EPA 905-73-001

Water Quality Model Of The Lower Fox River, Wisconsin

ABSTRACT

A mathematical model describing the interrelationship between the dissolved oxygen concentration of a river and its various sources and sinks has been adapted for use in a study of the Lower Fox River in Wisconsin. The analysis assumes steady-state conditions and describes the longitudinal distribution of dissolved oxygen in the river from Neenah-Menasha to Green Bay, a distance of approximately 40 miles (64.4 km).

The model was verified for various conditions of waste loading, river temperature, and river flow. The model was then used to evaluate the effect on water quality of implementing interim best practicable control technology effluent limitations for industrial dischargers and 90 percent BOD removal from municipal waste sources, as an estimate of levels of treatment required by the 1972 Amendments to the Federal Water Pollution Control Act and by orders issued by the Wisconsin DNR, respectively. The study indicated that implementation of the above effluent limits will result in a significant improvement in water quality in the Lower Fox River. A daily average dissolved oxygen concentration of 4 to 5 mg/l will be maintained under most flow conditions. During an extreme low flow and high temperature situation, the dissolved oxygen concentration could drop to 2 to 3 mg/l.

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NOMENCLATURE

α =	coefficient of dam reaeration	
A =	river cross-sectional area	(ft^2)
c =	concentration of dissolved oxygen	(mg/l)
c_a =	dissolved oxygen above a dam	(mg/l)
c_b =	dissolved oxygen below a dam	(mg/l)
chl-a =	concentration of chlorophyll-a	(mg/l)
c_s =	saturation value of dissolved oxygen	(mg/l)
D =	deficit of dissolved oxygen	(mg/l)
D_a =	deficit of dissolved oxygen above a dam	(mg/l)
D_b =	deficit of dissolved oxygen below a dam	(mg/l)
D_o =	initial dissolved oxygen deficit	(mg/l)
F =	percent of the river bottom covered by sludge deposits	(decimal)
H =	average river depth	(ft)
H_d =	height through which water falls over a dam	(ft)
K_a =	reaeration coefficient	(1/day)
K_d =	deoxygenation coefficient	(1/day)
K_n =	first order NBOD decay coefficient	(1/day)
K_r =	first order CBOD decay coefficient	(1/day)
L =	carbonaceous BOD (CBOD) distribution	(mg/l)
L_o =	initial carbonaceous BOD	(mg/l)
N =	nitrogenous BOD (NBOD) distribution	(mg/l)
P =	gross photosynthetic dissolved oxygen production	(mg O_2/l-day)
p =	period of algal photosynthesis, i.e., period of daylight	(days)
P_{av} =	average daily photosynthetic oxygen production	(mg/l-day)
Q =	river flow rate	(cfs)
R =	algal dissolved oxygen respiration	(mg O_2/l-day)
S =	benthic oxygen uptake coefficient (areal)	(gm O_2/m^2-day)
S^1 =	benthic oxygen uptake coefficient (volumetric)	(mg O_2/l-day)
T =	river temperature	(°C)
t =	time of travel	(days)
u =	average river velocity	(ft/sec)
W_d =	dissolved oxygen [illegible] or tributary	(lbs/day)
x =	distance [illegible]	(miles)
x_d =	spatial location [illegible]	(miles)

INTRODUCTION

Gross water pollution has existed in the Lower Fox River and Green Bay, Wisconsin for a number of years. Concentrated in this basin are eight urban areas and nineteen pulp and paper manufacturers that make intensive use of the river for disposal and assimilation of wastes. The lower river, approximately 40 miles (69.4 km) in length, flows in a northeasterly direction through a series of 18 locks and dams used for navigation and hydroelectric purposes. The drainage area of the basin is 419 square miles (1085 sq. km). (See figure 1)

Because of the continuing gross water pollution in the river, the U.S. Environmental Protection Agency (EPA) and the Wisconsin Department of Natural Resources (DNR) initiated a series of enforcement actions against the various industrial and municipal waste dischargers in the Lower Fox River basin. The Wisconsin DNR has issued orders requiring municipal waste sources to remove 90% of the biochemical oxygen demand contained in their waste influents. The 1972 Amendments to the Federal Water Pollution Control Act provide that municipalities shall provide, as a minimum, secondary treatment, and industries shall achieve "best practicable control technology" (BPT) by no later than 1977. Under the Act, EPA is required to define final effluent guidelines representing BPT by October 1973. The effluent limits for industrial dischargers used in this report and summarized in Table 5 were derived from interim guidelines in use by EPA in early 1973 which were developed in anticipation of the 1972 Amendments. The combination of 90% BOD removal for municipalities and the industrial limitations in Table 5 are referred throughout this report as the "[illegible] effluent limitations." The 1972 Amendments also require that in addition to meeting the municipal and

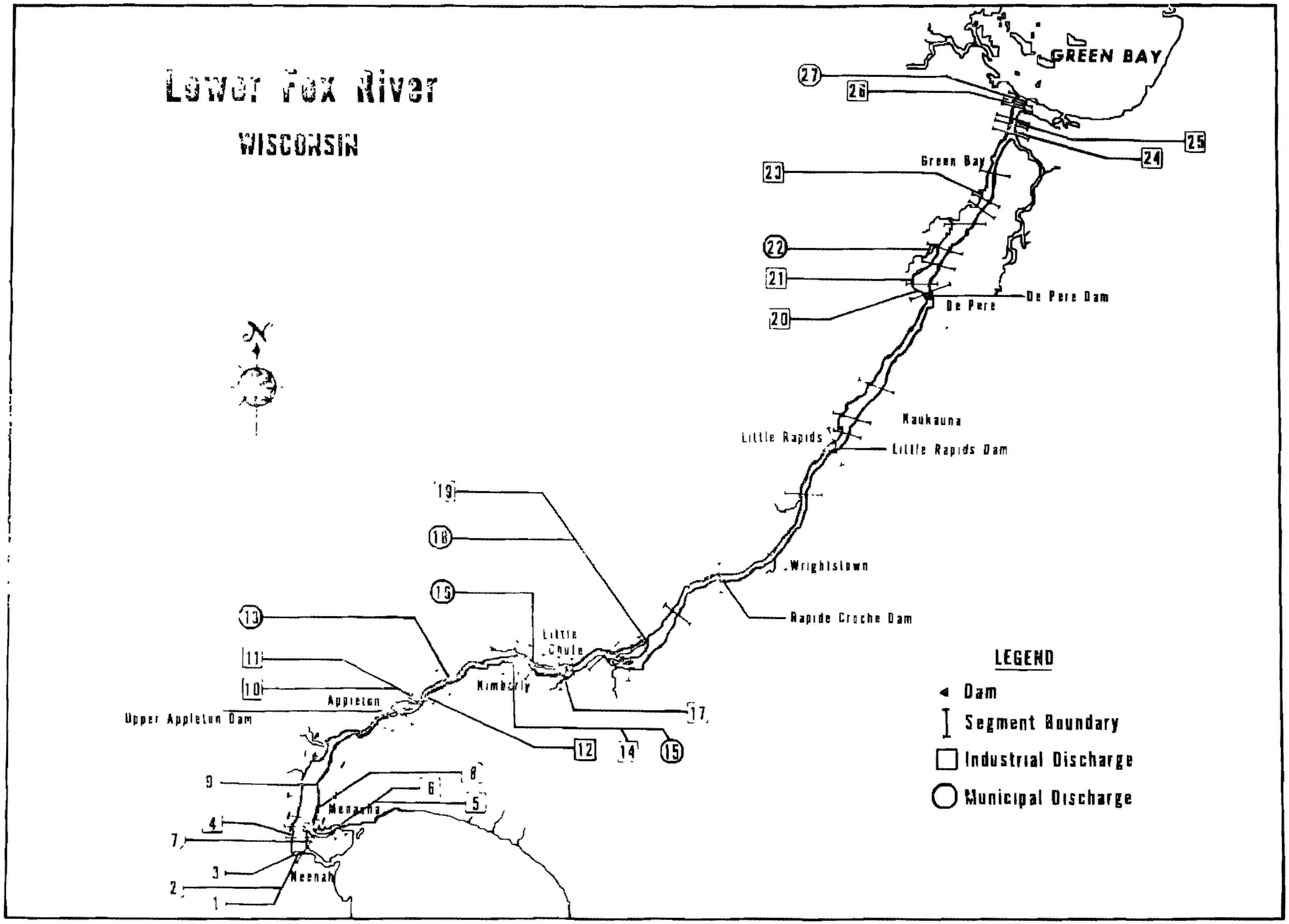

Lower Fox River
WISCONSIN
N
GREEN BAY
Green Bay
De Pere
De Pere Dam
Kaukauna
Little Rapids
Little Rapids Dam
Wrightstown
Rapide Croche Dam
Little Chute
Kimberly
Appleton
Upper Appleton Dam
Menasha
Neenah
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
LEGEND
Dam
Segment Boundary
Industrial Discharge
Municipal Discharge

Figure 1

industrial guidelines, the water quality standards must be met. For the Fox River upstream of the upper dam at Appleton, the water quality standards provide for all water uses including fish and aquatic life and recreational use. These uses require among other parameters that the dissolved oxygen shall not be lowered to less than 5.0 mg/l at any time. The Fox River from the upper dam at Appleton downstream to the Village of Wrightstown shall meet all standards except that the dissolved oxygen shall not be lowered to less than 3.0 mg/l during any consecutive 8 hours of a 24-hour period nor to less than 5.0 mg/l for the remainder of the day. The Fox River below the Village of Wrightstown downstream to the mouth shall meet all standards except that the dissolved oxygen shall not be lowered to less than 2.0 mg/l at any time.

In 1969, the engineering firm of Quirk, Lawler, and Matusky (QLM) developed a model of the river for the Wisconsin DNR. The data base used for verification of this model was not as complete as that presently available. Extensive river surveys performed during the summers of 1971 and 1972 have accumulated enough new data to allow a better estimate of certain parameters and thus permit the development of an updated model for the Lower Fox River.

The purpose of the work presented here was to evaluate the effect on the water quality of the Lower Fox River of implementing the proposed effluent limitations for industrial and municipal sources and to evaluate if these control levels would achieve existing water quality standards.

The scope of the study was limited to developing a steady-state, one-dimensional model based on available data and using an existing computer program. A discussion of the theoretical background is presented first, followed by a description of the development and verification of the model. An evaluation of the effect of the proposed effluent limitations on water quality in the Lower Fox River is then presented.

MODEL DEVELOPMENT

Theory

The dissolved oxygen concentration of a natural water system indicates the general "health" of a stream, and its ability, or inability, to maintain a diverse population of fish and aquatic life. The conservation of mass forms the basis for the fundamental relationships which describe the temporal and spatial distribution of dissolved oxygen in the natural water system. Both the net flux into and the effect of various sources and sinks within a unit volume of water determine the change in dissolved oxygen concentration with time. For a fresh water river such as the Lower Fox, the advective component of the flux is much more significant than the dispersive component. Hence, the dispersive term was neglected in the development of the model.

An understanding of the overall effect of the complex interactions among the system parameters can be gained by modeling the interrelationship between the various sources and sinks and the dissolved oxygen concentration in the river. The specific equation is developed by a mass balance employing the continuity equation and takes the following form: (Thomann, 1972)

$$\frac{\partial c}{\partial t} = -\frac{1}{A}\frac{\partial (Qc)}{\partial x} - K_d L - K_n N + K_a\ (C_s - C) - S^1(x,t) + P(x,t) - R(x,t) + K_a(C_a - C_b) \qquad (1)$$

in which

A = river cross-sectional area (ft^2)

C = concentration of dissolved oxygen (Do) (mg/l)

C_a = dissolved oxygen above a dam (mg/l)

C_b = dissolved oxygen below a dam (mg/l)

C_s = saturation value of dissolved oxygen (mg/l)

K_a = reaeration coefficient (1/day)

K_d = deoxygenation coefficient (1/day)

K_n = first order NBOD decay coefficient (1/day)

L = carbonaceous BOD (CBOD) distribution (mg/l)

N = nitrogenous BOD (NBOD) distribution (mg/l)

P = gross photosynthetic dissolved oxygen production (mg/l-day)

Q = river flow rate (cfs)

R = algal dissolved oxygen respiration (mg/l-day)

S^1 = benthic oxygen uptake coefficient (volumetric) (mg/l-day)

t = time (days)

x = distance downstream (miles)

In equation (1), the concentration of dissolved oxygen is assumed to be uniform in the lateral and vertical planes. The sources and sinks may be functions of their own concentrations or the concentration of another substance.

It is usually more convenient to introduce the dissolved oxygen deficit into the equations since all values will then be referenced to a zero dissolved oxygen deficit, the saturation value of dissolved oxygen. If D, the dissolved oxygen deficit ($D=C_s-C$) is substituted into equation (1) and if steady state conditions are assumed (i.e., no change in point source waste loadings with time), the solution is as follows, given the appropriate boundary conditions ($D=D_0$ at $x=o$) (Thomann, 1972):

$$D(x) = \left(\frac{W_d}{Q} + D_o\right) \exp(- K_a\ x/u) \qquad (2a)$$

$$+ \frac{K_d\ L_o}{K_a - K_r} [\exp(- K_r\ x/u) - \exp(- K_a\ x/u)] \qquad (2b)$$

$$+ \frac{K_n\ N_o}{K_a - K_n} [\exp(- K_n\ x/u) - \exp(- K_a\ x/u)] \qquad (2c)$$

$$- \frac{P}{K_a} [1 - \exp(- K_a\ x/u)] \qquad (2d)$$

$$+ \frac{R}{K_a} [1 - \exp(- K_a\ x/u)] \qquad (2e)$$

$$+ \frac{S}{K_a} [1 - \exp(- K_a\ x/u)] \qquad (2f)$$

$$- (D_a - D_b) \exp[- K_a(x - x_d)/u] \qquad (2g)$$

where

D_a = deficit of dissolved oxygen above a dam (mg/l)

D_b = deficit of dissolved oxygen below a dam (mg/l)

K_r = first order CBOD decay coefficient (1/day)

S^1 = benthic oxygen uptake coefficient (volumetric) (mg/l-day)

W_d = dissolved oxygen input from waste source or tributary (lbs./day)

X_d = spatial location of a dam (miles)

The various parts of the solution are interpreted as:

(2a) point source of DO, W_d, and initial value of DO deficit, D_o

(2b) deficit due to point source of [illegible]

(2c) deficit due to point source of [illegible]

(2d) deficit due to distributed algal photosynthesis

(2e) distributed algal respiration [illegible]

(2f) distributed benthic oxygen demand effect

(2g) deficit change due to reaeration from spillways over dams

A detailed discussion of each of the model components shown in Equation (2) is presented in the following sections. In these sections a discussion of the assumptions used in describing the component model is presented along with a summary of the values of the parameters selected for use in the verifications and predictions. The model is structured so that each of the input parameters may be varied spatially in the river.

