WATER QUALITY MODELING OF THE UPPER WISCONSIN RIVER FOR WASTELOAD ALLOCATION DEVELOPMENT

SEGMENT D

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ABSTRACT

The Wisconsin River from Biron to Castle Rock Flowage has been termed Segment D of the Wisconsin River. Segment D has been modeled using a finite difference water quality model known as QUAL III. The QUAL III model simulates dissolved oxygen, two terms of carbonaceous BOD, total phosphorus, organic nitrogen, ammonia, nitrite, nitrate, chlorophyll-a and sediment oxygen demand. The mode can be run in both steady state and dynamic modes.

The QUAL III model as developed was successfully calibrated for eight separate synoptic water quality surveys and verified with four additional synoptic water quality surveys. The surveys covered the years 1973-1980 and generally fell in the annual low flow periods. Wasteload allocations based on modeling results have been developed for the two major industrial dischargers on this river segment.

FORWARD

This report is the culmination of several years of effort to develop wasteload allocations for water quality limited segments and seasons on Segment D of the Wisconsin River. The report is structured to give an overview of the segment of river modeled, a general description of the model, the calibration, the verification, and a sensitivity analysis of the verified model.

In order to make the report more readable, few references are cited in the text. A bibliography appears at the end of the report as Appendix A. This bibliography is a compilation by subject of the various articles and references used during the last several years to develop the model for Segment D. Additional references concerning the development of the QUAL III model have been previously published in earlier modeling reports by the Department. These earlier reports are listed in the bibliography.

The authors wish to thank the many persons that assisted with the data collection. Special thanks are also extended to the Word Processing Center who typed the text and put up with the numerous revision to the text.

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I. DESCRIPTION OF POLLUTION PROBLEM

Biron Flowage to Petenwell Dam

The Wisconsin River between Biron Dam and Castle Rock Flowage is almost 50 miles long and flows past the communities of Biron, Wisconsin Rapids, Port Edwards and Nekoosa. This reach has been designated Segment D of the Upper Wisconsin River (UWR). There are six hydropower dams (Biron, Wisconsin Rapids, Centralia, Port Edwards, Nekoosa and Petenwell) that are owned by paper companies and/or utility corporations in this reach. The drainage area above Petenwell Dam is 5,970 square miles. Maps of the UWR and study area are presented in Figures 1 and 2.

There are several small tributary streams that discharge into Segment D. These tributaries account for 590 square miles of drainage area or 10% of the basin above Petenwell Dam.

The change in river elevation between Biron Dam and Petenwell Dam is 112 feet which yields an average gradient of 3.4 feet per mile. The river velocity is generally slow, as a result of the six mainstem impoundments located on Segment D. Lake Petenwell, the largest impoundment, has a surface area of 23,000 acres. The average hydraulic retention time of Lake Petenwell is about 43 days. The surface area and mean hydraulic retention times of the six mainstem impoundments of Segment D are listed in Table 1.

A United States Geological Survey stream gaging station has been located in the Wisconsin Rapids area since 1914. The station is currently located at Wisconsin Rapids Dam. The average river flow at Wisconsin Rapids is 4,948 cfs with a maximum flow of 70,400 cfs. The $Q_{7,10}$ flow is 1,280 cfs. River water is periodically diverted from the Wisconsin Rapids flowage into Cranberry Creek, a tributary of the Yellow River Basin, to be used for cranberry culture. This diversion normally occurs during the summer months or early fall and is about 50 to 100 cfs.

Table 1
Impoundment Characteristics for Segment D of the Wisconsin River

Impoundment	Surface Area (acres)	Mean Hydraulic Retention Time (days)
Biron Flowage	2,087	2.1
Wisconsin Rapids Flowage	453	1.0
Centralia Flowage	250	1.0
Port Edwards Flowage	150	1.0
Nekoosa Flowage	400	1.0
Lake Petenwell	23,000	42.5

