10/10	6.5/10.5
Anaconda Wire and Cable	do.	----	------	[2]30/30	[2]10/10	6.0/10.5
Do.	do.	----	------	[2]30/30	[2]10/10	6.0/10.5
Do.	do.	----	------	[2]30/30	[2]10/10	6.0/10.5
Do.	do.	----	------	[2]30/30	[2]10/10	6.0/10.5
Do.	do.	----	------	[2]30/30	[2]10/10	6.0/10.5
Do.	do.	----	------	[2]30/30	[2]10/10	6.0/10.5
Culligan Water Conditioning	do.	----	------	[2]20/30	------	6.0/11.0
Forest Ridge Subdivision	do.	----	[3]30/45	[3]30/45	------	6.0/9.0
Gas City waste-water treatment facility	do.	0.84	[3]30/45	[3]30/45	------	6.0/9.0
Marion wastewater-treatment facility	do.	12.0	[3]30/45	[3]30/45	------	6.0/9.0
Owens-Illinois, Inc.	do.	----	30	150	------	6.0/9.0
Do.	do.	----	30	150	------	6.0/9.0
Do.	do.	----	30	150	------	6.0/9.0
RCA[4]	do.	----	------	------	[2]20/20	6.5/10.5
County Line Mobile Home Park	Back Creek	----	[3]10/15	[3]10.15	------	6.0/9.0
Fairmount waste-water-treatment facility	do.	.24	[3]30/45	[3]30/45	------	6.0/9.0
Jonesboro waste-water-treatment facility	do.	.38	[3]30/45	[3]30/45	------	6.0/9.0
Madison-Grant High School	do.	----	[3]10/15	[3]10/15	------	6.0/9.0
Deerwood Court Mobile Home Park	Deer Creek	----	[3]30/45	[3]30/45	------	6.0/9.0

Table 1.--NPDES restrictions for municipalities and industries in the Mississinewa River basin, Grant County, Ind.--Continued

Discharger	Receiving stream	Flow (Mgal/d)	Five-day BOD (mg/L)	Suspended solids (mg/L)	Oil and grease (mg/L)	pH[1]
Indiana-Michigan Electric Co. and wastewater-treatment facility	Deer Creek	----	------	[2]20/30	------	6.0/9.0
Do.	do.	----	------	[2]20/32	[2]10/15	6.0/9.0
Ciscel Mobile Home Park	Little Newly ditch	----	[3]10/15	[3]10/15	------	6.0/9.0
Shady Brook Mobile Home Park	Lugar ditch	----	[3]30/45	[3]30/45	------	6.0/9.0
Foster Forbes	Massey Creek	----	------	[2]10/15	[2]10/15	6.0/9.0
Do.	do.	----	------	------	------	6.0/9.0
Do.	do.	----	------	------	------	6.0/9.0
Eastbrook High School	Monroe ditch	----	[3]30/45	[3]30/45	------	6.0/9.0
Colonial Crest Apartments	Pipe Creek	----	[3]30/45	[3]30/45	------	6.0/9.0
Oak Hill School	do.	----	[3]30/45	[3]30/45	------	6.0/9.0
Irving Brothers Gravel	Walnut Creek	----	------	[2]30/30	------	6.0/9.0

[1]Daily low/daily high.
[2]Daily average/daily maximum.
[3]Monthly average/weekly average.
[4]The use of brand names in this report is for identification purposes only and does not imply endorsement by the U.S. Geological Survey.

MODEL DESCRIPTION

A steady-state, one-dimensional, segmented water-quality model developed by Bauer and others (1979) was used in this study. The use of a steady-state, one-dimensional model is consistent with the objective of determining the assimilative capacity of the Mississinewa River at the critical low-flow condition. The modeling approach assumes that the various flows, loads, and other factors used do not vary significantly with time for a given simulation. The model uses a modified Streeter-Phelps equation that also incorporates nitrogenous, benthic, photosynthetic, and plant respiratory effects on the DO balance. The dissolved-oxygen balance is represented in the model by the following equation:

$$\text{Zero} = \frac{-1}{A} \partial \frac{(QD)}{dx} - K_a D + K_d L + K_n N - P + R + B \qquad (1)$$

where

- A is stream cross-sectional area,
- D the DO deficit defined as the difference between saturated DO concentration (C_s) and the observed DO concentration (C),
- Q the streamflow,
- x the downstream distance,
- K_a the atmospheric reaeration rate,
- K_d the deoxygenation rate for CBOD (carbonaceous biochemical-oxygen demand),
- L the ultimate CBOD,
- K_n the deoxygenation rate for NBOD (nitrogenous biochemical-oxygen demand),
- N the NBOD concentration,
- P the mean daily photosynthetic DO production,
- R the oxygen used by respiration,

and

- B the oxygen used by the stream-bottom deposits.

By integration, the dissolved-oxygen deficit becomes the sum of the following components:

$$D_o e^{-K_a t} \quad \text{the initial DO deficit,} \tag{2}$$

$$\frac{K_d L_o}{K_a - K_r}\left(e^{-K_r t} - e^{-K_a t}\right) \quad \text{the deficit due to CBOD,} \tag{3}$$

$$\frac{K_n N_o}{K_a - K_n}\left(e^{-K_n t} - e^{-K_a t}\right) \quad \text{the deficit due to NBOD,} \tag{4}$$

$$\frac{R}{K_a}\left(1 - e^{-K_a t}\right) \quad \text{the deficit due to plant respiration,} \tag{5}$$

$$\frac{B}{K_a}\left(1 - e^{-K_a t}\right) \quad \text{the deficit due to bottom deposits, and} \tag{6}$$

$$\frac{-P}{K_a}\left(1 - e^{-K_a t}\right) \quad \text{the deficit due to mean daily photosynthetic production,} \tag{7}$$

where

D_o is the DO deficit at some initial time, t_o,

t the traveltime down the stream,

L_o the ultimate CBOD concentration at some initial time, t_o

K_r the stream decay rate for CBOD,

N_o the ultimate NBOD concentration at some initial time, t_o,

and

e the base of the natural logarithm, 2.71828.

DATA COLLECTION

The modeled segment of the Mississinewa River drains a 698-mi^2 area and extends from RM (river mile) 45.65 at 10th Street, Jonesboro, to RM 31.60, downstream from Marion (fig. 2). Twenty sampling stations were selected for the initial survey in August 1977, but the number was increased to 25 for the June 1978 survey and to 22 for the August 1978 survey.

Water-quality data were collected every 3 to 4 hours for 24 hours at each stream site by the Indiana State Board of Health Water-Quality Surveillance Section. Municipal and industrial effluents were sampled at 2-hour intervals during the 24-hour period. Field measurements included dissolved-oxygen concentration, stream temperature, specific conductance, and pH. Time-weighted composite samples were analyzed by the Indiana State Board of Health laboratory for 5-day BOD (5-day biochemical-oxygen demand), total Kjeldahl nitrogen, ammonia nitrogen, nitrite nitrogen plus nitrate nitrogen, total phosphorus, chloride, fluoride, suspended solids, and fecal coliforms. Effluent samples from the August 1978 survey were composited proportionately to flow. Several long-term ultimate CBOD determinations from each survey were observed periodically throughout the incubation period. All water-quality data collected by the ISBH are in tables 2 through 4.

Ultimate CBOD for the August 1977 survey was measured by the Elmore method (Ludzack, 1966). In this procedure, the ultimate CBOD concentration is estimated initially by assuming it to be 30 percent of the chemical-oxygen demand. On the basis of this calculation, the sample is diluted to an estimated ultimate CBOD concentration of not more than 4 mg/L. The diluted samples were analyzed by standard methods in American Public Health Association and others (1976). Several investigators have reported significant variation in ultimate CBOD concentrations where different dilution ratios are used (Grant, 1976a, p. 6; Colston, 1975, p. 195). Consequently, for effluent samples collected in 1978, a single dilution ratio was used. Long-term CBOD's in 1978 were determined by the reaeration technique described by Hines and others (1977, p. 44). The nitrification inhibitor allylthiourea was added to the samples every 5 days.

The annual laboratory performance evaluation by the U.S. Environmental Protection Agency in 1978 indicated that water-quality analyses done by the Indiana State Board of Health were accurate to within 1 percent (S. R. Kin, Indiana State Board of Health, written commun., 1979).

Stream discharge was measured by the U.S. Geological Survey, during the August 1977 and August 1978 surveys and by the Indiana State Board of Health Water-Quality Surveillance Section during the June 1978 survey. Time of travel was measured by instantaneously injecting a slug of fluorescent dye into the stream at a bridge or other easily identifiable location and timing the movement of the resulting dye cloud as it passed one or more locations downstream. The time of travel at several different flow conditions is plotted against the concurrent discharge at the nearest gaging station in figures 3-10 (unpublished U.S. Geological Survey data).

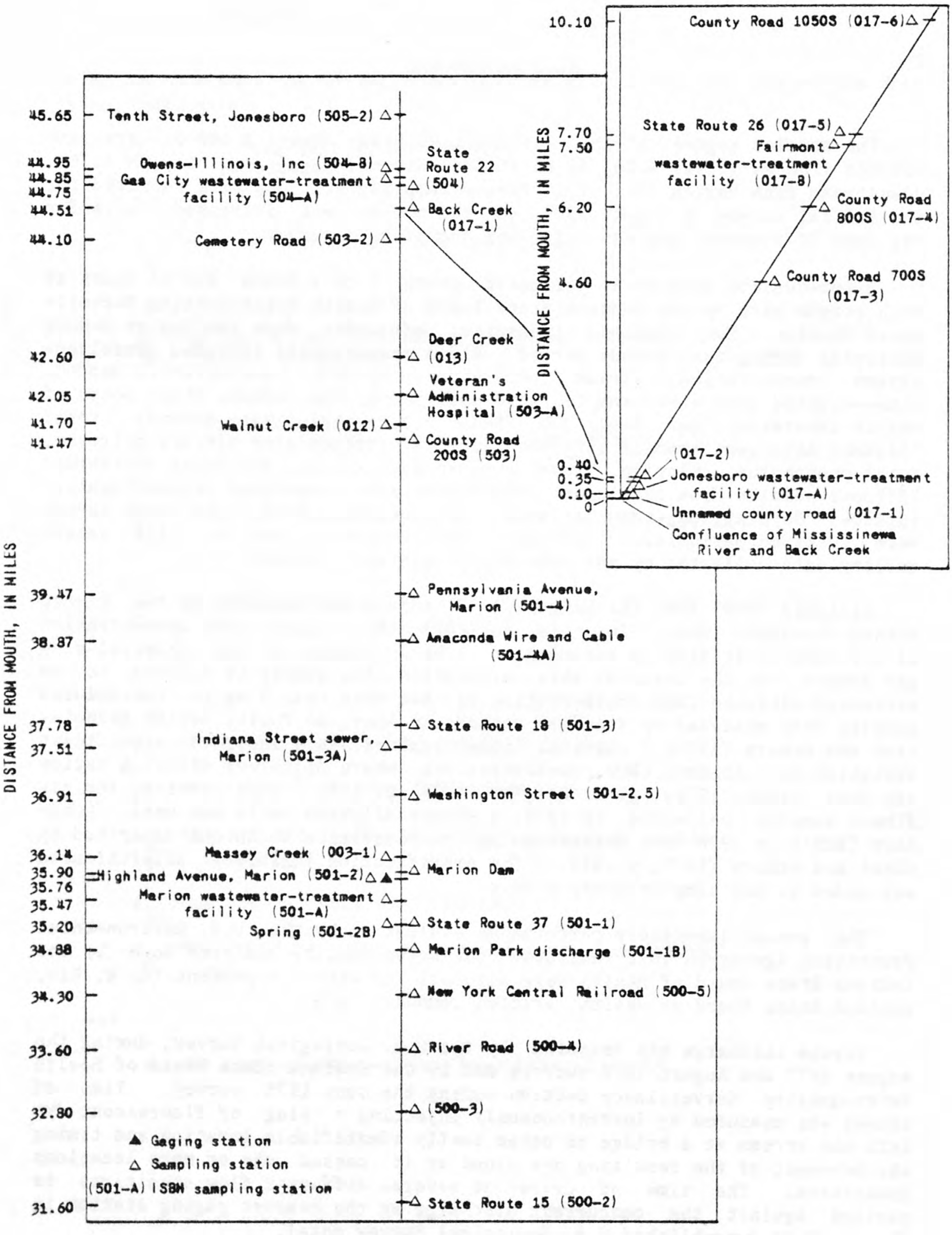

Figure 2.-- Locations of sampling stations, Mississinewa River and Back Creek, Grant County, Ind.

Table 2.--Water-quality analyses and discharge measurements for sampling stations in the Mississinewa River basin, Grant County, Ind., August 5, 1977

[Water-quality data collected by Indiana State Board of Health; discharge measured by U.S. Geological Survey]

Location and station in the Mississinewa River basin (ISBH sta. no. in parens)	River mile	Discharge (ft^3/s)	Median pH	Average temp.[1,2] (°C)	Average spec. cond.[1] (μmho/cm at 25°C)	Suspended solids (mg/L)	Average DO[1] (mg/L)	Five-day BOD (mg/L)	Twenty-day CBOD (mg/L)	Ammonia nitrogen (mg/L)	Nitrite plus nitrate nitrogen (mg/L)	Total Kjeldahl nitrogen (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Total phosphorus (mg/L)	Fecal coliform (colonies/100 mL)	Oil and grease (mg/L)
Mississinewa River at 10th Street Jonesboro (505-2)	45.65	26.9	7.5	24.5	-----	54	9.2	7.6	-----	<0.1	<0.1	----	56	----	0.18	40	3.6
Owens-Illinois, Inc. (504-B)	44.95	.93	7.8	27	944	28	6.8	11.7	-----	.14	.6	----	74	----	----	27	4.6
Gas City wastewater-treatment facility (504A)	44.85	.85	7.5	24.9	3,125	32	3.5	31.0	-----	12.0	2.9	----	470	12.0	----	20	5.5
Mississinewa River at State Route 22 (504)	44.75	----	8.0	25.0	908	48	10.0	7.3	-----	.2	1.4	----	80	.8	.49	4,000	4.4
Back Creek at County Road 1050S (017-6)	10.10	----	7.6	24.3	744	48	7.1	3.3	-----	.1	.5	.7	30	.5	.46	5,800	3.3
Back Creek at State Route 26 (017-5)	7.70	.14	7.4	23.7	798	20	4.1	4.8	-----	1.2	1.0	1.8	35	----	.68	1,200	4.4
Fairmount wastewater-treatment facility (017-B)	7.50	----	7.6	23.8	1,375	17	2.8	28	-----	13	2.3	14	95	----	3.5	120,000	3.1

Table 2.--Water-quality analyses and discharge measurements for sampling stations in the Mississinewa River basin, Grant County, Ind., August 5, 1977--Continued

Location and station in the Mississinewa River basin (ISBH sta. no. in parens)	River mile	Dis-charge (ft³/s)	Median pH	Aver-age temp.[1,2] (°C)	Aver-age spec. cond.[1] (µmho/cm at 25°C)	Sus-pended solids (mg/L)	Aver-age DO[1] (mg/L)	Five-day BOD (mg/L)	Twenty-day CBOD (mg/L)	Ammonia nitrogen (mg/L)	Nitrite plus nitrate nitrogen (mg/L)	Total Kjeldahl nitrogen (mg/L)	Chlo-ride (mg/L)	Fluo-ride (mg/L)	Total phos-phorus (mg/L)	Fecal coli-form (colo-nies/100 mL)	Oil and grease (mg/L)
Back Creek at County Road 800S (017-4)	6.20	----	7.6	23.8	1,123	9	4.0	6.1	-----	5.4	0.7	6.4	63	----	1.3	12,000	---
Back Creek at County Road 700S (017-3)	4.60	.80	7.7	25	976	14	4.7	5.7	-----	3.1	.7	---	56	----	1.3	1,100	4.6
Back Creek upstream from Jonesboro wastewater-treatment facility (017-2)	.40	1.01	7.7	24	838	8	7.7	2.8	-----	.3	1.6	---	45	.4	.77	3,600	4.2
Jonesboro wastewater-treatment facility (017-A)	.35	-----	7.4	23.8	2,850	28	5.6	25	-----	5.0	9.6	---	440	.4	4.6	320,000	5.5
Back Creek at confluence with Mississinewa River (017-1)	44.51	1.21	8.0	24.0	1,025	15	6.4	6.2	-----	.2	3.1	---	93	.3	1.2	1,300	3.0
Deer Creek at confluence with Mississinewa River (013)	42.60	3.93	7.4	23.2	-----	6	6.6	1.3	-----	<.1	.2	---	45	----	.06	600	2.8

Table 2.--Water-quality analyses and discharge measurements for sampling stations in the Mississinewa River basin, Grant County, Ind., August 5, 1977--Continued

Location and station in the Mississinewa River basin (ISBH sta. no. in parens)	River mile	Dis-charge (ft^3/s)	Median pH	Aver-age temp.[1,2] (°C)	Aver-age spec. cond.[1] (µmho/cm at 25°C)	Sus-pended solids (mg/L)	Aver-age DO[1] (mg/L)	Five-day BOD (mg/L)	Twenty-day CBOD (mg/L)	Ammonia nitrogen (mg/L)	Nitrite plus nitrate nitrogen (mg/L)	Total Kjeldahl nitrogen (mg/L)	Chlo-ride (mg/L)	Fluo-ride (mg/L)	Total phos-phorus (mg/L)	Fecal coli-form (colo-nies/100 mL)	Oil and grease (mg/L)
Mississinewa River at County Road 200S (S03)	41.47	-----	8.1	25.4	-----	48	16.9	11.0	-----	<.1	.1	---	77	----	.20	320	3.1
Mississinewa River at at Pennsylvania Avenue, Marion (S01-4)	39.47	-----	7.5	26.2	-----	46	15.3	10.0	-----	<.1	<.1	---	74	----	.15	250	3.6
Mississinewa River at State Route 18 (S01-3)	37.78	-----	7.8	25.8	-----	28	11.8	7.3	-----	<.1	<.1	---	60	.7	.11	5,000	4.0
Massey Creek (003-1)	36.14	1.04	7.7	26.8	-----	12	6.8	2.6	-----	<.1	.7	---	40	----	.10	4,600	3.3
Mississinewa River at Highland Avenue, Marion (S01-2)	35.76	29.3	8.0	25.7	-----	22	7.8	6.4	-----	.2	<.1	---	80	----	.12	820	2.8
Marion waste-water-treatment facility (S01-A)	35.47	11.39	7.0	23.4	-----	7	4.2	----	6.2	1.0	9.3	2.2	91	1.2	.97	67,000	1.9
Mississinewa River at State Route 37 (S01-1)	35.20	-----	7.5	25.2	-----	22	8.9	----	10.8	.5	3.5	2.0	93	.9	.45	890	3.6

[1] Averages based on stream samples collected every 3 to 4 hours and effluent samples collected every 2 hours for 24 hours.

[2] Temperature of stream and effluents.

Table 3.--Water-quality analyses and discharge measurements for stations in the Mississinewa River basin, Grant County, Ind., June 7, 1978

[Water-quality data collected and discharge measured by Indiana State Board of health]

Location and station In the Mississinewa River basin (ISBH sta. no. in parens)	River mile	Discharge (ft^3/s)	Median pH	Average temp.[1,2] (°C)	Suspended solids (mg/L)	Average DO[1] (mg/L)	Five-day BOD (mg/L)	Seventeen day CBOD (mg/L)	Ammonia nitrogen (mg/L)	Nitrite plus nitrate nitrogen (mg/L)	Total Kjeldahl nitrogen (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Total phosphorus (mg/L)	Fecal coliform (colonies/ 100 mL)	Oil and grease (mg/L)
Mississinewa River at 10th Street, Jonesboro (505-2)	45.65	108.3	8.3	22.8	26	8.5	2.7	----	<0.1	2.0	0.5	34	0.6	---	--------	---
Owens-Illinois, Inc. (504-B)	44.95	.93	---	14.8	12	7.9	3.8	----	.2	1.1	.5	25	---	0.1	3,100	7.3
Gas City wastewater-treatment facility (504-A)	44.85	1.5	---	17.8	76	4.3	24	----	13	.5	18	340	---	2.7	390,000	4.5
Mississinewa River at State Route 22 (504)	44.75	------	---	22.6	28	7.6	2.2	----	.1	2.1	.9	36	.6	---	-------	---
Back Creek at County Route 1050S (017-6)	10.10	-----	7.9	19.6	28	7.0	1.8	----	.1	1.0	1.0	23	---	----	-------	---
Back Creek at State Route 26 (017-5)	7.70	.86	7.7	18.8	10	3.0	7.7	----	1.3	.6	2.4	24	---	---	-------	---
Fairmount wastewater-treatment facility (017-B)	7.50	.41	---	14.9	76	1.3	20	----	15	.1	20	110	---	4.4	850,000	5.3

Table 3.--Water-quality analyses and discharge measurements for stations in the Mississinewa River basin, Grant County, Ind., June 7, 1978--Continued

Location and station In the Mississinewa River basin (ISBH sta. no. in parens)	River mile	Discharge (ft^3/s)	Median pH	Average temp.[1,2] (°C)	Suspended solids (mg/L)	Average DO[1] (mg/L)	Five-day BOD (mg/L)	Seventeen day CBOD (mg/L)	Ammonia nitrogen (mg/L)	Nitrite plus nitrate nitrogen (mg/L)	Total Kjeldahl nitrogen (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Total phosphorus (mg/L)	Fecal coliform (colonies/ 100 mL)	Oil and grease (mg/L)
Back Creek at County Road 800S (017-4)	6.20	3.67	7.7	18.6	3	4.6	5.4	----	2.5	1.2	3.5	35	---	---	------	---
Back Creek at County Road 700S (017-3)	4.60	-----	7.9	20.2	8	8.2	5.0	----	1.9	1.3	2.6	33	---	---	------	---
Back Creek upstream from Jonesboro wastewater-treatment facility (017-2)	.40	4.36	8.1	20.2	17	7.6	6.2	----	.3	2.4	1.2	32	---	---	------	---
Jonesboro wastewater-treatment facility (017-A)	.35	.35	---	17	20	4.5	24	----	12	2.0	17	74	---	3.6	2,400,000	4.8
Back Creek at confluence with Mississinewa River (017-1)	44.51	4.86	8.0	19.6	12	7.7	7.6	----	.5	2.5	1.5	35	---	---	------	---
Mississinewa River at Cemetery Road (503-2)	44.10	-----	----	----	33	---	2.8	----	<.1	2.0	.9	36	---	---	------	---
Deer Creek at confluence with Mississinewa River (013)	42.6	8.37	8.1	20.4	7	7.5	1.9	----	<.1	3.0	.5	32	---	---	------	---

Table 3.--Water-quality analyses and discharge measurements for stations in the Mississinewa River basin, Grant County, Ind., June 7, 1978--Continued

Location and station in the Mississinewa River basin (ISBH sta. no. in parens)	River mile	Discharge (ft^3/s)	Median pH	Average temp.[1,2] (°C)	Suspended solids (mg/L)	Average DO[1] (mg/L)	Five-day BOD (mg/L)	Seventeen day CBOD (mg/L)	Ammonia nitrogen (mg/L)	Nitrite plus nitrate nitrogen (mg/L)	Total Kjeldahl nitrogen (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Total phosphorus (mg/L)	Fecal coliform (colonies/100 mL)	Oil and grease (mg/L)
Walnut Creek at confluence with Mississinewa River (012)	41.70	0	8.0	19.8	30	9.8	4.2	----	<0.1	0.4	1.0	62	-----	-----	------	---
Mississinewa River at County Road 200S (503)	41.47	----	8.3	21.6	64	<.9	3.0	----	<.1	2.1	.9	----	-----	-----	------	---
Mississinewa River at Pennsylvania Avenue, Marion (501-4)	39.47	----	8.3	22.2	17	8.6	3.1	----	<.1	2.0	.6	37	----	-----	750	---
Mississinewa River at State Route 18 (501-3)	37.78	----	8.3	22.0	26	8.8	2.8	----	<.1	2.1	.6	37	----	-----	350	---
Massey Creek (003-1)	36.14	1.04	8.1	23.2	32	7.0	3.6	----	.2	.3	.6	40	----	-----	1,100	3.4
Mississinewa River at Highland Avenue, Marion (501-2)	35.76	180.6	8.3	22.2	29	9.7	5.1	----	<.1	2.0	1.0	37	----	-----	2,100	8.2
Marion wastewater-treatment facility (501-A)	35.47	14.7	7.8	19.0	13	6.8	---	25.9	<.1	15	---	----	----	0.88	------	---
Mississinewa River at State Route 37 (501-1)	35.20	----	8.3	22.0	32	10.2	---	6.6	.1	1.9	.9	----	----	-----	------	---

Table 3.--Water-quality analyses and discharge measurements for stations in the Mississinewa River basin, Grant County, Ind., June 7, 1978--Continued

Location and station in the Mississinewa River basin (ISBH sta. no. in parens)	River mile	Discharge (ft^3/s)	Median pH	Average temp.[1,2] (°C)	Suspended solids (mg/L)	Average DO[1] (mg/L)	Five-day BOD (mg/L)	Seventeen day CBOD (mg/L)	Ammonia nitrogen (mg/L)	Nitrite plus nitrate nitrogen (mg/L)	Total Kjeldahl nitrogen (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Total phosphorus (mg/L)	Fecal coliform (colonies/ 100 mL)	Oil and grease (mg/L)
Mississinewa River at New York Central Railroad (500-5)	34.30	----	---	23	82	9.8	5.9	----	0.3	2.0	1.8	36	-----	----	------	---
Mississinewa River at River Mile 32.80 (500-3)	32.80	----	---	23	32	9.5	7.5	----	.4	2.0	1.8	39	-----	----	------	---
Mississinewa River at State Route 15 (500-2)	31.60	----	8.3	23.3	18	8.0	---	6.5	.4	2.0	1.1	--	-----	----	------	---

[1] Averages based on stream samples collected every 3 to 4 hours and effluent samples collected every 2 hours for 24 hours.

[2] Temperature of stream and effluents.