Initial Conditions

Values for initial conditions of dissolved oxygen, carbonaceous BOD, and total nitrogen in the Neenah-Menasha Channel were obtained either from recently available river survey data, or from the results of an extensive statistical analysis of dissolved oxygen and carbonaceous BOD data presented in the report prepared by Quirk, Lawler, and Matusky, Engineers.

Generally, the initial concentration of dissolved oxygen was at or above saturation at Neenah-Menasha due to photosynthetic activity of the aquatic plants (QLM, 1969). For the model verifications, observed values of dissolved oxygen (all above saturation) were used. For the model predictions, the saturation value was used.

Where available, initial carbonaceous BOD values, measured by the Wisconsin DNR, were used. In the remainder of the analyses, an initial value of 6 mg/l was chosen based on the results presented in the QLM study (QLM, 1969).

Relatively few measurements of total oxidizable nitrogen were available for use in the analysis. A review of the existing data suggested that the value of 1.0 mg/l was a reasonable [illegible]

Atmospheric Reaeration

The atmospheric reaeration coefficient, K_a, was calculated using O'Connor's formulation (Dobbins and O'Connor, 1958),

$$K_a \text{ (1/day)} = \frac{12.9\mu^{1/2}}{H^{3/2}} \tag{3}$$

in which,

μ = average stream velocity (ft/sec)

H = average depth (ft)

The O'Connor equation forms a reasonable basis for estimating the reaeration coefficient for a wide range of depth and velocity conditions (average depth ranging from about 1 foot to 30 feet [0.3 m to 9.1 m] and average velocities in the range from 0.5 to 1.6 ft/sec [0.15 m/sec to 0.49 m/sec]) encountered in the Lower Fox River.

The effect of temperature on the reaeration coefficient has been experimentally determined to be represented by

$$(K_a)_T = (K_a)_{20} (1.024)^{(T-20)} \tag{4}$$

for T in degrees centigrade.

Biochemical Oxygen Demand

As shown in Equation (2), there is a distinction made between the oxygen demand of the carbonaceous material (CBOD) in a waste effluent, and the nitrogenous oxygen demanding component (NBOD) of the effluent.

Carbonaceous BOD

The removal rate of carbonaceous organic matter, expressed as K_r, is a result of oxidation and physical settling of the organic materials. For oxidation alone, as might result from a soluble organic waste, the reaction rate is expressed as K_d -- the rate of oxidation of the organic substance. The two reaction rates, K_r and K_d, associated with the decay of CBOD are shown in Equation (2b).

Previous studies have shown that the primary mechanism for CBOD removal is the oxidation of organic matter (QLM, 1969). Although settling of the suspended matter does occur, the rate of removal via this mechanism is small compared to oxidation. For the analysis, the removal rate, K_r, was assumed to be essentially equal to the oxidation rate, K_d.

Values for the CBOD coefficient, K_d, were taken directly from the QL&M report. In that study, K_d was reported to be a function of river flow between about 1,000 cfs (1,699 cu m/min) and 4,000 cfs (6,797 cu m/min) for the area from Appleton dam (mp 32.1) to De Pere dam (mp 7.3). For flows greater than 4000 cfs (6,797 cu m/min) the rate coefficient was considered constant. Beyond De Pere dam, K_d was independent of river flow and was assumed constant at 0.12/day.

For the present study, observed flows of about 2,000 cfs (3,398 cu m/min) to 2,500 cfs (4,248 cu m/min) resulted in corresponding deoxygenation coefficients of about 0.2 to 0.3/day.

Long term (20-day) CBOD measurements were available at several places in the river. From these measurements, the ratio of ultimate to 5-day BOD was calculated. This ratio varied from 1.29 to 2.36, as shown in the following table.

Table 1

Ratio of Ultimate to 5-Day

Carbonaceous BOD

Location	Ratio $CBODu/CBOD_5$	
	QLM Report (1969)	Wisconsin DNR (1972)
Segment 1-13	1.88	(Menasha Channel) 1.81
Segment 14-18	2.19	
Segment 19	1.89	
Segment 20-25	1.66	
Segment 26-32	1.89	(Rapide Croche Dam) 1.95
Segment 33-40	2.36	(DePere Dam) 2.35
Segment 41-45	1.29	

Source: Quirk, Lawler, and Matusky, Engineers, 1969

Nitrogenous BOD

The assumption of a first-order kinetics model to describe the process of nitrification is a simplification of a rather complex set of consecutive reactions. In reality, organic and ammonia nitrogen are oxidized through a series of reactions, shown below, to nitrite and nitrate nitrogen. This oxidation process draws on the oxygen resources of the river and is included as a component in the model.

The ammonia formed from organic nitrogen, together with direct discharges of ammonia from waste sources, is oxidized to nitrite by Nitrosomonas bacteria, as follows:

$$(NH_4)^+ + OH^- + 1.5O_2 \xrightarrow{bacteria} H^+ + NO_2^- + 2H_2O$$

The reaction requires 3.43 pounds of oxygen for each pound of ammonia nitrogen oxidized to nitrite.

The nitrite formed is then oxidized to nitrate by <u>Nitrobacter</u> as follows:

$$NO_2^- + 0.5O_2 \xrightarrow{\text{bacteria}} NO_3^-$$

This reaction requires 1.14 pounds of oxygen for one pound of nitrite nitrogen oxidized to nitrate.

The total oxygen consumption in the nitrification process is 4.57 pounds of oxygen for each pound of ammonia nitrogen. Thus, the nitrogenous BOD (NBOD) is equal to 4.57 times the concentration of total oxidizable forms of nitrogen (ammonia + organic nitrogen).

In the present analysis, active nitrogenous oxidation is assumed to commence in the first segment in the Neenah-Menasha channel. This assumption is considered valid on the basis of high concentrations of algae and related nutrients entering the Lower Fox River from Lake Winnebago.

The rate coefficient, K_n, is dependent on river temperature and the concentration of dissolved oxygen. Under conditions of low dissolved oxygen, nitrification is inhibited and, at values below 1.5 mg/l dissolved oxygen, nitrification ceases. The maximum rate of nitrification at high levels of dissolved oxygen was 0.143/day (QLM, 1969).

The effect of temperature on the reaction rate of nitrification is given by

$$(K_n)_T = (K_n)_{20}(1.04)^{(T-20)} \qquad (5)$$

for temperatures greater than 10°C. At river temperatures of less than 10°C, nitrification is suppressed.

Estimates of point source loadings of total oxidizable nitrogen (NH_3-N + organic-N) were applied to industrial and municipal dischargers. A comparison of observed total nitrogen values for July 14, 1972, with a computed mass balance of total nitrogen, is shown in Figure 2.

Photosynthesis and Respiration

Lake Winnebago contributes large concentrations of algae to the Lower Fox River in the summer months. The algae and rooted aquatic plants, through the processes of photosynthesis and respiration, serve both as a source and a sink of dissolved oxygen in the river. In the steady state model presented herein, the complex interactions involved in photosynthesis and respiration are simplified by relating the chlorophyll - a concentration in the river to an oxygen source term, P, and a sink term, R.

Chlorophyll - a measurements at various locations in the river were available from recent surveys by Sager and Wiersma. Estimates of the gross oxygen production and respiration due to algae concentrations were made by using the empirical relationship between chlorophyll - a concentration and maximum oxygen production established by Ryther and Yentsch and reported by Di Toro (1969). This relationship is:

$$P = 0.25 \text{ chl - a} \qquad (6)$$

where

P = gross photosynthetic dissolved oxygen production (mg O_2/l-day)

chl - a = chlorophyll - a concentration (μg/l)

The relationship between the algal respiration rate, R, and chlorophyll - a concentration is:

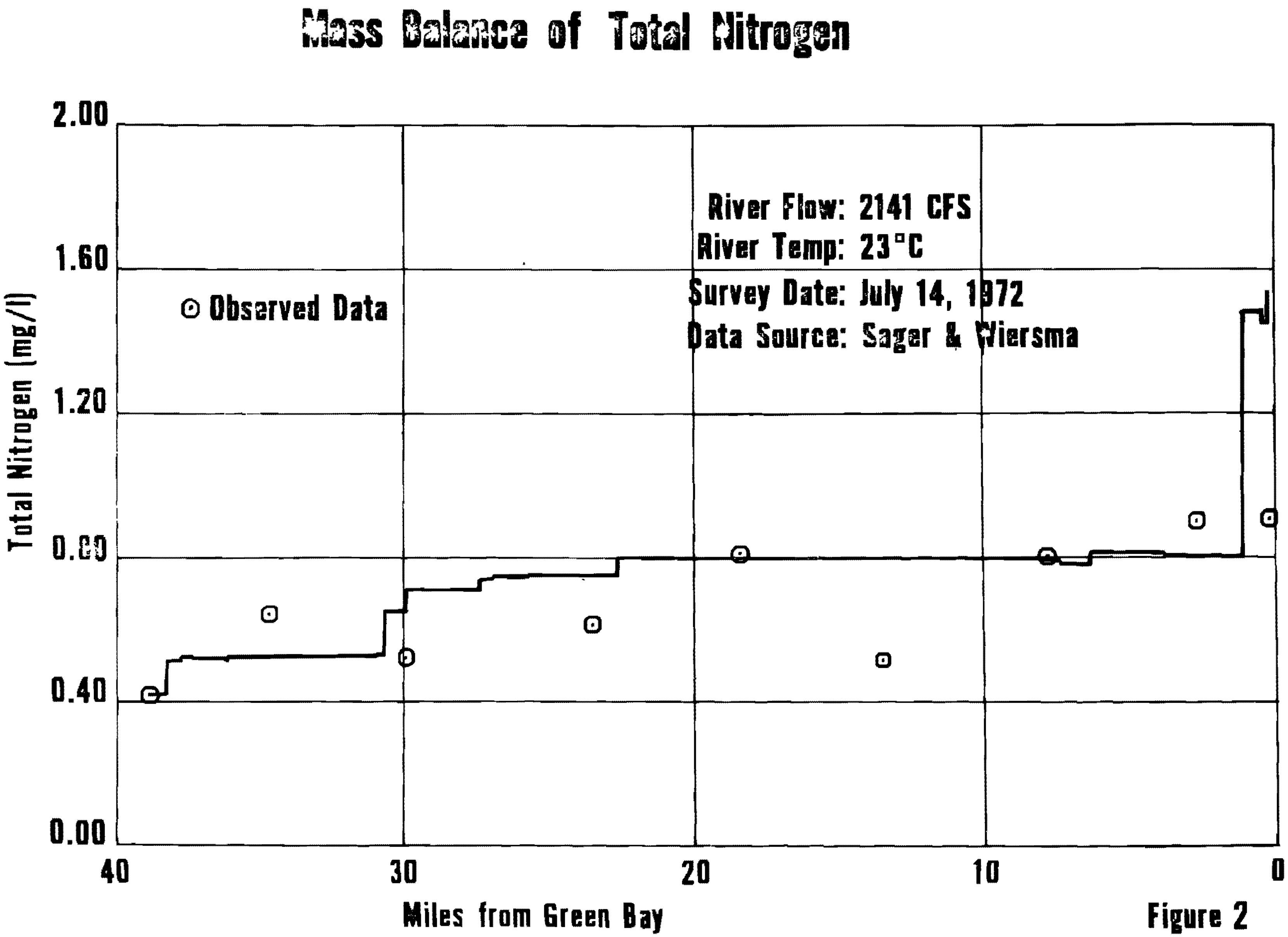

Mass Balance of Total Nitrogen
2.00
1.60
1.20
0.80
0.40
0.00
Total Nitrogen (mg/l)
Observed Data
River Flow: 2141 CFS
River Temp: 23°C
Survey Date: July 14, 1972
Data Source: Sager & Wiersma
40
30
20
10
0
Miles from Green Bay

Figure 2

$$R = 0.025 \text{ chl} - \underline{a} \quad (7)$$

The average daily rate of photosynthetic dissolved oxygen production, P_{av}, is given by:

$$P_{av} = P \; 2p/\pi \quad (8)$$

where

p = fractional period of sunlight in a day

The unfortunate implication is that a constant ratio of P/R = 10 exists for all algal populations. This is not true, since the ratio is known to vary considerably. However, comparison of results from this empirical relation and data presented in the QLM report from light and dark bottle measurements agree reasonably well and so lend confidence in the empirical relation used in the analysis.

Table 2 shows the spatial variation of maximum gross algal oxygen production and respiration used in preparing two verifications of survey data and a prediction of 1978 conditions.

TABLE 2

SPATIAL VARIATION OF ALGAL OXYGEN PRODUCTION

AND RESPIRATION (mgO_2/l-day)

July 28, 1971			June 20-21, 1973			1978 Prediction		
Segment	P	R	Segment	P	R	Segment	P	R
1-11	35.0	3.50	1-14	21.3	2.13	1-14	14.0	1.4
12-28	28.78	2.88	15-22	21.3	2.13	15-22	11.0	1.1
29-33	21.25	2.13	23-27	12.5	1.25	23-27	8.0	0.8
34-40	16.25	1.63	28-45	12.5	1.25	28-45	6.0	0.6
41-45	11.25	1.13						

Source: Sager and Wiersma, 1972

(1978 Prediction conditions are estimates)

Benthic Oxygen Demand

The continuous discharge of settleable waste material from municipal and industrial sources for many years has resulted in the formation of sludge banks throughout the river. The bottom conditions in the river vary from rather thick deposits of sludge to relatively shallow deposits of decaying organic material from natural sources such as dead algae. The surface layer of sludge, in direct contact with the water, undergoes aerobic decomposition, during which dissolved oxygen resources are depleted from the overlying water. Assuming that the river is vertically well mixed, this benthic or sludge oxygen demand (SOD) is the distributed sink of dissolved oxygen shown as S in Equations (1) and (2).

Values for S were orginally taken from the literature. Thomas (1970) reported SOD values of up to 2.3 mgs O_2/m^2-day in unpolluted sections of the Willamette River in Oregon. For sections of the river covered with fresh paper mill sludge deposits, values as high as 19.5 mgs O_2/m^2-day were reported, with the average uptake rate in the range from 3.6 to 9.8 mgs O_2/m^2-day. McKeown (1968) reported a range of 1.5 to 5.0 mgs O_2/m^2-day for sludge deposits from pulp and paper mill wastes at various locations. Review of other literature (Thomann, 1972) indicates a range of 4 to 10 mgs O_2/m^2-day SOD for cellulosic fiber sludge.

Both Thomas and McKeown describe a rapid decrease in sludge oxygen demand as the sludge ages. According to Thomas, within 90 days after decomposition, the SOD had dropped to half of the maximum value at the time of deposition. McKeown reported a decrease to about one-third of the maximum SOD within 80 days of deposition.