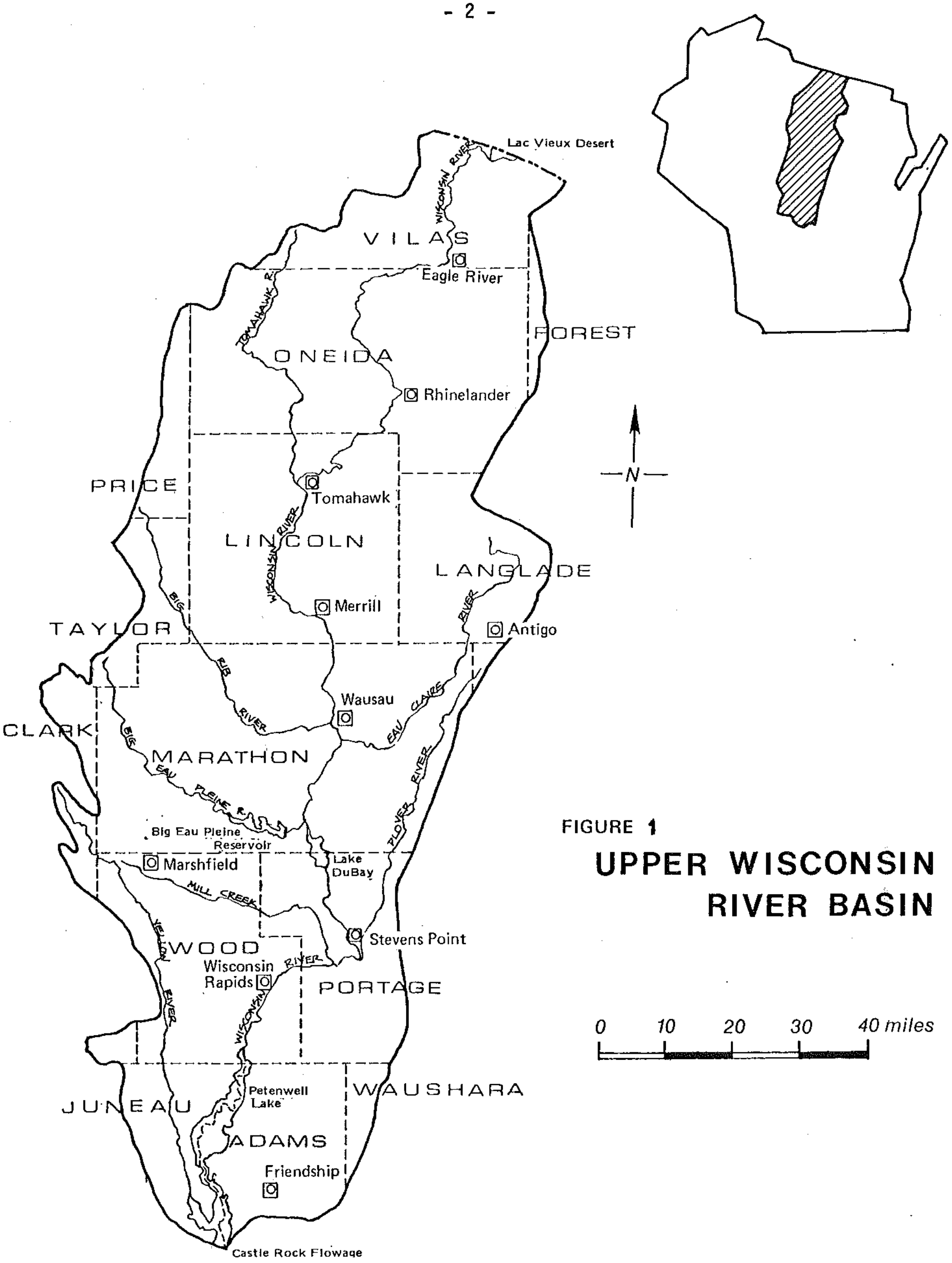


FIGURE 1

UPPER WISCONSIN RIVER BASIN

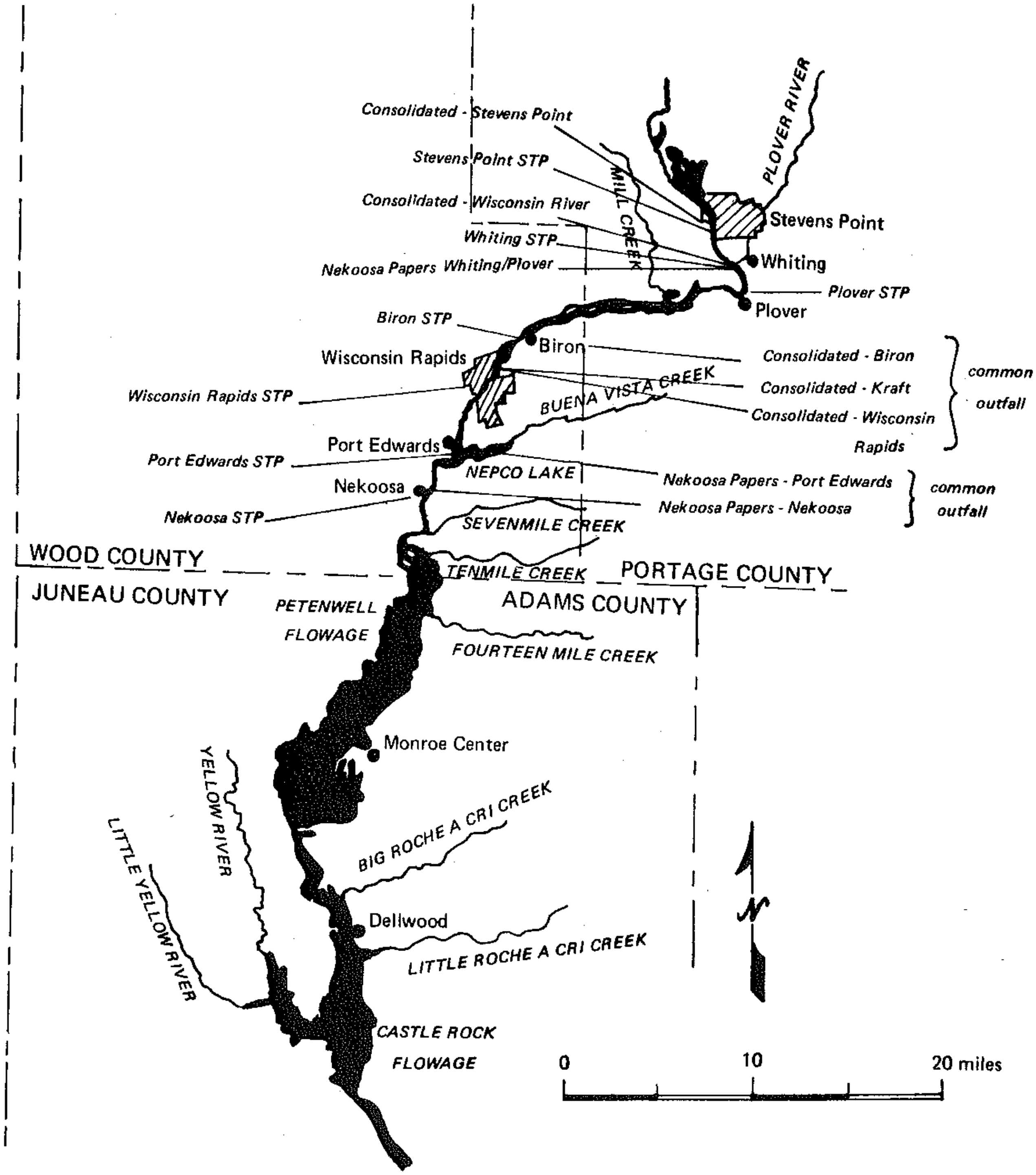


Figure 2. Southern mainstem sub-basin with Segment D dischargers.