Table 4.--Water-quality analyses and discharge measurements for sampling stations in the Mississinewa River basin, Grant County, Ind., August 15, 1978

[Water-quality data collected by Indiana State Board of Health; discharge measured by U.S. Geological Survey]

Location and station in the Mississinewa River basin (ISBH sta. no. in parens)	River mile	Discharge (ft^3/s)	Median pH	Average temp. (°C)	Suspended solids (mg/L)	Average DO[1] (mg/L)	Five-day BOD (mg/L)	Twenty-day CBOD (mg/L)	Ammonia nitrogen (mg/L)	Nitrate plus nitrate nitrogen (mg/L)	Total Kjeldahl nitrogen (mg/L)
Mississinewa River at 10th Street, Jonesboro (505-2)	45.65	71.8	8.3	26.0	75	14.0	---	9.8	<0.1	0.7	1.6
Owens-Illinois, Inc. (504-8)	44.95	.9	7.0	23.3	15	6.1	---	9.7	.1	.2	.7
Gas City wastewater treatment facility (504-A)	44.85	.9	7.6	23.7	32	4.8	---	50.3	12.0	.8	---
Mississinewa River at State Route 22 (504)	44.75	----	8.4	26.0	98	14.2	---	9.5	.1	.6	1.7
Back Creek at confluence with Mississinewa River (017-1)	44.51	4.1	7.7	23.8	14	5.0	---	9.7	2.8	2.1	3.8
Mississinewa River at Cemetery Road (503-2)	44.10	----	8.5	25.7	60	17.2	---	14.1	.1	.4	2.0
Deer Creek at confluence with Mississinewa River (013)	42.60	3.9	8.0	24.0	13	7.2	12.0	----	<.1	3.5	2.3
Walnut Creek at confluence with Mississinewa River (012)	41.70	1.7	7.7	24.6	26	7.8	<.1	----	<.1	.3	.3
Mississinewa River at County Road 200S (503)	41.47	----	8.3	26.0	64	19.1	7.6	----	.1	.4	2.0
Mississinewa River at Pennsylvania Avenue, Marion (501-4)	39.47	----	8.4	25.8	100	17.4	---	20.7	.2	.2	2.2
Anaconda Wire and Cable (501-4A)	38.87	.1	9.0	26.6	7	7.3	---	9.7	.1	<.1	.4
Mississinewa River at State Route 18 (501-3)	37.78	----	8.4	24.9	52	19.0	---	20.4	.2	<.1	2.1

Table 4.--Water-quality analyses and discharge measurements for sampling stations in the Mississinewa River basin, Grant County, Ind., August 15, 1978--Continued

Location and station in the Mississinewa River basin (ISBH sta. no. in parens)	River mile	Discharge (ft^3/s)	Median pH	Average temp.[1,2] (°C)	Suspended solids (mg/L)	Average DO[1] (mg/L)	Five-day BOD (mg/L)	Twenty-day CBOD (mg/L)	Ammonia nitrogen (mg/L)	Nitrate plus nitrate nitrogen (mg/L)	Total Kjeldahl nitrogen (mg/L)
Indiana Street sewer, Marion (501-3A)	37.51	0.04	7.5	20.1	100	3.8	150	493.0	29.0	<0.1	50.0
Mississinewa River at Washington Street (501-2.5)	36.91	------	8.3	24.5	62	16.6	-----	12.3	.2	<.1	1.4
Massey Creek at confluence with Mississinewa River (003-1)	36.14	1.1	8.0	26.8	19	6.1	2.1	------	.1	.1	.6
Mississinewa River at Marion dam	35.90	------	8.4	25.0	58	12.3	8.6	------	.1	.1	1.5
Mississinewa River at Highland Avenue, Marion (501-2)	35.76	112.3	8.4	25.0	68	12.1	-----	14.2	.1	.2	2.2
Marion wastewater-treatment facility (501-A)	35.47	20.7	7.6	22.2	18	7.8	-----	8.7	7.9	.5	9.2
Mississinewa River at State Route 37 (501-1)	35.20	------	8.3	25.1	38	11.5	-----	14.3	1.7	.2	3.3
Marion Park discharge (501-1B)	34.88	.1	8.0	23.0	7	7.5	<1.0	------	<.1	.2	.2
Mississinewa River at River Road (500-4)	33.60	------	8.2	25.4	36	9.7	9.7	------	.5	.3	2.3
Mississinewa River at State Route 15 (500-2)	31.60	120.2	8.3	26.1	63	8.9	-----	13.2	.3	.6	2.0

[1]Averages based on stream samples collected every 3 to 4 hours and effluent samples collected every 2 hours for 24 hours.

[2]Temperature of stream and effluents.

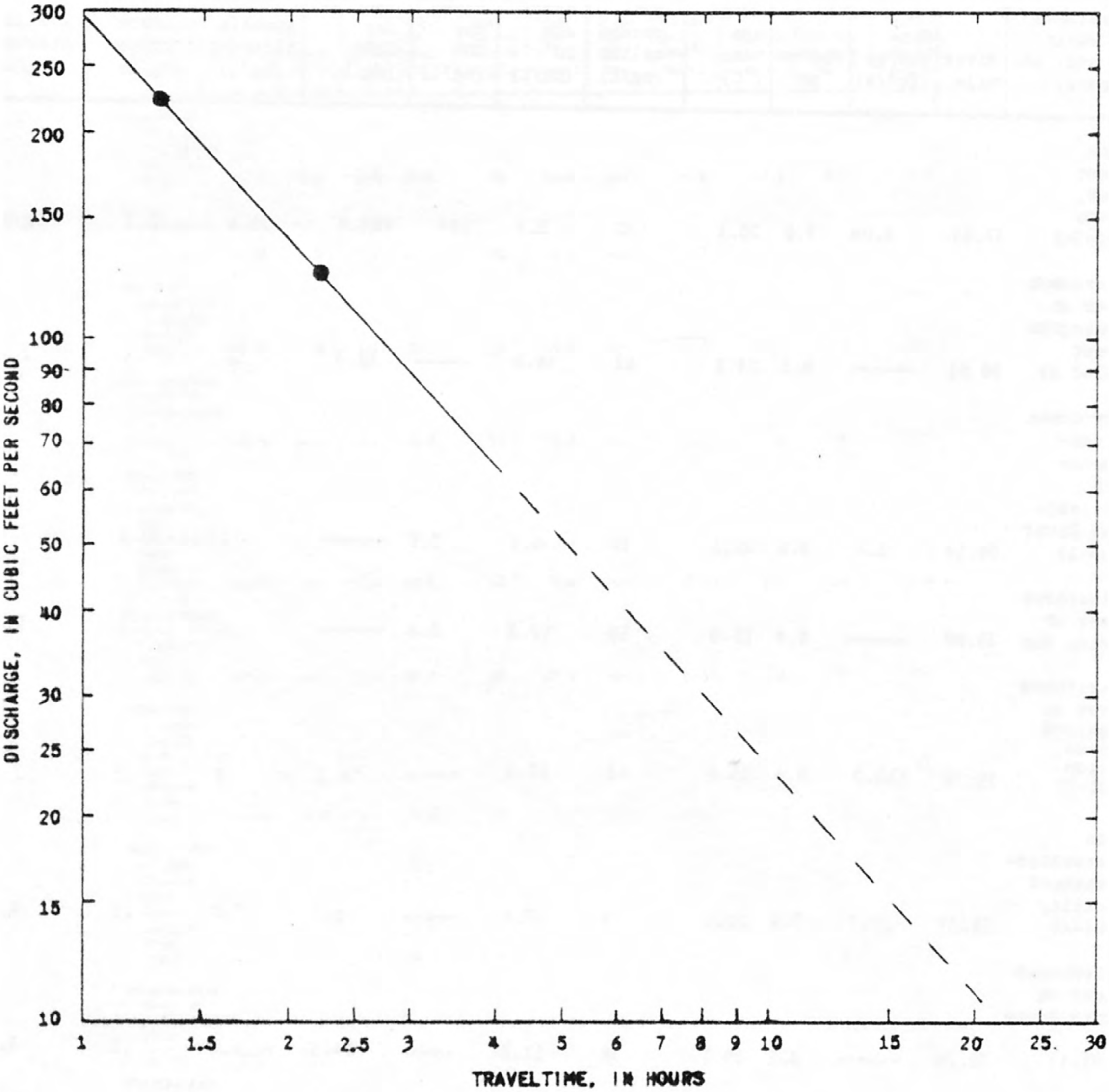

Figure 3.— Relation of discharge to traveltime of the peak dye concentration for the Mississinewa River, river miles 45.65 to 44.75.

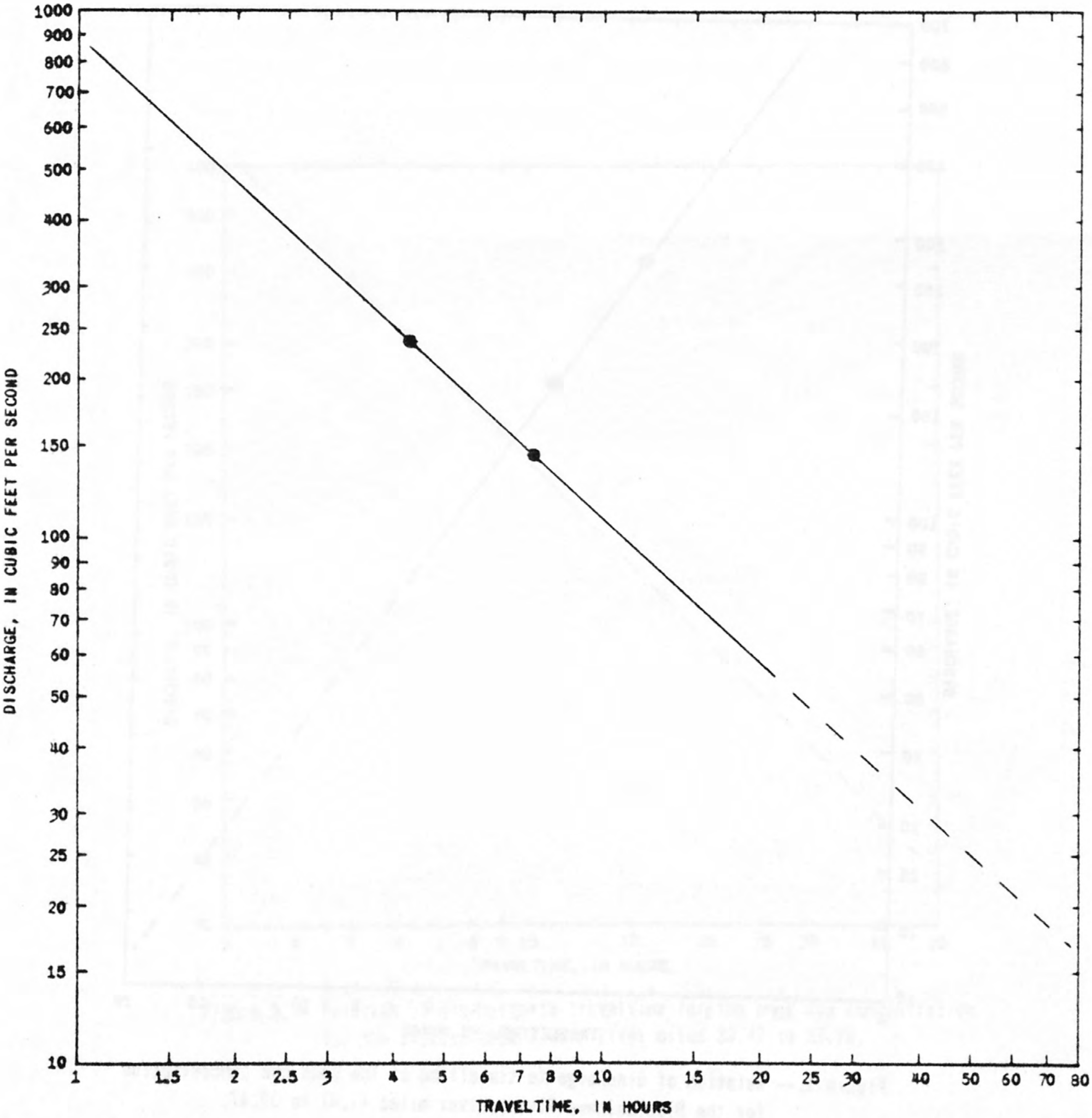

Figure 4.-- Relation of discharge to traveltime of the peak dye concentration for the Mississinewa River, river miles 44.75 to 41.47.

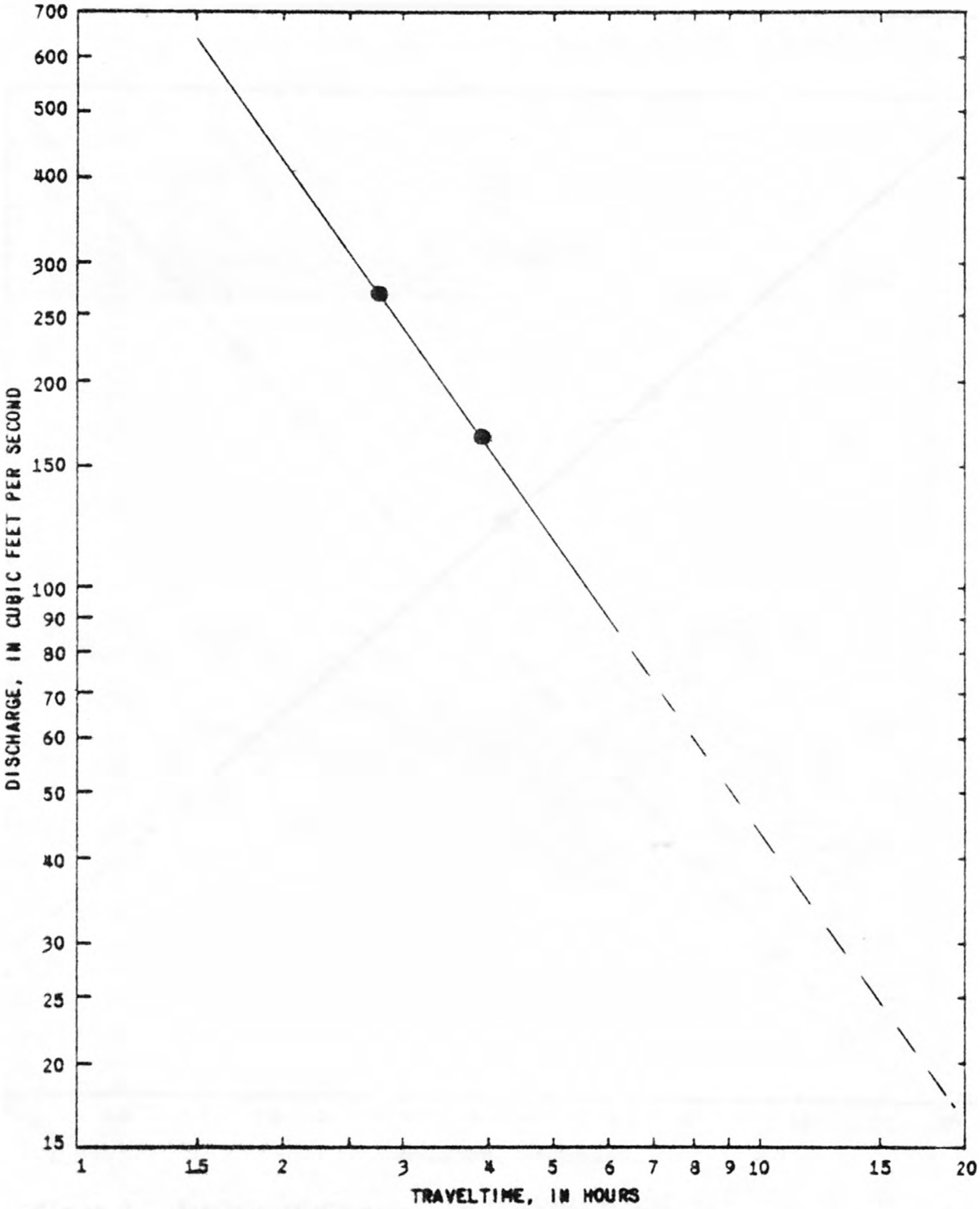

Figure 5.-- Relation of discharge to traveltime of the peak dye concentration for the Mississinewa River, river miles 41.47 to 39.47.

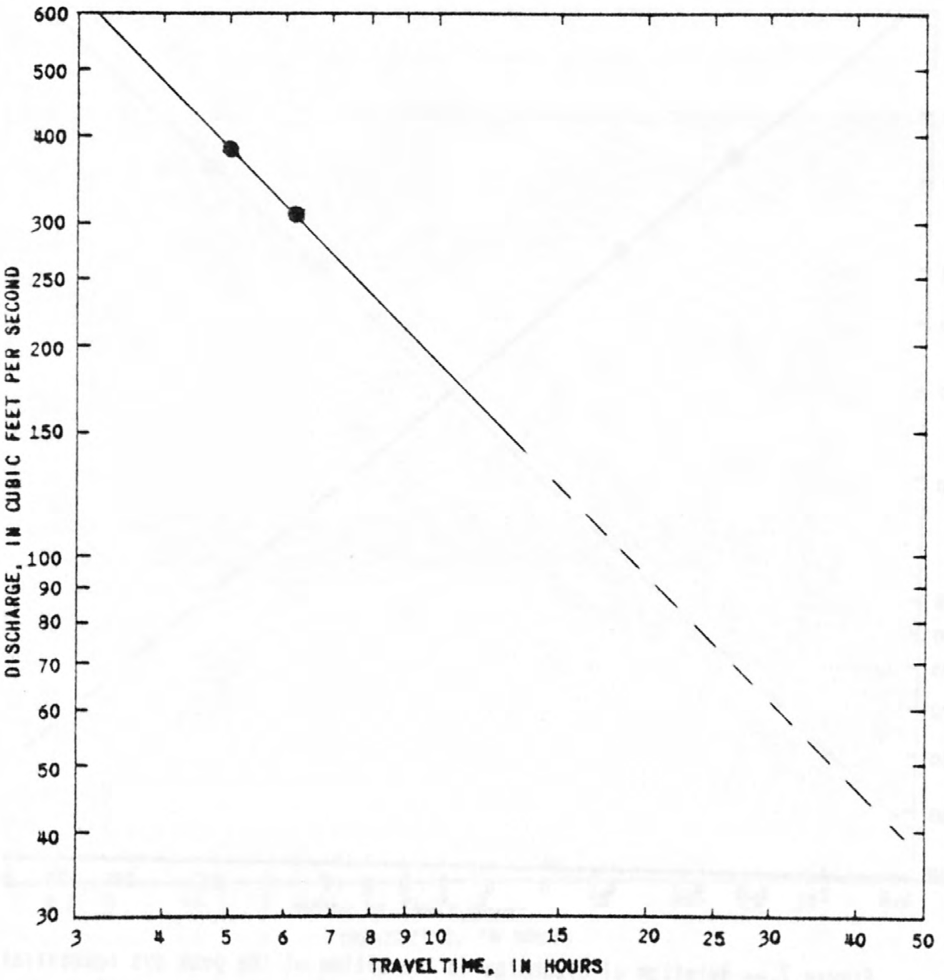

Figure 6.— Relation of discharge to traveltime for the peak dye concentration for the Mississinewa River, river miles 39.47 to 37.78.

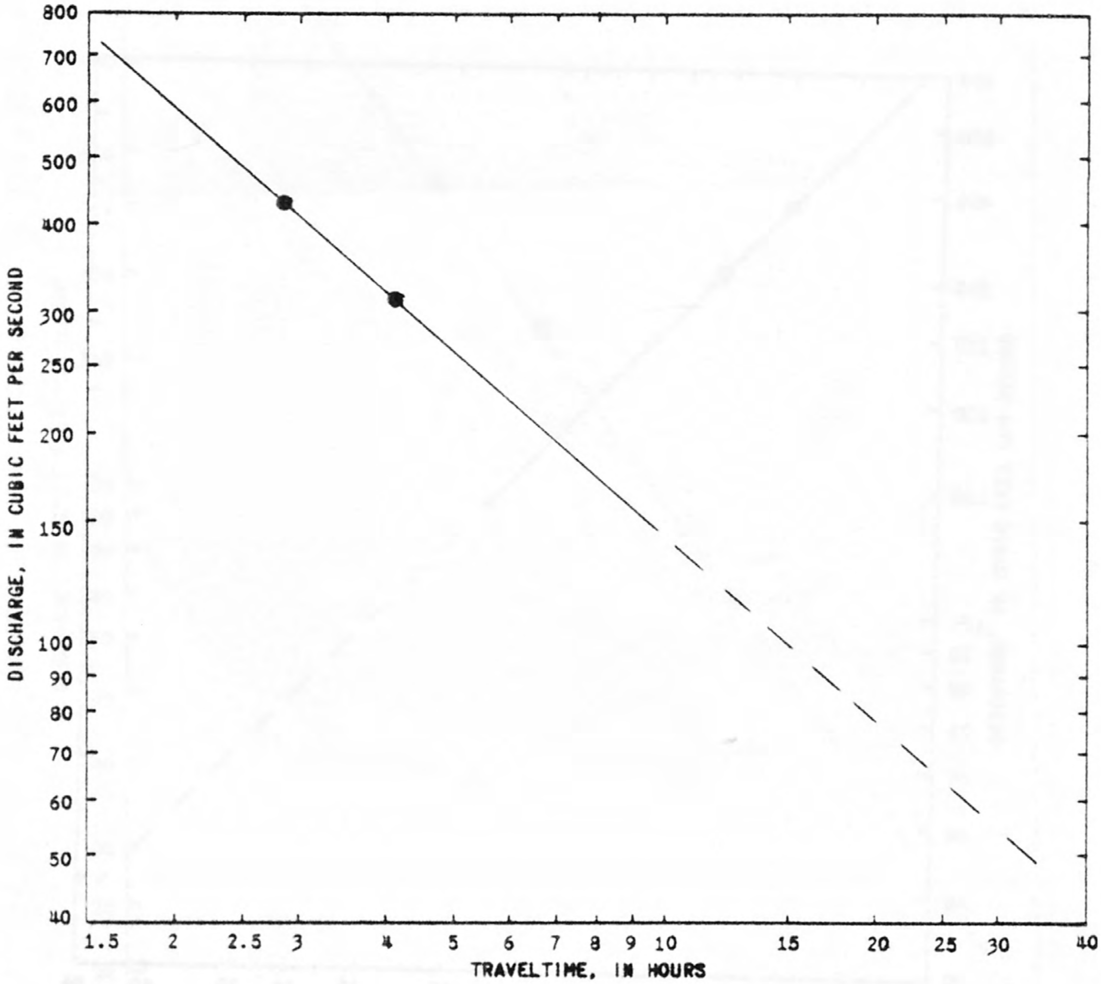

Figure 7.-- Relation of discharge to traveltime of the peak dye concentration for the Mississinewa River, river miles 37.78 to 36.90.

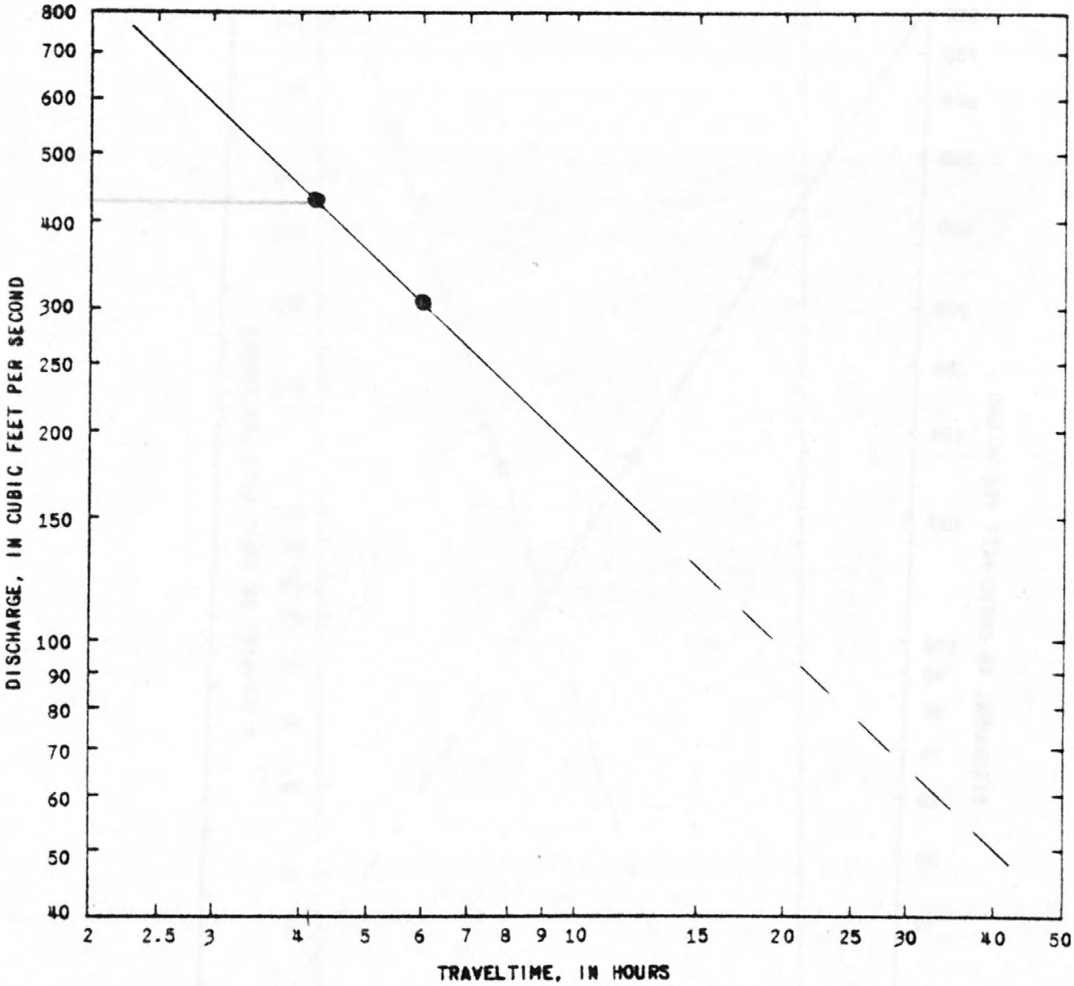

Figure 8.-- Relation of discharge to traveltime of the peak dye concentration for the Mississinewa River, river miles 36.90 to 35.76.