Based on the above information, a maximum SOD of 5.0 mgs O_2/m^2-day was utilized for most analyses presented herein. A value of 2.5 mgs O_2/m^2-day was used for predicting future conditions in anticipation of decreased loadings of settleable materials to the river and of aging of the existing sludge deposits in the river.

Although the average value for the benthic oxygen demand will be about 2.5 mgs O_2/m^2-day, it possibly will be higher than this at a few locations. Sludge deposition in the Lower Fox River was recently studied by Springer (1972). Under most flow conditions, significant sludge deposition was found to occur in segments 6 to 11 and 28 to 45. Since fresh sludge deposits may well settle in these locations in the future, the benthic uptake rate could be higher than that assumed in the present analysis.

Subsequent to the development of the present model, the Wisconsin DNR conducted laboratory measurements of the benthic oxygen uptake due to sludge deposits taken from the river. These studies indicated an uptake range of 2.5 to 3.2 mgs O_2/m^2-day for areas having relatively little sludge. In more grossly polluted areas, SOD values of 6 to 20 mgs O_2/m^2-day were measured (Wisconsin DNR, 1973). Results of the Wisconsin DNR studies support the SOD values taken from the literature and used for the Fox River analysis. The measured range of 2.5 to 3.2 mgs O_2/m^2-day for areas relatively free of sludge deposits supports the assumption made in evaluating future conditions that the average SOD will be near these values after installation of adequate treatment.

Effects of river temperature on the benthic oxygen uptake rate can be approximated in the 10° to 30° range by

$$(S)_T = (S)_{20} (1.065)^{(T-20)} \quad (9)$$

where T is river temperature in degrees centigrade.

Below 10°C, the rate decreases more rapidly than indicated by Equation (9) and approaches zero in the range of 0° to 5°C.

Reaeration Over Dams

The reaeration occurring at dams along the river is similar to the natural phenomenon of atmospheric reaeration and always drives the dissolved oxygen concentration of the water toward the saturation value. In the Lower Fox River, the major sources of continuous artifical reaeration are the waterfalls over dams located at De Pere (mp 7.3), Little Rapids (mp 13.1), Rapide Croche (mp 19.18), and Upper Appleton (mp 32.1). Although there are 19 dams located on the river, these four dams were considered to be the significant sources of reaeration based on observations made by the Wisconsin DNR during recent field studies and as clearly indicated in the data shown in Figures 4 and 5.

For the Mohawk River and Barge Canal in New York State, Mastropietro (Mastropietro, 1972) developed an equation similar to the following for reaeration over dams:

$$D_a - D_b = \alpha H_d D_a \quad (10)$$

D_a = dissolved oxygen deficit above dam (mg/l)

D_b = dissolved oxygen deficit below dam (mg/l)

H_d = height through which the waterfalls (ft.)

α = empirical coefficient for dam reaeration

Mastropietro used an α value of 0.037 in his work. However, for the Lower Fox River, coefficients determined from field data were substituted in describing reaeration over dams. A summary of the dam heights and coefficients is presented in Table 3.

TABLE 3

REAERATION OVER DAMS

DAM	MILEPOINT	HEIGHT (FT.)	α
De Pere	7.30	9.8	0.037
Little Rapids	13.10	6.1	0.115
Rapide Croche	19.18	9.4	0.037
Upper Appleton	32.10	8.0	0.065

Total dissolved oxygen transferred at the various dams could be as high as 4 to 5 mg/l if the dissolved oxygen concentration at the dam headwater is at, or near, zero.

Physical Parameters

Geometric characteristics of the river, such as average depths, widths and cross-sectional areas are necessary to determine the assimilative capacity of the river since these parameters combined with the river flow rate determine velocity. Each of the terms in Equation (2) is a function of river velocity.

Average widths and depths were obtained directly from the QLM report. Cross sectional areas in the river were then readily computed from this information. River segments used in the model presented in this report, were those used in the QLM study. Table 4 presents the average depths, widths, and cross-sectional areas used in the analysis.

In the development of the model, the Menasha Channel was arbitrarily considered as a tributary to the main branch of the Lower Fox River entering at river milepoint 37.24 in Segment 6. River flow from Lake Winnebago was proportioned between Menasha and Neenah Channel by a consideration of the respective dam spillway dimensions and current measurements taken during stream surveys. Flow in Menasha Channel was calculated by QLM to be 0.54 of the total river flow, with the flow in Neenah Channel being the difference, or 0.46 of the total river flow.

Seiche Effect

Green Bay, at the mouth of the Lower Fox River, is sufficiently large to be subject to a phenomenon similar to oceanic tides. This phenomenon, the seiche effect, will cause long period oscillations in the river similar to the waves caused by tides in a coastal estuary. Neither amplitude, current, nor dye tracer measurements of any detail were available to fully evaluate the effect of the seiche in Green Bay on the Lower Fox River.

Aerial photographs obtained during a recent study of (EPA, 1972) thermal discharges in Lake Michigan clearly indicate current reversals at about 1.3 miles from Green Bay near the confluence of the East River and the Lower Fox. Contrary to the conclusion presented in the QLM report, it is evident that longitudinal backmixing does appear to significantly alter the distribution of pollutants in the river below De Pere at certain times. The effect of backmixing can be seen in the results of a recent river survey shown in Figure 6.

TABLE 4

PHYSICAL PARAMETERS

Segment No.	Depth (feet)	Width (feet)	Cross-Sectional Area (sq.ft.)	Mile Points	Location
1	2	488	976	38.63 - 38.1	Neenah Dam - Bergstrom Paper (Neenah Channel)
2	2.5	1,608	4020	38.1 - 37.62	Bergstrom Paper - Kimberly-Clark (Lakeview)
3	3	2,326	6978	37.62 - 37.24	Kimberly-Clark - James Is.
4	2	305	610	38.18 - 37.92	Menasha Channel - John Strange Paper
5	2	356	712	37.92 - 37.24	John Strange Paper - James Is.
6	4	2,915	1166	37.24 - 36.83	James Is. - Menasha Lock (Main River)
7	4.5	3,252	14634	36.83 - 36.0	Menasha Lock - Menasha (9th Street)
8	5.5	2,739	15065	36.0 - 34.8	Menasha (9th Street) Strobe Is.
9	9	1,093	9837	34.8 - 34.3	Strobe Is. - Mud Creek
10	9.6	1,045	10032	34.3 - 33.96	Mud Creek - Grignon Rapids Channel
11	6.6	556	3670	33.96 - 32.1	Grignon Rapids Channel - Dam, Wis--Mich. Power
12	4	419	1676	32.1 - 31.65	Wis-Mich. Power - Dam, Fox River Paper
13	4.5	444	1998	31.65 - 30.8	Fox River Paper - Dam, Formost Dairies
14	1.6	387	619	30.8 - 30.56	Dam, Formost Dairies Consolidated Paper
15	5.8	629	3648	30.56 - 29.73	Consolidated Paper Appleton Sewage Plant
16	6.7	626	4194	29.73 - 27.24	Appleton Sewage Plant Kimberly-Clark (Kim.)
17	3.3	806	2660	27.24 - 26.8	Kimberly-Clark (Kim.) Little Chute (Jefferson St
18	6.7	680	4556	26.8 - 26.4	Little Chute - Guard Lock, Little Chute
19	6.4	1,030	6592	26.4 - 25.6	Guard Lock, Little Chute - Dam, Combined Locks Paper
20	2.8	533	1492	25.6 - 25.1	Combined Locks Paper - Sanitorium Road
21	6.3	553	3484	25.1 - 23.93	Sanitorium Road - LaFollette Park,Kaukauna
22	6.0	150	900	23.93 - 23.2	LaFollette Park,Kaukauna - Thilmany Paper
23	6.0	150	900	23.2 - 22.5	Thilmany Paper Lagoons

TABLE 4 (Con't)

PHYSICAL PARAMETERS

Segment No.	Depth (feet)	Width (feet)	Cross-Sectional Area (sq.ft.)	Mile Points	Location
24	4.7	1,386	6514	22.5 - 21.0	Lagoons - mile point 21.0
25	7.5	627	4703	21.0 - 19.18	Mile point 21.0 Rapide Croche Dam
26	4	605	2420	19.18 - 17.4	Rapide Croche Dam - Plum Creek
27	5.8	502	2912	17.4 - 15.0	Plum Creek - Apple Creek
28	7.7	575	4428	15.0 - 13.1	Apple Creek - Dam Little Rapids
29	5.5	919	5055	13.1 - 12.6	Dam, Little Rapids - Lost Dauphin State Park
30	5	1,629	8145	12.6 - 12.1	Lost Dauphin State Park - Hickory Grove Sanitorium
31	5.7	1,780	10146	12.1 - 10.4	Sanitorium - Old Plank Rd. DePere
32	10.3	903	9301	10.4 - 7.3	Old Plank Rd, DePere - Dam, DePere
33	3.4	1,438	4889	7.3 - 6.97	Dam, DePere - U. S. Paper Mills
34	6.6	1,640	10824	6.97 - 6.25	U.S. Paper Mills - DePere Sewage Plant
35	7.4	1,160	8584	6.25 - 5.7	DePere Sewage Plant - Ashwaubenon Creek
36	5.6	2,083	11665	5.7 - 4.8	Ashwaubenon Creek - Dutchman Creek
37	5.6	2,715	15204	4.8 - 4.0	Dutchman Creek - Reimers Meat Products
38	9	1,338	12042	4.0 - 3.7	Reimers Meat Products - Fort Howard Paper
39	13	1,154	15002	3.7 - 2.63	Fort Howard Paper - Porlier Street Green Bay
40	21	618	12978	2.63 - 1.3	Porlier Street - East River
41	19	845	16055	1.3 - 1.0	East River - Charmin Paper Co.
42	20	594	11880	1.0 - 0.7	Charmin Paper Co. - Green Bay Packaging
43	13	765	9945	0.7 - 0.33	Green Bay Packaging - Reiss Coal Co.
44	16.5	850	14025	0.33 - 0.14	Reiss Coal Co. - Green Bay Yacht Club
45	13	938	12194	0.14 - 0.0	Green Bay Yacht Club Green Bay

Source: (Quirk, Lawler and Matusky Engineers, 1969)

Because of the backmixing effect, the distribution of pollutants is altered such that the concentration of dissolved oxygen occasionally tends to increase below De Pere, rather than decrease, as would be expected due to the magnitude of the waste loads discharged into the river.

Since the observed phenomena are similar to tidal effects in a coastal estuary, the effect of current reversals, i.e., a seiche, can be accounted for in the model by the addition of a term describing the mass flux due to longitudinal dispersion in Equation (1).

Data were not available to permit evaluation of the effect of current reversals on water quality predicted by the present model. Since the seiche phenomena is not a continuous occurrence, as are estaurine tides, the integrity of the model reported herein is not affected for situations in which the effects of dispersion are negligible.

Survey Data

Two recent sources of extensive data greatly facilitated construction of the model. Sager and Wiersma's 1971 and 1972 study of water quality in the Lower Fox River and Green Bay provided temperature, dissolved oxygen and chlorophyll - a measurements at ten locations in the river. In addition, the Wisconsin DNR conducted stream surveys on the Lower Fox River throughout the summer of 1972, the results of which were made available to the EPA.

Sager and Wierma's data is a result of a single surface grab sample taken at locations where the river was considered to be well mixed. The data furnished by the Wisconsin DNR represents several measurements of dissolved oxygen across the width of the river at numerous locations on the river.

Observation of the data indicates the existence of a rather significant gradient in the lateral and vertical planes of the river, demonstrating that the river is not truly a completely mixing system as is assumed in a one-dimensional model.

Despite the apparent lack of complete mixing in some portions of the river, the computed profiles of dissolved oxygen do agree sufficiently well with the observed data to validate the assumption of an approximately uniform concentration of dissolved oxygen in the lateral and vertical planes in each segment of the river.

Proposed Effluent Limitations

The 1972 Amendments to the Federal Water Pollution Control Act changed the major emphasis of water pollution control from water quality standards to effluent limitations, regulating the amount of pollutants discharged from specific point sources. The 1972 Amendments required that EPA define the "best practicable control technology currently available" for various categories of industrial operations and determine maximum allowable effluent limitations. The Act requires that all dischargers provide at least this level of treatment and meet existing water quality standards no later than July, 1977.

"Best practicable control technology currently available" effluent limits are in the process of being defined for the pulp and paper industry. These limitations will be expressed in terms of pounds of $CBOD_5$, suspended solids, and other materials allowed to be discharged per ton of product and are being established for the numerous specific operations in the pulp and paper industry. These limits were not completed at the time of this evaluation; therefore, previously developed "interim" guidelines (Table 5) were used.

These compare very closely to the initial draft of the guidelines being developed for the type of papermills located on the Fox River.

Also, the various municipal waste facilities in the basin are required by Wisconsin DNR orders to achieve a minimum of 90 percent removal of influent BOD. These requirements compare closely with the minimum Federal requirements of secondary treatment for municipalities as defined in the promulgated regulations (40 CFR 133).

The proposed effluent limitation represented by 90% BOD removal at municipalities and the interim guideline limitations shown in Table 5 are the basis for the water quality predictions made in this report.

A location map indicating the study area, municipal and industrial waste sources, and river segmentation, and the dams considered to be significant sources of reaeration is shown in Figure 1. Table 5 lists the various pount sources in the river by identification number, segment and river milepoint. It also gives estimated waste loadings assuming implementation of estimated effluent limitations for industries and for municipalities.

Non-point sources of BOD and other pollutants, primarily from urban and rural runoff, were not evaluated in detail in this report. At certain times of the year, these sources may contribute significant amounts of waste loads to the river, although the extent of this contribution has not been established.