The major point sources of pollutant loading to the river in the Wisconsin Rapids area results from the discharge of two pulp and paper mills (Consolidated Papers and Nekoosa Papers), one major municipal sewage treatment plant (Wisconsin Rapids), one minor industrial discharge (Vulcan Materials) and two small municipal sewage treatment plants (Port Edwards and Nekoosa). The Village of Biron also discharged municipal wastewaters to the Wisconsin River at one time. In August of 1983 Biron began discharging to the Wisconsin Rapids municipal sewage treatment plant.

Continuous automatic water quality monitoring stations are located at Biron, Centralia and Petenwell Dams. These stations have been operating since 1971 and provide dissolved oxygen, temperature, pH and conductivity data on an hourly basis. The most serious water quality problems, as reflected by low dissolved oxygen levels, have occurred at the inflow to Lake Petenwell during low flow summer conditions. Serious dissolved oxygen depletion in Lake Petenwell was evident during winter conditions prior to pollution abatement activities by the pulp and paper mills in the mid 1970's. Since 1978, winter dissolved oxygen levels have generally exceeded 7.0 mg/l.

Nonpoint source pollution may influence the Wisconsin River during certain periods. It is believed that much of this pollution originates from tributaries located in the central portion of the Upper Wisconsin River near Wausau. The tributaries discharging to Segment D are not believed to contribute significantly to the nonpoint source pollution level compared to that which is added to the river above Biron Dam. Nonpoint source pollution from sources above Biron Dam have been responsible for an unusual dissolved oxygen depletion during snowmelt runoff that extended into and through Segment D. Further, the contribution of nutrients from nonpoint and point source pollution is believed to contribute to algae blooms in Segment D, particularly in Lake Petenwell.

II. Model Synthesis

A. Introduction

The QUAL III model was developed from the QUAL II model of Water Resources Engineering, Inc. between 1975 and 1978. During this period, data was continually being collected for use with the model. Because the model and its data requirements changed somewhat during the development, it is necessary to describe the kinetics that the model uses in this report. A more technical account of the model kinetics can be found in "QUAL III Water Quality Model Documentation". It is available from the Water Quality Evaluation Section of the Wisconsin DNR.

Stream surveys were taken every summer from 1973 through 1980 during the annual low flow period. Stream surveys were also taken during other periods of the year in 1975, 1978 and 1979. In addition, miscellaneous data was collected including SOD measurements using an instream bell jar technique and algae growth rate measurements using a light and dark bottle technique. Effluent samples were collected for specific laboratory analysis including longterm BOD at least on an annual basis for each discharger. An elaboration of the data requirements and the data available will be presented in Section III.

B. Modeling Kinetics

The QUAL III model attempts to account for the major parameters that affect the dissolved oxygen in a flowing stream. It is a one dimensional finite element model. This means that it can only evaluate concentration changes in the direction of the flowing stream (longitudinal gradients), and not across the width of the stream (lateral gradients) or vertically over the depth, and that the river is represented as a series of well mixed compartments which are linked together to form the river much like beads on a chain. Thus the physical representation of the system is a simplification of the complex mixing process that actually occurs in a flowing stream. The biological processes are simplified in a similar manner. The complicated interactions that determine the rate of growth of a bacterial population feeding on an available but limited food supply are reduced to a simple exponential function to describe the time rate of decrease of the food (for example, BOD).

Although the kinetics are simplifications of reality, there remains a key factor that determines the success of the model; mass balance. This means the quantity of a material that is entered into the model must be accounted for in the final solution in the same way as an accountant balances the books. If mass balance is maintained throughout the system, then the accuracy of the model is determined by the correctness of the routing scheme and the choice of rate constants for transformations of one substance to another. A large part of modeling then depends on these last two points; representation of the major pathways of physical, biological and chemical reactions and sufficient data to choose transformation rates. The reaction pathways are developed from research or theory and depend on our current understanding of aquatic environments. The transformation rates used are based on data from field experiments.

Frequently, it is not possible to devise experiments isolating the information of interest without affecting the system, and therefore the results, in an unknown way. For example, the BOD test in a laboratory gives us the BOD decay rate for the sample in a laboratory situation, but this may not necessarily be representative of the instream rate. The act of taking the sample and placing it in a glass bottle changes the system, and therefore, the bottle decay rates will probably not be valid. The BOD test, laboratory SOD, instream SOD and light and dark bottles are examples of measurements of rates that may be biased by the experimental procedure. Care must always be used when interpreting data but particular care must be used when dealing with measurements of rates.