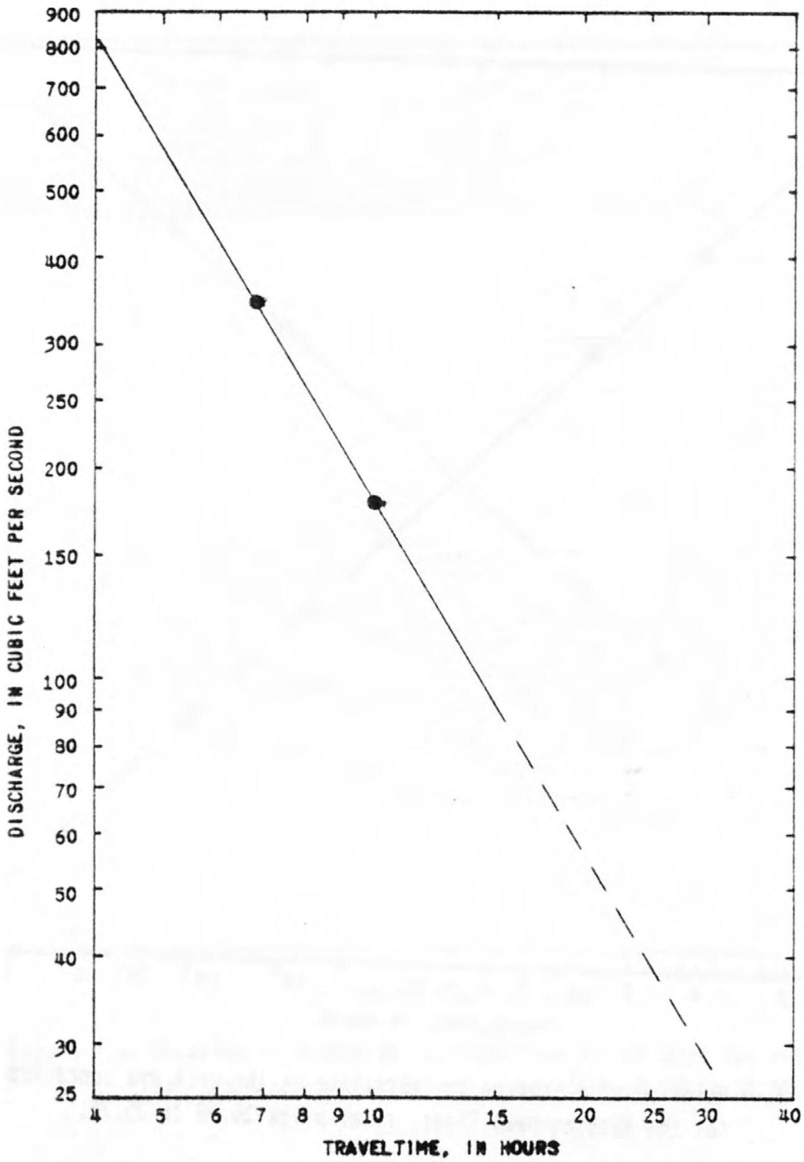

Figure 9.— Relation of discharge to traveltime of the peak dye concentration for the Mississinewa River, river miles 35.76 to 35.20.

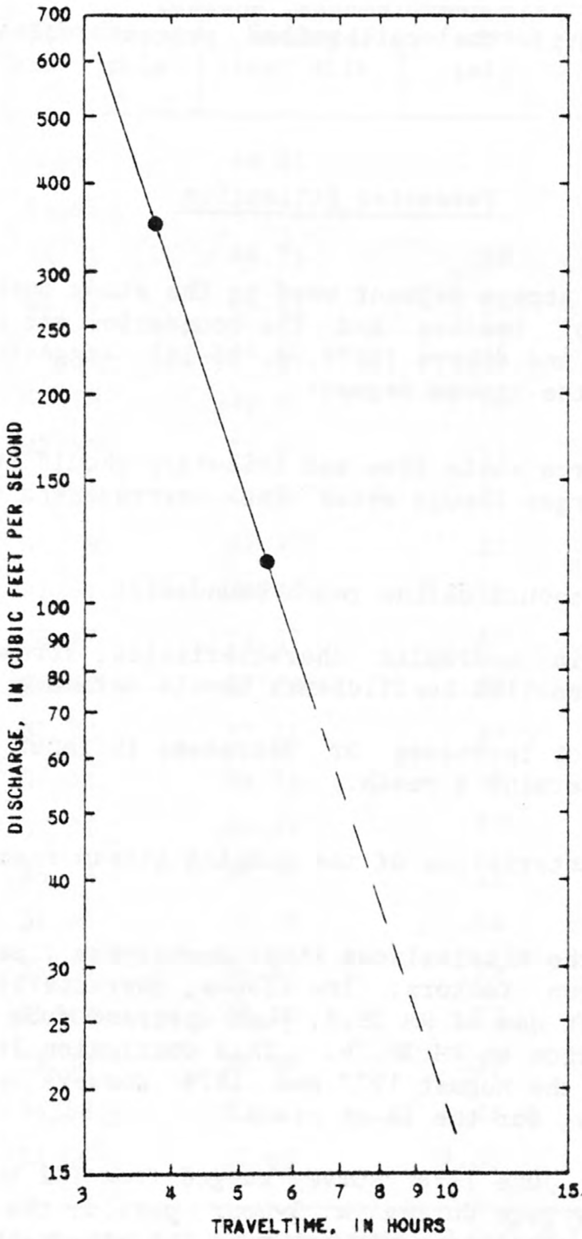

Figure 10.-- Relation of discharge to traveltime of the peak dye concentration for the Mississinewa River, river miles 35.20 to 31.60.

MODEL CALIBRATION

Model calibration is the process of determining the various model parameters used to describe the system of interest. Some of these parameters may be determined from field measurements, whereas others may have to be estimated initially, until the calibration process indicates appropriate refinements.

Parameter Estimation

For modeling, the stream segment used in the study must be divided into reaches. The number of reaches and the boundaries are determined by the program user. Bauer and others (1979, p. 15-16) suggested the following criteria for dividing the stream segment:

1. Each point-source waste flow and tributary should start a reach. Discharges should enter the upstream end of the reach.

2. Linear runoff should define reach boundaries.

3. Major changes in hydraulic characteristics, stream temperature, or reaction coefficients should define a reach.

4. Future inputs or increases or decreases in input should be used to determine a reach.

The physical characteristics of the modeled stream reaches are presented in table 5.

The hydrology of the Mississinewa River downstream from Gas City is controlled primarily by two factors: low slopes, characteristic of the Tipton Till Plain, and a 10-ft dam at RM 35.9, just upstream from the U.S. Geological Survey gage at Marion at RM 35.76. This conclusion is supported by the long travel times for the August 1977 and 1978 surveys, which were 9.8 and 3.1 days, respectively, for the 14-mi reach.

Flow during the June 1978 survey ranged from 162 to 377 ft^3/s at the U.S. Geological Survey gage during a 5-hour period, the result of a small storm. Because these conditions did not meet the steady-state assumption of the model, the June 1978 data were not used in the model calibration.

The two sets of model-input parameters used in the calibration of the dissolved-oxygen model for the Mississinewa River include water-quality and hydrologic data representing initial upstream conditions, waste and tributary inputs, and main-stem sites (tables 6 and 7).

Table 5.--Physical characteristics for modeled stream reaches, Mississinewa River basin, Grant County, Ind.

Reach	Starting river mile	Ending river mile	Length of reach (mi)	Average slope (ft/mi)	Average[1] width (ft)
1	45.65	44.95	0.70	5.0	32
2	44.95	44.85	.10	5.0	---
3	44.85	44.75	.10	5.0	---
4	44.75	44.51	.24	2.1	189
5	44.51	44.10	.41	1.6	---
6	44.10	42.60	1.50	2.1	---
7	42.60	42.05	.55	2.0	---
8	42.05	41.70	.35	2.3	---
9	41.70	41.47	.23	3.0	---
10	41.47	39.47	2.00	2.2	---
11	39.47	38.87	.60	1.1	---
12	38.87	37.78	1.09	1.1	---
13	37.78	37.51	.27	1.1	203
14	37.51	36.91	.60	1.1	---
15	36.91	36.14	.77	1.1	---
16	36.14	35.90	.12	1.1	---
17	35.90	35.76	.14	60.0	---
18	35.76	35.47	.29	8.62	---
19	35.47	35.20	.27	8.52	---
20	35.20	34.88	.32	2.19	---
21	34.88	33.60	1.28	2.83	---
22	33.60	31.60	2.00	2.80	194

[1] Values correspond to a discharge of 280 ft^3/s at the U.S. Geological Survey gage at Marion.

Table 6.--Model input for the Mississinewa River, Grant County, Ind., August 5, 1977

[All rates corrected to 20° Celsius; water-quality data collected by Indiana State Board of Health; hydrologic data collected by U.S. Geological Survey]

Reach	Upstream boundary of modeled reach (ISBH sta. no. in parens)	River mile	Discharge (ft^3/s)	Time of travel to next site (hours)	Ultimate CBOD (mg/L)	NBOD (mg/L)	DO (mg/L)	Temp. (°C)	K_r (day^{-1})	K_d (day^{-1})	K_n (day^{-1})	K_a (day^{-1})	Net photosynthesis (mg/L)/d	Linear runoff: Discharge (ft^3/s)	Linear runoff: Ultimate CBOD (mg/L)	Linear runoff: NBOD (mg/L)	Linear runoff: DO (mg/L)
1	Mississinewa River at 10th Street, Jonesboro (505-2)	45.65	26.90	6.69	14.1	0.4	9.20	25.0	0.11	0.11	0.0	0.83	2.5	-0.39	2.1	0.4	2.0
2	Owens-Illinois, Inc. (504-B)	44.95	.90	.96	22.9	.4	6.80	27.0	.11	.11	.0	.83	2.5	-.06	2.1	.4	2.0
3	Gas City wastewater-treatment facility (504-A)	44.85	.85	.96	62.6	52.0	3.50	24.9	.11	.14	.0	.83	5.0	-.06	2.1	.4	2.0
4	Mississinewa River at State Route 22 (504)	44.75	-----	3.14	----	----	----	----	.11	.14	.6	.26	8.0	-.13	2.1	.4	2.0
5	Back Creek at confluence with Mississinewa River (017-1)	44.51	1.20	24.00	11.5	.9	6.40	24.0	.20	.15	.6	.24	8.0	-1.05	2.1	.4	2.0
6	Deer Creek at confluence with Mississinewa River (013)	42.60	3.90	7.10	11.9	.4	6.60	23.2	.10	.13	.6	.24	8.0	-.30	2.1	.4	2.0
7	Veterans Admin. Hospital (503-A)	42.05	.20	4.59	4.0	.4	6.96	25.0	10	.13	.6	.28	8.0	-.19	2.1	.4	2.0
8	Walnut Creek at confluence with Mississinewa River (012)	41.70	.00	3.01	----	---	----	----	.20	.13	.6	.37	9.0	-.13	2.1	.4	2.0
9	Mississinewa River at County Road 200 S (503)	41.47	-----	12.50	----	---	----	----	.17	.15	.0	.57	10.0	-1.10	2.1	.4	2.0
10	Mississinewa River at Pennsylvania Avenue, Marion (501-4)	39.47	-----	21.30	----	---	----	----	.09	.15	.0	.05	2.5	-.33	2.1	.4	2.0

Table 6.--Model input for the Mississinewa River, Grant County, Ind., August 5, 1977--Continued

Reach	Upstream boundary of modeled reach (ISBH sta. no. in parens)	River mile	Dis-charge (ft^3/s)	Time of travel to next site (hours)	Ultimate CBOD (mg/L)	NBOD (mg/L)	DO (mg/L)	Temp. (°C)	K_r (day^{-1})	K_d (day^{-1})	K_n (day^{-1})	K_a (day^{-1})	Net photo-synthesis [(mg/L/d)]	Linear runoff: Discharge (ft^3/s)	Linear runoff: Ultimate CBOD (mg/L)	Linear runoff: NBOD (mg/L)	Linear runoff: DO (mg/L)
11	Anaconda Wire and Cable (S01-A)	38.87	0.10	38.70	10.6	0.4	8.10	25.0	0.09	0.15	0.0	0.05	1.5	-0.60	2.1	0.4	2.0
12	Mississinewa River at State Route 18 (S01-3)	37.78	----	13.30	----	-----	----	----	.05	.15	.0	.03	1.5	-.15	2.1	.4	2.0
13	Indiana Street sewer, Marion (S01-3A)	37.51	.04	67.50	520.0	125.6	3.80	25.0	.05	.16	.0	.03	1.5	-1.18	2.1	.4	2.0
14	Massey Creek at confluence with Mississinewa River (003-1)	36.14	1.00	11.80	4.8	.4	6.80	26.8	.03	.15	.0	.03	1.5	-.14	2.1	.4	2.0
15	Mississinewa River at Marion dam	35.90	----	7.38	-----	-----	----	----	.03	.15	.0	1.77	2.0	-.08	2.1	.4	2.0
16	Mississinewa River at Highland Avenue, Marion (S01-2)	35.76	----	1.35	----	-----	----	----	.20	.15	.0	2.73	2.0	-.08	2.1	.4	2.0
17	Marion wastewater-treatment facility (S01-A)	35.47	11.40	1.25	6.5	4.4	4.20	23.4	.20	.14	3.0	2.71	17.0	-.07	2.1	.4	2.0
18	Mississinewa River at St. Rt. 37 (S01-1)/ Spring (S01-2B)	35.20	.20	3.68	2.1	.4	7.10	25.0	.30	.13	3.0	1.55	14.0	-.41	2.1	.4	2.0
19	Mississinewa River at River Road (S00-4)	33.60	----	4.91	----	-----	----	----	.60	.12	2.0	2.93	9.0	-.22	2.1	.4	2.0

Table 7.--Model input for the Mississinewa River, Grant County, Ind., August 15, 1978

[All rates corrected to 20° Celsius; water-quality data collected by Indiana State Board of Health; hydrologic data collected by U.S. Geological Survey]

Reach	Upstream boundary of modeled reach (ISBH sta. no. in parens)	River mile	Discharge (ft^3/s)	Time of travel to next site (hours)	Ultimate CBOD (mg/L)	NBOD (mg/L)	DO (mg/L)	Temp. (°C)	K_r (day^{-1})	K_d (day^{-1})	K_n (day^{-1})	K_a (day^{-1})	Net photosynthesis [(mg/L/d)]	Linear runoff: Discharge (ft^3/s)	Linear runoff: Ultimate CBOD (mg/L)	Linear runoff: NBOD (mg/L)	Linear runoff: DO (mg/L)
1	Mississinewa River at 10th Street, Jonesboro (505-2)	45.65	71.8	2.72	10.3	0.4	14.0	26.0	0.1	0.11	0.0	2.10	15.0	1.95	2.1	0.4	2.0
2	Owens Illinois, Inc. (504-B)	44.95	.9	.39	10.0	.4	6.1	23.3	.1	.11	.0	2.13	30.0	.13	2.1	.4	2.0
3	Gas City wastewater-treatment facility (504-A)	44.85	.9	.39	54.0	52.0	4.8	23.7	.1	.14	.0	2.13	30.0	.28	2.1	.4	2.0
4	Mississinewa River at State Route 22 (504)	44.75	----	.99	----	----	----	----	.1	.14	.0	.84	40.0	.67	2.1	.4	2.0
5	Back Creek at confluence with Mississinewa River (017-1)	44.51	4.1	1.28	9.8	12.1	5.0	23.8	-5.0	.17	.0	.63	40.0	.86	2.1	.4	2.0
6	Mississinewa River at Cemetery Road (503-2)	44.10	----	6.59	----	----	---	----	-.1	.15	.0	.84	25.0	4.45	2.1	.4	2.0
7	Deer Creek at confluence with Mississinewa River (013)	42.60	3.9	2.26	24.0	.4	7.2	24.0	-.1	.13	.0	.79	20.0	1.53	2.1	.4	2.0
8	Veterans Admin. Hospital (503-A)	42.05	.2	1.44	4.0	.4	10.0	26.0	-.1	.13	.0	.91	20.0	.77	2.1	.4	2.0
9	Walnut Creek at confluence with Mississinewa River (012)	41.70	1.7	.95	2.0	.4	7.8	24.6	-4.1	.13	.0	1.21	10.0	.64	2.1	.4	2.0
10	Mississinewa River at County Road 200 S (503)	41.47	----	5.75	----	----	----	----	-.8	.15	.0	1.26	10.0	5.56	2.1	.4	2.0
11	Mississinewa River at Pennsylvania Avenue, Marion (501-4)	39.47	----	6.39	----	----	----	----	.0	.15	.0	.17	10.0	1.67	2.1	.4	2.0

Table 7.--Model input for the Mississinewa River, Grant County, Ind., August 15, 1978--Continued

Reach	Upstream boundary of modeled reach (ISBH sta. no. in parens)	River mile	Discharge (ft³/s)	Time of travel to next site (hours)	Ultimate CBOD (mg/L)	NBOD (mg/L)	DO (mg/L)	Temp. (°C)	K_r (day⁻¹)	K_d (day⁻¹)	K_n (day⁻¹)	K_a (day⁻¹)	Net photosynthesis [(mg/L/d)]	Linear runoff: Discharge (ft³/s)	Linear runoff: Ultimate CBOD (mg/L)	Linear runoff: NBOD (mg/L)	Linear runoff: DO (mg/L)
12	Anaconda Wire and Cable (501-4A)	38.87	0.1	11.61	10.6	0.4	8.0	25.0	0.0	0.15	0.0	0.15	10.0	3.34	2.1	0.4	2.0
13	Mississinewa River at State Route 18 (501-3)	37.78	----	4.34	-----	-----	----	----	.0	.15	.0	.10	4.0	.75	2.1	.4	2.0
14	Indiana Street sewer, Marion (501-3A)	37.51	.4	9.66	520.0	125.6	3.8	20.1	.1	.16	.0	.10	4.0	1.67	2.1	.4	2.0
15	Mississinewa River at Washington Street, Marion (501-2.5)	36.91	1.1	8.96	-----	-----	----	----	.1	.16	.0	.13	4.0	2.14	2.1	.4	2.0
16	Massey Creek at confluence with Mississinewa River (003-1)	36.14	----	2.79	4.2	.4	6.1	26.8	.1	.15	.0	.13	4.0	.33	2.1	.4	2.0
17	Mississinewa River at Marion dam	35.90	----	1.75	-----	-----	----	----	.1	.14	.0	7.37	12.0	.42	2.1	.4	2.0
18	Mississinewa River at Highland Avenue, Marion (501-2)	35.76	----	.65	-----	-----	----	----	.3	.14	.0	5.5	40.0	-.93	2.1	.4	2.0
19	Marion wastewater-treatment facility (501-A)	35.47	20.7	.60	8.9	34.2	7.8	25.0	.3	.14	6.0	5.5	40.0	-.86	2.1	.4	2.0
20	Mississinewa River at State Route 37 (501-1)/ Spring (501-2B)	35.20	.2	.40	2.1	.4	7.0	25.1	.3	.14	5.0	2.21	25.0	-1.01	2.1	.4	2.0
21	Mississinewa River at Marion Park discharge (501-1B)	34.88	.1	1.80	2.1	.4	11.0	25.4	-3.0	.13	5.0	2.31	25.0	-3.73	2.1	.4	2.0
22	Mississinewa River at River Road (500-4)	33.60	----	2.95	-----	-----	----	----	3.0	.12	3.0	4.69	10.0	-6.34	2.1	.4	2.0

Differences in streamflow between two points that could not be attributed to effluent discharge or tributaries by mass-balance analysis was accounted for by linear runoff. Linear runoff was assumed to be proportional to the number of miles in a modeled reach.

The mean daily dissolved-oxygen concentration for stations on the Mississinewa River averaged 136 and 175 percent of saturation for the surveys in August 1977 and 1978, respectively. Diel dissolved-oxygen fluctuations for the August 1978 survey were less than 2.0 mg/L, and, in most of the stations studied, the minimum dissolved-oxygen concentration was at least never less than 100 percent of saturation. Dissolved-oxygen concentration was determined only twice for most of the stations sampled during the August 1977 survey. Data collected by the Marion wastewater-treatment facility from June 1976 through September 1978 (table 8) were used to determine whether the dissolved-oxygen concentrations observed during the two water-quality surveys were representative for the Mississinewa River on a yearly basis. These data indicate that the dissolved-oxygen concentration of the Mississinewa River frequently exceeds the saturation concentration during the summer months. The observed dissolved-oxygen supersaturation is due to photosynthetic activity and slow mixing rates that prevent a dissolved-oxygen equilibrium from being quickly established. There was no dissolved-oxygen sag and recovery was downstream from either the Gas City or Marion wastewater-treatment facilities during the two water-quality surveys.

Algal productivity in the Mississinewa is enhanced by long detention times, high temperatures, and nutrient enrichment resulting from the several wastewater-treatment facilities and industries that discharge into the rivers and tributaries and, possibly, from nonpoint agricultural runoff. Williams (1964) and Hynes (1970, p. 98) found that the algal biomass of large rivers is almost everywhere dominated by diatoms. However, exceptions to the general pattern of diatom dominance do occur and are usually observed in parts of river systems having long detention times (Rickert and others, 1977).

Phytoplankton concentrations were not determined during the two water-quality surveys. Because macrophytes were not observed, suspended algal populations are probably responsible for the photosynthetic activity. Total plankton counts determined by the Indiana State Board of Health for the Mississinewa River at RM 28, downstream from the modeled segment, for June 27, August 1, and August 29, 1978, ranged from 924/mL to 81,972/mL. Diatoms accounted for an average of 86 percent of the total plankton population. (Ken Frato, Indiana State Board of Health, written commun., 1979.)

Long-term CBOD measurements were made for only a small percentage of the samples collected during the August 1977 and June 1978 surveys (tables 9 and 10). Five-day BOD measurements were made for the other samples. The authors used the ratio of ultimate CBOD to 5-day CBOD from the long-term CBOD measurements to estimate the ultimate CBOD concentrations for those samples in which only a 5-day BOD measurement was made. This method gives reliable estimates of ultimate CBOD concentration (Stamer and others, 1979). The concentration of ultimate CBOD was assumed to be 1.9 times that of the 5-day BOD for all samples.

Fifteen long-term CBOD measurements were made on samples collected from the August 1978 survey (table 11). The ratio of ultimate CBOD to 5-day CBOD, calculated from data in table 11, ranged from 1.78 to 2.23 for stream samples and from 1.64 to 2.87 for effluents. Figure 11 is a plotting of CBOD data for ISBH station 503-2 at RM 44.10. Figure 12 is a plotting of CBOD data for ISBH station 501-3 at RM 37.78.

The ultimate CBOD concentration of discharges at Anaconda Wire and Cable, Indiana Street sewer, and Marion Park, which were not sampled during the August 1977 and June 1978 surveys, were assumed to be the same as the ultimate CBOD concentrations during the August 1978 survey.

A plot of the percentages of long-term CBOD remaining against time (Thomas, 1950) provided an estimate of the deoxygenation rate for CBOD, K_d (figs. 13 and 14 and tables 9-11). Because more long-term CBOD measurements were made during the August 1978 survey than during the other two surveys, the August 1978 measurements were used to determine the CBOD deoxygenation rates for both the August 1977 and 1978 model calibrations. Values of K_d for the August 1978 survey ranged from 0.11 day^{-1} at 20°C, at RM 45.65 upstream from Gas City, to 0.16 day^{-1} at 20°C, at RM 35.90 upstream from the Marion dam.

The stream-decay rate for CBOD, K_r, was calculated on the basis of CBOD load rather than concentration. Load was used so that changes in concentration due to dilution could be taken into account (Thomann, 1972, p. 96).

$$K_r = \ln \left[\frac{C_d}{C_u} \right] t^{-1} \tag{8}$$

where

K_r is the stream-decay rate for CBOD, in day^{-1},

C_d and C_u the loads of CBOD at downstream and upstream sites, respectively, in pounds per day,

t the time of travel between the two sites, in days,

and

ln the natural logarithm, base e.