TABLE 5

SUMMARY OF WASTE DISCHARGES

Number	Source	Segment	River mile point	June 20-21, 1972 Effluent Levels			Proposed Effluent Limitations		
				Flow (mgd)	$CBOD_5$ (lbs/day)	NBOD (lbs/day)	Flow (mgd)	$CBOD_5$ (lbs/day)	NBOD (lbs/day)
1.	Kimberly -Clark (Neenah)	2	40.1	1.7	55	55	TO NEENAH-MENASHA STP		
2.	Kimberly-Clark (Badger Globe)	2	39.9	0.7	263	46		"	
3.	Bergstorm Paper	2	39.8	5.0	20057	2200		"	
4.	Kimberly-Clark (Lakeview)	3	39.2	5.4	640	466	3.6	550	466
5.	Gilbert Paper	5	39.8	2.5	0	0	TO NEENAH-MENASHA STP		
6.	John Strange	5	39.8	2.0	760	0	1.0	1000	0
7.	Neenah-Menasha STP	6	37.6	15.2	3470	3287	24.0	7000	3287
8.	George Whiting	7	38.7	0.5	200	16	0.4	100	16
9.	Menasha Sanitary District #4	8	36.0	0.6	2792	330	0.6	935	330
10.	Riverside Paper	14	33.3	2.4	1805	238	0.4	90	238
11.	Foremost Foods	14	30.8	1.3	299	0	1.3	60	0
12.	Consolidated Paper	15	30.1	17.9	52406***	6880	18.0	4900	6880
13.	Appleton STP	16	30.0	10.0	2150***	3363	14.2	4139	3363
14.	Kimberly-Clark (Kimberly)	17	29.0	11.0	17490	1828	11.0	1658	2658*
15.	Kimberly STP	17	27.0	0.4	90	265	0.6	100	265
16.	Little Chute STP	18	26.9	0.4	167	130	0.8	100	130
17.	Appleton Papers	20	27.0	8.3	30695	530	8.3	2000	530
18.	Kaukauna STP	24	23.1	1.1	144	854	1.2	232	854
19.	Thilmany Paper	24	23.0	27.1	20642	2568	19.2	4260	2628*
20.	Nicolet Paper	33	7.0	3.3	438	0	3.2	945	4953*
21.	U.S. Paper	34	6.8	0	0	0	TO DE PERE STP		
22.	DePere STP	35	6.2	1.7	1180	1628	2.2	1543	1628
23.	Fort Howard Paper	39	3.7	15.2	52850	0	22.6	8500	2157*
24.	Charmin Paper	42	1.0	13.7	47385	36670	6.0	7000	1316**
25.	Green Bay Packaging	43	0.7	2.6	1700	137	1.8	3150	150*
26.	American Can	44	0.3	35.9	88466***	112	5.4	4215	510**
27.	Green Bay Metro STP	45	0.1	13.5	25481***	5631	39.0	14600	5631**
	TOTAL WASTE LOAD				371630	67234		67077	37990

* Represents information from NPDES permits

** Estimated in anticipation of future conditions

***Values for wastewater discharges for these facilities were taken from the Refuse Act Permit Program applications and, therefore, represent average daily conditions, not those for June 20-21, 1972.

RESULTS

The following analysis demonstrates a reasonable degree of correlation between observed data and computed results for varying conditions of river flow, river temperature and waste loadings.

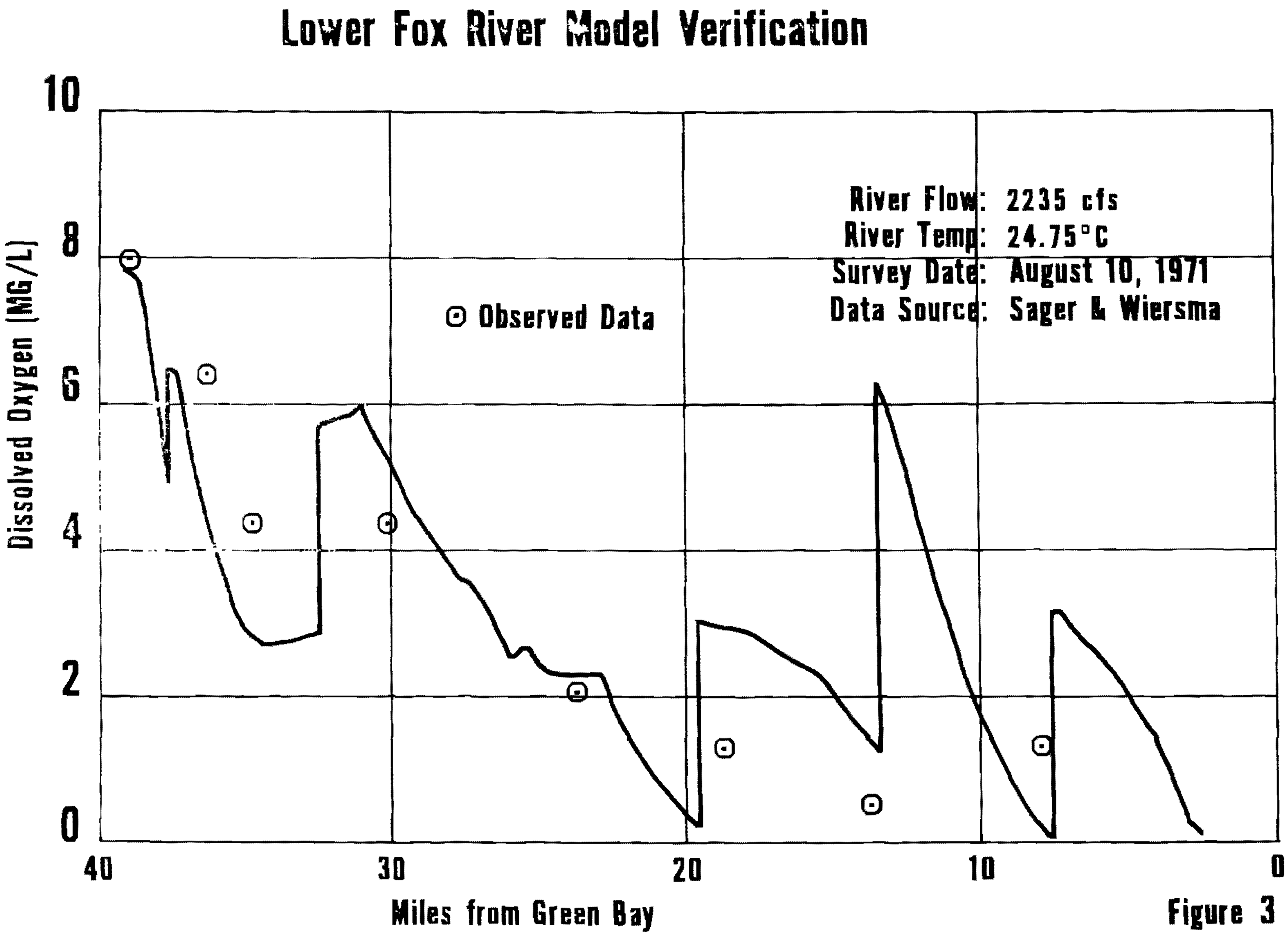
Model Verification

Figures 3 through 6 depict the comparison between the observed data and the computed profiles of dissolved oxygen for the river survey data that was analyzed.

Comparisons were made for river flow rates varying from 1,340 cfs (2,277 cu m/min) to 2,250 cfs (3,823 cu m/min) and river temperatures ranging from 21° to 25°C.

The comparison shown in Figure 5 for the data collected on July 5 and 6, 1972 is of particular significance since several of the pulp and paper mills were shut down for the Fourth of July holiday. The observed data and the computed profile both show a significant improvement in water quality as a result of decreasing some of the waste loads to the river. The good agreement between the computed profile and this particular set of data lends confidence in the ability of the model to predict future water quality conditions as a result of implementing the proposed effluent limitations on the Lower Fox River.

Also of interest is the observed data shown in Figures 4 and 5. The survey data indicate rather high concentration gradients of dissolved oxygen in the lateral and vertical planes at certain locations on the river, most notably near the Menasha Channel, Appleton Papers, below the Rapide Croche Dam. and near the mouth of the river at Green Bay. Despite the vertical stratification of dissolved oxygen due to benthic deposits and the apparent lack of complete mixing near waste outfalls, the agreement between the observed



Lower Fox River Model Verification
10
8
6
4
2
0
Dissolved Oxygen (MG/L)
River Flow: 2235 cfs
River Temp: 24.75°C
Survey Date: August 10, 1971
Data Source: Sager & Wiersma
Observed Data
40
30
20
10
0
Miles from Green Bay

Figure 3

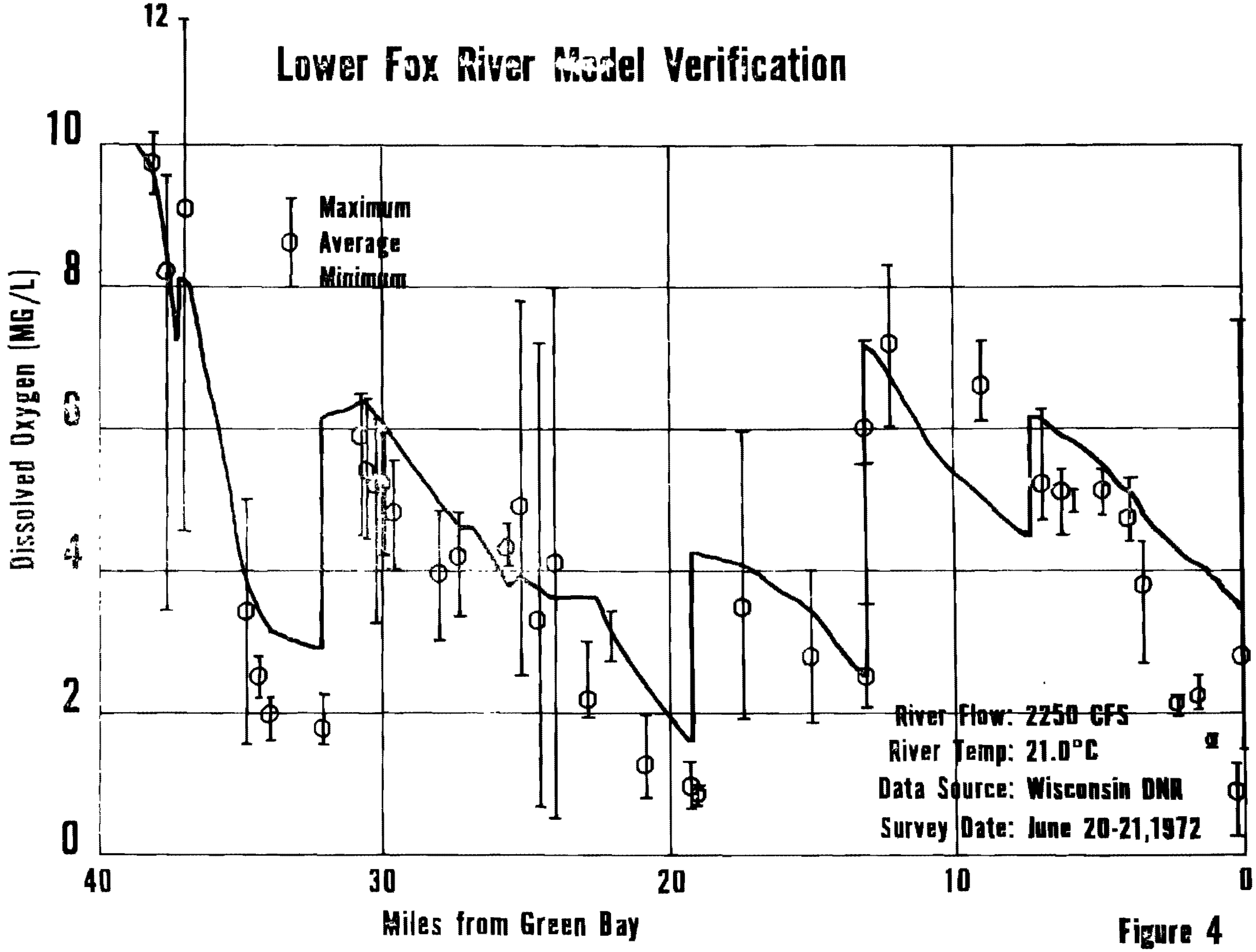

Lower Fox River Model Verification
Maximum
Average
Minimum
Dissolved Oxygen (MG/L)
12
10
8
6
4
2
0
40
30
20
10
0
Miles from Green Bay
River Flow: 2250 CFS
River Temp: 21.0°C
Data Source: Wisconsin DNR
Survey Date: June 20-21,1972

Figure 4

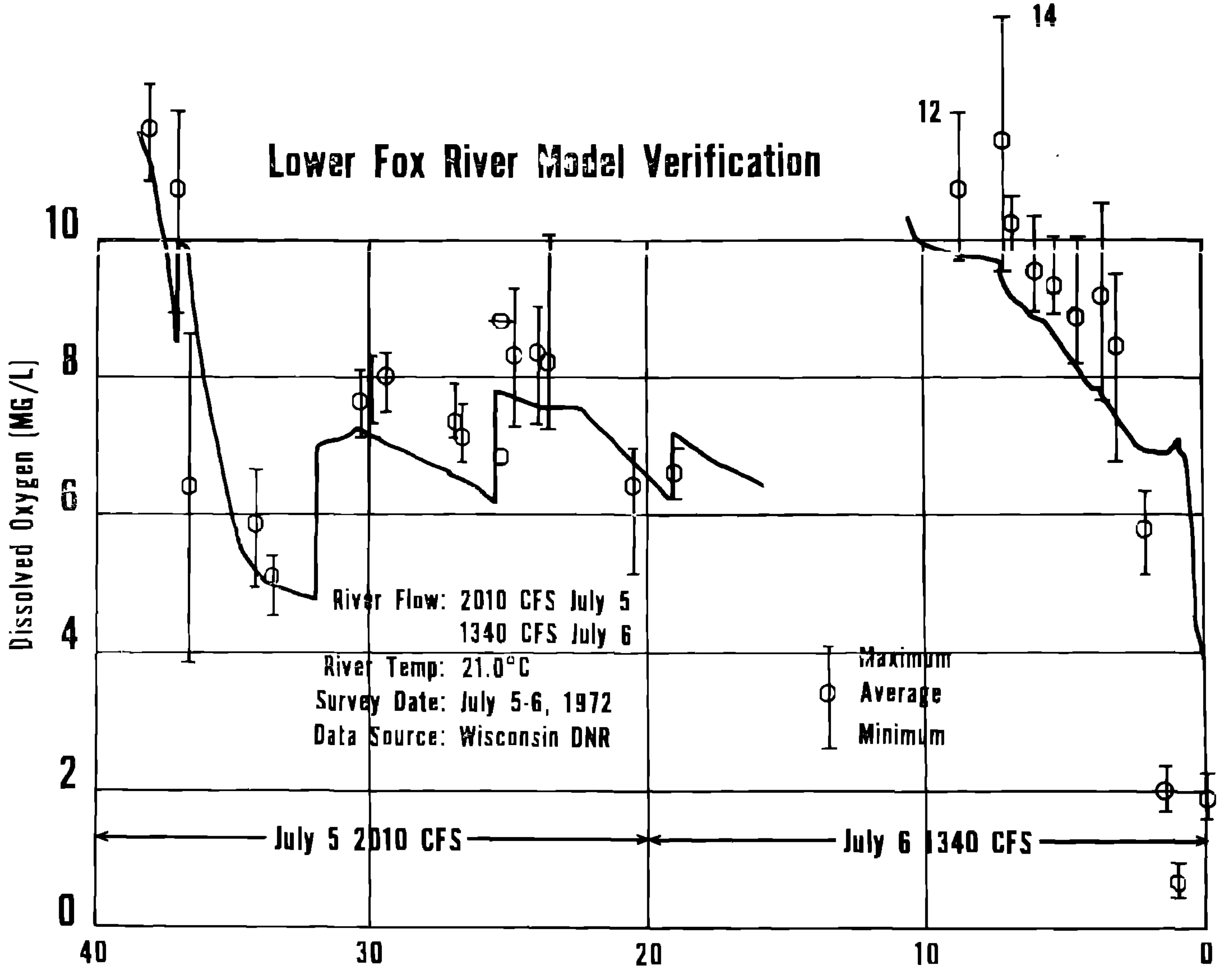

Lower Fox River Model Verification
Dissolved Oxygen (MG/L)
0
2
4
6
8
10
12
14
River Flow: 2010 CFS July 5
1340 CFS July 6
River Temp: 21.0°C
Survey Date: July 5-6, 1972
Data Source: Wisconsin DNR
Maximum
Average
Minimum
July 5 2010 CFS
July 6 1340 CFS
40
30
20
10
0
Miles from Green Bay