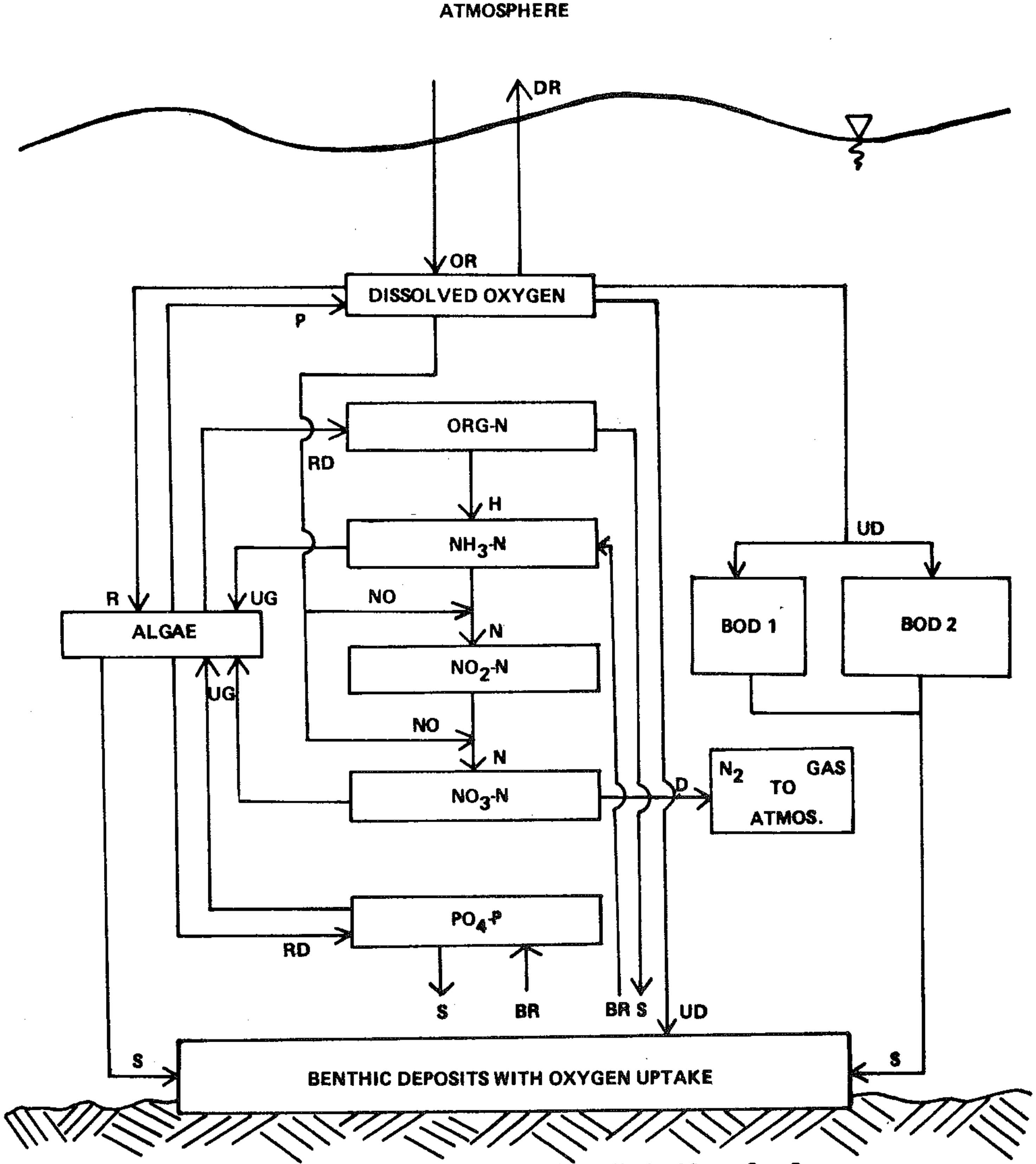
Model simulation becomes a particularly powerful tool for describing complex interactions and rates of transformation. The calibration of a model can be used to determine the rate coefficients to reproduce the observed data. If the model is calibrated to several sets of observations, the choice of coefficients that will fit the data becomes more and more confined so long as the model is a good representation of the system. The QUAL III model represents an aquatic system according to certain well defined pathways of material transformation, inputs, losses and decay rates. The system representation can be seen in Figure 3 . The following subsections will deal with each of the allowed interactions of the routed parameters.

BIOCHEMICAL OXYGEN DEMAND

The oxygen demanding potential of a wastewater is the main parameter in any water quality model that is attempting to predict dissolved oxygen profiles in a river. Oxygen demand can be caused by a number of factors, but the two most common are chemical reactions and biological uptake. A chemical demand is caused, as the name implies, by any chemical reaction that will tie up oxygen, such as the reduction of ferric iron ions to ferrous iron ions.

Biological demand is the most prevalent oxygen demand from sewage treatment plant effluents or any highly organic waste stream, such as paper and pulp waste. The oxygen demand is a result of the activity of heterotrophic and autrophic bacteria feeding on the organic material and ammonia and oxidizing it to carbon dioxide, water and nitrate. The growth of a bacterial population feeding on the waste is determined by the environmental conditions in the stream. Factors such as pH, temperature, type of bacteria and type of waste are important in determining how fast the organic material will be stabilized and the amount and rate of oxygen demand exerted. Modeling the bacterial kinetics of such a system would become a very complicated task. It is more practical and common to use the remaining food supply as the model parameter (for example the remaining BOD) instead of the standing population of bacteria. This simplification makes the model usable from a practical standpoint without sacrificing accuracy.