Table 9.--Carbonaceous biochemical-oxygen-demand data for sampling stations in the Mississinewa River basin, Grant County, Ind., August 5, 1977

[Day, number of days after beginning of analysis; data collected and analyzed by Indiana State Board of Health]

Location and station: Marion wastewater-treatment facility (501-A)			Location and station: Mississinewa River at State Route 37 (501-1)			Location and station: Mississinewa River at State Route 15 (501-2)		
Day	CBOD (mg/L)	Percent remaining	Day	CBOD (mg/L)	Percent remaining	Day	CBOD (mg/L)	Percent remaining
2	1.8	72	2	2.8	74	2	1.5	77
4	3.3	49	4	4.2	61	4	2.7	59
5	3.5	46	5	5.4	50	5	3.0	54
7	3.7	43	7	7.1	34	7	4.0	39
10	4.5	31	10	7.8	28	10	4.8	27
14	5.5	15	14	9.4	13	14	5.7	14
17	6.0	8	17	10.8	--	17	6.3	4
20	6.2	1	20	10.8	--	20	6.5	1
Ultimate CBOD = 6.5 mg/L K_d (base e) = 0.17 day^{-1}			Ultimate CBOD = 10.8 mg/L K_d (base e) = 0.15 day^{-1}			Ultimate CBOD = 6.6 mg/L K_d (base e) = 0.21 day^{-1}		

Table 10.--Carbonaceous biochemical-oxygen-demand data for sampling stations in the Mississinewa River basin, Grant County, Ind., June 7, 1978

[Day, number of days after beginning of analysis; data collected and analyzed by Indiana State Board of Health]

Location and station: Marion wastewater-treatment facility (501-A)			Location and station: Mississinewa River at State Route 37 (501-1)			Location and station: Mississinewa River at State Route 15 (500-2)		
Day	CBOD (mg/L)	Percent remaining	Day	CBOD (mg/L)	Percent remaining	Day	CBOD (mg/L)	Percent remaining
1	1.5	95	1	1.0	86	1	1.4	79
2	3.3	88	2	2.2	68	2	2.4	63
3	8.1	70	3	3.3	52	3	3.4	47
4	10.1	63	4	3.6	47	4	3.9	40
5	12.5	54	5	4.0	41	5	4.3	34
6	14.5	46	6	4.5	34	6	4.7	28
8	17.7	35	8	5.0	26	8	5.2	19
9	18.8	30	9	5.1	25	9	5.3	18
12	23.2	14	12	5.6	17	12	5.7	12
14	24.6	9	14	6.2	9	14	6.2	5
15	25.0	7	15	6.3	8	15	6.4	2
17	25.9	4	17	6.6	3	17	6.5	--
Ultimate CBOD = 27.0 mg/L K_d (base e) = 0.19 day^{-1}			Ultimate CBOD = 6.8 mg/L K_d (base e) = 0.18 day^{-1}			Ultimate CBOD = 6.5 mg/L K_d (base e) = 0.18 day^{-1}		

Table 11.--Carbonaceous biochemical-oxygen-demand data for sampling stations in the Mississinewa River basin, Grant County, Ind., August 15, 1978

[Day, number of days after beginning of analysis; data collected and analyzed by Indiana State Board of Health]

Location and station: Tenth Street, Jonesboro (505-2)			Location and station: Owens-Illinois, Inc. (504-B)			Location and station: Gas City wastewater-treatment facility (504-A)		
Day	CBOD (mg/L)	Percent remaining	Day	CBOD (mg/L)	Percent remaining	Day	CBOD (mg/L)	Percent remaining
1	1.7	84	1	1.4	86	1	3.9	93
3	3.6	65	3	2.0	80	3	15.1	72
5	4.8	53	5	4.1	59	5	21.6	60
7	5.5	47	8	5.2	48	8	30.3	44
10	7.2	30	10	6.6	34	10	35.7	34
14	8.5	18	13	7.3	27	13	40.4	25
18	9.4	9	17	8.8	12	17	47.0	13
20	9.8	5	20	9.7	3	20	50.3	7

Tenth Street, Jonesboro (505-2)	Owens-Illinois, Inc. (504-B)	Gas City wastewater-treatment facility (504-A)
Ultimate CBOD = 10.3 mg/L	Ultimate CBOD = 10.0 mg/L	Ultimate CBOD = 54.0 mg/L
K_d (base e) = 0.11 day^{-1}	K_d (base e) = 0.16 day^{-1}	K_d (base e) = 0.13 day^{-1}

Table 11.--Carbonaceous biochemical-oxygen-demand data for sampling stations in the Mississinewa River basin, Grant County, Ind., August 15, 1978--Continued

Location and station: Mississinewa River at State Route 22 (504)			Location and station: Back Creek at confluence with Mississinewa River (017-1)			Location and station: Mississinewa River at Cemetery Road (503-2)		
Day	CBOD (mg/L)	Percent remaining	Day	CBOD (mg/L)	Percent remaining	Day	CBOD (mg/L)	Percent remaining
1	1.7	83	1	1.6	84	1	1.7	88
3	3.4	66	3	3.7	62	3	4.7	67
5	4.7	53	5	4.9	50	5	6.7	53
7	5.1	49	7	6.1	38	7	8.8	39
10	7.0	29	10	7.4	25	10	10.9	24
14	8.4	15	14	8.5	13	14	12.5	13
18	9.1	8	18	9.5	3	18	13.6	5
20	9.5	4	20	9.7	1	20	14.1	1

Ultimate CBOD = 9.9 mg/L
K_d (base e) = 0.14 day^{-1}

Ultimate CBOD = 9.8 mg/L
K_d (base e) = 0.14 day^{-1}

Ultimate CBOD = 14.3 mg/L
K_d (base e) = 0.17 day^{-1}

Table 11.--Carbonaceous biochemical-oxygen-demand data for sampling stations in the Mississinewa River basin, Grant County, Ind., August 15, 1978--Continued

Location and station: Mississinew River at Pennsylvania Avenue (501-4)			Location and station: Anaconda Wire and Cable (501-4A)			Location and station: Mississinewa River at State Route 18 (501-3)		
Day	CBOD (mg/L)	Percent remaining	Day	CBOD (mg/L)	Percent remaining	Day	CBOD (mg/L)	Percent remaining
1	2.5	88	1	0.4	96	1	2.4	89
3	6.7	68	3	2.0	81	3	6.4	70
5	10.4	51	5	4.6	57	5	10.3	51
7	13.2	37	8	6.2	42	7	14.0	33
10	16.2	23	10	6.6	38	10	16.3	22
14	18.1	14	13	9.0	15	14	18.0	14
18	20.0	5	17	9.3	12	18	19.5	7
20	20.7	1	20	9.7	9	20	20.4	3
Ultimate CBOD = 21.0 mg/L K_d (base e) = 0.15 day^{-1}			Ultimate CBOD = 10.6 mg/L K_d (base e) = 0.13 day^{-1}			Ultimate CBOD = 21.0 mg/L K_d (base e) = 0.15 day^{-1}		

Table 11.--Carbonaceous biochemical-oxygen-demand data for sampling stations in the Mississinewa River basin, Grant County, Ind., August 15, 1978--Continued

Location and station: Indiana Street sewer (501-3A)			Location and station: Mississinewa River at Highland Avenue (501-2)			Location and station: Mississinewa River at State Route 37 (501-1)		
Day	CBOD (mg/L)	Percent remaining	Day	CBOD (mg/L)	Percent remaining	Day	CBOD (mg/L)	Percent remaining
1	136.8	74	1	2.0	87	1	1.6	89
3	262.9	49	3	5.3	65	3	4.3	71
5	316.4	39	5	8.0	47	5	6.0	60
7	355.5	32	7	9.7	35	7	7.8	47
10	401.7	23	10	12.0	20	10	10.4	30
14	440.8	15	14	12.9	14	14	12.4	16
18	479.6	8	18	13.9	7	18	13.5	9
20	493.0	5	20	14.2	5	20	14.3	3

Ultimate CBOD = 520.0 mg/L
K_d (base e) = 0.13 day^{-1}

Ultimate CBOD = 15.0 mg/L
K_d (base e) = 0.15 day^{-1}

Ultimate CBOD = 14.8 mg/L
K_d (base e) = 0.14 day^{-1}

Table 11.--Carbonaceous biochemical-oxygen-demand data for sampling stations in the Mississinewa River basin, Grant County, Ind., August 15, 1978--Continued

Location and station: Marion wastewater-treatment facility (501-A)			Location and station: Mississinewa River at State Route 15 (500-2)			Location and station: Mississinewa River at Washington Street (501-2.5)		
Day	CBOD (mg/L)	Percent remaining	Day	CBOD (mg/L)	Percent remaining	Day	CBOD (mg/L)	Percent remaining
1	---	94	1	2.0	86	1	1.6	87
3	0.5	65	3	5.7	59	3	3.7	70
5	3.1	42	5	7.8	44	5	5.6	55
8	5.2	37	7	9.0	35	7	7.6	39
10	5.6	18	10	10.2	27	10	10.0	20
13	7.3	18	14	11.5	17	14	11.0	12
17	8.3	7	18	12.6	9	18	11.7	6
20	8.7	2	20	13.2	5	20	12.3	2
Ultimate CBOD = 8.9 mg/L K_d (base e) = 0.20 day^{-1}			Ultimate CBOD = 13.9 mg/L K_d (base e) = 0.12 day^{-1}			Ultimate CBOD = 12.5 mg/L K_d (base e) = 0.16 day^{-1}		

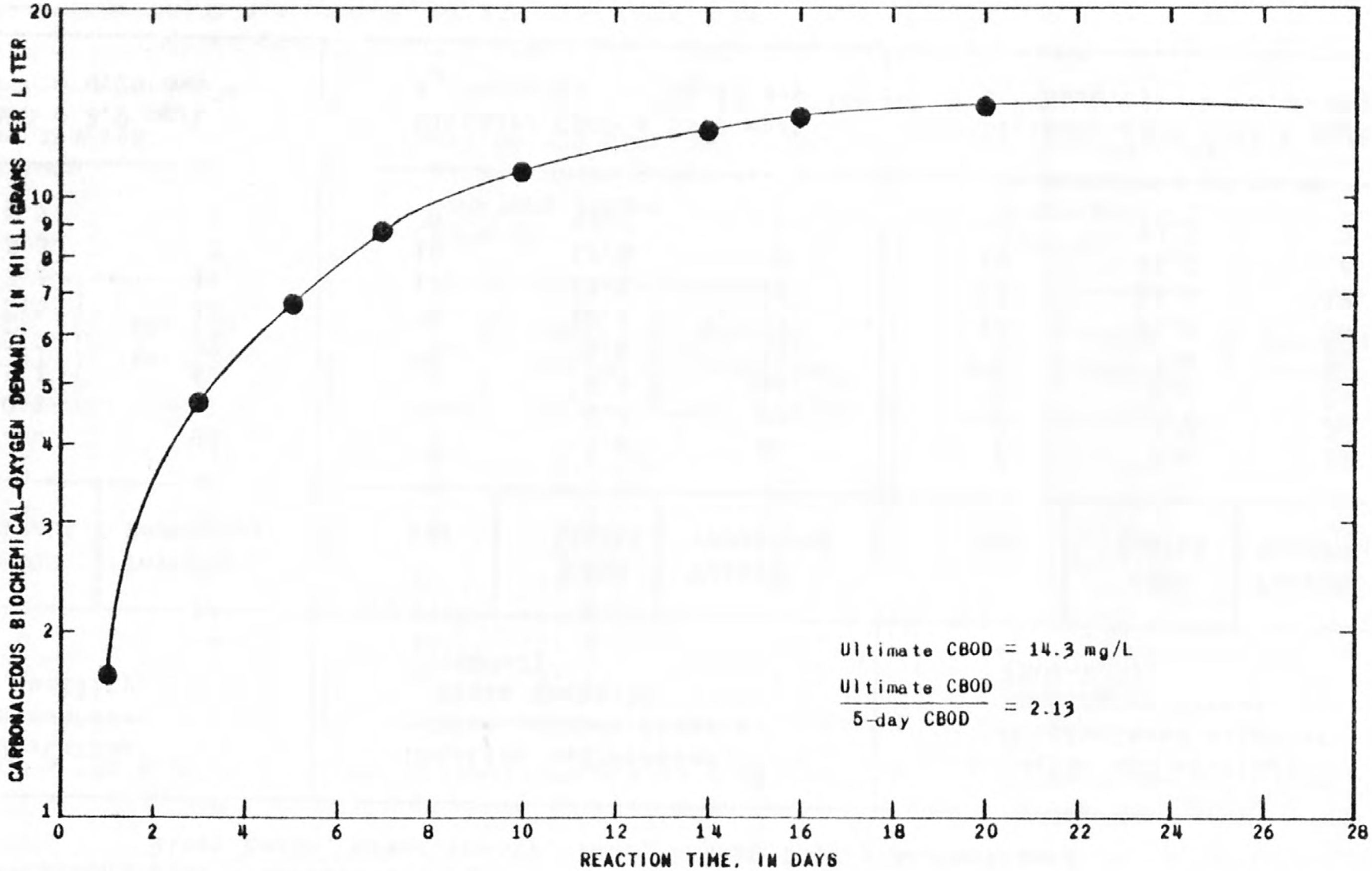

Figure 11.-- Relation of carbonaceous biochemical-oxygen demand to time at river mile 44.10, Mississinewa River, August 15, 1978.

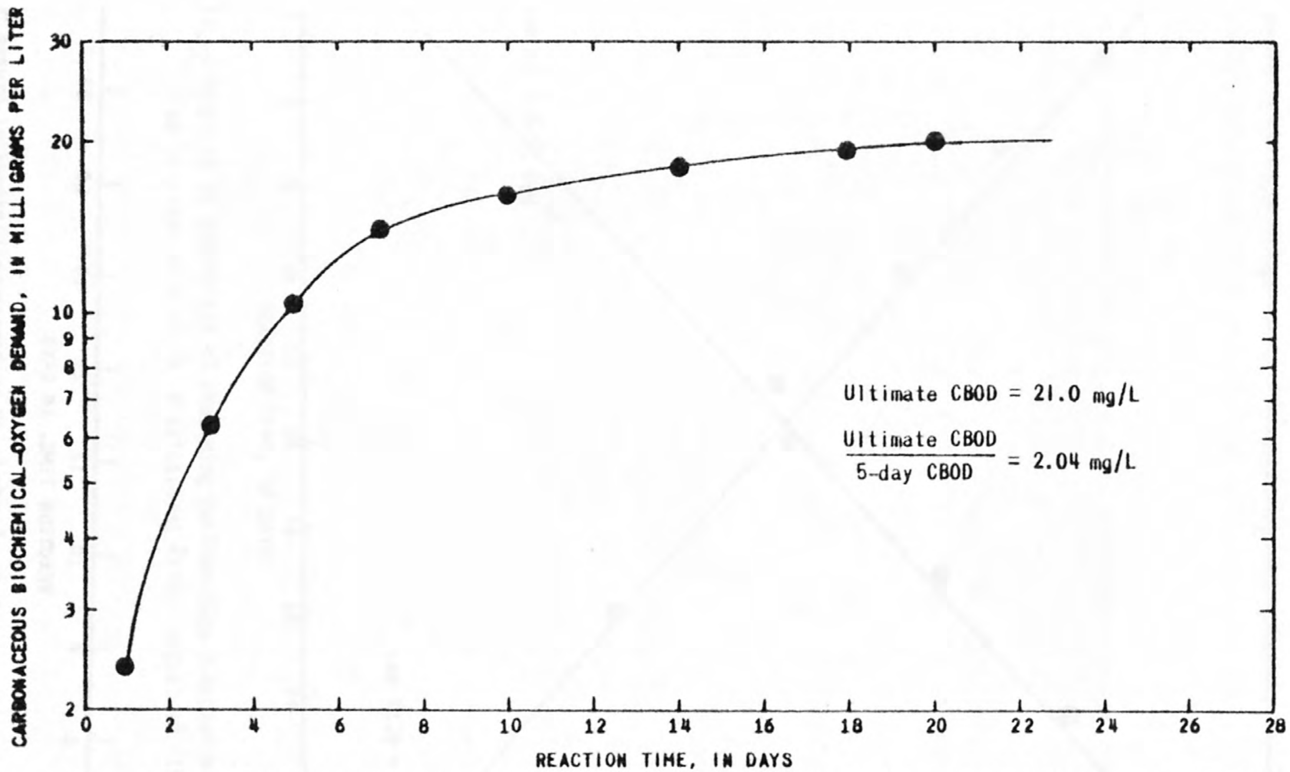

Figure 12.-- Relation of carbonaceous biochemical-oxygen demand to time at river mile 37.78, Mississinewa River, August 15, 1978.

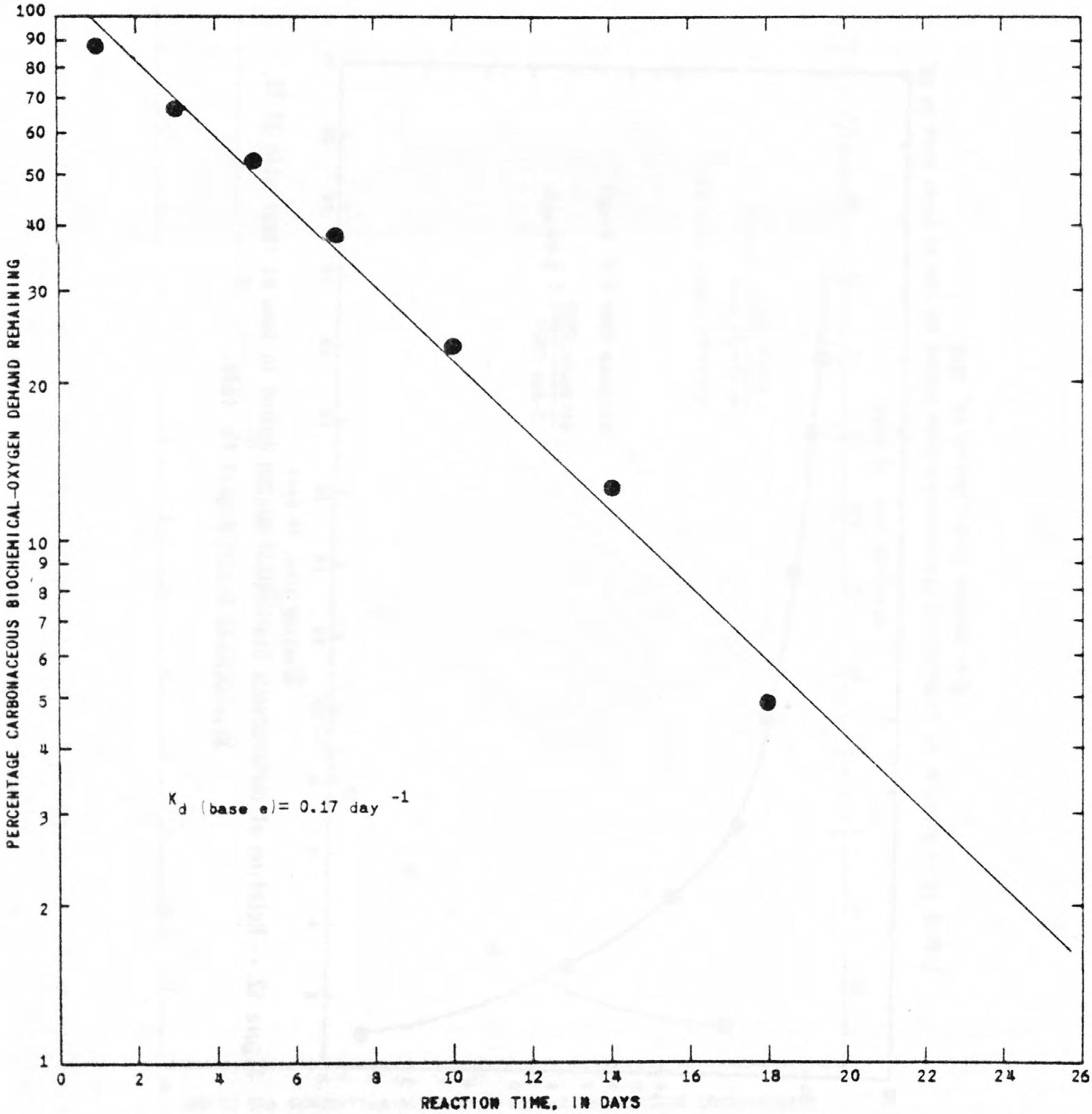

Figure 13.-- Relation of percentage of remaining carbonaceous biochemical-oxygen demand to time at river mile 44.10, Mississinewa River, August 15, 1978.

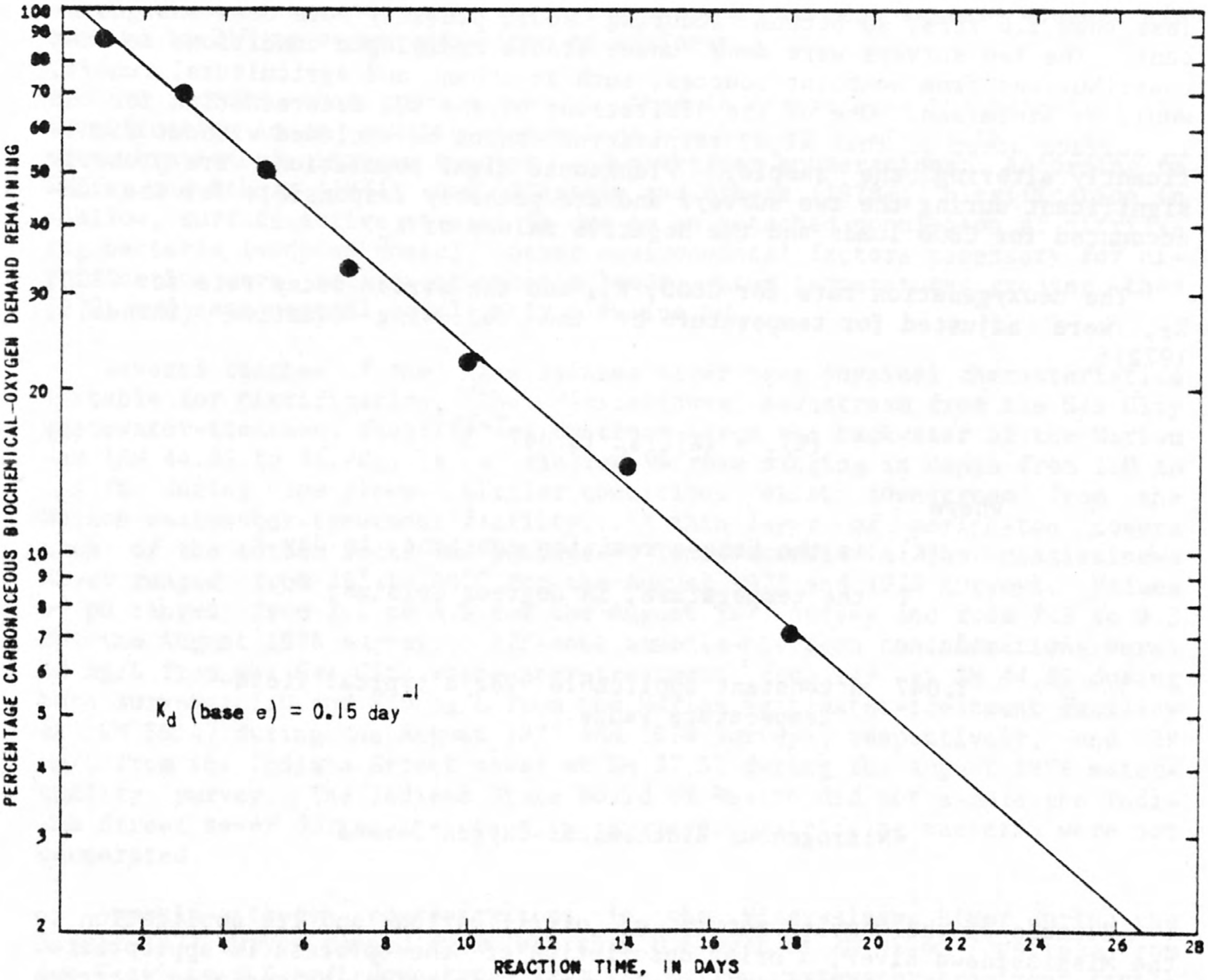

Figure 14.-- Relation of percentage of remaining carbonaceous biochemical-oxygen demand to time at river mile 37.78, Mississinewa River, August 15, 1978.

In both model calibrations, in-stream CBOD loads were higher than could be accounted for by mass balancing known inputs. Values of K_r necessary to match observed stream CBOD concentrations ranged from -0.2 to 0.6 day^{-1} for the August 1977 calibration and from -5.0 to 3.0 day^{-1} at 20°C for the August 1978 calibration. Negative values of K_r may be attributed to bottom scour, nonpoint-source pollution, or algal respiration in the BOD analysis. Stream velocities in the Mississinewa River during the two surveys were low, less than 1.0 ft/s, so bottom scouring would probably have been insignificant. The two surveys were done under stable hydrologic conditions so that contributions from nonpoint sources, such as urban and agricultural runoff, would be minimized. One of the limitations of the BOD determination for use in surface water is that algal respiration cannot be excluded without significantly altering the sample. Planktonic algal populations were probably significant during the two surveys and are probably responsible for the unaccounted for CBOD loads and the negative values of K_r.

The deoxygenation rate for CBOD, K_d, and the stream decay rate for CBOD, K_r, were adjusted for temperature by the following equation (Shindala, 1972):

$$(K)_T = (K)_{20°C} \, (1.047^{T-20°C}) \tag{9}$$

where

(K) is the base-e reaction constant, in day^{-1},

T the temperature, in degrees Celsius,

and

1.047 a constant applicable over a typical field-temperature range.

Nitrogenous Biochemical-Oxygen Demand

Because of the complex nature of nitrification and its application to the Mississinewa River, a brief description of the process is appropriate. In the broadest sense, nitrification is the biologically mediated increase in the oxidation state of reduced organic or inorganic forms of nitrogen. A narrower definition restricts nitrification to the autotrophic oxidation of ammonia to nitrate; nitrite is an intermediate compound. The two-step oxidation by nitrifying bacteria is as follows:

Ammonia oxidation (<u>Nitrosomonas</u>)

$$NH_4^+ + {}^3/_2\, O_2 = NO_2^- + 2H^+ + H_2O + \text{energy} \tag{10}$$

Nitrite oxidation (<u>Nitrobacter</u>)

$$NO_2^- + {}^1/_2\, O_2 = NO_3^- + \text{energy} \tag{11}$$

The amounts of dissolved oxygen consumed by this process can be significant. Wezernak and Gannon (1967) found experimentally that 3.22 mg of molecular oxygen is needed to convert 1 mg of ammonia nitrogen (NH_4 - N) to nitrite nitrogen (NO_2 - N) and that 1.11 mg is needed to convert 1 mg of nitrite nitrogen to nitrate nitrogen [NO_2 - N to NO_3 - N]. In a typical non-nitrified secondary effluent, the ammonia-nitrogen concentration may range from 12 to 50 mg/L (Metcalf and Eddy, Inc., 1972, p. 231). The potential oxygen demand placed on the receiving stream in this example would range from 62 to 217 mg oxygen per liter of effluent.

The factors that should be evaluated in determining the potential for nitrification in an aquatic environment are habitat suitability, changes in concentration of nitrogen species, and nitrifier enumerations. According to Tuffey and others (1974) and Finstein and others (1978), nitrification in shallow, surface-active streams is due to an attached population of nitrifying bacteria (nonplanktonic). Other environmental factors necessary for nitrification are sufficient ammonia loads, water temperatures greater than 20°C, and near-neutral or slightly alkaline pH.

Several reaches of the Mississinewa River have physical characteristics suitable for nitrification. The Mississinewa, downstream from the Gas City wastewater-treatment facility and upstream from the backwater of the Marion dam (RM 44.85 to 41.70), is a shallow stream ranging in depth from 1.0 to 3.0 ft during low flows. Similar conditions exist downstream from the Marion wastewater-treatment facility. A thin layer of periphyton covers much of the bottom rocks and cobbles. Temperatures in the Mississinewa River ranged from 25° to 26°C for the August 1977 and 1978 surveys. Values of pH ranged from 7.1 to 8.5 for the August 1977 survey and from 7.3 to 9.2 for the August 1978 survey. Effluent ammonia-nitrogen concentrations were: 12 mg/L from the Gas City wastewater-treatment facility at RM 44.85 during both surveys; 1.0 and 7.9 mg/L from the Marion wastewater-treatment facility at RM 55.47 during the August 1977 and 1978 surveys, respectively; and 29 mg/L from the Indiana Street sewer at RM 37.51 during the August 1978 water-quality survey. The Indiana State Board of Health did not sample the Indiana Street sewer during the other two surveys. Nitrifying bacteria were not enumerated.

Ammonia-nitrogen concentrations in the Mississinewa River during the August 1977 survey ranged from less than 0.1 mg/L at RM 45.65 (upstream from Gas City) to 0.5 mg/L downstream from the Marion wastewater-treatment facility. At 43 percent of the stations sampled, the ammonia-nitrogen concentration was less than the detection limit of the method used, 0.1 mg/L. Nitrite-nitrogan plus nitrate-nitrogen concentrations in the Mississinewa River ranged from less than 0.1 mg/L at RM 45.65 to 3.5 mg/L downstream from the Marion wastewater-treatment facility. The general decrease in the instream ammonia-nitrogen and nitrite-nitrogen plus nitrate-nitrogen load, downstream from the Gas City and Marion wastewater-treatment facilities, may be attributed to nitrification and (or) algal uptake.

Ammonia-nitrogen concentrations in the Mississinewa River during the August 1978 survey ranged from less than 0.1 mg/L at RM 45.65 to 1.7 mg/L downstream from the Marion wastewater-treatment facility. The concentration of nitrite nitrogen plus nitrate nitrogen in the Mississinewa River ranged from less than 0.1 mg/L at RM 37.78 (downstream from Gas City) to 0.7 mg/L at RM 45.65.

An increase in the nitrite-nitrogen plus nitrate-nitrogen load corresponding to a decrease in the ammonia-nitrogen load was observed with distance downstream from the Marion wastewater-treatment facility. Because this condition suggests nitrification, the authors decided to include nitrification in the model calibration.