Figure 5

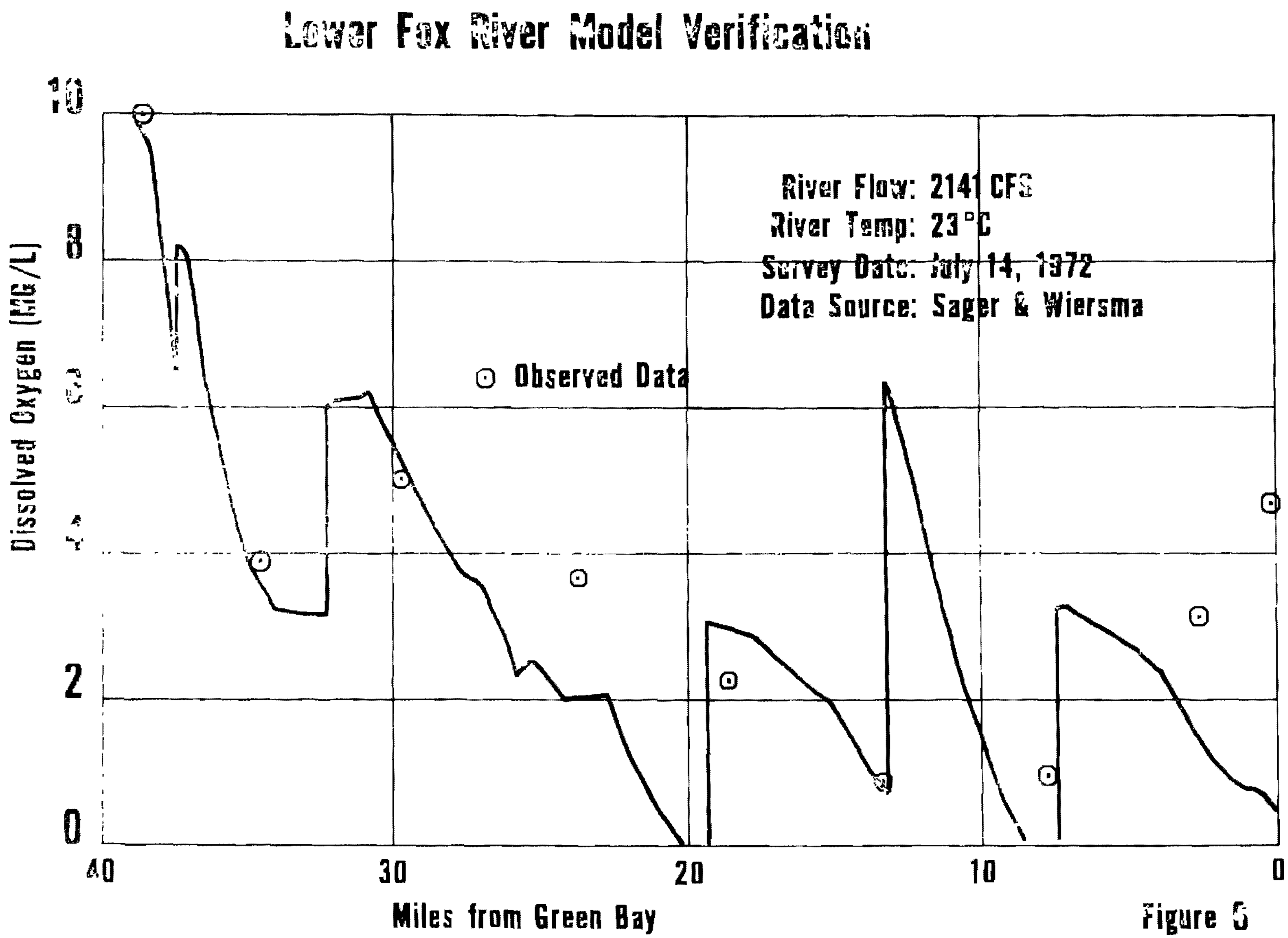

Lower Fox River Model Verification
River Flow: 2141 CFS
River Temp: 23°C
Survey Date: July 14, 1972
Data Source: Sager & Wiersma
Observed Data
Dissolved Oxygen (MG/L)
10
8
2
0
40
30
20
10
0
Miles from Green Bay

Figure 5

data and the computed profile, which assumed an average, and uniform concentration, is good. The observed data shown in Figures 3 and 6 do not demonstrate significant gradients since only one sample (assumed to be representative of a completely mixed system) was taken at each location.

The observed data for July 14, 1972 shown in Figure 6 possibly demonstrate the backmixing interaction between the mouth of the Lower Fox River and Green Bay. Because of this effect. the distribution of pollutants is altered so that the concentration of dissolved oxygen occasionally tends to increase below De Pere. The backmixing effect, similar to estuarine tidal effects, was not considered in the development of this model, since the phenomenon is not a continuous occurrence.

Model Sensitivity

Using August 10, 1971 actual conditions, the sensitivity of the model to the benthic oxygen demand, the carbonaceous BOD decay coefficient and the nitrogenous BOD decay coefficient were evaluated. Table 6 presents the sensitivity of the model to these parameters at three critical locations on the river. The analysis indicates that the water quality is most sensitive to the benthic oxygen demand and the rate of CBOD deoxygenation. The model is relatively insensitive to the variations in the maximum rate coefficient for nitrification, as can be seen in Table 6. If further refinement of this model is to be obtained, additional field work is needed to, in more detail, evaluate the spatial distribution of sludge deposits, the resultant oxygen uptake rate, and the rate of CBOD utilization.

Water Quality Predictions

The preceding analysis demonstrated the ability of the model to reproduce observed data for varying conditions of flow, temperature, and waste

TABLE 6

Model Verification Sensitivity

Survey Date - August 10, 1971

Parameter	m.p. 35.0	m.p. 15.0	m.p. 0.0
	Dissolved oxygen (mg/l)		
Benthic Uptake Rate			
S = 2.5 g/m²-day	4.75	2.53	0.59
*S = 5.0 g/m²-day	3.24	0.80	0.0
S = 10.0 g/m²-day	0.23	0.0	0.0
CBOD Decay Rate			
Kd = 0.15/day	4.78	2.79	0.0
*Kd = 0.30/day	3.24	0.80	0.0
Kd = 0.60/day	0.92	0.0	0.0
NBOD Decay Rate			
*K_n = 0.14/day	3.24	0.80	0.0
K_n = 0.28/day	2.78	0.62	0.0
K_n = 0.56/day	2.07	0.49	0.0

m.p. = mile point from mouth

* Value used in verification

loadings in the river. The verified model was then used to evaluate the improvement in water quality as a result of implementing the proposed effluent limitations.

Figure 7 depicts the average response of water quality to implementation of the required effluent limitations for all waste sources on the river.

Conditions assumed for the prediction represent a fairly extreme summertime condition with a 7-day 10-year low-flow of 1,127 cfs (1,915 cu m/min), a stream temperature of 21°C, and relatively low algal populations in the river. The daily average concentration of dissolved oxygen is about 6 mg/l, falling significantly below this in the region past De Pere (mp 7.3), although still above 4 mg/l.

The profile shown in Figure 7 is not meant to be a precise forecast of future water quality conditions in the Lower Fox River; rather the analysis indicates a significantly improved water quality as a result of implementing the projected effluent limitations for point sources.

The shaded area in Figure 7 approximates the average diurnal variation to be expected from algal photosynthesis and respiration, and other periodic fluctuations in parameters such as benthic uptake rate and natural background conditions of water quality. The variation in dissolved oxygen due to algal activity has, in the past, averaged about 1 mg/l with a range from 1 to 3 mg/l above and below the daily average concentration as measured by the Wisconsin Department of Natural Resources automatic monitors. It is assumed that diurnal variations will occur under future conditions, yet it is difficult to forecast the magnitude of such a fluctuation for future conditions.

Lower Fox River Model Prediction

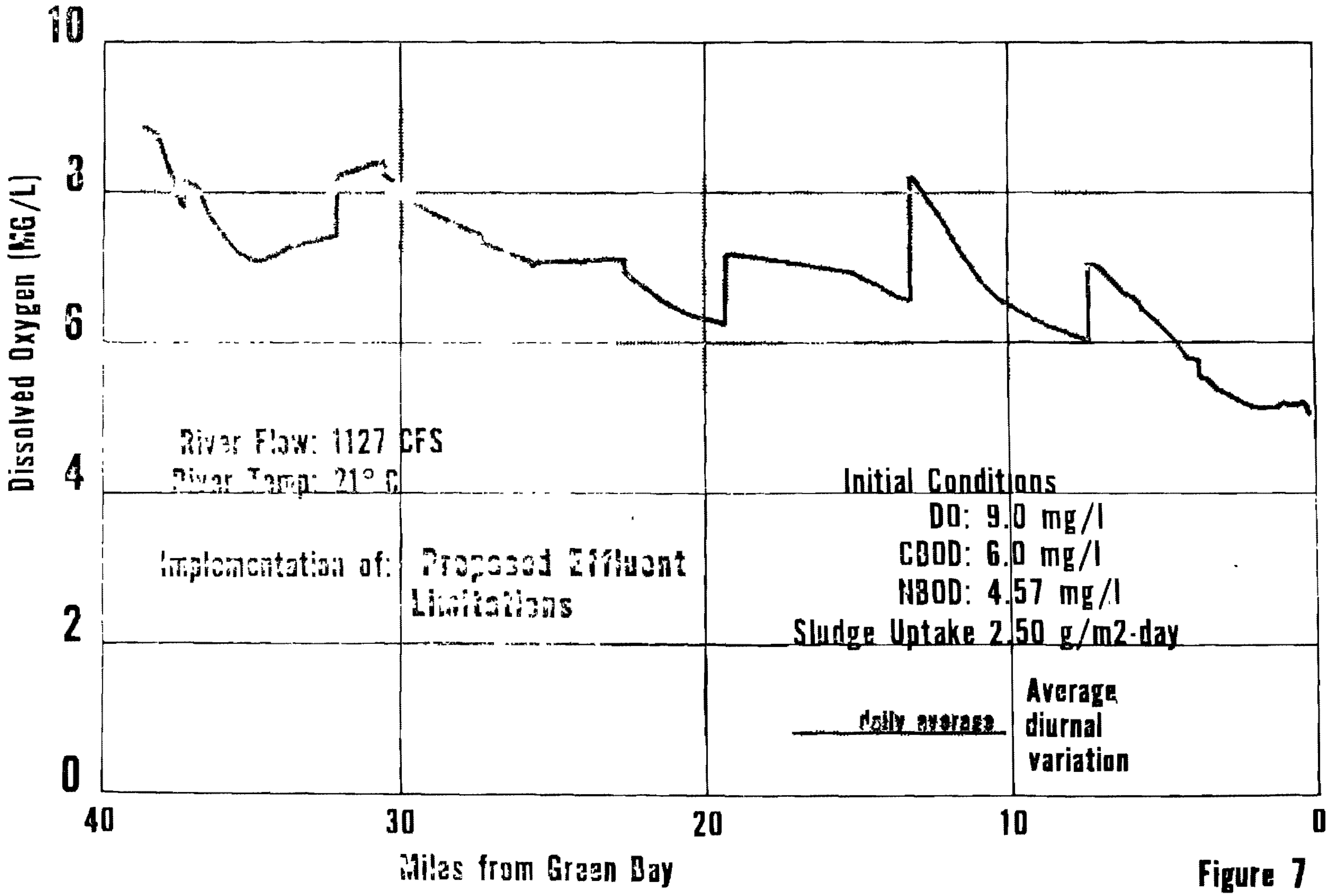


Figure 7

The predictions are based on the assumption of a linear system. The terms in equations 1 and 2 assume that the biological systems can be modeled by linear functions. However, it is realized there exist some nonlinear biological feedback mechanisms. For example, the improvement in dissolved oxygen in the future may provide more suitable conditions for nitrifying bacteria, and the predicted profile may be slightly less than that shown in Figure 7. The effect of reduced waste discharges on algal growth and the resultant effect on water quality may also alter the projected profile shown in Figure 7, but the extent of this alteration is uncertain.

The prediction shown in Figure 7 represents the best estimates available for the various significant input parameters with consideration given to the effects of decreased waste loading to the river upon each of the parameters. A summary of the values used in the prediction analysis including an approximate occurrence frequency for each parameter and the range of values reported in the literature is shown in Table 7.

Further evidence of the effect of reducing waste loads and the resultant improvement in water quality is shown in Figure 8. In this figure, the survey data and model verification for June 20-21, 1972 (Figure 4) is superimposed on a model prediction that uses the flow and temperature conditions that occurred on the survey date. Thus, the prediction in Figure 8 indicates what the average dissolved oxygen would have been had the proposed effluent limitations been in effect as compared to existing loading levels. Clearly, there will be a marked improvement in average dissolved oxygen levels in the river, and existing water quality standards should be achieved.