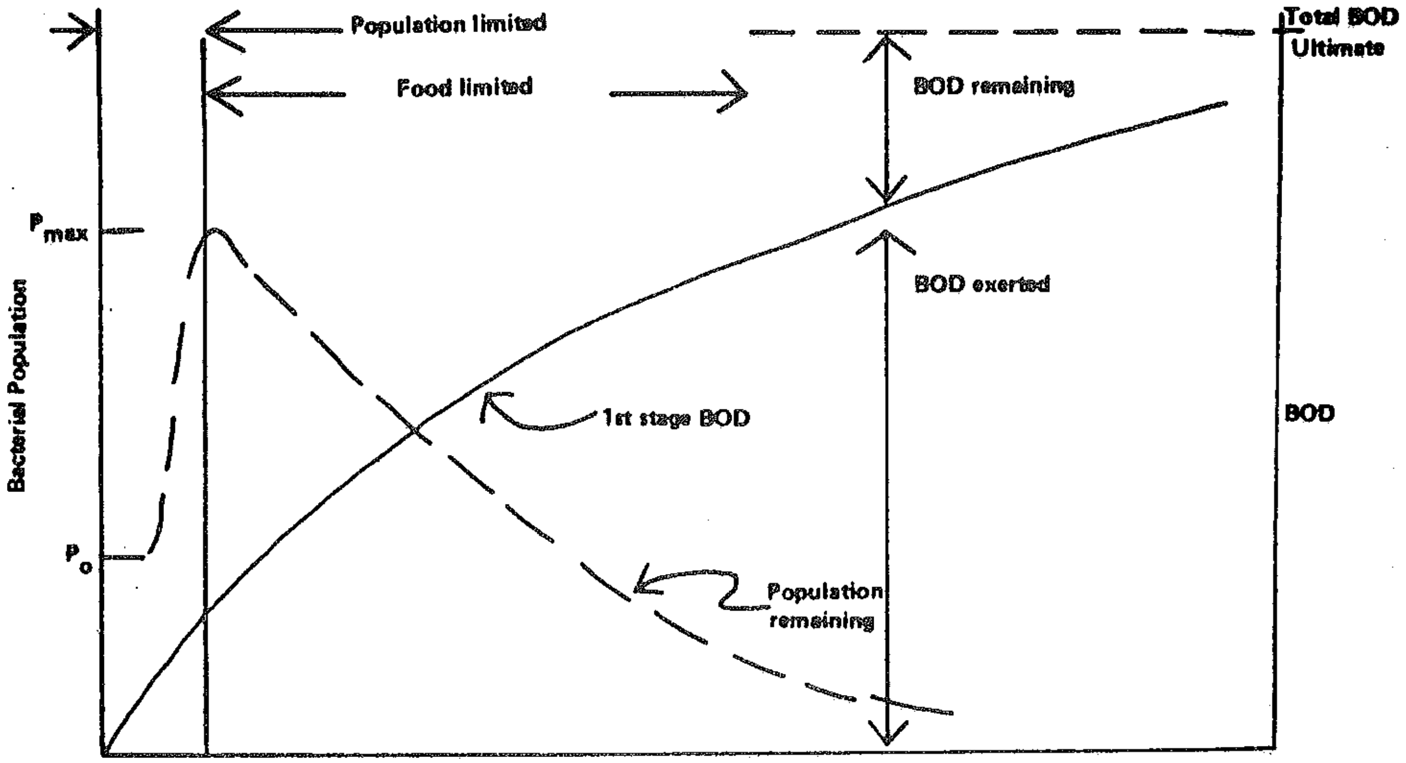
FIGURE 3



S	– Settling	UD	– Uptake of Oxygen From Decay
D	– Denitrification	UG	– Utilization for Growth
N	– Nitrification	P	– Photosynthesis
NO	– Nitrification Oxygen Uptake	R	– Respiration
BR	– Benthic Release	RD	– Release from Respiration and Mortality
OR-DR	– Oxygen Reaeration or Deaeration	H	– Hydrolysis

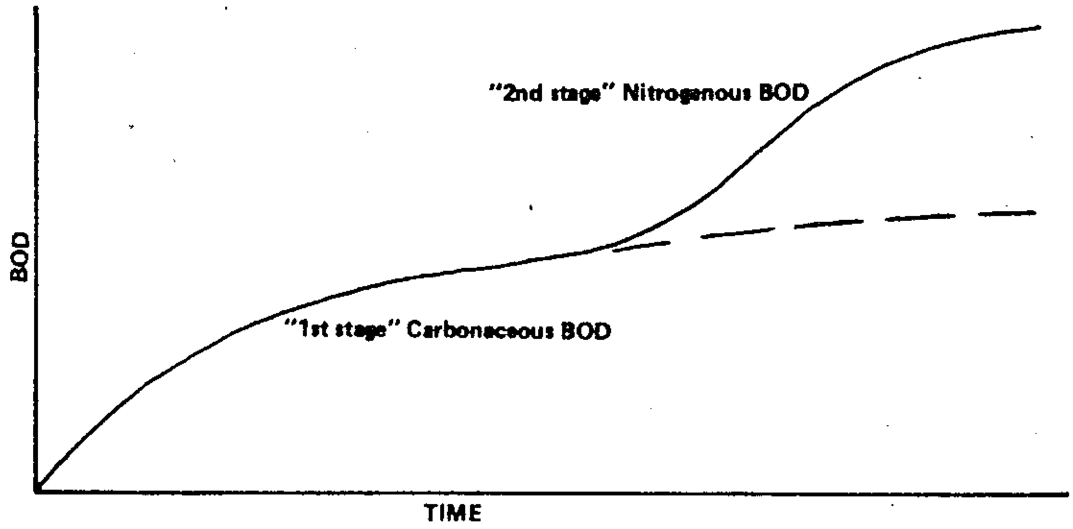
The biological oxygen demand exerted in any period is determined by the rate at which a bacterial population consumes the available organic material and by the size of bacterial population. When organic material is first discharged into a stream, the bacterial population will not be nearly as high as the food supply will support. Therefore, the population will grow very rapidly to a maximum level which is determined by the amount of food. This early phase of the BOD is characterized as "population limited"; the rate of BOD exertion is controlled by the size of the population which is expanding very quickly. Heterotrophic bacteria multiply fast enough such that the population will reach its maximum in a few hours. From this point on, the bacterial population will level and then decrease in proportion to the available food that remains. This second phase of the BOD is characterized as "food limited" meaning that the bacterial population, and therefore the rate of food uptake, is controlled by the amount of food remaining. Figure 4 illustrates a typical BOD curve showing the two phases. A model that uses the exponential decrease of BOD to simulate the bacterial population-food relationship is essentially assuming that the system is always in the "food limited" stage. The lag time of a few hours before the system reaches a truly "food limited" state does not usually cause a simulation problem. If the river has several dischargers that overlap causing already high populations of bacteria, then any discrepancy due to this lag tends to decrease to an even smaller amount. This type of BOD-bacterial population relationship was first proposed by Streeter and Phelps in the 1920's.