A mass-balance for nitrogen species was not achieved for the two water-quality surveys on the Mississinewa. Whether changes in the concentration of ammonia nitrogen or nitrate nitrogen in the Mississinewa are attributable to nitrification alone would be difficult to determine. Nitrification causes a decrease in the ammonia-nitrogen concentration and an increase in the nitrate-nitrogen concentration. However, the ammonia-nitrogen concentration of the stream may increase, owing to the hydrolysis of organic nitrogen or the reduction of nitrate nitrogen, or may decrease, owing to aquatic plant consumption, equilibration, or conversion to organic nitrogen for cell synthesis by heterotrophic bacteria. Factors other than nitrification effecting a change in nitrate-nitrogen concentration in a stream include denitrification, respiratory reduction, and assimilatory reduction (Ruane and Krenkel, 1977). Consequently, because of the difficulty in estimating the significance of these processes, a mass balance for nitrogen species from upstream to downstream locations is not always achieved. During the two August water-quality surveys on the Mississinewa, aquatic plant consumption may have been partly responsible for the observed ammonia-nitrogen loss.

For the model calibration, the deoxygenation rates for NBOD (K_n) were determined on the basis of the change in ammonia-nitrogen load and first-order kinetics.

$$K_{n,\ \text{first order}} = \ln \left[\frac{C_d}{C_u} \right] t^{-1} \qquad (12)$$

where

$K_{n,\ \text{first order}}$ is the first-order kinetics deoxygenation rate for NBOD, in day^{-1},

C_d and C_u the loads of ammonia nitrogen at upstream and downstream sites, respectively, in pounds per day,

t the time of travel between the two sites, in days,

and

ln the natural lograithm, base e.

For example, the deoxygenation rate for NBOD, downstream from the Marion wastewater-treatment facility, in the reach from stations 500-4 to 500-2 (RM 33.60 to 31.60) was estimated to be 3.0 day^{-1} at 20°C.

$$K_n = \ln \frac{\left[\frac{194.4}{341.2} \right]}{0.123\ d}$$

$$K_n = 4.57\ day^{-1} \text{ at } 25°C$$

$$K_n = 2.97\ day^{-1} \text{ at } 20°C$$

Nitrogenous decay coefficients were adjusted for temperature by the following equation (Shindala, 1972):

$$(K)_T \text{ nitrogenous } = K_{20°C}(1.09^{T-20°C}) \quad (13)$$

where

(K) is the base-e reaction constant, in day^{-1},

T the temperature, in degrees Celsius,

and

1.09 a constant applicable over a typical field-temperature range.

Calculated nitrogenous decay coefficients varied widely. For the August 1977 calibration, K_n ranged from 0.6 day^{-1} at 20°C, downstream from the Gas City wastewater-treatment facility, to 3.0 day^{-1} at 20°C, downstream from the Marion wastewater-treatment facility. Nitrification was assumed to be negligible in the reach extending from the confluence of Walnut Creek and the Mississinewa River at RM 41.70 to the Marion wastewater-treatment facility at RM 35.47 because little change in nitrogen species load was observed during the two surveys. Nitrification rates used in the August 1978 calibration ranged from 0.0 day^{-1} to 6.0 day^{-1} at 20°C.

Benthic-Oxygen Demand

A visual inspection of the modeled reach revealed no significant benthic deposits. Benthic-oxygen demand was not measured during the two surveys and was not included in the model.

Reaeration is generally the most important single parameter used in describing a stream's ability to assimilate biodegradable material. Many of the common empirical or semi-empirical equations used to predict reaeration assume that gaseous exchange varies directly with stream velocity and inversely with stream depth and that reaeration increases with decreasing flow (Churchill and others, 1962; O'Connor and Dobbins, 1958; Owens and others, 1964; Thackston and Krenkel, 1969). However, channel morphology should also be considered in the determination of reaeration. Langbein and Durum (1967) indicated that gaseous-exchange rates increase with decreasing flow in riffles but decrease in pools. The low slopes of most Indiana streams usually cause the pooled condition to predominate. In addition, several investigators using the radioactive-tracer technique to determine reaeration reported a strong correlation between reaeration and channel slope (Tsivoglou and Neal, 1976; Foree, 1976). Foree (1976), in a study of small streams in Kentucky, observed a general tendency for reaeration to decrease with decreasing specific discharge (discharge per unit area).

The equation used to predict reaeration in this study is the energy-dissipation model developed by Tsivoglou and Neal (1976, p. 2686).

$$K_a = 0.110\ SV, \quad \text{when } 1 \leq Q \leq 10\ ft^3/s \qquad (14)$$

$$K_a = 0.054\ SV, \quad \text{when } 25 \leq Q \leq 3{,}000\ ft^3/s \qquad (15)$$

where

K_a is the base-e reaeration rate, at 20°C, in day^{-1},

0.110 and 0.054 the gaseous-escape coefficients for equations 14 and 15, respectively, in $feet^{-1}$,

S the stream channel slope, in feet per mile,

V the stream velocity, in miles per day,

and

Q the stream discharge, in cubic feet per second.

Grant (1976b), using the radioactive-tracer technique to determine reaeration in small streams in Wisconsin with flows less than 37 ft^3/s, determined a gaseous-escape coefficient of 0.081 $ft^{-1} \pm$ 0.014 ft^{-1} at 20°C. This coefficient is in fair agreement with the gaseous-escape coefficient determined by Tsivoglou and Neal (1976) for small streams.

Wilson and Macleod (1974) concluded from a statistical evaluation of 16 predictive reaeration equations that equations containing slope give better results than equations based on velocity and depth. In a similar study, Rathbun (1977) compared 19 reaeration equations with reaeration rates determined directly and concluded that the energy-dissipation model of Tsivoglou and Neal (1976, p. 2686) is the best overall equation.

Reaeration rates were adjusted for temperature by the following equation (Shindala, 1972):

$$(K)_T \text{ reaeration} = (K)_{20^\circ C}\,(1.021^{T-20^\circ C}), \qquad (16)$$

where

(K) is the base-e reaction constant, in day^{-1},

T the temperature, in degrees Celsius,

and

1.021 a constant applicable over a typical field-temperature range.

Photosynthesis

Net photosynthesis was evaluated by both the single-station and two-station methods developed by Odum (1956) as modified by Stephens and Jennings (1976).

In flowing water, where the incoming water has a metabolic composition similar to that of the outflowing water, a single sampling point may be sufficient to provide a representative diel curve of change in oxygen concentration. Where the metabolic characteristics of the inflowing water are not similar to those of the outflowing water, as in polluted stream reaches, a two-station or upstream-downstream analysis should be made.

The single-station method generates a relation describing the rate of change in dissolved-oxygen concentration per unit time and representing a 24-hour period of community metabolism for the stream at one point. The two-station method provides a diel relation representing the rate of change between stations at discrete sampling intervals. The models assume that production can occur only during daylight hours and that any change in dissolved-oxygen concentration during this period, after correction for diffusion, is due to production. Any change in dissolved-oxygen concentration during hours of darkness, after correction for diffusion, is attributed to respiration. Diel dissolved-oxygen fluctuations for the August 1978 survey were small, and, at most of the stations studied, the minimum dissolved-oxygen concentration was never less than 100 percent of saturation. The results of these calculations for the August 1978 survey, as well as values needed to "match" the observed dissolved-oxygen concentration in the stream, are presented in table 12. The dissolved-oxygen data collected during the August 1977 survey were insufficient to estimate net-photosynthetic oxygen production.

For the August 1978 survey, calculated net-photosynthetic DO-production values were much lower than those necessary to "match" observed dissolved-oxygen concentrations. Several possible explanations for this discrepancy should be mentioned. Although applicable to unpolluted streams, the method has not been tested on streams receiving significant waste loads. Additionally, the carbonaceous and nitrogenous biochemical-oxygen demands may have been overestimated. Furthermore, algal respiration and decay could confound the interpretation of calculated coefficients K_d and K_r. For the modeled reach, algae and nitrifying organisms could both be in competition for available ammonia nitrogen. In the model calibration, ammonia-nitrogen loss was assumed to be due to nitrification rather than to algal uptake.

To determine if the assumed DO deficits due to NBOD and CBOD could account for the difference between calculated and "adjusted" net-photosynthetic dissolved-oxygen production values, the authors computed the dissolved-oxygen profile for the August 1978 survey for an assumed constant in-stream CBOD decay rate (K_r) of 0.2 day^{-1} and zero nitrification. Under these conditions, where the dissolved-oxygen deficit was significantly reduced, calculated photosynthetic dissolved-oxygen production was still much lower than necessary to equal the observed in-stream dissolved-oxygen concentrations.

Average photosynthetic dissolved-oxygen production values reported by O'Connor and others (1970) for the Grand, Clinton, Truckee, and Flint Rivers ranged from 7.6 to 22.5 (mg/L)/day. All these rivers receive wastewater effluents similar to those received by the Mississinewa. Consequently, the photosynthetic values used in this study may not be unrealistic.

Table 12.--Comparison of calculated net-photosynthetic, dissolved-oxygen production values for modeled stream reaches with values used in model calibration for the Mississinewa River, Grant County, Ind.

Upstream boundary of modeled reach (river miles)	Calculated net-photosynthetic, dissolved-oxygen production, August 15, 1978		Net-photosynthetic, dissolved-oxygen production values used in August 15, 1978, model calibration [(mg/L)/d]	Net-photosynthetic, dissolved-oxygen production values used in August 5, 1977, model calibration [(mg/L)/d]
	Odum's (1956) single-station method [(mg/L)/d]	Odum's (1956) two-station method [(mg/L)/d]		
45.65	3.32	----	15.0	2.5
44.95	3.32	----	30.0	2.5
44.85	3.32	----	30.0	5.0
44.75	2.67	-7.7	40.0	8.0
44.51	2.67	-7.7	40.0	----
44.10	4.5	.2	25.0	8.0
42.60	4.5	.2	20.0	8.0
42.05	4.5	.2	20.0	8.0
41.70	4.5	.2	10.0	9.0
41.47	7.3	2.9	10.0	10.0
39.47	5.3	2.9	10.0	2.5
38.87	5.3	.8	10.0	1.5
37.78	2.0	.8	4.0	1.5
37.51	2.0	.6	4.0	----
36.91	1.3	.6	4.0	1.5
36.14	1.3	.6	4.0	1.5
35.90	3.2	28.9	12.0	2.0
35.76	3.7	28.9	40.0	2.0
35.47	3.7	28.9	40.0	17.0
35.20	1.2	7.8	25.0	----
34.88	1.2	7.8	25.0	14.0
34.30	-.2	1.0	10.0	9.0

Model-Calibration Results

The calculated and observed CBOD, NBOD, and dissolved-oxygen concentrations, as well as calculated flows, are illustrated in figures 15 through 22. Several observations of these results follow.

The calculated and observed values for CBOD and dissolved oxygen agree fairly closely. A modified form of the normalized-mean error, defined by Wilson and MacLeod (1974) was used as the criterion for comparison and is defined in equation 17.

$$\text{Normalized-mean error} = \left[\sum_{i=1}^{N} \frac{|A_{calc} - A_{obs}|}{A_{obs} N} \right] 100 \text{ percent} \qquad (17)$$

where

A_{calc} and A_{obs} are the calculated and observed values, respectively,

and

N the number of observations.

The absolute value of the error term has been included in the equation to avoid the cancelling of positive and negative errors, which gives a small error estimate, when, in fact, large positive and negative errors exist.

The normalized-mean error for CBOD was 1.3 percent for the August 1977 survey and 5.1 percent for the August 1978 survey. The normalized-mean error for dissolved oxygen was 3.2, and 1.9 percent for the August 1977 and 1978 surveys, respectively.

Calculated and observed NBOD concentrations differ considerably. The normalized-mean error was 33.3 and 117.2 percent for the August 1977 and 1978 calibrations, respectively. A lack of "fit" downstream from the Gas City and Marion wastewater-treatment facilities, at RM 44.75 and 35.20, respectively, may have been due to nonrepresentative sampling, a result of incomplete mixing of the waste effluent with the stream. In addition, nitrification is the only NBOD removal process accounted for in the model. Other removal processes such as algal uptake were not included and may account for a considerable amount of the variation.

Data collected during the August 1977 and June 1978 water-quality surveys indicate that the dissolved-oxygen concentration of Back Creek at Jonesboro had completely recovered from the effects of the Fairmount wastewater-treatment facility.

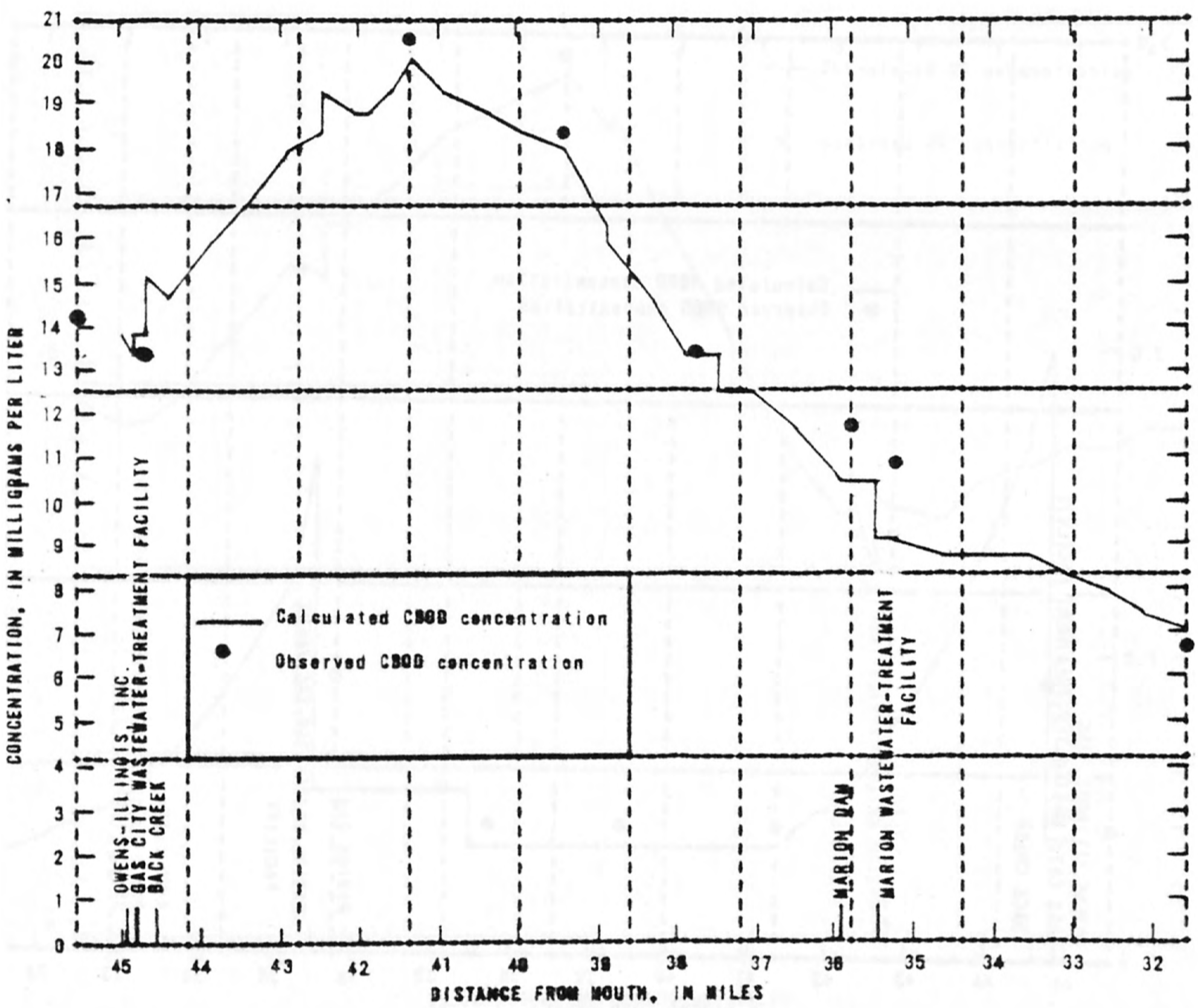

Figure 15.— Calculated and observed carbonaceous biochemical-oxygen-demand concentrations in Mississinewa River, August 5, 1977.

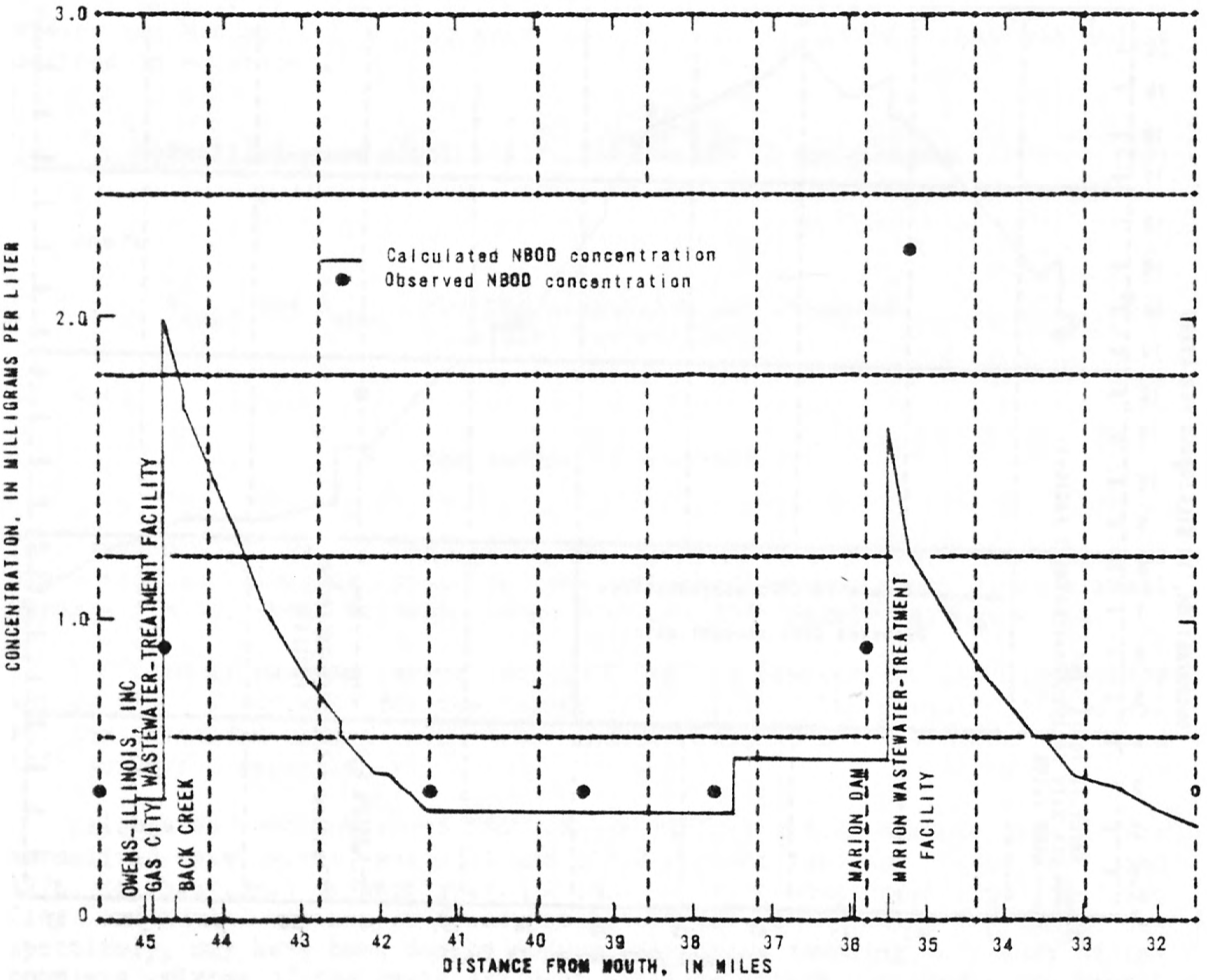

Figure 16.-- Calculated and observed nitrogenous biochemical-oxygen-demand concentrations in Mississinewa River, August 5, 1977.

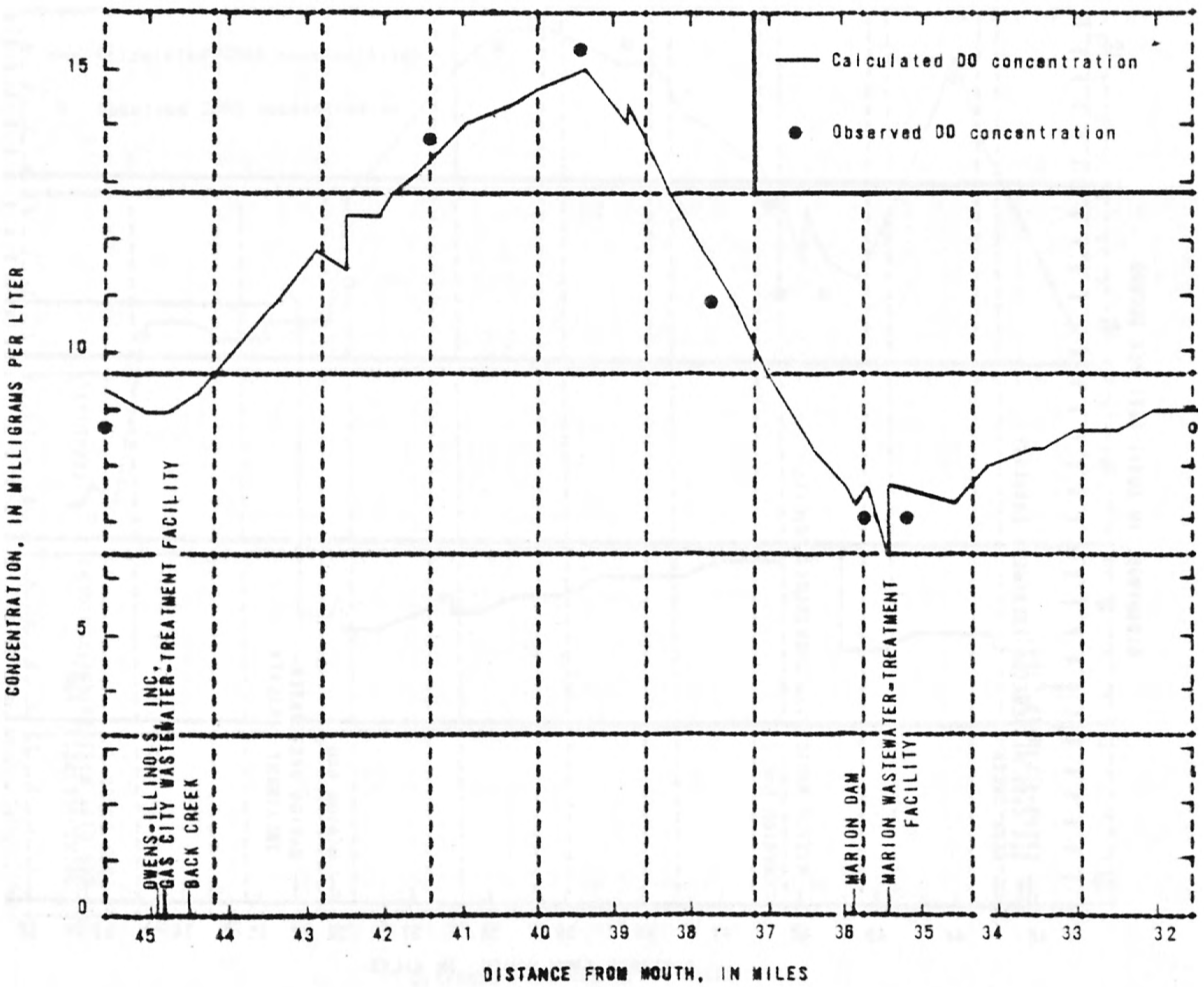

Figure 17.-- Calculated and observed dissolved-oxygen concentrations in Mississinewa River, August 5, 1977.

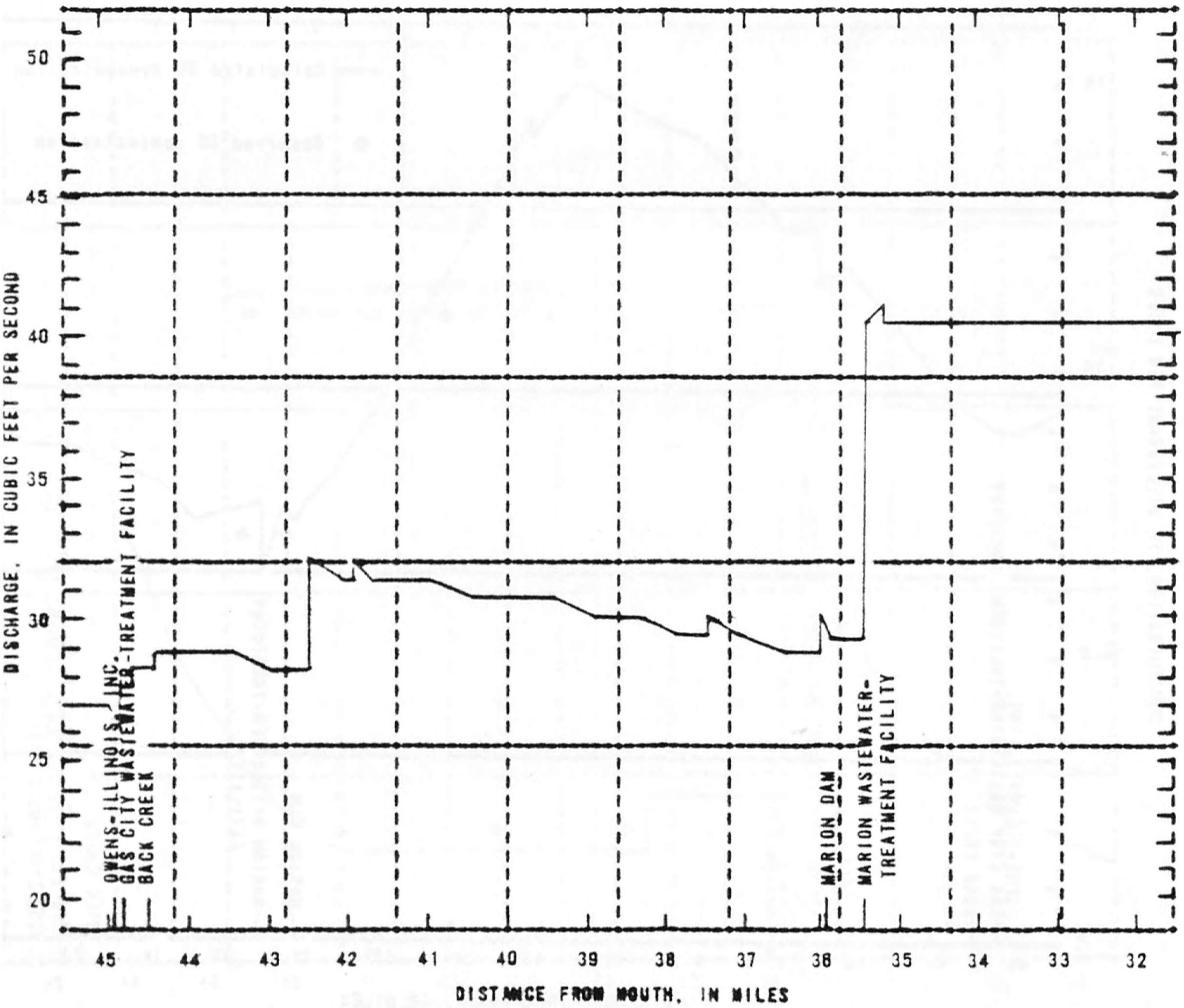

Figure 18.-- Discharge in Mississinewa River, August 5, 1977.