TABLE 7

SUMMARY OF PARAMETERS USED IN STREAM ANALYSIS

PARAMETER NAME (SYMBOL)	VALUE USED FOR VERIFICATION	VALUE USED FOR PREDICTION	PREDICTION VALUE OCCURRENCE FREQUENCY	REPORTED VALUES FOR FOX RIVER	REPORTED VALUES FROM LITERATURE	SENSITIVITY AT MILE POINT 0.0
Flow (Q) cfs	As measured daily by U.S.G.S. -- --	-- 1127 2254	-- 7 day, 10 year low flow	-- --	-- --	-- from 1127 to 2254 ΔD.O. = +1.98
Sludge Uptake (S) gms O_2/m^2-day	5.0	2.5	2.5 is literature value for unpolluted streams	2.5 to 20	1.5 to 19	from 2.5 to 5.0 ΔD.O. = -4.04 mg/1
Algal Productivity (Pmm) mg/1-day	As measured by Sager	14 maximum	Median value of available data	2.0 to 45	--	from 7 to 14 ΔD.O. = +2.86 mg/1
CBOD decay (Kd) 1/day	As reported in QLM. Measured values varied with flow.	0.15 0.124 below DePere Dam	Lowest observed because of low flow	0.124 - 0.6	0.1 - 0.6 without settling	from 0.15 to 0.3 ΔD.O. = -0.58 mg/1
Temperature (T) °C	As measured on survey date -- --	-- 21°C 25°C	See Temp. - Flow Correlation	0 - 31 -- --	-- -- --	from 21 to 25 ΔD.O. = -1.60 mg/1
NBOD decay (Kn) 1/day	0.14 maximum As reported in QLM	0.14 maximum	Not available	0.14	0.1 to 0.6	from 0.14 to 0.6 ΔD.O. = -0.31 mg/1
Initial CBOD mg/1	As measured or 6.0	6.0	50 to 80% of values are ≤ 6.0	1 to 9	--	from 3.0 to 6.0 ΔD.O. = -0.59 mg/1
Initial NBOD mg/1	Usually 4.6	4.6	About 50%	2.3 to 11.2	--	from 4.6 to 9.2 ΔD.O. = -0.17 mg/1
Initial D.O. mg/1	As measured on survey date	C_s, the saturation value	70 to 90% of the values are greater than C_s	C_s ±4 mg/1	--	for initial D.O. = C_s-2, ΔD.O. <0.25 mg/1 at mp 2(
Industrial-Municipal Loadings lbs/day	As reported to WDNR or EPA	EPA production guidelines	--	--	--	For 20% reduction beyond guidelines ΔD.O. = +0.48

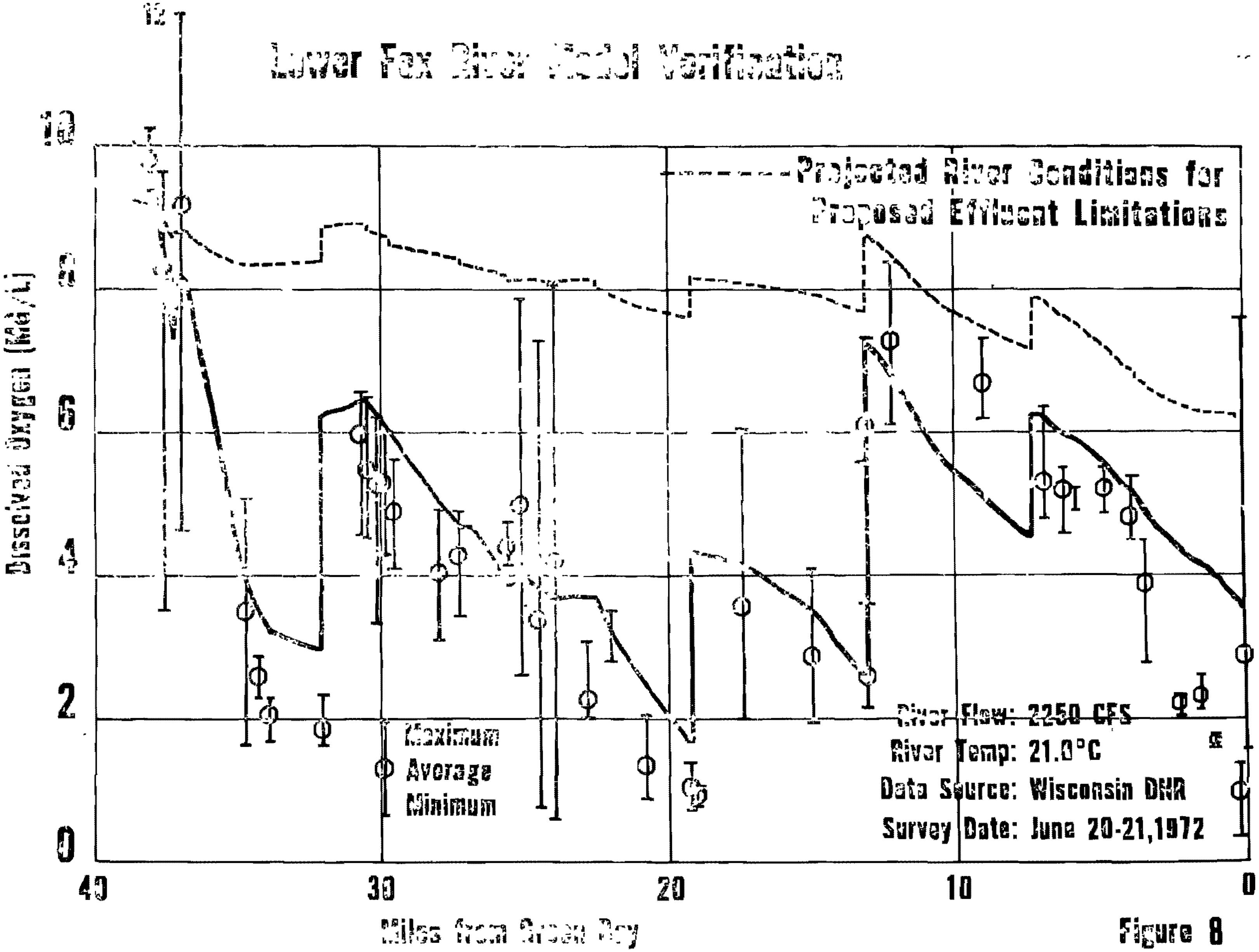

Lower Fox River Model Verification
Projected River Conditions for Proposed Effluent Limitations
Dissolved Oxygen (Mg/L)
Maximum
Average
Minimum
River Flow: 2250 CFS
River Temp: 21.0°C
Data Source: Wisconsin DNR
Survey Date: June 20-21,1972
Miles from Green Bay
0
2
4
6
8
10
12
40
30
20
10
0

Figure 8

A sensitivity analysis was performed on the model prediction to demonstrate the range of response to be expected for various combinations of reasonable ranges of the parameters. The results of the analysis are shown in Table 8 for three critical river milepoints. Inspection of Table 8 would indicate that the Lower Fox River is most sensitive to the following parameters (shown in decreasing order of sensitivity): benthic oxygen uptake rate, algal photosynthesis, river flow, temperature, and deoxygenation rate for CBOD.

Sensitivity of the prediction to the benthic oxygen demand is shown in Figure 9. As stated in the previous discussion on benthic oxygen demand, all evidence indicates that the average value will be nearer to 2.5 than to 5.0 gms O_2/m^2-day, once the sources of the sludge deposits are controlled. This is due to the rapid lowering of the uptake rate as the sludge ages. Hence, an average oxygen uptake rate for sludge of 2.5 gms O_2/m^2-day was used in the prediction.

Figure 10 shows the sensitivity of the model prediction to variations in gross algal oxygen production. The middle profile, which is the same as that shown in Figure 7, uses average algal oxygen production values estimated from the chlorophyll-a data provided by Sager and Wiersma. For comparison purposes, profiles equal to double and one half the calculated algal oxygen production values were utilized. These profiles do not represent a normally expected situation, but are included to show the range of sensitivity to algal oxygen production.

TABLE 8

Model Prediction Sensitivity to Parameter Changes

Parameter	m.p. 35.0	m.p. 15.0	m.p. 0.0
Benthic Uptake Rate			
* S = 2.5 g/m²-day	7.53	6.74	4.09
S = 5.0 g/m²-day	5.35	4.55	0.05
Algal Productivity			
P = 1/2 P¹mg/l-day	5.50	5.39	1.23
* P = P¹mg/l-day	7.53	6.74	4.09
P = 2P¹mg/l-day	11.60	9.44	9.81
CBOD Decay Rate (K_r = K_d)			
* K_d = 0.15/day	7.53	6.74	4.09
K_d = 0.3/day	5.91	5.24	3.51
K_d = 0.6/day	3.89	6.43	2.40
NBOD Decay Rate			
* K_n = 0.14/day	7.53	6.74	4.09
K_n = 0.3/day	6.77	5.48	4.07
K_n = 0.6/day	5.89	5.46	3.73
Initial CBOD			
CBOD' = 3.0 mg/l	8.49	7.24	4.68
* CBOD' = 6.0 mg/l	7.53	6.74	4.09
CBOD' = 9.0 mg/l	6.55	6.24	3.49
Initial NBOD			
* NBOD' = 4.6 mg/lm	7.53	6.74	4.09
NBOD' = 9.2 mg/l	7.23	6.62	3.92
River Flow			
* Q = 1127 cfs	7.53	6.74	4.09
Q = 2254 cfs	6.87	7.62	6.07
Temperature			
* T = 21°C	7.53	6.74	4.09
T = 25°C	6.07	5.49	2.49

*Base Conditions:

Q = 1127 cfs
T = 21°C
S = 2.5 g/m²-day
K_d = 0.15/day

K_n = 0.14/day
CBOD' = 6.0 mg/l
NBOD' = 4.6 mg/l
P = 14.0 mgO_2/l-day
@ mp 38.53

Lower Fox River Model Sensitivity

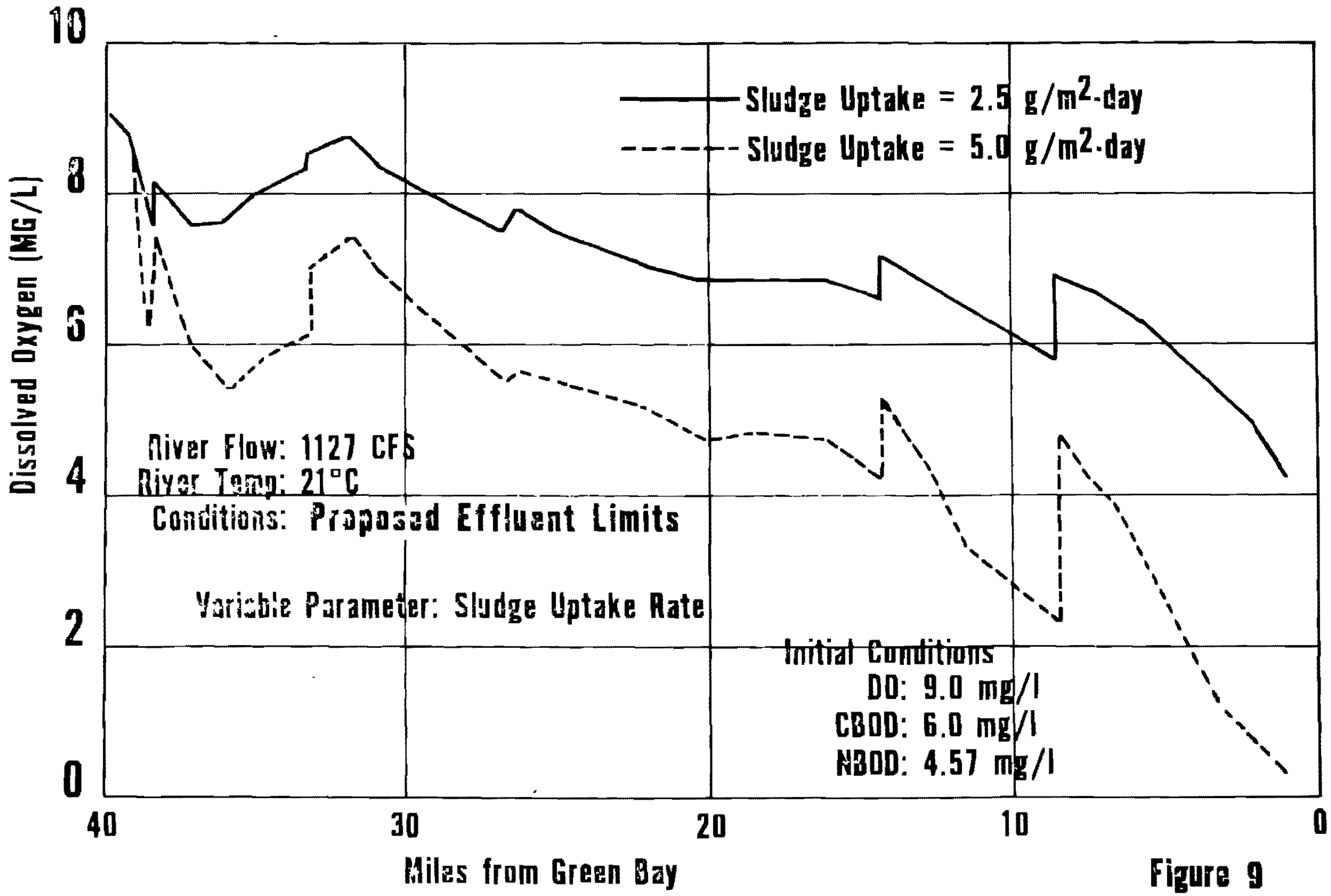
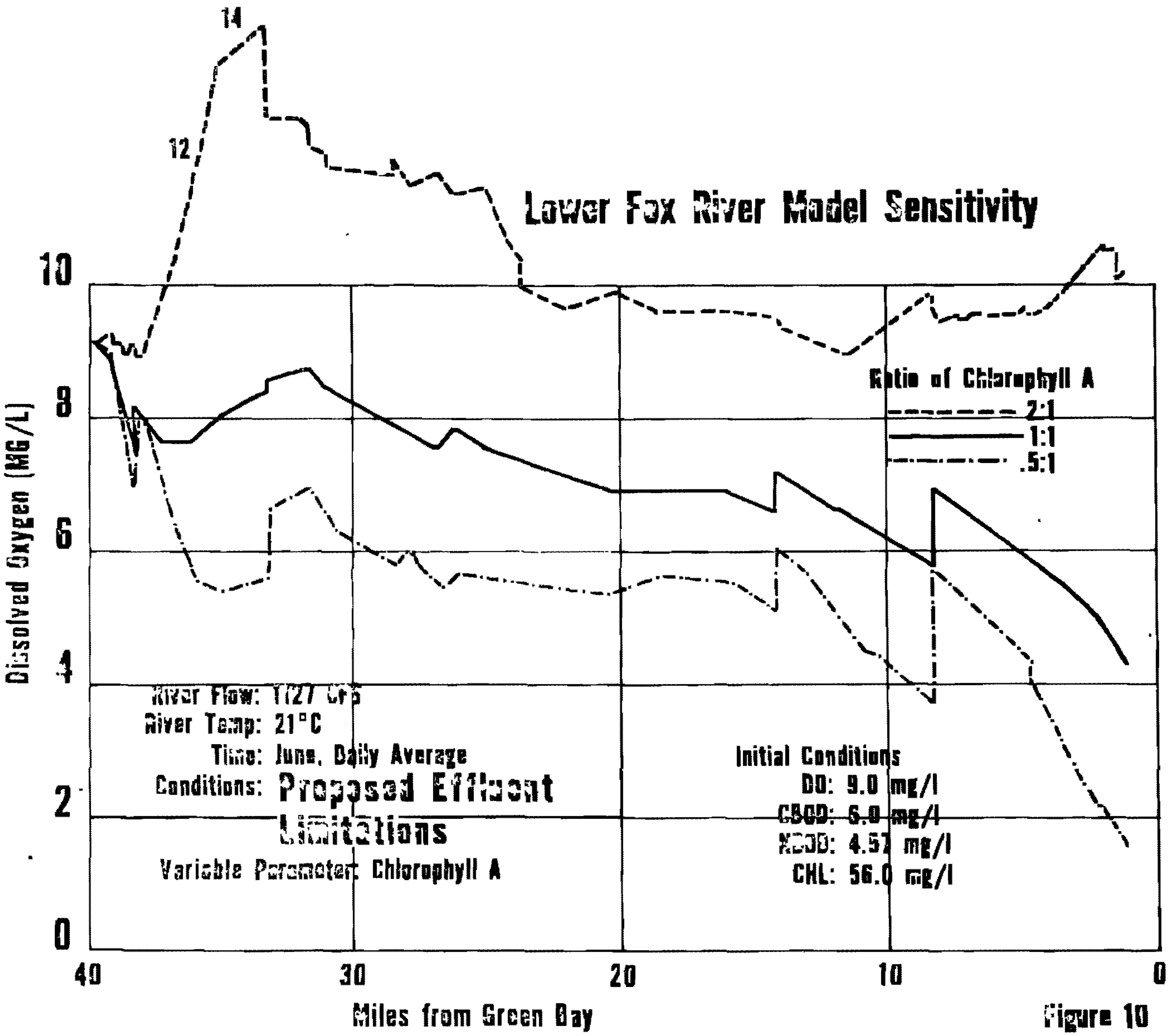