FIGURE 4

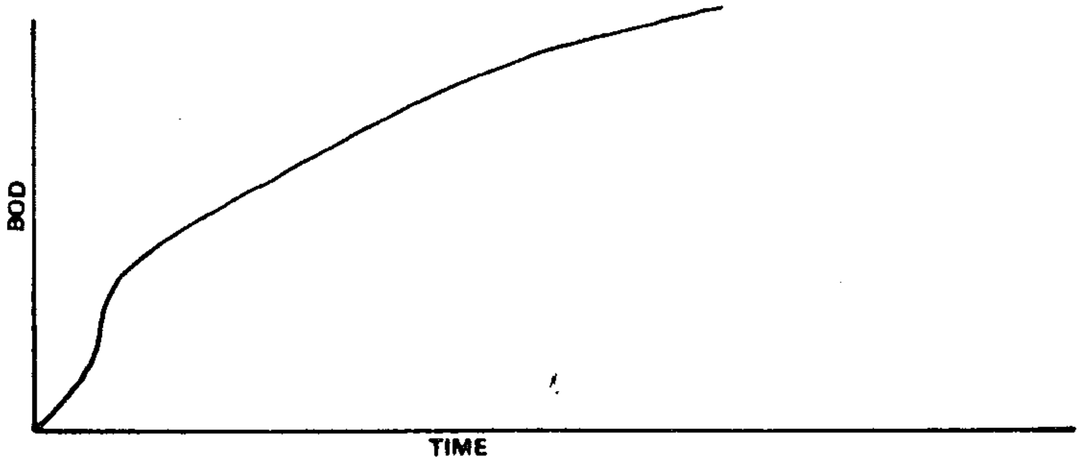


The initial population of bacteria (Po) quickly grows to the maximum population (Pmax) that the available food will allow. From that point on the remaining food determines the bacterial population.

FIGURE 5



A typical two stage BOD involves two "humps" that characterize the carbonaceous and nitrogenous BOD seperately as above. Occasionally nitrification occurs so quickly that the carbonaceous portion can not be separated by inspection as seen below.



The longterm BOD test is used to calculate the "ultimate carbonaceous BOD demand" in the sample. This ultimate BOD is then compared to the BOD_5 measured in the same sample and that reported by the discharger. The comparison of the ultimate carbonaceous BOD to the measured and reported BOD_5 gives a ratio that is used to determine the amount of ultimate CBOD discharged based on reported measurements of BOD_5. For wastewaters this ratio is input to the model along with daily reported values of BOD_5 for each discharger to represent the ultimate carbonaceous BOD entering the system.

The amount of BOD in a waste stream is typically measured in a standardized five day test. The result of the test is referred to as BOD_5 and is given as a concentration of oxygen demand in milligrams per liter (same as parts per million). Most effluents are routinely measured for oxygen demand in this way. Unfortunately, the BOD_5 values do not give the complete picture of the waste's oxygen demanding characteristics. It is necessary to complete a more detailed series of tests for modeling purposes.

The BOD in a waste can be a result of organic carbon compound decay as well as inorganic nitrogen compound decay. The first of these is referred to as carbonaceous BOD, the latter nitrogenous BOD. Nitrogenous BOD is typically exerted after the carbonaceous portion is well under way since the autrophic bacteria responsible for nitrification grow much slower than are the heterotrophic carbonaceous consuming bacteria. In the QUAL III modeling scheme, the nitrogen compounds are handled in a special way and are not treated in an analogous way to the carbonaceous BOD. It is, therefore, necessary to take special steps to remove the nitrogenous demand portion from a BOD test in order for the results to be applicable to the model. One method of doing this is to selectively inhibit the autrophic bacteria by chemical addition in the BOD test. At present, the recommended way of doing this is by the addition of N-serve (2-chloro-6-trichloromethyl pyridine) to the BOD test bottle. This addition effectively stops nitrification but at the same time has little effect on the carbonaceous uptake. A second method involves plotting the daily oxygen demand of a BOD test and noting from inspection when the "second hump" in the curve occurs. The amount of demand characterized by the second hump is usually due to nitrification and can be subtracted from the remaining curve to isolate the carbonaceous portion. This technique is only successful if nitrification does not account for any oxygen demand in the first few days of the BOD test. A third method involves measuring the amount of different nitrogen forms several times throughout a BOD test and subtracting the stoichiometric oxygen equivalent of the nitrification from the total oxygen demand curve.

The full characterization of a river water or wastewater BOD is done by means of a longterm BOD test. This involves placing the sample in an oversized (2,120 milliliters) BOD bottle. The sample bottle is then tested with a polargraphic probe for dissolved oxygen on a daily basis for the duration of the test. If the dissolved oxygen drops below 2 mg/l, the sample bottle is reaerated by bubbling air through it and a second reading is taken after reaerating. The total accumulated oxygen demand is plotted as in Figure 5 to form a longterm BOD curve. Tests of this nature can be either total BOD tests or nitrogen inhibited tests as referred to above. A filtered fraction can also be prepared by filtering the sample prior to placing it in the longterm BOD bottle. Filtered samples are normally run on river samples containing high algae levels to preclude algae interference. Caution must be exercised as particulate carbonaceous oxygen demanding material may be filtered out in addition to the algae.