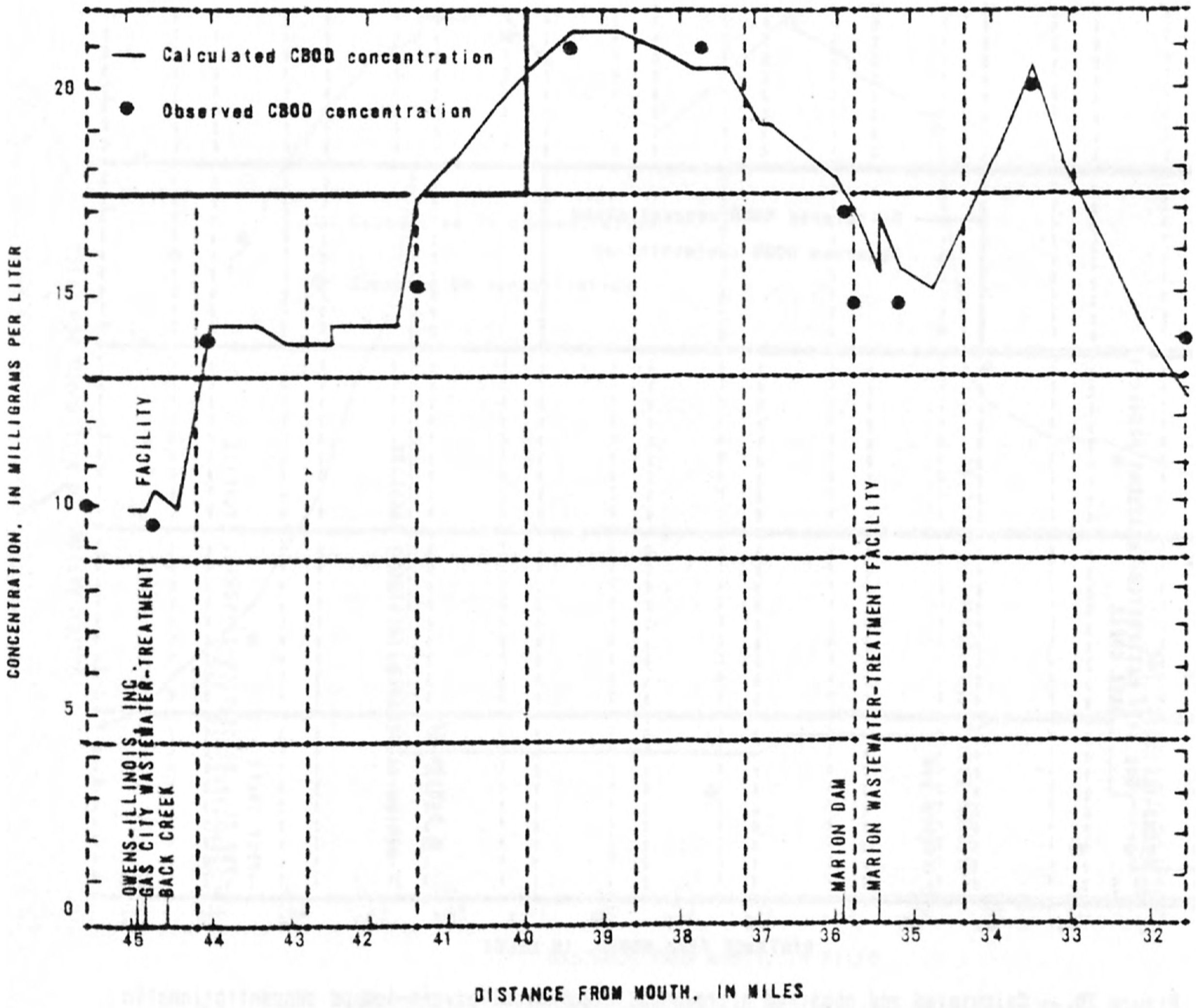

Figure 19.-- Calculated and observed carbonaceous biochemical-oxygen-demand concentrations in Mississinewa River, August 15, 1978.

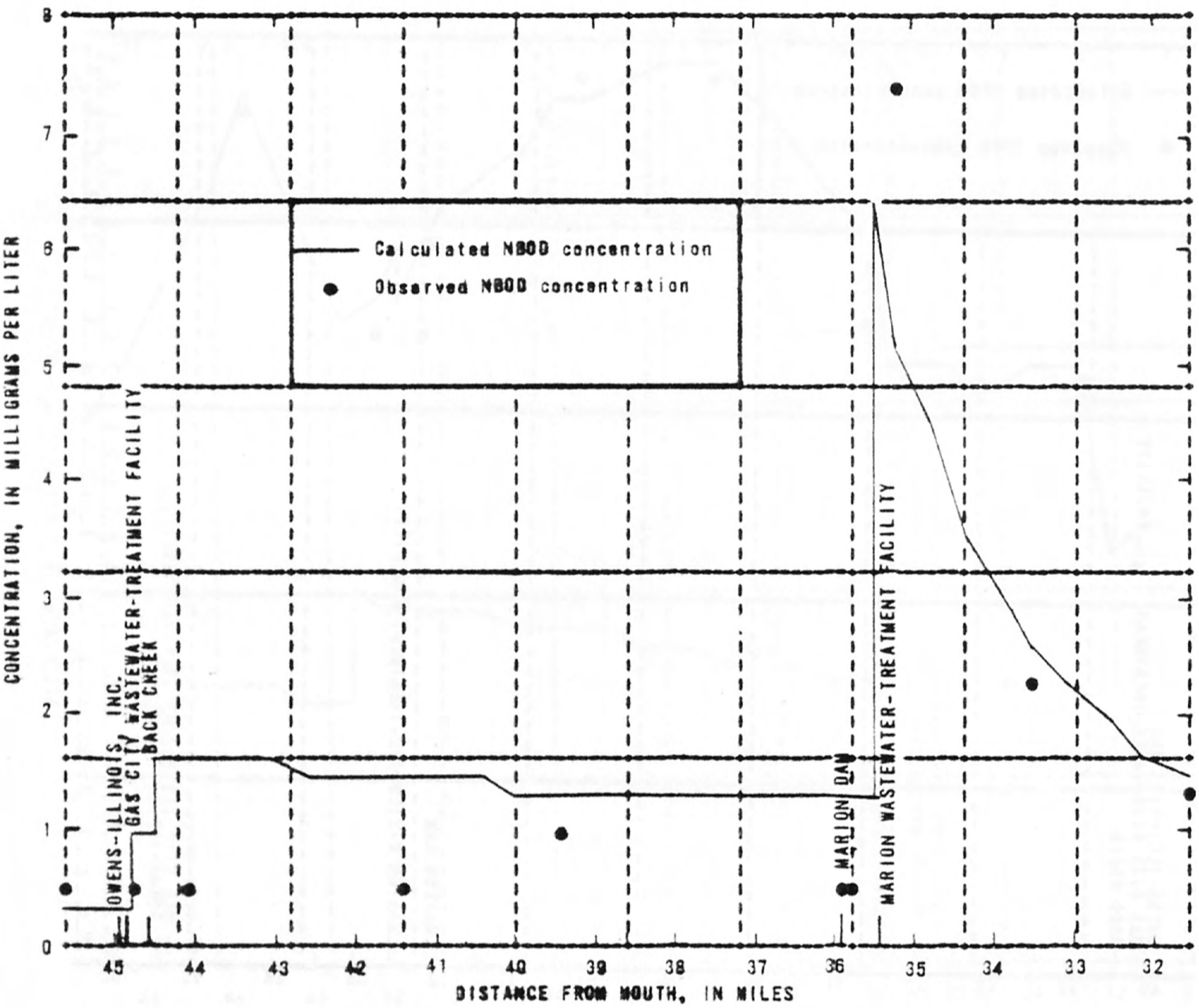

Figure 20.-- Calculated and observed nitrogenous biochemical-oxygen-demand concentrations in Mississinewa River, August 15, 1978.

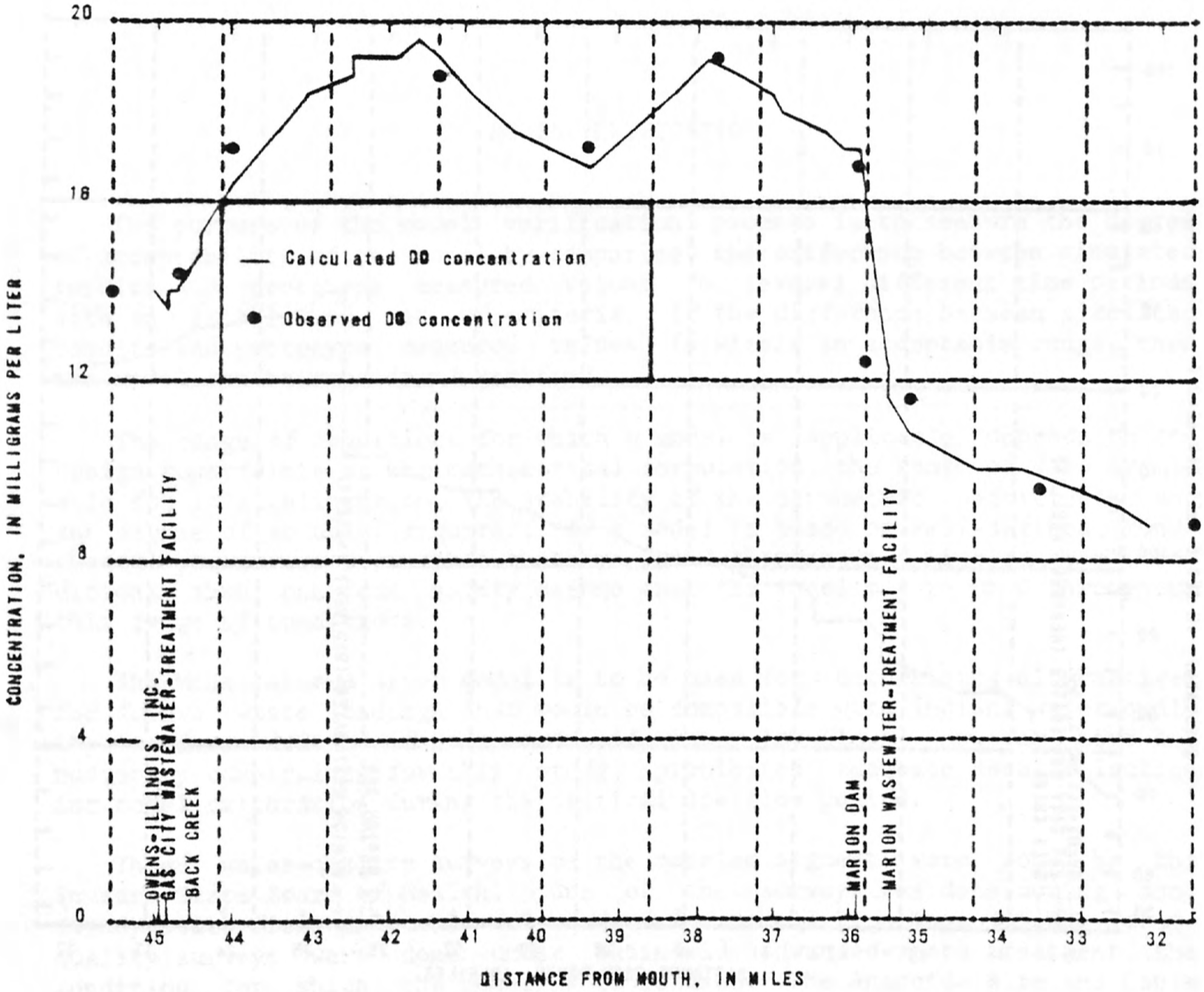

Figure 21.— Calculated and observed dissolved-oxygen concentrations in Mississinewa River, August 15, 1978.

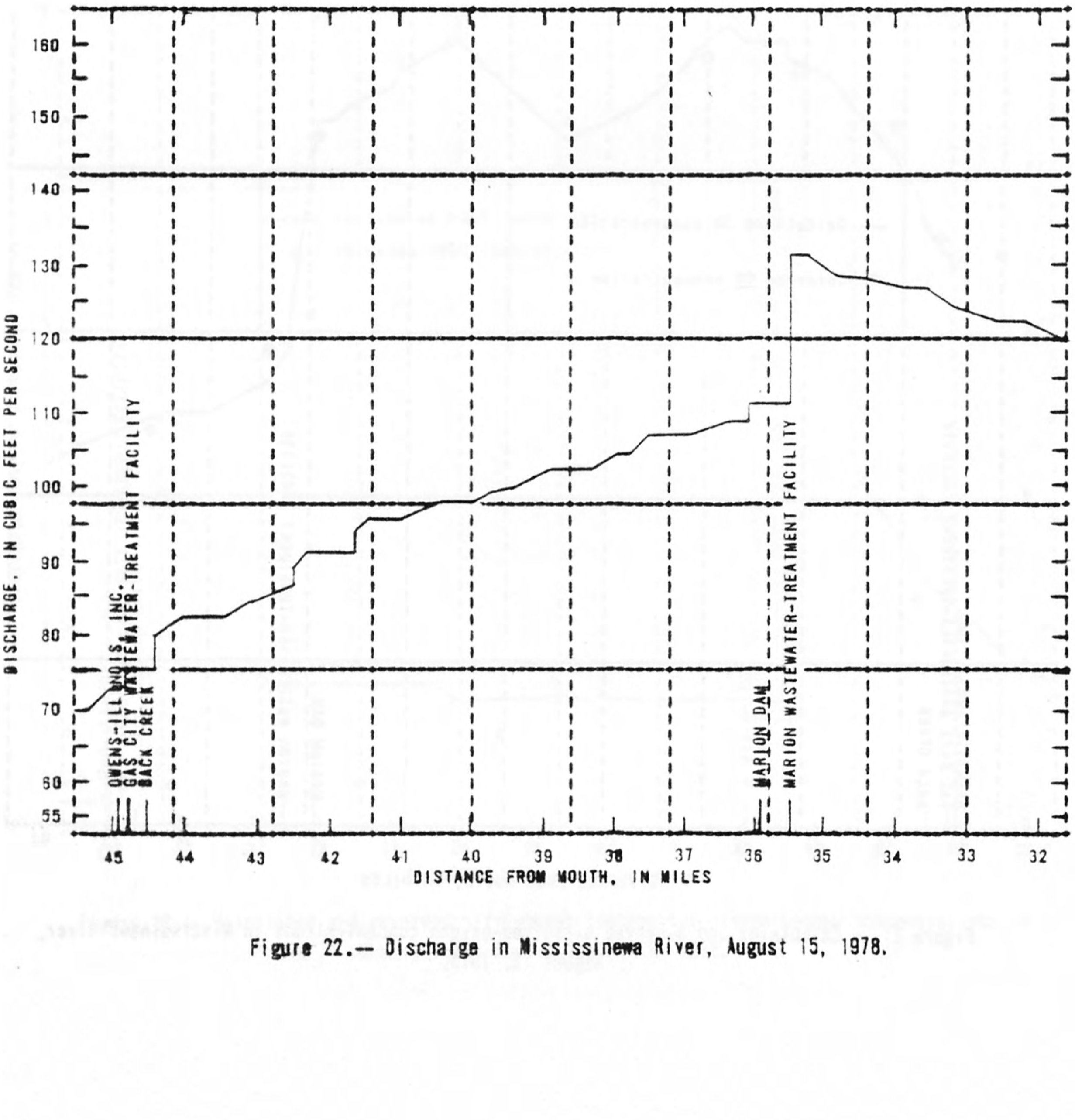

Figure 22.— Discharge in Mississinewa River, August 15, 1978.

No dissolved-oxygen sag and recovery was observed in the Mississinewa River in either survey downstream from the Gas City and Marion wastewater-treatment facilities or other point-source discharges. Algal productivity, combined with a low rate of gaseous exchange (reaeration), seemed to dominate the dissolved-oxygen dynamics of this system during the two surveys and, thus, to prevent an oxygen deficit.

MODEL VERIFICATION

The purpose of the model verification process is to measure the degree of acceptability of the model by comparing the difference between simulated results and prototype measured values for several different time periods with an established set of criteria. If the difference between simulated results and prototype measured values is within an acceptable range, then the model can be considered verified.

The range of conditions for which a model is applicable depends on the design constraints of the mathematical formulation, the range of data available for it's calibration, the stability of the parametric coefficients, and the degree of accuracy required. If a model is based on well-defined, fundamental processes or concepts that are valid throughout a wide range of conditions, then one can safely assume that the model may be used throughout this range of conditions.

The Mississinewa River model is to be used for determining alternatives for future waste loadings that would be compatible with Indiana water-quality standards defined for summer and winter low flows. However, time and budgetary constraints for this study, prohibited adequate data collection for model calibration during the critical low-flow period.

Three water-quality surveys on the modeled segment were done by the Indiana State Board of Health. One of the surveys was done during non-steady-state flows and could not be used for modeling. None of the water-quality surveys were done under basin-wide advanced-waste treatment, the condition for which the model is to be used. The Anaconda Wire and Cable outfalls at RM 38.87, the Indiana Street sewer at RM 37.51, and several tributaries were not sampled during the August 1977 and June 1978 surveys.

Algal productivity was significant in the modeled segment of the Mississinewa River and confounded the interpretation of calculated values of K_d, K_r, and K_n. Algal productivity was not measured during the two water-quality surveys. Because the available data were limited, the authors made numerous assumptions to determine the model-input parameters for the Mississinewa River. The error associated with some of these assumptions may be significant.

The predictive capability necessary to describe the stream processes in the Mississinewa River for a wide range of flow conditions has not been achieved. Consequently, the coefficients used in the model calibrations may not represent stream processes during the low-flow condition. The extrapolation of the calibration parameters to the low-flow $Q_{7,10}$ condition is an approximation of undetermined accuracy.

The Mississinewa River model cannot be considered verified at the low-flow $Q_{7,10}$ condition. However, lack of verification does not disqualify the Mississinewa River model for qualitative use in the waste-load assimilation analysis.

Because of significant variations in concentration of several of the model parameters, conclusions from the waste-load assimilation studies were based on a sensitivity analysis of several of the critical parameters, particularly nitrification. The purpose of this analysis was to determine the effect of these variations on the predictions of the model.

WASTE-LOAD ASSIMILATION

Waste-load assimilation studies were made for both the summer (June-August) and winter (November-March) low flows to determine the combination of waste loadings that would meet the current Indiana water-quality standards for the years 1978, 1980, 1987, and 2000.

Procedures

Procedures for determining the waste-load assimilative capacity of streams were furnished by the Indiana State Board of Health (1977). In the NPDES permit (Indiana State Board of Health, 1978), daily maximum and daily-average discharge loadings are given for industries, and weekly and monthly averages are given for the municipalities. (See table 1.)

To determine the waste-load assimilative capacity of the stream, as defined by the water-quality standards, the authors initially used maximum daily loadings (twice the monthly average) for the largest municipal discharger and average weekly loadings for the remainder of the municipal dischargers. For industries, the maximum daily loadings were initially used (Indiana State Board of Health, 1977). Where no CBOD permit had been issued, the combined data from the ISBH monthly report of operations for June-August and data from the ISBH Surveillance Section were used to determine an appropriate value.

Effluent limits for ammonia-nitrogen and dissolved-oxygen concentrations have not yet been established for the municipalities and industries in the Mississinewa River basin. The ammonia-nitrogen concentration of effluents at the four municipal wastewater-treatment facilities during the three water-quality surveys ranged from less than 0.1 mg/L at the Marion wastewater-treatment facility to 15 mg/L at the Fairmount wastewater-treatment facility. According to Metcalf and Eddy, Inc., (1972), the ammonia-nitrogen concentration of untreated domestic sewage ranges from 12 to 50 mg/L. The amount of ammonia removal in conventional secondary treatment is usually small. The extent of nitrification in the activated-sludge process is usually insignificant because the detention times for nitrifiers to proliferate are usually too short. Jenkins and Garrison (1968) found that, for a domestic wastewater treated by the activated-sludge process at a temperature of 21° to 22° C, a mean-cell residence time of at least 10 days was needed to ensure nitrification. As a result, the Indiana State Board of Health requested that 15 mg/L be used as the effluent ammonia-nitrogen concentration (65 mg/L NBOD) for the waste-load assimilation study. This value was assumed to be more representative of the effluent ammonia-nitrogen concentration expected during low flows than the ammonia-nitrogen concentration observed during the two water-quality surveys (Aolad Hossain, oral commun., 1978). A representative ammonia-nitrogen concentration for each wastewater-treatment facility is critical to the waste-load assimilation study of the Mississinewa River.

The initial dissolved-oxygen concentration of the wastewater effluents was assumed to be 80 percent of saturation (Aolad Hossain, Indiana State Board of Health, oral commun., 1978).

The Indiana Street sewer was included in the waste-load allocation for 1978 only because the sewer will probably have been connected to the existing sanitary sewer system by 1980.

Where the water-quality standards were not met, the CBOD and NBOD loads for the wastewater-treatment facilities were reduced until the appropriate standards were met. The determination of the combination of CBOD and NBOD loads that would just meet the Indiana water-quality standards defined the assimilative capacity of the stream.

Guidelines for the critical temperature and streamflow conditions used in the waste-load assimilation study were provided by the Indiana State Board of Health (1977). The summer $Q_{7,10}$ flow for the Mississinewa River at Marion, 22 ft^3/s, was used in the summer waste-load assimilation study model, and the annual $Q_{7,10}$ flow, 17 ft^3/s (Rohne, 1972, p. 72), was used in the winter model.

A temperature of 25°C was used in the summer waste-load assimilation study model. This temperature is based on the mean daily water temperature, which is exceeded 10-20 percent of the time for the months June through August. A temperature of 7°C was used in the winter model. This temperature is the average of the daily mean water temperature for October, the month with the lowest flow (Horner, 1976, p. 95). Temperatures for the Mississinewa River were estimated by the following equation:

$$T = M + A\,[\sin(0.0172\,\underline{d} + C)] \quad \text{(Shampine, 1977, p. 13)} \qquad (18)$$

where

T is the temperature at a given site on a specific day, in degrees Celsius,

M is 12.15, the mean annual stream temperature, in degrees Celsius,

A is 12.70, the stream temperature amplitude, in degrees Celsius,

$\underline{d}$ is the Julian date,

and

C is 4.30, the angle-phase coefficient, in radians.

For the headwaters, concentrations of constituents used in the waste-load assimilation study were assumed to be: ultimate CBOD, 5.0 mg/L; NBOD, 0.4 mg/L; and dissolved oxygen, 100 percent of saturation.

The deoxygenation rate for CBOD (K_d) was determined from the average of the rates used in the model calibrations. Because the stream-decay rate for CBOD (K_r) seemed to be strongly influenced by algal respiration in the model calibration, an average of the rates used in the model calibration could not be used in the waste-load assimilation. Also, because advanced-waste treatment will probably become operational for the wastewater-treatment facilities in 1980-81 and should remove much of the suspended load from the wastewater effluent, a constant 0.2 day^{-1} at 20°C was assumed for K_n in the waste-load assimilation study. This value is low and assumes very little settling of CBOD but is in the range of values for "normal BOD decay coefficients" reported by Thomann (1972, p. 97).

Sufficient data were not available to determine the relation between streamflow and the deoxygenation rate for NBOD (K_n) in the reaches downstream from the Marion wastewater-treatment facility. Therefore, the waste-load assimilative capacity of these reaches during summer low flows was estimated for three different rates of nitrification. The first estimate of the stream waste-load assimilative capacity was based on the average of the K_n values used in the two model calibrations. The deoxygenation rate for NBOD in this estimate ranged from 3.0 to 4.5 day^{-1} at 20°C, downstream from the Marion wastewater-treatment facility. Because additional water-quality data as well as nitrifier enumerations are needed before these rates can be verified, the waste-load assimilation capacity was also determined for average values of K_n reported in the literature. The second and third estimates of the stream waste-load assimilative capacity downstream from the Marion wastewater-treatment facility were determined for first-order reaction coefficients of 0.3 and 0.6 day^{-1} at 20°C. These coefficients represent the average and upper limit of the "normal range" of values for large rivers (Thomann, 1972, p. 97).

The stream waste-load assimilative capacity downstream from the Gas City wastewater-treatment facility was determined for an NBOD deoxygenation rate of 0.3 day^{-1} at 20°C. This value is the average of the rates used in the model calibrations. As in the model calibration, nitrification was assumed to be negligible in reaches upstream from the Gas City wastewater-treatment facility, as well as in the reaches within river miles 41.47 to 35.47 (upstream from the Marion wastewater-treatment facility). K_n for these reaches was set equal to zero.

During winter, nitrification was assumed to be negligible, owing to the inhibition of nitrifying organisms at low stream temperatures (Thomann and others, 1971). Therefore, for the winter waste-load assimilation study, ammonia nitrogen was treated as a nonbiodegradable constituent, and K_n was set equal to zero.

Reaeration rate coefficients were computed by the energy-dissipation equation of Tsivoglou and Neal (1976), as discussed in the section "Reaeration."

All rate coefficients were corrected for temperature, as discussed in the appropriate sections of "Parameter Estimation."

Benthic-oxygen demand, as in the model calibration, was not included in the waste-load assimilation study.

Net-photosynthetic-oxygen production varies both daily and seasonally and cannot reliably be predicted. Under certain environmental conditions, net-photosynthetic-oxygen production can be positive and can add oxygen to the water, whereas for other conditions it can be negative and be an oxygen deficit. Because net-photosynthetic-oxygen production cannot be predicted, it was not included in the waste-load assimilation study.

Sufficient data were not collected to determine the waste-load assimilation capacity of Back Creek; however, the following assumptions were made to determine appropriate input parameters for Back Creek at the confluence with the Mississinewa River at RM 44.51:

1. Dissolved oxygen in Back Creek upstream from the Jonesboro wastewater-treatment facility was completely recovered from the effects of the Fairmount wastewater-treatment facility.

2. Streamflow at RM 0.40, upstream from the Jonesboro wastewater-treatment facility, ranged from 0.46 to 1.08 ft^3/s.

3. Headwater concentrations of ultimate CBOD and NBOD were 5.6 mg/L and 1.3 mg/L, respectively. (Concentrations were based on 8-5-77 data.)

4. Discharge for the Jonesboro wastewater-treatment facility for 1978 was 0.59 ft^3/s. The Jonesboro facility is to be phased out in 1980 or 1981 and, therefore, was included in only the 1978 waste-load assimilation study.