Figure 9



Lower Fox River Model Sensitivity
Dissolved Oxygen (MG/L)
Miles from Green Bay
Ratio of Chlorophyll A
2:1
1:1
.5:1
River Flow: 1727 CFS
River Temp: 21°C
Time: June, Daily Average
Conditions: Proposed Effluent Limitations
Variable Parameter: Chlorophyll A
Initial Conditions
DO: 9.0 mg/l
CBOD: 6.0 mg/l
NBOD: 4.57 mg/l
CHL: 56.0 mg/l

Figure 10

Frequency of Occurrence Below Given Dissolved Oxygen Levels

Although the set of parameters chosen to generate the prediction shown in Figure 7 represent fairly extreme summertime conditions, it is recognized that other combinations of low-flow and high temperatures would result in lower dissolved oxygen profiles. In order to approximately determine how often lower dissolved oxygen profiles would occur as a result of various extreme combinations of low-flow and temperature, 10 years of daily data from 1961 to 1971 were analyzed. The results of this analysis are shown in Table 9 for the normally critical point just above De Pere Dam at mile point 7.3. The table shows the number of days when extreme combinations of flow and temperature, if used as input parameters in the model, would have resulted in a daily average dissolved oxygen concentration of less than a given oxygen level.

TABLE 9

Frequency of Occurrence Below Given Dissolved Oxygen Levels at Mile Point 7.3

Daily Average DO level (mg/l)	Average Number of Occurrences Below Given Level (days/yr)	Anticipated Range of Observed Below Given Level (days/yr)
5	36	2-71
4	8-9	0-32
3	0	0

SUMMARY

The effect of the various wastewater inputs on water quality in the Lower Fox River can be modeled in a rational quantitative manner. Such a model was used to evaluate future water quality in the river assuming implementation of a proposed effluent program consisting of "best practicable control technology currently available" (interim estimates) for industrial waste sources and 90 percent BOD removal for municipal waste dischargers as required by the 1972 Amendments to the Federal Water Pollution Control Act and by Wisconsin State Orders. The approach presented herein has been shown to offer a reasonable basis for estimating the effects on water quality of implementing the proposed effluent program in the Fox River basin. The results of the study indicate that if the effluent limitations are implemented, there will be a significant improvement in water quality, and a daily average dissolved oxygen concentration of 4 to 5 mg/l will be maintained in all areas under most conditions and will not fall below 4 mg/l more than 2% of the time. During extreme low-flow and high temperature situations, the dissolved oxygen concentration could drop to about 2 to 3 mg/l.

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A P P E N D I X

P R O G R A M L I S T I N G

```
C     ******************************* HAL  ****************************************
C
C                        DISSOLVED OXYGEN STREAM MODEL
C
C     PROGRAMMMED AT HYDROSCIENCE, INC. ,WESTWOOD, NJ(1967)
C     MODIFIED BY ANDREW STODDARD, EPA, REGION 5 (1972)
C      *************************************************************************
C
C                             DISCUSSION OF MODEL
C
C     THIS PROGRAM DESCRIBES THE INTERRELATIONSHIP BETWEEN THE DISSOLVED
C     OXYGEN IN A STREAM AND ITS VARIOUS SOURCES AND SINKS SUCH AS
C     ATMOSPHERIC REAERATION AND THE OXIDATION OF BOD. THE MODEL
C     EVALUATES THE DAILY AVERAGE, ONE-DIMENSIONAL SPATIAL PROFILE OF THE
C     CONCENTRATIONS OF DISSOLVED OXYGEN AND BOD UNDER STEADY-STATE CONDITIONS.
C     IN THIS MODEL THE DISPERSIVE COMPONENT OF THE MASS FLUX IS CONSIDERED
C     INSIGNIFICANT. THE MODEL IS, THEREFORE,ADVECTIVE AND PREDICTS THE
C     LONGITUDINAL DISTRIBUTION OF DISSOLVED OXYGEN AND BOD DUE TO THE EFFECTS
C     OF THE VARIOUS POINT SOURCES OF WASTEWATER DISCHARGES, TRIBUTARIES, AND
C     BACKGROUND WATER QUALITY CONDITIONS IN THE SEGMENT UNDER CONSIDERATION.
C     THE CONCENTRATION PROFILES ARE COMPUTED ALONG THE LONGITUDINAL AXIS
C     OF THE RIVER  AND ARE ASSUMED TO BE UNIFORM IN DEPTH AND WIDTH IN EACH
C     SEGMENT.  THE CONCENTRATION AT THE UPSTREAM END OF A SEGMENT IS DETERMINED
C     BY A MASS BALANCE EQUATION. IN THIS EVALUATION THE MODEL USES A NUMBER OF
C     BIOLOGICAL, PHYSICAL, AND CHEMICAL CHARACTERISTICS WHICH ARE UNIQUE TO
C     THE STREAM UNDER INVESTIGATION.
C
C      *************************************************************************
C
C     SOURCES AND SINKS CONSIDERED IN EVALUATING PROFILE OF DISSOLVED OXYGEN
C
C       CARBONACEOUS BOD
C       NITROGENOUS BOD
C       BENTHIC OXYGEN DEMAND
C       ALGAL RESPIRATION AND PHOTOSYNTHESIS
C       ATMOSPHERIC REAERATION
C       REAERATION OVER DAMS
C       INPUT FROM WASTE SOURCES AND/OR TRIBITARIES
C
C      *************************************************************************
C
C                            INPUT PARAMETERS
C
C          VARIABLE NAME                                            UNITS
C
C     STREAM= NAME AND LOCATION OF STREAM
C     RUNDES= DESCRIPTION OF PARTICULAR SET OF DATA
C     SEGID= LOCATION OF SEGMENT BY LANDMARKS AND NUMBER
C     CO= INITIAL CONCENTRATION OF DISSOLVED OXYGEN                 MG/L
C     FLOLO= INITIAL CARBONACEOUS BOD (CBOD)                        MG/L
C     FLONO=INITIAL NITROGENOUS BOD  (NBOD)                         MG/L
C     XTOT= INITIAL MILEPOINT OF STREAM MODEL                       MILES
C     XCODE= 1  FOR INCREASING MILEPOINT
C     XCODE=  0  FOR DECREASING MILEPOINT
```

```
      C     NTOT= TOTAL NUMBER OF SEGMENTS IN SYSTEM
      C     WC= DO FROM WASTE LOAD AND/OR TRIBUTARY                  LBS/DAY
      C     WL= CBOD 5 FROM WASTE SOURCE AND/OR TRIBUTARY            LBS/DAY
      C     WN= NBOD FROM WASTE LOAD AND/OR TRIBUTARY                LBS/DAY
      C     QO= RIVER FLOW UPSTREAM OF SEGMENT BOUNDARY              CFS
      C     QA= FLOW OF WASTE SOURCE AND/OR TRIBUTARY                MGD
      C     RR= ALGAL RESPIRATION RATE                               MG/L-DAY
      C     PMM= ALGAL PHOTOSYNTHETIC OXYGEN SOURCE                  MG/L-DAY
      C     DELTA= INTERVAL OF COMPUTATION IN SEGMENT                MILES
      C     FLENG= LENGTH OF SEGMENT                                 MILES
      C     CONST= +1 FOR CONSTANT CROSS SECTIONAL AREA
      C              IN SEGMENT
      C          = 0 FOR LINEARLY INCREASING AREA IN
      C              SEGMENT
      C     AREA= CROSS SECTIONAL AREA FOR CONST=+1                  SQ FT
      C     SLOPE= SLOPE OF LINEAR AREA FUNCTION FOR
      C            CONST=0                                           SQ FT/MILE
      C     FINT= INTERCEPT OF LINEAR AREA FUNCTION AT
      C            UPSTREAM BOUNDARY                                 SQ FT
      C     FL= RATIO OF ULTIMATE CBOD TO 5 DAY CBOD
      C     FN= RATIO OF ULTIMATE NBOD TO 5 DAY NBOD
      C     TEMP= STREAM TEMPERATURE                                 DEG CENTIGRADE
      C     CS= SATURATION VALUE OF DISSOLVED OXYGEN                 MG/L
      C     HDAM= HEIGHT OF A DAM IN SEGMENT                         FT
      C     ALPHA=COEFFICIENT FOR REAERATION OVER DAMS
      C
      C     COEFFICIENTS FOR BRITISH DAM REAERATION EQUATION
      C     A= 1.25--CLEAR TO SLIGHTLY POLLUTED WATER
      C      = 1.00--POLLUTED WATER
      C      = 0.80--SEWAGE EFFLUENT
      C     B= 1.00--WEIR WITH FREE FALL
      C      = 1.30--STEP WEIRS OR CASCADES
      C
      C     F= FRACTION OF SLUDGE COVER ON BOTTOM                    DECIMAL
      C     FLOKR= CBOD REMOVAL COEFF AT 20 C                        1/DAY
      C     FLOKR= CBOD DECAY COEFF AT 20 C                          1/DAY
      C     FLOKN= NBOD DECAY RATE AT 20 C                           1/DAY
      C     S= OXYGEN UPTAKE RATE FROM BENTHIC DEPOSITS              GM/SQ METER-DAY
      C     DEPTH = AVERAGE DEPTH IN SEGMENT                         FT
      C
      C      ****************************************************************
      C
0001        DIMENSION D(30),FLOL(30),FLON(30),C(30),XX(30),FOFX(30),
           1STREAM(20),SEGID(20),RUNDES(20)
0002        NCHUN=3
      C     NCHUN=1  AS INITIAL COUNTER FOR SEGMENT SYSTEM OF STREAM MODEL.
      C     ANALYSIS FOR LOWER FOX RIVER USED NCHUN=3 DUE TO SEGMENT SYSTEM
      C     IN QLM REPORT. IN EPA ANALYSIS MENASHA CHANNEL WAS CONSIDERED AS A
      C     TRIBUTARY TO LOWER FOX RIVER . THIS DELETED SEGMENTS 4-5 USED IN
      C     QLM MODEL (1969).
      C
0003        READ(5,1250)(STREAM(K),K=1,20)
0004        READ (5,1250)(RUNDES(K),K=1,20)
0005   1250 FORMAT(20A4)
```

```
0006      1201 FORMAT(8F10.2)
0007           WRITE(6,1300)(STREAM(K),K=1,20)
0008      1300 FORMAT(1H1,//,20A4,//)
0009           WRITE(6,1255)(RUNDES(K),K=1,20)
0010      1255 FORMAT(/,20A4,/)
0011       910 READ(5,1203)CO,FLOLO,FLONO,XTOT,XCODE,NTOT
0012      1203 FORMAT(5F10.2,I10)
0013           WRITE(6,1212)
0014      1212 FORMAT(/,'**************************************************
              1*****************************************************',/)
0015           WRITE(6,1301)CO,FLOLO,FLONO,XTOT,XCODE,NTOT
0016      1301 FORMAT(15X,'--INITIAL CONDITIONS--',//,8X,'CO',5X,'FLOLO',5X,
              1'FLONO',6X,'XTOT',5X,'XCODE',6X,'NTOT',/,5F10.2,I10)
0017         1 CONTINUE
0018           X=0.
          C
          C    DATA INPUT FOR EACH SEGMENT
0019           READ(5,1250)(SEGID(K),K=1,20)
0020           WRITE(6,1407)(SEGID(K),K=1,20)
0021      1407 FORMAT(/,'--------------------------------------------------
              1-----------------------------------------------------
              2',/,20A4,/,40X,'INPUT',/)
0022           READ(5,1201) WC,WL,WN,QO,QA,CS,TEMP
0023           READ(5,1201) DELTA,FLENG,CONST,AREA,SLOPE,FINT,HDAM,DEPTH
0024           READ(5,1201) FL,FN,FLOKR,FLOKD,FLOKN,S,F
0025           READ(5,1202) PMM,RR,A,B,ALPHA
0026           WRITE(6,1207)
0027      1207 FORMAT(/,8X,'WC',8X,'WL',8X,'WN',8X,'QO',8X,'QA',8X,'CS',6X,'TEMP'
              1)
0028           WRITE(6,1201) WC,WL,WN,QO,QA,CS,TEMP
0029           WRITE(6,1208)
0030      1208 FORMAT(/,5X,'DELTA',5X,'FLENG',5X,'CONST',6X,'AREA',5X,'SLOPE',6X,
              1'FINT',6X,'HDAM',5X,'DEPTH')
0031           WRITE(6,1201) DELTA,FLENG,CONST,AREA,SLOPE,FINT,HDAM,DEPTH
0032           WRITE(6,1209)
0033      1209 FORMAT(/,8X,'FL',8X,'FN',5X,'FLOKR',5X,'FLOKD',5X,'FLOKN',9X,'S',
              19X,'F')
0034           WRITE(6,1201) FL,FN,FLOKR,FLOKD,FLOKN,S,F
0035           WRITE(6,1210)
0036      1210 FORMAT(/,7X,'PMM',8X,'RR',9X,'A',9X,'B',5X,'ALPHA')
0037           WRITE(6,1202) PMM,RR,A,B,ALPHA
          C
          C    COMPUTATION OF ATMOSPHERIC REAERATION RATE (FLOKA)
0038           FLOKA=12.9*((QO/AREA)**(.5))*((DEPTH)**(-1.5))
0039           WRITE(6,1211)FLOKA
0040      1211 FORMAT(/,5X,'FLOKA',/,F10.2)
0041           WRITE(6,1206)
0042      1206 FORMAT(/,40X,'OUTPUT',/)
0043           WRITE(6,1205)
0044      1202 FORMAT(4F10.2,F10.3)
0045      1205 FORMAT(/,11X,'MP',1X,'D FICIT',3X,'TERM1',3X,'TERM2',3X,'TERM3',
              13X,'TERM4',3X,'TERM5',3X,'TERM6',[illegible],'COOD',4X,'NBOD',6X,'DO',//)
          C
          C    [illegible] UPTAKE RATE TO MG/L-DAY
```

```
0046          S=(S/(DEPTH*.3048))*F
        C
        C     ADJUSTMENT OF RATE REACTIONS FOR STREAM TEMPERATURE
0047          FLOKA=FLOKA*1.024**(TEMP-20.)
0048          FLOKD=FLOKD*1.04**(TEMP-20.)
0049          FLOKR=FLOKR*1.04**(TEMP-20.)
0050          FLOKN=FLOKN*1.08**(TEMP-20.)
0051          S=S*1.065**(TEMP-20.)
        C
        C     MASS BALANCE COMPUTATION AT UPSTREAM END OF SEGMENT
        C
        C     CONVERTS WASTE SOURCE FLOW IN MGD TO CFS
0052          QA=QA*1.54723
0053          WC=WC/5.4
0054          WL=WL/5.4
0055          WN=WN/5.4
0056          Q1=Q0+QA
0057          C1=(Q0*C0+WC)/Q1
0058          D1=CS-C1
0059          FLOL1=(Q0*FLOL0+WL)/Q1
0060          FLON1=(Q0*FLON0+WN)/Q1
        C
        C     TEST FOR CROSS SECTIONAL AREA FUNCTION
0061          IF(CONST)2,2,3
        C      ***********************************************************************
        C
        C     CONSTANT CROSS SECTIONAL AREA
0062        3 I=1
0063          FLOJA=-(FLOKA*AREA/Q1/16.4)
0064          FLOJN=-(FLOKN*AREA/Q1/16.4)
0065          FLOJR=-(FLOKR*AREA/Q1/16.4)
        C
        C     TEST FOR DAM REAERATION EQ TO USE
0066          IF(HDAM-20.)100,100,101
0067      100 IF(TEMP-25.)102,102,101
0068      102 IF(TEMP-15.)101,103,103
        C     COMPUTE DEFICIT USING MOHAWK R. EQUATION
0069      103 DEF6=ALPHA*D1*HDAM
0070          GO TO 6
        C     COMPUTE DEFICIT USING BRITISH EQUATION
0071      101 Z6= (1.+(0.11*A*B)*(1.+0.046*TEMP)*HDAM)**(-1.0)
0072          DEF6= D1*(1.-Z6)
        C
        C     COMPUTATION OF COMPONENT SOURCES AND SINKS OF DO DEFICIT
        C
        C     DEFICIT DUE TO POINT SOURCE OF CBOD
0073        6 TERM1=(FL*FLOKD*FLOL1/(FLOKA-FLOKR))*(EXP(FLOJR*X)-EXP(FLOJA*X))
        C
        C     DEFICIT DUE TO POINT SOURCE OF NBOD
0074          TERM2=(FN*FLOKN*FLON1/(FLOKA-FLOKN))*(EXP(FLOJN*X)-EXP(FLOJA*X))
        C
        C     DEFICIT DUE TO DISTRIBUTED BENTHIC DEMAND
0075          [illegible]
```

```
C     DEFICIT DUE TO POINT SOURCE OF DISSOLVED OXYGEN
      TERM4=D1*EXP(FLOJA*X)
C
C     DEFICIT DUE TO ALGAL RESPIRATION AND PHOTOSYNTHESIS
      TERM5=((RR-(PHM*2./3.1416))/FLOKA)*(1.-EXP(FLOJA*X))
C
C     DEFICIT DUE TO REAERATION OVER A DAM
      TERM6=-DEF6*(EXP(FLOJA*X))
C
C     TOTAL DEFICIT OF DISSOLVED OXYGEN
      D(I)= TERM1+TERM2+TERM3+TERM4+TERM5+TERM6
      C(I)=CS-D(I)
      IF(C(I))30,40,40
   30 C(I)=0.
C
C     COMPUTATION OF CBOD AND NBOD DISTRIBUTION
   40 FLOL(I)=FLOL1*EXP(FLOJR*X)
      FLON(I)=FLON1*EXP(FLOJN*X)
C
C     TEST FOR INCREASING OR DECREASING RIVER MILEPOINT
      IF(XCODE)560,560,550
  550 XX(I)=XTOT+X
      GO TO 551
  560 XX(I)=XTOT-X
  551 CONTINUE
C
C     TEST FOR END OF SEGMENT
      IF (X-FLENG)4,5,500
    4 X=X+DELTA
      WRITE(6,1408)XX(I),D(I),TERM1,TERM2,TERM3,TERM4,TERM5,TERM6,
     1FLOL(I),FLON(I),C(I)
 1408 FORMAT(5X,11F8.2)
      I=I+1
      GO TO 6
  500 X=FLENG
      GO TO 6
    5 WRITE(6,1408)XX(I),D(I),TERM1,TERM2,TERM3,TERM4,TERM5,TERM6,
     1FLOL(I),FLON(I),C(I)
C
C     REINITIALIZATION OF BOUNDARY CONDITIONS AT UPSTREAM END OF SEGMENT
      CO=C(I)
      FLOLO=FLOL(I)
      FLONO=FLON(I)
      XTOT=XX(I)
C
C     TEST FOR FINAL SEGMENT IN RIVER SYSTEM
      NCHUN=NCHUN+1
      IF(NCHUN-NTOT)1,1,20
C      *********************************************************************
C
C     LINEARLY INCREASING AREA WITH CONSTANT SLOPE
    2 I=1
      XO=FINT/SLOPE
      FLOWA=(FLOWA SLOPE [illegible])
```

```
          FLOJN=-(FLOKN*SLOPE/Q1/16.4)
          FLOJR=-(FLOKR*SLOPE/Q1/16.4)
        9 FOFX(I)=(X*X+2.*X*XO)/2.
          XJA=FLOJA*FOFX(I)
          XJN=FLOJN*FOFX(I)
          XJR=FLOJR*FOFX(I)
C
C         TEST FOR DAM REAERATION EQ TO USE
          IF(HDAM-15.)300,300,301
      300 IF(TEMP-25.)302,302,301
      302 IF(TEMP-20.)301,303,303
C         COMPUTE DEFICIT USING MOHAWK R  EQUATION
      303 DEF6=ALPHA*D1*HDAM
          GO TO 305
C         COMPUTE DEFICIT USING BRITISH EQ
      301 Z6=(1.+(0.11*A*B*HDAM)*(1.+0.046*TEMP))**(-1.0)
          DEF6= D1*(1.-Z6)
      305 CONTINUE
C
C         COMPUTATION OF COMPONENT SOURCES AND SINKS OF DO DEFICIT
C
C         DEFICIT DUE TO POINT SOURCE OF CBOD
          TERM1=(FL*FLOKD*FLOL1/(FLOKA-FLOKR))*(EXP(XJR)-EXP(XJA))
C
C         DEFICIT DUE TO POINT SOURCE OF NBOD
          TERM2=(FN*FLOKN*FLON1/(FLOKA-FLOKN))*(EXP(XJN)-EXP(XJA))
C
C         DEFICIT DUE TO DISTRIBUTED BENTHIC DEMAND
          TERM3=(S/FLOKA)*(1.-EXP(XJA))
C
C         DEFICIT DUE TO POINT SOURCE OF DISSOLVED OXYGEN
          TERM4=DI*EXP(XJA)
C
C         DEFICIT DUE TO ALGAL RESPIRATION AND PHOTOSYNTHESIS
          TERM5=((RR-(PMM*2.*.5/3.1416))/FLOKA)*(1.-EXP(FLOJA*X))
C
C         DEFICIT DUE TO REAERATION OVER A DAM
          TERM6=-DEF6*(EXP(XJA))
C
C         TOTAL DEFICIT OF DISSOLVED OXYGEN
          D(I)= TERM1+TERM2+TERM3+TERM4+TERM5+TERM6
          C(I)=CS-D(I)
          IF(C(I))50,60,60
       50 C(I)=0.
C
C         COMPUTATION OF CBOD AND NBOD DISTRIBUTION
       60 FLOL(I)=FLOL1*EXP(XJR)
          FLON(I)=FLON1*EXP(XJN)
C
C         TEST FOR INCREASING OR DECREASING RIVER MILEPOINT
          IF(XCODE)660,660,650
      650 XX(I)=XTOT [illegible]
          GO TO [illegible]
      660 XX(I)=XTOT-[illegible]
```

```
0138         651 CONTINUE
           C
           C         TEST FOR END OF SEGMENT
0139             IF(X-FLENG)10,5,502
0140          10 X=X+DELTA
0141             WRITE(6,1408)XX(I),D(I),TERM1,TERM2,TERM3,TERM4,TERM5,TERM6,
                1FLUL(I) ,FLON(I),C(I)
0142             I=I+1
0143             GO TO 9
0144         502 X=FLENG
0145             GO TO 9
0146          20 CONTINUE
0147             STOP 9999
0148             END
```