The analysis of the longterm BOD curves is a multi-step procedure that typically involves an analysis of total and inhibited samples. The total curve is scanned to detect the beginning time of nitrification and its magnitude and duration, if at all possible. If the nitrification hump is discernable enough, it can be visually subtracted and the ultimate CBOD can be determined from the remaining curve. If the nitrification is not clear, then the inhibited curve must be scanned to determine the ultimate BOD. Figures 6 to 8 are typical examples of total and inhibited longterm BODs.

Figures 6 and 7 show the total BOD curves. From the figures we can see that nitrification began on about the eighth day indicating that nitrification may possibly occur in a five day test (such as the discharger runs for reporting purposes). The BOD does not appear to lag at the beginning of the test.

The right (tail) portion of all three figures indicates that the waste is not fully stabilized after 90 days. Also, the tail of all three figures departs significantly from the shape of a single term first order exponential curve. This departure is typical of many of the longterm BOD tests conducted on pulp and paper mill effluents. The gradual upward slopes of the tail of the curves suggest that they can be fit using a two-term carbonaceous BOD equation that assumes both BOD terms are acting simultaneously. The equation representing this is of the form:

$$L(t) = Lo_1 \ (1 - e^{-K_{11}t}) + Lo_2 \ (1 - e^{-K_{12}t})$$

Where Lo_1, Lo_2 = ultimate BOD associated with each term, K_{11}, K_{12} = decay rates for each term, $L(t)$ = total BOD at time t. The procedure used to "fit" this equation into a longterm curve such as Figure 8 is outlined in Appendix B. The curves in all three figures can be quite accurately described using the two-term equation.

The technique described above was applied to all major dischargers along the upper Wisconsin River. At least two samples of final effluent were taken for measurement of the longterm BOD fractions. Samples were also taken of raw waste and, where possible, primary clarified waste for longterm BOD analysis. Most longterm BOD samples measured by the State Laboratory of Hygiene were analyzed using the above described technique.

The above analysis then yields the several parameters required by the QUAL III model to describe an effluent BOD. These include: 1) the reported BOD_5 value, 2) the ratio of the ultimate BOD (as measured in the longterm test) to the reported BOD_5, 3) the fraction of the ultimate CBOD that is in the "slow term" of the ultimate CBOD and 4) the fraction of the reported BOD_5 that may represent nitrogenous BOD rather than carbonaceous BOD. Table 2 presents a list of each of these parameters used for Segment D of the Wisconsin River in the model for calibration and verification purposes.