5. Concentrations of ultimate CBOD and NBOD in the Jonesboro wastewater effluent were 90 and 60 mg/L, respectively.

6. Time of travel from the Jonesboro wastewater-treatment facility to the Mississinewa River was 0.34 day.

7. K_r was 0.34 day^{-1} at 25°C.

8. K_n was 4.95 day^{-1} at 25°C.

On the basis of these assumptions, the concentrations of ultimate CBOD and NBOD for Back Creek, at the confluence with the Mississinewa River, were estimated to be 35.6 and 4.7 mg/L, respectively, for the 1978 waste-load assimilation study. Headwater concentrations of CBOD and NBOD (5.6 and 1.3 mg/L, respectively) were assumed for the waste-load assimilation studies after the Jonesboro wastewater-treatment facility has been phased out.

Results and Discussion

According to the Indiana State Board of Health (1977), a part of the assimilative capacity of a stream reach should be reserved for future growth and development. Two modeling techniques are acceptable in this regard.

First, a percentage of the assimilative capacity of the stream can be left as a reserve. This capacity should be no greater than 30 percent of the assimilative capacity and, ideally, should be the capacity required to assimilate probable future growth for the planning period. The size of the reserve is dependent on the rate of growth and the length of time of the planning period.

Second, the waste loads and flows for the existing dischargers (except industries) may be projected to the end of the planning period (year 2000) and may be used as input into the calibrated waste-load allocation model.

For this study a modification of the second modeling technique was used. The ISBH projected waste loads and flows for the existing discharges to the year 2000 (table 13). These projections were to be used in a calibrated and verified waste-load allocation model, and the necessary concentrations were to be determined for the discharges to meet current water-quality standards. However, the model used for the waste-load assimilation studies cannot be considered to be calibrated and verified because the stream conditions to be simulated were significantly different from those used in the model calibration attempts.

Table 13.--Population and flow projections through the year 2000 for municipalities in the Mississinewa River basin, Grant County, Ind.

[Vince Sommers, Indiana State Board of Health, oral commun., 1979]

Input	Year			
	1978	1980	1987	2000
	Gas City wastewater-treatment facility			
Population	6,100	--------	12,140	16,912
Flow (Mgal/day)	.84	1.3	2.0	3.5
	Fairmount wastewater-treatment facility			
Population	3,668	3,694	3,800	3,997
Flow (Mgal/day)	.30	.34	.46	.70
	Jonesboro wastewater-treatment facility[1]			
Population	3,005	--------	---------	--------
Flow (Mgal/day)	.38	--------	---------	--------
	Marion wastewater-treatment facility			
Population	40,574	--------	---------	67,300
Flow (Mgal/day)	9.3	9.54	10.4	12.0

[1]Jonesboro wastewater-treatment facility is to be phased out in 1980 or 1981.

Net photosynthesis was significant for the two model calibration attempts but could not be included in the waste-load assimilation. The data used for model calibration were collected under basinwide secondary treatment, whereas the waste-load assimilation study, for most of the planning period, was simulated for conditions under basinwide advanced-waste treatment. Consequently, the results of these studies (presented in figs. 23 through 27 and table 14) must be considered preliminary. The goals were an average dissolved-oxygen concentration of 5.0 mg/L and maximum ammonia-nitrogen concentrations of 2.5 mg/L for summer low flows and 4.0 mg/L for winter low flows.

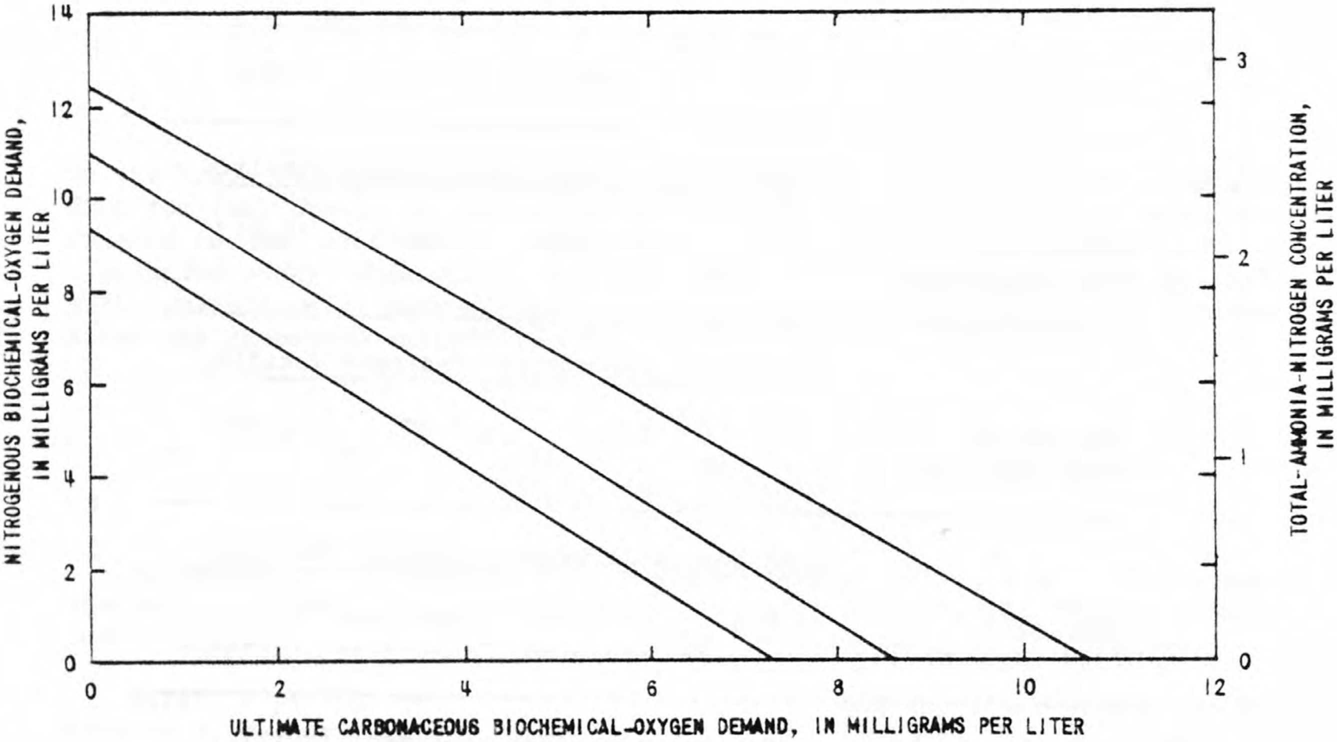

Figure 23.-- Projected alternative carbonaceous and nitrogenous waste loadings for Owens-Illinois, Inc., and the Gas City wastewater-treatment facility on the Mississinewa River that meet the minimum 24-hour average dissolved-oxygen concentration (5.0 mg/L) currently required for Indiana streams during summer low flows, where K_n (first-order kinetics deoxygenation rate for NBOD) ranges from 0.0 to 0.3 day^{-1}.

The dissolved-oxygen standard of 5 mg/L could not be met for summer low flows downstream from Gas City with an assumed 60 mg/L ultimate CBOD limit for Owens-Illinois, Inc., and no discharge limits (based on the NPDES permit). Effluent from Owens-Illinois, Inc., was included in the waste-load allocation process to meet current water-quality standards downstream from Gas City. For modeling, effluent from both Owens-Illinois, Inc., and the Gas City wastewater-treatment facility was assumed to be discharged into the Mississinewa River at RM 44.85.

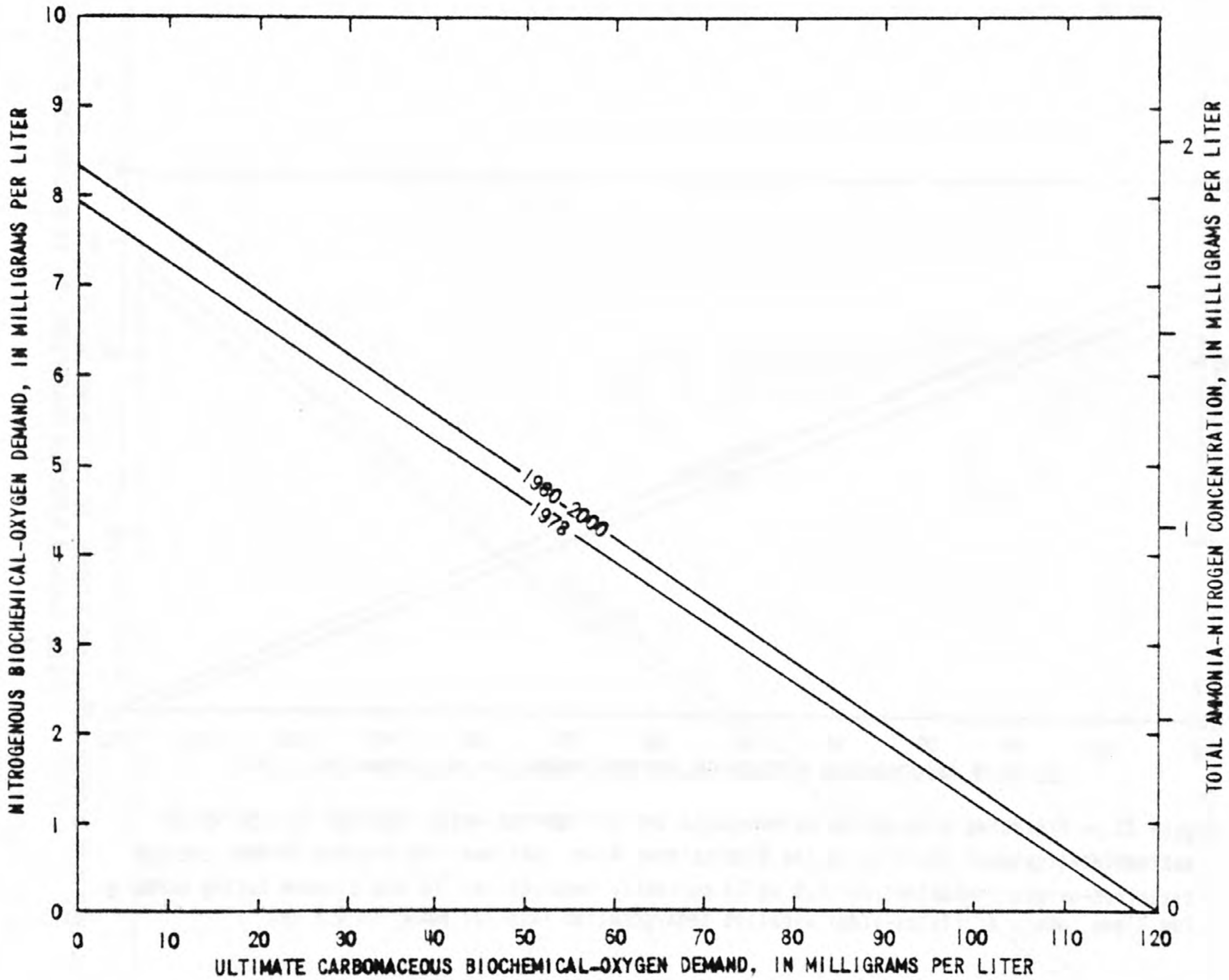

Figure 24.-- Projected alternative carbonaceous and nitrogenous waste loadings for the Marion wastewater-treatment facility on the Mississinewa River that meet the minimum 24-hour average dissolved-oxygen concentration (5.0 mg/L) currently required for Indiana streams during summer low flows, where K_n (first-order kinetics deoxygenation rate for NBOD) ranges from 3.0 to 4.5 day^{-1}:

Model simulations indicate that the assumed waste load from the Indiana Street sewer will result in violations of the dissolved-oxygen standard for the 1978 summer low-flow condition. Because the dissolved-oxygen standard could not be met, no alternative waste loadings are provided in figure 23 for the 1978 summer low-flow condition.

Several observations about the three estimates of the stream waste-load assimilative capacity downstream from the Marion wastewater-treatment facility should be made.

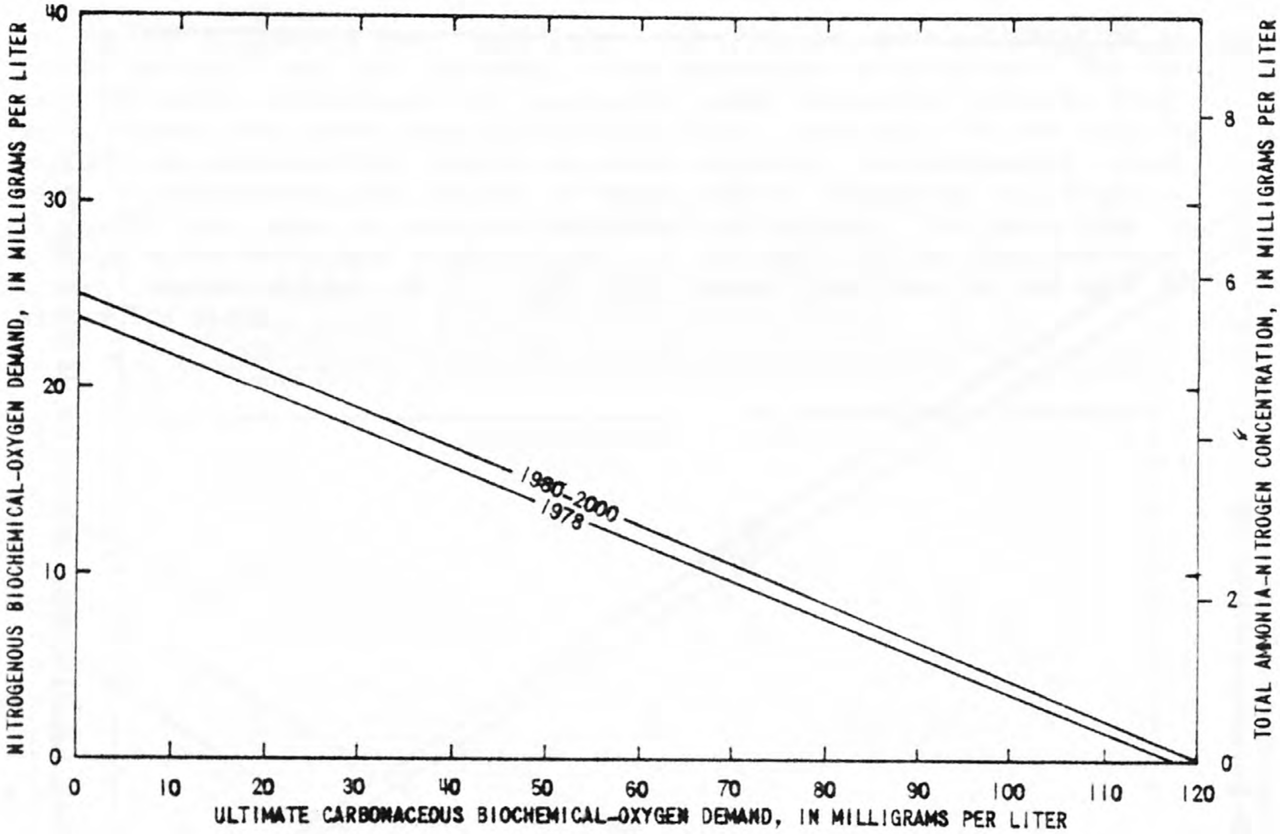

Figure 25.-- Projected alternative carbonaceous and nitrogenous waste loadings for the Marion wastewater-treatment facility on the Mississinewa River that meet the minimum 24-hour average dissolved-oxygen concentration (5.0 mg/L) currently required for Indiana streams during summer low flows, where K_n (first-order kinetics deoxygenation rate for NBOD) in 0.6 day^{-1}.

Model simulations indicate that nitrification is the most significant factor affecting the dissolved-oxygen concentration during summer low flows. All three estimates of the stream waste-load assimilative capacity indicate that the current in-stream dissolved-oxygen standard (5 mg/L) will not be met by the assumed effluent ammonia-nitrogen concentration (15 mg/L) from the Gas City and Marion wastewater-treatment facilities.

During winter low flows, ammonia toxicity rather than dissolved oxygen becomes the limiting water-quality criterion in the Mississinewa River. Projected 5-day BOD concentrations for effluents from the Gas City, Fairmount, and Marion wastewater-treatment facilities (10, 10, and 15 mg/L, respectively), after advanced waste treatment begins, will not violate the dissolved-oxygen standard. A dissolved-oxygen sag could not be simulated in the modeled segment downstream from the Marion wastewater-treatment facility. Because of the effect of low temperatures on the rates of deoxygenation, the minimum dissolved-oxygen concentration will occur downstream from the modeled segment.

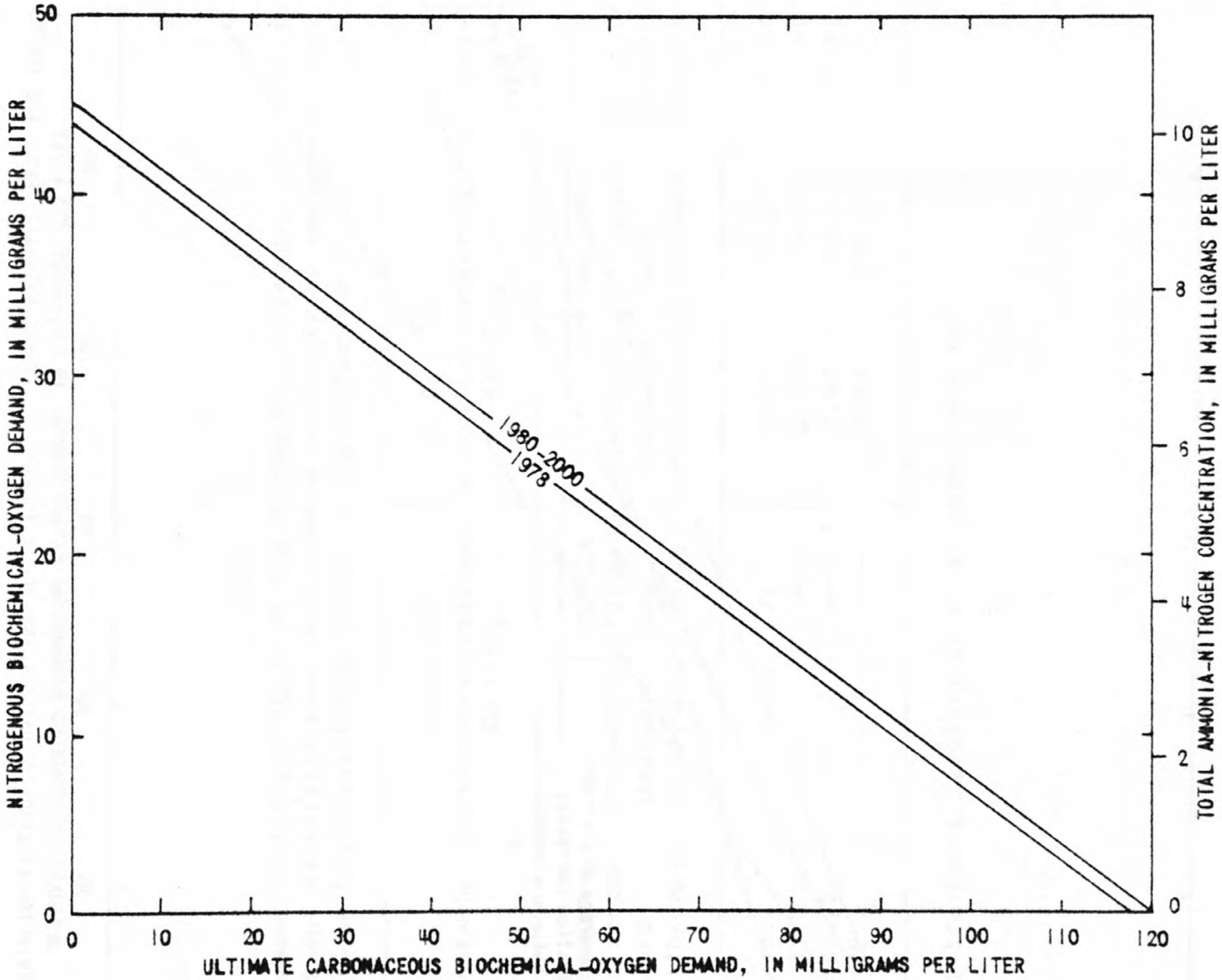

Figure 26.-- Projected alternative carbonaceous and nitrogenous waste loadings for the Marion wastewater-treatment facility on the Mississinewa River that meet the minimum 24-hour average dissolved-oxygen concentration (5.0 mg/L) currently required for Indiana streams during summer low flows, where K_n (first-order kinetics deoxygenation rate for NBOD) is 0.3 day^{-1}.

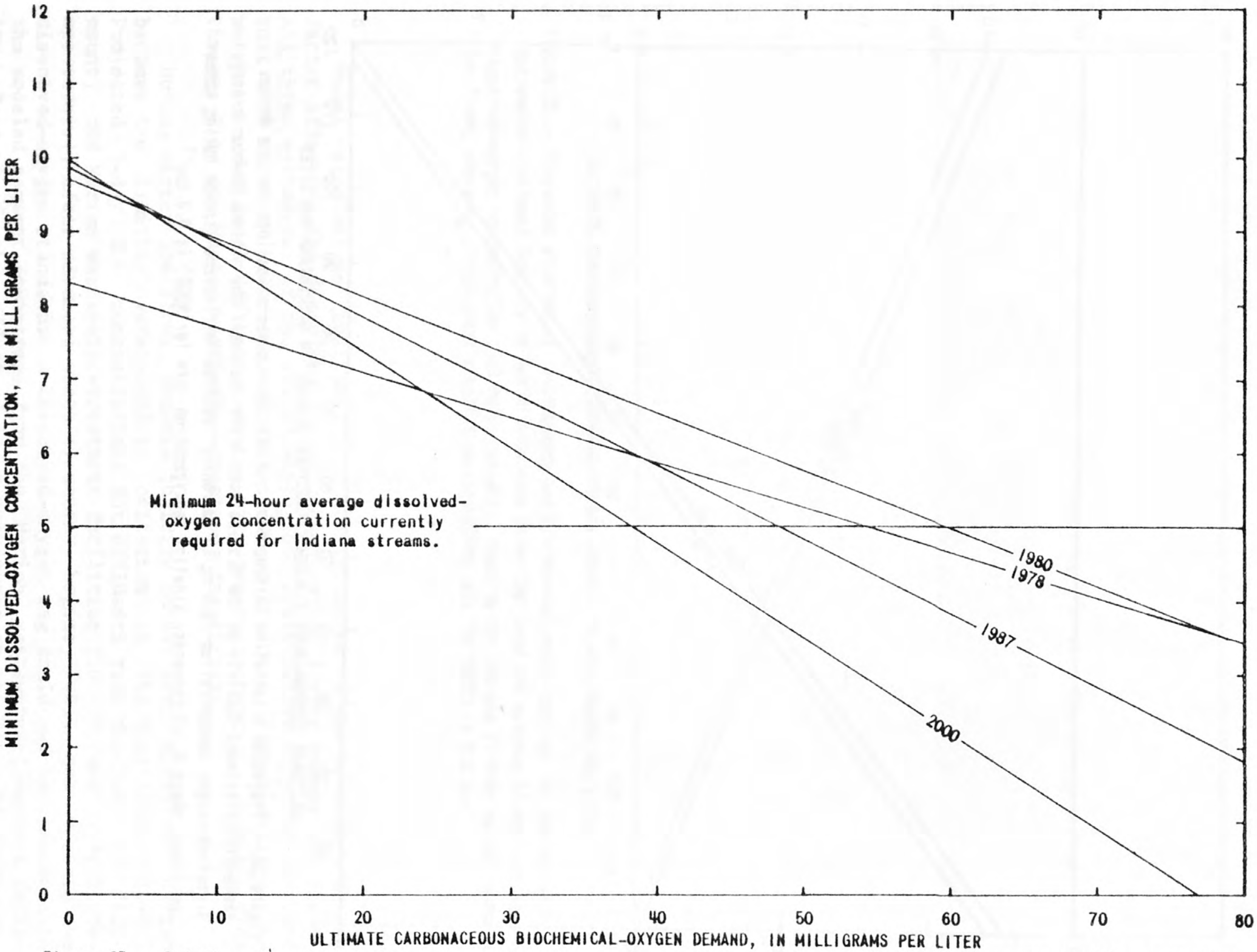

Figure 27.-- Relation of projected alternative carbonaceous waste loadings for Owens-Illinois, Inc., and the Gas City wastewater-treatment facility to the minimum in-stream dissolved-oxygen concentration for winter low flows.

Table 14.--Total ammonia-nitrogen loads at the Fairmount, Jonesboro, Gas City, and Marion wastewater-treatment facilities that will provide an in-stream ammonia-nitrogen concentration of 4 mg/L in the Mississinewa River during winter low flows

Year	Fairmount wastewater-treatment facility		Jonesboro[1] wastewater-treatment facility		Gas City wastewater-treatment facility		Marion wastewater-treatment facility	
	Projected discharge (Mgal/day)	Ammonia-nitrogen load (lb/day)	Projected discharge (Mgal/day)	Ammonia-nitrogen load (lb/day)	Projected discharge (Mgal/day)	Ammonia-nitrogen load (lb/day)	Projected discharge (Mgal/day)	Ammonia-nitrogen load (lb/day)
1978	0.30	16.8	0.38	21.2	0.84	47.0	9.30	464.1
1980	.34	15.5	----	----	1.30	59.3	9.54	435.5
1987	.46	20.26	----	----	2.00	88.1	10.40	458.1
2000	.70	29.3	----	----	3.50	146.5	12.0	502.0

[1]Jonesboro wastewater-treatment facility is to be phased out in 1980 or 1981.

Suggestions for future water-quality studies on the Mississinewa River that can help verify the existing model and clarify the effect of various factors on the dissolved-oxygen dynamics include: (1) Additional water-quality surveys, similar to the survey done in August 1978, at steady-state, low-flow conditions on the Mississinewa River after advanced-waste treatment begins at the wastewater-treatment facilities; (2) in-stream sampling in the mixing zone, where samples are collected in equal-width increments across the stream transect and are composited so that the volume from each increment is proportional to the discharge; (This type of sampling is preferable to grab samples from stream reaches, where a sample collected in mid-channel may not be representative of the average stream condition.) (3) sampling of effluents, where the flows vary significantly during the sampling period, composited proportionately to flow rather than time; (4) direct determination of reaeration for several stream reaches on the Mississinewa River; (5) enumeration of nitrifier populations of both the bottom materials and the water column downstream from wastewater-treatment facilities to determine if sufficient populations are available to exert a significant oxygen demand; (6) quantification of the effect of photosynthesis on the dissolved-oxygen dynamics of the Mississinewa River for different flow conditions, including the $Q_{7,10}$; and (7) additional dye studies for better definition of time of travel during low-flow conditions.