DOCUMENTATION

TABLE 2

DATA INPUT REQUIREMENTS

COLUMN

Card	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80
1	STREAM------------------------(entire field)--							
2	RUNDES------------------------(entire field)--							
3	CO	FLOLO	FLONO	XTOT	XCODE	NTOT		
4	SEGID-------------------------(entire field)--							
5	WC	WL	WN	QO	QA	CS	TEMP	
6	DELTA	FLENG	CONST	AREA	SLOPE	FINT	HDAM	DEPTH
7	FL	FN	FLOKR	FLOKD	FLOKN	S	F	
8	EMM	RR	A	B	ALPHA			

Notes:

(a) Repeat cards four through eight for total number (NTOT) of segments
(b) STREAM, RUNDES, and SEGID are alpha-numeric variables with 20A4 format, data entered col. 1-80
(c) NTOT is an integer variable with I2 format in col. 59-60
(d) ALPHA is a floating point variable with F10.3 format
(e) All other variables are floating point with F10.2 format

SAMPLE INPUT CARDS

STREAM

1 LOWER FOX RIVER--LAKE WINNEBAGO TO GREEN BAY

RUNDES

2 [illegible] 20-21-1970 WISC DNR

	CF	FLDLO	FLDHD	XTOT	XSLOPE	NTOT
3	10.0	5.0	11.6	33.93	0.0	45

SECID

4 SEGMENT 1 NEENAH-DAM - BERGSTROM PAPER CO

	RC	WL	WH	DO	DA	CS	TEMP	
5	0.0	0.0	0.0	1029.3	0.0	9.2	20.0	
	DELTA	**FLENG**	**CONST**	**AREA**	**SLOPE**	**FINT**	**HDAM**	**DEPTH**
6	0.53	0.53	1.0	976.0	0.0	0.0	0.0	2.0
	FL	**FN**	**FLOKR**	**FLOKD**	**FLOKN**	**S**	**F**	
7	1.88	1.0	0.3	0.3	0.14	5.0	0.5	
	PAM	**RR**	**A**	**B**	**ALPHA**			
8	[illegible]1.3	2.13	0.	0.	0.0			

SECID

4 SEGMENT 2 BERGSTROM PAPER CO - KIMIEPLY CLARK(LAKEVIEW)

	WC	WL	WH	DO	DA	CS	TEMP
9	[illegible]1.7	200[illegible]5.	23[illegible].	1029.3	2.4	9.2	20.

SAMPLE OUTPUT

LOWER FOX RIVER--LAKE WINNEBAGO TO GREEN [illegible]

VERIFICATION SURVEY DATA [illegible] WIS. DNR

--INITIAL CONDITIONS--

CO	FLOLO	FLOMD	XTOT	XCODE	NTOT
10.00	0.00	11.65	30.63	0.0	45

SEGMENT 1

INPUT

UC	WL	WN	QD	QA	CS	TEMP	
0.0	0.0	0.0	1028.30	0.0	9.20	20.00	
DELTA	**FLENG**	**CONST**	**AREA**	**SLOPE**	**FINT**	**HDAM**	**DEPTH**
0.53	0.53	1.00	976.00	0.0	0.0	0.0	2.00
FL	**FN**	**FLOKR**	**FLOKD**	**FLOKN**	**S**	**F**	
1.00	1.00	0.30	0.30	0.14	5.00	0.50	
RA	**RR**	**A**	**B**	**ALPHA**			
21.30	2.10	0.0	0.0	0.0			
FLOKA							
4.30							

OUTPUT

MP	DEFICIT	TERM1	TERM2	TERM3	TERM4	TERM5	TERM6	CBOD	NBOD	DO
30.63	-0.80	0.0	0.0	0.0	-0.80	0.0	0.0	6.00	11.60	10.00
30.10	-0.57	0.10	0.05	0.12	-0.69	-0.13	0.0	5.95	11.55	9.77

SEGMENT 2

INPUT

WC	WL	WN	QD	QA	CS	TEMP	
61.70	20375.00	2301.00	1028.30	7.40	9.20	20.00	
DELTA	**FLENG**	**CONST**	**AREA**	**SLOPE**	**FINT**	**HDAM**	**DEPTH**
[illegible]	[illegible]	1.00	[illegible]	[illegible]	[illegible]	0.0	2.50
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	

FL	FN	FLOKR	FLOKD	FLOKN	S	F
1.2[illegible]	1.00	0.12	[illegible].12	[illegible]	5.00	[illegible]

PMM	RR	A	B	ALPHA
[illegible]2.50	1.25	0.0	0.0	[illegible]

FLOKA
0.00

OUTPUT

MP	DEFICIT	TERM1	TERM2	TERM3	TERM4	TERM5	TERM6	CBOD	NBOD	DO
0.33	6.09	0.0	0.0	0.0	6.0[illegible]	[illegible].0	0.[illegible]	19.02	[illegible]	[illegible]
0.14	5.19	0.21	0.05	0.07	6.05	-0.19	0.0	[illegible]3.93	6.41	[illegible].01

SEGMENT 45

INPUT

WC	WL	WN	DO	QZ	CS	TEMP
112.00	23481.00	5631.00	2250.00	[illegible].50	9.[illegible]	20.00

DELTA	FLENG	CONST	AREA	SLOPE	FINT	HDAM	DEPTH
0.14	0.14	1.00	12194.00	0.0	0.0	0.0	13.00

FL	FN	FLOKR	FLOKD	FLOKN	S	F
1.25	1.00	0.12	0.12	[illegible]	5.00	1.00

PMM	RR	A	B	ALPHA
12.50	1.25	0.0	0.0	0.[illegible]

FLOKA
0.12

OUTPUT

MP	DEFICIT	TERM1	TERM2	TERM3	TERM4	TERM5	TERM6	CBOD	NBOD	DO
0.14	6.21	0.0	0.0	0.0	6.21	0.0	0.0	20.76	8.79	2.99
-0.00	6.29	0.15	0.04	0.06	6.18	-0.12	0.0	20.65	8.75	2.91