SUMMARY AND CONCLUSIONS

A one-dimensional, steady-state, dissolved-oxygen model has been calibrated, and alternatives for waste-load allocation have been developed for the Mississinewa River in Grant County, Ind. Because of time and budgetary constraints, data collected were not sufficient to verify the model at the flow condition used in the waste-load assimilation study. Preliminary studies indicate that algal photosynthesis and nitrification are the most significant factors affecting the dissolved-oxygen concentration in the river. The stream reaeration capacity alone is not sufficient to maintain an average dissolved-oxygen concentration of 5 mg/L in the river during summer low flows. Consequently, projected CBOD and NBOD waste loads from the Indiana State Board of Health for Owens-Illinois, Inc., and the Gas City and Marion wastewater-treatment facilities will result in violation of the water-quality standard for dissolved oxygen.

The time of travel for Back Creek is sufficient to assimilate the waste load from the Fairmount wastewater-treatment facility.

During winter low flows, ammonia toxicity rather than dissolved oxygen becomes the limiting water-quality criterion. Projected BOD limits for the period after the implementation of advanced-waste treatment, do not exceed the in-stream dissolved-oxygen standard.

Future wastes in the Mississinewa River basin will probably have to be discharged into the reach downstream from the Marion dam at RM 35.90, because the natural reaeration in this reach is significantly greater than that upstream from the dam.

The effect of stormwater discharge and combined sewer overflows on water quality was not evaluated. This information, as well as additional information on the process of nitrification and algal productivity, would be useful.

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Table 8.--Water-quality analyses for two sampling stations on the Mississinewa River, Grant County, Ind., June 1976 through September 1978

[Data collected and analyzed by Marion wastewater-treatment facility]

Location and station on the Mississinewa River (ISBH sta. no. in parens)	River mile	Date	Time[1] (hours)	Temp. (°C)	DO (mg/L)	DO (percent saturation)	pH	Five-day BOD (mg/L)
Highland Ave. bridge (501-2)	35.76	06-07-76	1400	25	8.6	104	7.4	5
State Route 37 (501-1)	35.20	06-07-76	1415	--	9.3	113	8.0	4
Highland Ave. bridge (501-2)	35.76	06-18-76	1400	27	15.3	195	8.5	14
State Route 37 (501-1)	35.20	06-18-76	1415	28	15.8	205	8.5	14
Highland Ave. bridge (501-2)	35.76	06-25-76	1315	--	7.0	---	7.8	36
State Route 37 (501-1)	35.20	06-25-76	1330	--	7.0	---	7.8	50
Highland Ave. bridge (501-2)	35.76	06-29-76	1345	27	7.3	93	7.9	5
State Route 37 (501-1)	35.20	06-29-76	1400	--	7.1	90	8.0	6
Highland Ave. bridge (501-2)	35.76	07-07-76	1315	25	9.6	117	7.6	3
State Route 37 (501-1)	35.20	07-07-76	1330	--	8.7	106	7.8	2
Highland Ave. bridge (501-2)	35.76	07-17-76	2345	--	11.4	---	7.7	8
State Route 37 (501-1)	35.20	07-17-76	2400	--	10.6	---	7.8	6
Highland Ave. bridge (501-2)	35.76	07-23-76	1345	27	12.0	152	8.3	7
State Route 37 (501-1)	35.20	07-23-76	1400	--	11.7	148	8.3	7

Table 8.--Water-quality analyses for two sampling stations on the Mississinewa River, Grant County, Ind., June 1976 through September 1978--Continued

Location and station on the Mississinewa River (ISBH sta. no. in parens)	River mile	Date	Time[1] (hours)	Temp. (°C)	DO (mg/L)	DO (percent saturation)	pH	Five-day BOD (mg/L)
Highland Ave. bridge (501-2)	35.76	07-30-76	1345	26	7.9	99	8.0	5
State Route 37 (501-1)	35.20	07-30-76	1400	--	8.4	105	8.0	4
Highland Ave. bridge (501-2)	35.76	08-04-76	1520	25	11.4	139	8.9	12
State Route 37 (501-1)	35.20	08-04-76	1530	--	10.8	132	8.6	10
Highland Ave. bridge (501-2)	35.76	08-23-76	1555	26	6.9	86	7.0	8
State Route 37 (501-1)	35.20	08-23-76	1605	--	9.4	118	7.8	7
Highland Ave. bridge (501-2)	35.76	08-27-76	1545	26	8.4	105	7.9	5
State Route 37 (501-1)	35.20	08-27-76	1600	--	8.9	111	8.0	3
Highland Ave. bridge (501-2)	35.76	09-10-76	1640	21	6.6	75	7.7	9
State Route 37 (501-1)	35.20	09-10-76	1650	--	6.9	78	7.7	6
Highland Ave. bridge (501-2)	35.76	09-21-76	1620	20	8.5	96	7.7	7
State Route 37 (501-1)	35.20	09-21-76	1640	--	9.6	107	7.5	3

Table 8.--Water-quality analyses for two sampling stations on the Mississinewa River, Grant County, Ind., June 1976 through September 1978--Continued

Location and station on the Mississinewa River (ISBH sta. no. in parens)	River mile	Date	Time[1] (hours)	Temp. (°C)	DO (mg/L)	DO (per-cent satura-tion)	pH	Five-day BOD (mg/L)
Highland Ave. bridge (501-2)	35.76	09-28-76	1555	18	8.8	95	8.0	6
State Route 37 (501-1)	35.20	09-28-76	1610	--	9.7	105	8.1	5
Highland Ave. bridge (501-2)	35.76	09-30-76	1610	--	12.0	---	8.3	8
State Route 37 (501-1)	35.20	09-30-76	1620	--	12.0	---	8.2	6
Highland Ave. bridge (501-2)	35.76	10-13-76	2330	19	9.4	104	8.0	8
State Route 37 (501-1)	35.20	10-13-76	2340	--	9.0	99	8.0	9
Highland Ave. bridge (501-2)	35.76	10-25-76	1610	12	12.0	114	7.9	7
State Route 37 (501-1)	35.20	10-25-76	1620	--	11.1	106	7.9	9
Highland Ave. bridge (501-2)	35.76	10-28-76	1545	10	17.4	155	8.1	4
State Route 37 (501-1)	35.20	10-28-76	1600	12	16.0	150	8.2	5
Highland Ave. bridge (501-2)	35.76	11-15-76	1550	8	12.4	107	8.0	1
State Route 37 (501-1)	35.20	11-15-76	1600	--	12.6	109	8.2	4

Table 8.--Water-quality analyses for two sampling stations on the Mississinewa River, Grant County, Ind., June 1976 through September 1978--Continued

Location and station on the Mississinewa River (ISBH sta. no. in parens)	River mile	Date	Time[1] (hours)	Temp. (°C)	DO (mg/L)	DO (percent saturation)	pH	Five-day BOD (mg/L)
Highland Ave. bridge (501-2)	35.76	11-18-76	1545	10	14.0	127	7.9	2
State Route 37 (501-1)	35.20	11-18-76	1555	--	14.6	133	7.9	1
Highland Ave. bridge (501-2)	35.76	11-24-76	1505	7	14.9	126	7.8	1
State Route 37 (501-1)	35.20	11-24-76	1515	--	15.0	127	7.9	2
Highland Ave. bridge (501-2)	35.76	11-29-76	1530	4	12.6	98	7.8	2
State Route 37 (501-1)	35.20	11-29-76	1540	--	12.8	99	8.0	2
Highland Ave. bridge (501-2)	35.76	12-08-76	1620	4	13.8	107	7.9	1
State Route 37 (501-1)	35.20	12-08-76	1635	--	14.4	111	7.9	1
Highland Ave. bridge (501-2)	35.76	12-16-76	1540	10	14.0	127	7.7	1
State Route 37 (501-1)	35.20	12-16-76	1555	--	13.8	125	7.8	1
Highland Ave. bridge (501-2)	35.76	12-22-76	1600	2	15.5	115	7.8	-
State Route 37 (501-1)	35.20	12-22-76	1625	8	14.2	123	7.8	-
Highland Ave. bridge (501-2)	35.76	12-30-76	1515	14	14.0	139	7.8	1
State Route 37 (501-1)	35.20	12-30-76	1525	--	13.8	137	7.8	2

Table 8.--Water-quality analyses for two sampling stations on the Mississinewa River, Grant County, Ind., June 1976 through September 1978--Continued

Location and station on the Mississinewa River (ISBH sta. no. in parens)	River mile	Date	Time[1] (hours)	Temp. (°C)	DO (mg/L)	DO (percent saturation)	pH	Five-day BOD (mg/L)
Highland Ave. bridge (501-2)	35.76	01-07-77	1125	5	11.0	88	7.4	2
State Route 37 (501-1)	35.20	01-07-77	1145	5	11.2	90	7.7	0
Highland Ave. bridge (501-2)	35.76	01-20-77	1225	6	8.5	72	7.4	2
State Route 37 (501-1)	35.20	01-20-77	1235	8	10.3	88	7.6	2
Highland Ave. bridge (501-2)	35.76	01-27-77	1330	4	8.0	64	7.3	1
State Route 37 (501-1)	35.20	01-27-77	1345	6	10.2	86	7.4	1
Highland Ave. bridge (501-2)	35.76	02-08-77	1350	8	7.7	66	7.4	2
State Route 37 (501-1)	35.20	02-08-77	1400	8	9.8	84	7.5	1
Highland Ave. bridge (501-2)	35.76	02-16-77	1410	4	10.0	77	7.6	4
State Route 37 (501-1)	35.20	02-16-77	1415	7	10.4	87	7.5	3
Highland Ave. bridge (501-2)	35.76	03-05-77	1535	5	11.2	90	7.6	7
State Route 37 (501-1)	35.20	03-05-77	1543	4	11.2	85	7.6	5
Highland Ave. bridge (501-2)	35.76	03-12-77	1920	14	9.3	93	7.7	-
State Route 37 (501-1)	35.20	03-12-77	1927	13	9.3	91	7.8	-

Table 8.--Water-quality analyses for two sampling stations on the Mississinewa River, Grant County, Ind., June 1976 through September 1978--Continued

Location and station on the Mississinewa River (ISBH sta. no. in parens)	River mile	Date	Time[1] (hours)	Temp. (°C)	DO (mg/L)	DO (percent saturation)	pH	Five-day BOD (mg/L)
Highland Ave. bridge (501-2)	35.76	03-15-77	----	--	----	---	---	2
State Route 37 (501-1)	35.20	03-15-77	----	--	----	---	---	2
Highland Ave. bridge (501-2)	35.76	03-21-77	1225	9	10.8	96	7.8	2
State Route 37 (501-1)	35.20	03-21-77	1235	8	10.8	94	7.8	2
Highland Ave. bridge (501-2)	35.76	03-30-77	1355	18	8.8	96	7.6	5
State Route 37 (501-1)	35.20	03-30-77	1405	16	8.8	92	7.6	4
Highland Ave. bridge (501-2)	35.76	04-11-77	1500	20	9.5	105	7.8	2
State Route 37 (501-1)	35.20	04-11-77	1510	19	9.7	106	8.1	1
Highland Ave. bridge (501-2)	35.76	04-16-77	1535	22	12.5	145	8.4	6
State Route 37 (501-1)	35.20	04-16-77	1545	23	12.8	152	8.5	6
Highland Ave. bridge (501-2)	35.76	04-30-77	1615	18	9.9	106	7.3	2
State Route 37 (501-1)	35.20	04-30-77	1625	17	10.1	106	7.3	2
Highland Ave. bridge (501-2)	35.76	05-14-77	1545	23	8.9	106	7.9	2
State Route 37 (501-1)	35.20	05-14-77	1555	23	9.1	108	8.0	2

Table 8.--Water-quality analyses for two sampling stations on the Mississinewa River, Grant County, Ind., June 1976 through September 1978--Continued

Location and station on the Mississinewa River (ISBH sta. no. in parens)	River mile	Date	Time[1] (hours)	Temp. (°C)	DO (mg/L)	DO (percent saturation)	pH	Five-day BOD (mg/L)
Highland Ave. bridge (501-2)	35.76	05-25-77	1235	27	9.6	122	7.8	7
State Route 37 (501-1)	35.20	05-25-77	1245	27	6.4	81	7.8	8
Highland Ave. bridge (501-2)	35.76	05-27-77	1330	27	10.0	127	7.8	9
State Route 37 (501-1)	35.20	05-27-77	1340	27	9.9	126	7.8	8
Highland Ave. bridge (501-2)	35.76	05-31-77	1325	27	13.6	173	8.1	8
State Route 37 (501-1)	35.20	05-31-77	1330	27	12.4	158	8.0	7
Highland Ave. bridge (501-2)	35.76	06-06-77	1330	22	10.0	117	7.8	-
State Route 37 (501-1)	35.20	06-06-77	1335	22	10.0	117	7.9	-
Highland Ave. bridge (501-2)	35.76	06-21-77	1405	26	12.0	150	---	-
State Route 37 (501-1)	35.20	06-21-77	1415	26	12.6	158	---	-
Highland Ave. bridge (501-2)	35.76	06-30-77	1330	25	5.7	70	7.7	5
State Route 37 (501-1)	35.20	06-30-77	1230	25	6.2	77	7.6	6
Highland Ave. bridge (501-2)	35.76	08-05-77	0900	25	6.7	82	7.7	4
State Route 37 (501-1)	35.20	08-05-77	0910	25	6.2	75	7.6	4

Table 8.--Water-quality analyses for two sampling stations on the Mississinewa River, Grant County, Ind., June 1976 through September 1978--Continued

Location and station on the Mississinewa River (ISBH sta. no. in parens)	River mile	Date	Time[1] (hours)	Temp. (°C)	DO (mg/L)	DO (per-cent satura-tion)	pH	Five-day BOD (mg/L)
Highland Ave. bridge (501-2)	35.76	08-12-77	1035	24	5.9	71	7.2	5
State Route 37 (501-1)	35.20	08-12-77	----	24	5.5	65	7.5	4
Highland Ave. bridge (501-2)	35.76	08-22-77	1310	23	10.0	119	7.2	5
State Route 37 (501-1)	35.20	08-22-77	1320	23	9.1	108	7.2	3
Highland Ave. bridge (501-2)	35.76	08-26-77	1410	27	16.5	209	9.0	11
State Route 37 (501-1)	35.20	08-26-77	1420	27	17.2	218	9.0	11
Highland Ave. bridge (501-2)	35.76	09-07-77	1950	21	6.3	72	7.4	5
State Route 37 (501-1)	35.20	09-07-77	2000	--	5.9	67	7.4	3
Highland Ave. bridge (501-2)	35.76	09-13-77	1535	22	8.7	105	7.3	8
State Route 37 (501-1)	35.20	09-13-77	1540	22	8.5	102	7.7	5
Highland Ave. bridge (501-2)	35.76	09-16-77	1040	22	7.5	90	7.3	5
State Route 37 (501-1)	35.20	09-16-77	1050	21	7.5	89	7.5	5
Highland Ave. bridge (501-2)	35.76	09-21-77	0815	19	9.0	99	7.5	3
State Route 37 (501-1)	35.20	09-21-77	0820	--	8.4	92	7.8	2

Table 8.--Water-quality analyses for two sampling stations on the Mississinewa River, Grant County, Ind., June 1976 through September 1978--Continued

Location and station on the Mississinewa River (ISBH sta. no. in parens)	River mile	Date	Time[1] (hours)	Temp. (°C)	DO (mg/L)	DO (percent saturation)	pH	Five-day BOD (mg/L)
Highland Ave. bridge (501-2)	35.76	09-30-77	----	20	12.0	135	7.8	7
State Route 37 (501-1)	35.20	09-30-77	1000	20	11.0	124	7.9	7
Highland Ave. bridge (501-2)	35.76	10-04-77	1100	17	8.3	86	7.8	4
State Route 37 (501-1)	35.20	10-04-77	----	--	8.3	86	7.9	4
Highland Ave. bridge (501-2)	35.76	10-14-77	1315	23	8.3	99	8.0	2
State Route 37 (501-1)	35.20	10-14-77	----	23	8.5	101	7.6	1
Highland Ave. bridge (501-2)	35.76	10-17-77	1420	13	10.2	99	8.0	2
State Route 37 (501-1)	35.20	10-17-77	1440	14	10.0	100	8.0	2
Highland Ave. bridge (501-2)	35.76	10-26-77	1042	17	8.1	85	7.8	2
State Route 37 (501-1)	35.20	10-26-77	1047	17	8.0	84	7.8	2
Highland Ave. bridge (501-2)	35.76	11-07-77	1340	15	10.0	102	7.8	7
State Route 37 (501-1)	35.20	11-07-77	1345	16	10.0	104	7.7	7
Highland Ave. bridge (501-2)	35.76	11-17-77	1500	14	10.1	101	8.1	4
State Route 37 (501-1)	35.20	11-17-77	1505	11	10.4	97	8.0	3

Table 8.--Water-quality analyses for two sampling stations on the Mississinewa River, Grant County, Ind., June 1976 through September 1978--Continued

Location and station on the Mississinewa River (ISBH sta. no. in parens)	River mile	Date	Time[1] (hours)	Temp. (°C)	DO (mg/L)	DO (per-cent satura-tion)	pH	Five-day BOD (mg/L)
Highland Ave. bridge (501-2)	35.76	11-21-77	1445	9	11.4	99	8.1	1
State Route 37 (501-1)	35.20	11-21-77	1500	10	11.4	102	8.1	1
Highland Ave. bridge (501-2)	35.76	11-30-77	1455	5	12.0	97	7.9	8
State Route 37 (501-1)	35.20	11-30-77	1505	--	11.8	95	8.0	7
Highland Ave. bridge (501-2)	35.76	12-15-77	1355	4	11.5	90	7.7	5
State Route 37 (501-1)	35.20	12-15-77	1405	4	12.0	94	7.8	6
Highland Ave. bridge (501-2)	35.76	12-31-77	1350	4	11.3	89	7.8	3
State Route 37 (501-1)	35.20	12-31-77	1355	--	11.2	88	7.8	3
Highland Ave. bridge (501-2)	35.76	01-11-78	1415	2	12.0	88	7.8	3
State Route 37 (501-1)	35.20	01-11-78	1420	2	11.8	86	7.8	4
Highland Ave. bridge (501-2)	35.76	01-18-78	1530	5	10.8	87	7.7	3
State Route 37 (501-1)	35.20	01-18-78	1530	5	10.8	87	7.7	1
Highland Ave. bridge (501-2)	35.76	01-25-78	1400	8	12.2	108	7.7	.9
State Route 37 (501-1)	35.20	01-25-78	1400	8	12.6	112	7.8	2.1

Table 8.--Water-quality analyses for two sampling stations on the Mississinewa River, Grant County, Ind., June 1976 through September 1978--Continued

Location and station on the Mississinewa River (ISBH sta. no. in parens)	River mile	Date	Time[1] (hours)	Temp. (°C)	DO (mg/L)	DO (percent saturation)	pH	Five-day BOD (mg/L)
Highland Ave. bridge (501-2)	35.76	02-02-78	1432	8	9.7	83	7.5	0.6
State Route 37 (501-1)	35.20	02-02-78	1432	8	10.2	87	7.4	1.1
Highland Ave. bridge (501-2)	35.76	02-10-78	1420	10	10.3	93	7.5	.9
State Route 37 (501-1)	35.20	02-10-78	1420	10	10.4	94	7.4	1.1
Highland Ave. bridge (501-2)	35.76	02-17-78	1412	9	11.4	100	7.7	1.5
State Route 37 (501-1)	35.20	02-17-78	1412	9	11.3	99	7.5	.3
Highland Ave. bridge (501-2)	35.76	02-23-78	1102	7	11.3	96	7.4	.6
State Route 37 (501-1)	35.20	02-23-78	1102	7	11.8	100	7.1	.7
Highland Ave. bridge (501-2)	35.76	03-02-78	----	--	10.2	121	7.1	1.4
State Route 37 (501-1)	35.20	03-02-78	1320	23	10.8	129	7.1	.5
Highland Ave. bridge (501-2)	35.76	03-08-78	1330	--	12.9	121	7.6	7.5
State Route 37 (501-1)	35.20	03-08-78	1330	11	12.5	111	7.5	.6
Highland Ave. bridge (501-2)	35.76	03-20-78	1435	--	12.1	110	7.6	3.0
State Route 37 (501-1)	35.20	03-20-78	1435	10	11.9	108	7.4	3.6

Table 8.--Water-quality analyses for two sampling stations on the Mississinewa River, Grant County, Ind., June 1976 through September 1978--Continued

Location and station on the Mississinewa River (ISBH sta. no. in parens)	River mile	Date	Time[1] (hours)	Temp. (°C)	DO (mg/L)	DO (percent saturation)	pH	Five-day BOD (mg/L)
Highland Ave. bridge (501-2)	35.76	03-28-78	----	--	10.4	96	7.7	2.1
State Route 37 (501-1)	35.20	03-28-78	1344	11	10.3	95	7.7	1.8
Highland Ave. bridge (501-2)	35.76	03-31-78	1430	--	9.6	108	8.0	1.6
State Route 37 (501-1)	35.20	03-31-78	----	20	9.8	109	8.1	1.7
Highland Ave. bridge (501-2)	35.76	04-06-78	1320	--	9.8	104	7.6	4.6
State Route 37 (501-1)	35.20	04-06-78	----	17	9.7	103	7.3	4.7
Highland Ave. bridge (501-2)	35.76	04-12-78	1444	--	9.6	102	7.3	1.9
State Route 37 (501-1)	35.20	04-12-78	----	17	9.4	100	7.6	1.5
Highland Ave. bridge (501-2)	35.76	04-24-78	1333	--	9.5	102	7.6	3.1
State Route 37 (501-1)	35.20	04-24-78	----	18	9.7	104	7.8	3.3
Highland Ave. bridge (501-2)	35.76	04-28-78	1421	--	9.5	100	7.6	2.1
State Route 37 (501-1)	35.20	04-28-78	----	17	9.3	98	7.5	1.5
Highland Ave. bridge (501-2)	35.76	05-03-78	1335	--	9.2	102	7.4	1.5
State Route 37 (501-1)	35.20	05-03-78	----	19	9.2	102	7.8	1.5

Table 8.--Water-quality analyses for two sampling stations on the Mississinewa River, Grant County, Ind., June 1976 through September 1978--Continued

Location and station on the Mississinewa River (ISBH sta. no. in parens)	River mile	Date	Time[1] (hours)	Temp. (°C)	DO (mg/L)	DO (percent saturation)	pH	Five-day BOD (mg/L)
Highland Ave. bridge (501-2)	35.76	05-12-78	1315	--	9.7	104	8.0	2.2
State Route 37 (501-1)	35.20	05-12-78	----	19	10.2	110	8.0	2.9
Highland Ave. bridge (501-2)	35.76	05-18-78	1400	--	8.6	98	7.6	.5
State Route 37 (501-1)	35.20	05-18-78	----	21	8.5	97	7.3	.3
Highland Ave. bridge (501-2)	35.76	05-25-78	1420	--	8.1	96	8.0	.9
State Route 37 (501-1)	35.20	05-25-78	----	23	8.2	98	7.6	1.0
Highland Ave. bridge (501-2)	35.76	06-01-78	1540	--	10.1	131	7.8	3.8
State Route 37 (501-1)	35.20	06-01-78	----	28	10.3	134	8.0	4.0
Highland Ave. bridge (501-2)	35.76	06-09-78	1517	--	8.9	107	8.4	2.5
State Route 37 (501-1)	35.20	06-09-78	----	24	9.3	112	8.2	2.6
Highland Ave. bridge (501-2)	35.76	06-15-78	1045	--	10.0	114	8.2	5.0
State Route 37 (501-1)	35.20	06-15-78	----	21	10.2	116	8.2	5.1
Highland Ave. bridge (501-2)	35.76	06-22-78	1430	--	11.5	---	8.0	5.5
State Route 37 (501-1)	35.20	06-22-78	----	--	11.2	---	8.0	5.1

Table 8.--Water-quality analyses for two sampling stations on the Mississinewa River, Grant County, Ind., June 1976 through September 1978--Continued

Location and station on the Mississinewa River (ISBH sta. no. in parens)	River mile	Date	Time[1] (hours)	Temp. (°C)	DO (mg/L)	DO (percent saturation)	pH	Five-day BOD (mg/L)
Highland Ave. bridge (501-2)	35.76	06-29-78	1430	--	7.7	---	7.9	2.5
State Route 37 (501-1)	35.20	06-29-78	----	--	7.9	---	7.9	2.9
Highland Ave. bridge (501-2)	35.76	07-05-78	1430	28	7.7	99	7.7	1.0
State Route 37 (501-1)	35.20	07-05-78	----	--	7.5	96	7.7	.5
Highland Ave. bridge (501-2)	35.76	07-12-78	1030	--	8.4	---	7.8	2.0
State Route 37 (501-1)	35.20	07-12-78	----	--	9.0	---	7.9	2.4
Highland Ave. bridge (501-2)	35.76	07-19-78	1000	--	12.6	---	7.8	7.6
State Route 37 (501-1)	35.20	07-19-78	----	--	12.1	---	7.8	7.8
Highland Ave. bridge (501-2)	35.76	07-26-78	1420	29	10.5	139	8.1	6.4
State Route 37 (501-1)	35.20	07-26-78	----	--	11.2	148	8.1	6.8
Highland Ave. bridge (501-2)	35.76	08-03-78	1400	--	10.2	---	8.0	7.7
State Route 37 (501-1)	35.20	08-03-78	----	--	10.9	---	7.9	7.5
Highland Ave. bridge (501-2)	35.76	08-09-78	1100	25	10.0	122	8.2	4.0
State Route 37 (501-1)	35.20	08-09-78	----	--	9.6	117	8.0	7.2

Table 8.--Water-quality analyses for two sampling stations on the Mississinewa River, Grant County, Ind., June 1976 through September 1978--Continued

Location and station on the Mississinewa River (ISBH sta. no. in parens)	River mile	Date	Time[1] (hours)	Temp. (°C)	DO (mg/L)	DO (percent saturation)	pH	Five-day BOD (mg/L)
Highland Ave. bridge (501-2)	35.76	08-16-78	1530	29	12.6	167	8.6	8.1
State Route 37 (501-1)	35.20	08-16-78	----	--	12.0	159	8.6	6.6
Highland Ave. bridge (501-2)	35.76	08-23-78	1130	--	7.3	---	7.3	2.3
State Route 37 (501-1)	35.20	08-23-78	----	--	7.4	---	7.4	2.6
Highland Ave. bridge (501-2)	35.76	08-30-78	1430	21	6.7	76	7.4	3.0
State Route 37 (501-1)	35.20	08-30-78	----	--	6.8	77	7.2	2.7
Highland Ave. bridge (501-2)	35.76	09-06-78	1000	--	8.9	---	7.6	4.9
State Route 37 (501-1)	35.20	09-06-78	----	--	9.0	---	7.7	5.1

[1]The time 1400 hours is equivalent to 2:00 p.m.