FIGURE 6

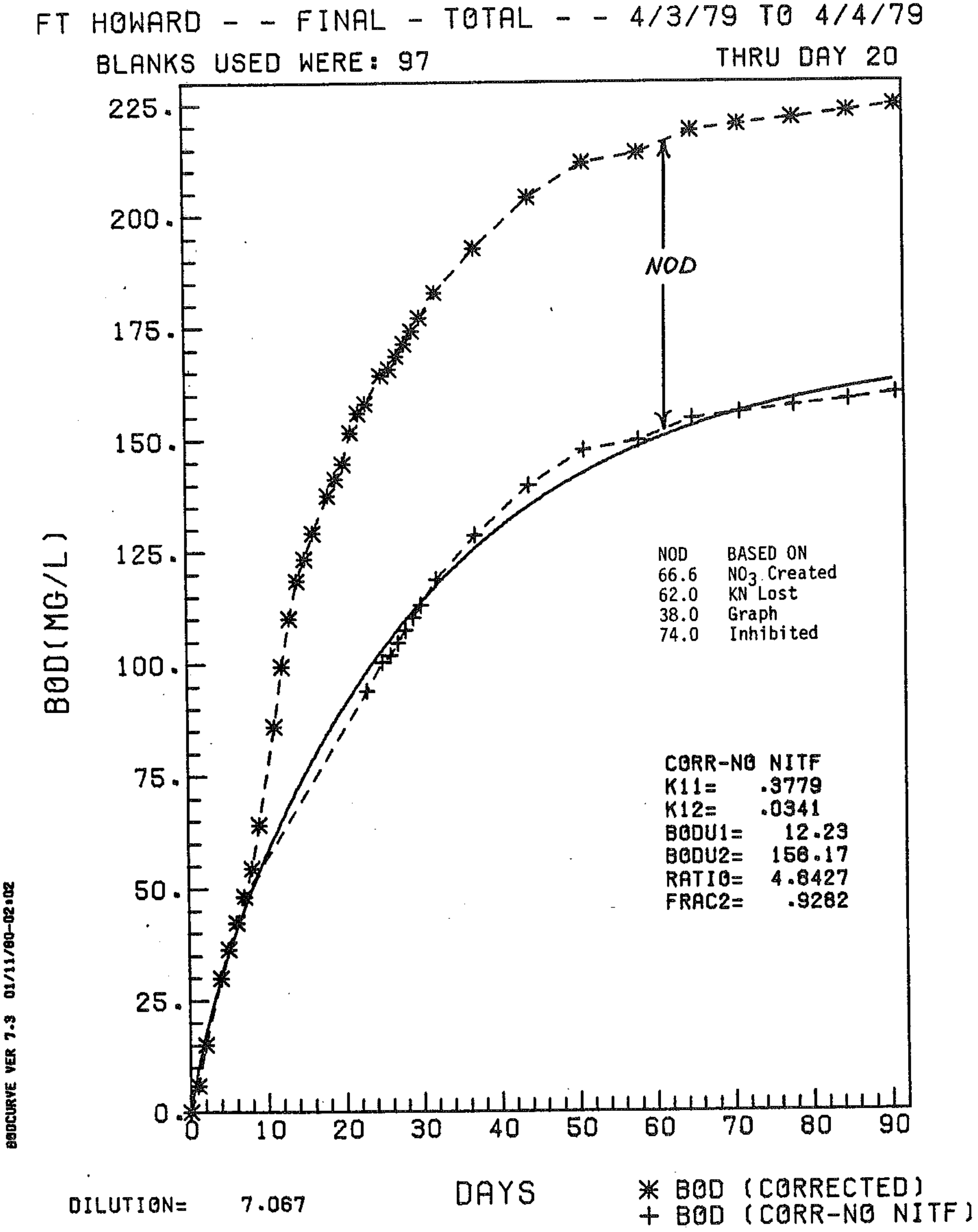

FT HOWARD - - FINAL - TOTAL - - 4/3/79 TO 4/4/79
BLANKS USED WERE: 97
THRU DAY 20
BOD(MG/L)
225.
200.
175.
150.
125.
100.
75.
50.
25.
0.
0
10
20
30
40
50
60
70
80
90
DAYS
NOD
NOD BASED ON
66.6 NO3 Created
62.0 KN Lost
38.0 Graph
74.0 Inhibited
CORR-NO NITF
K11= .3779
K12= .0341
BODU1= 12.23
BODU2= 158.17
RATIO= 4.8427
FRAC2= .9282
DILUTION= 7.067
✳ BOD (CORRECTED)
+ BOD (CORR-NO NITF)
BODCURVE VER 7.3 01/11/80-02:02

FIGURE 7

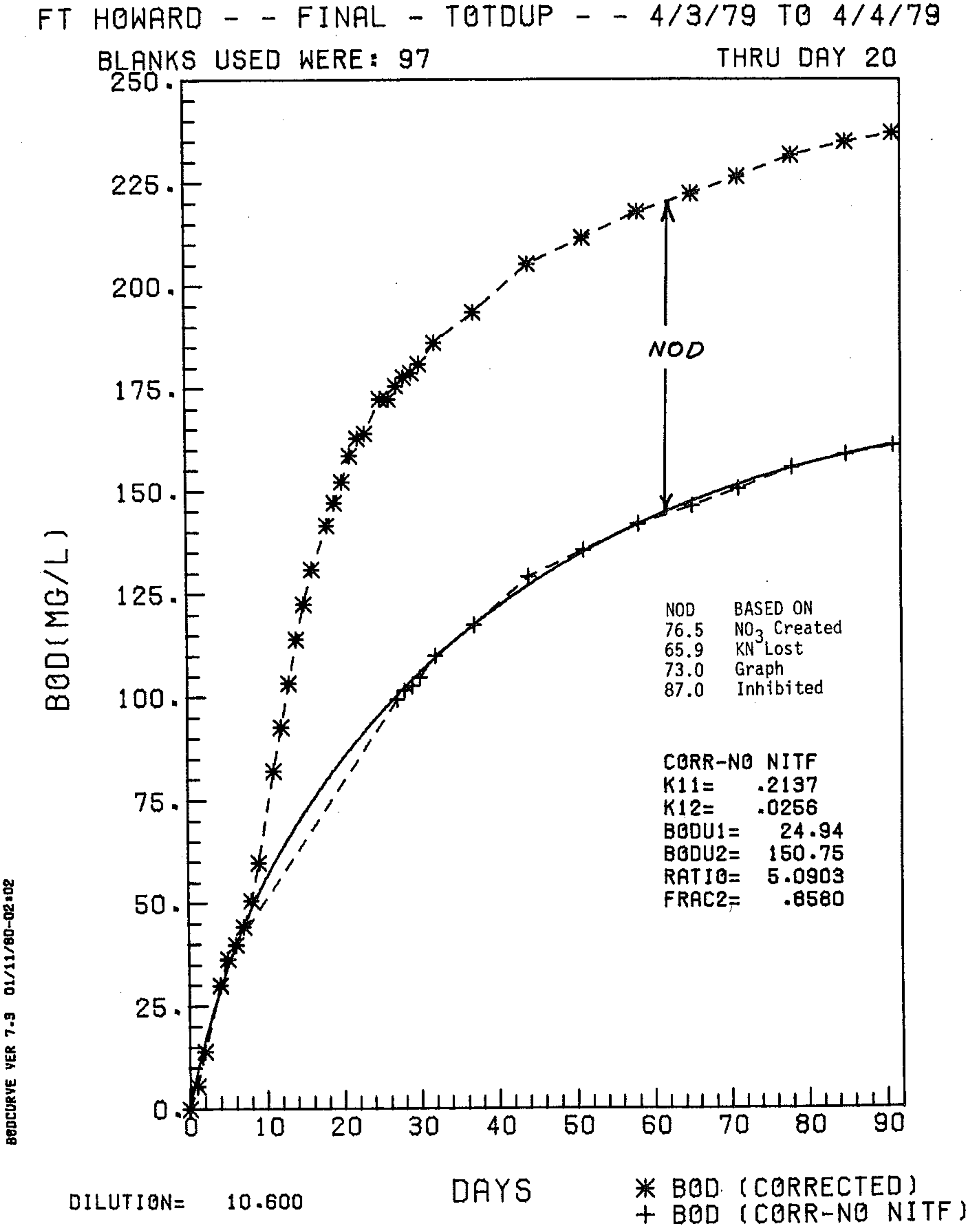
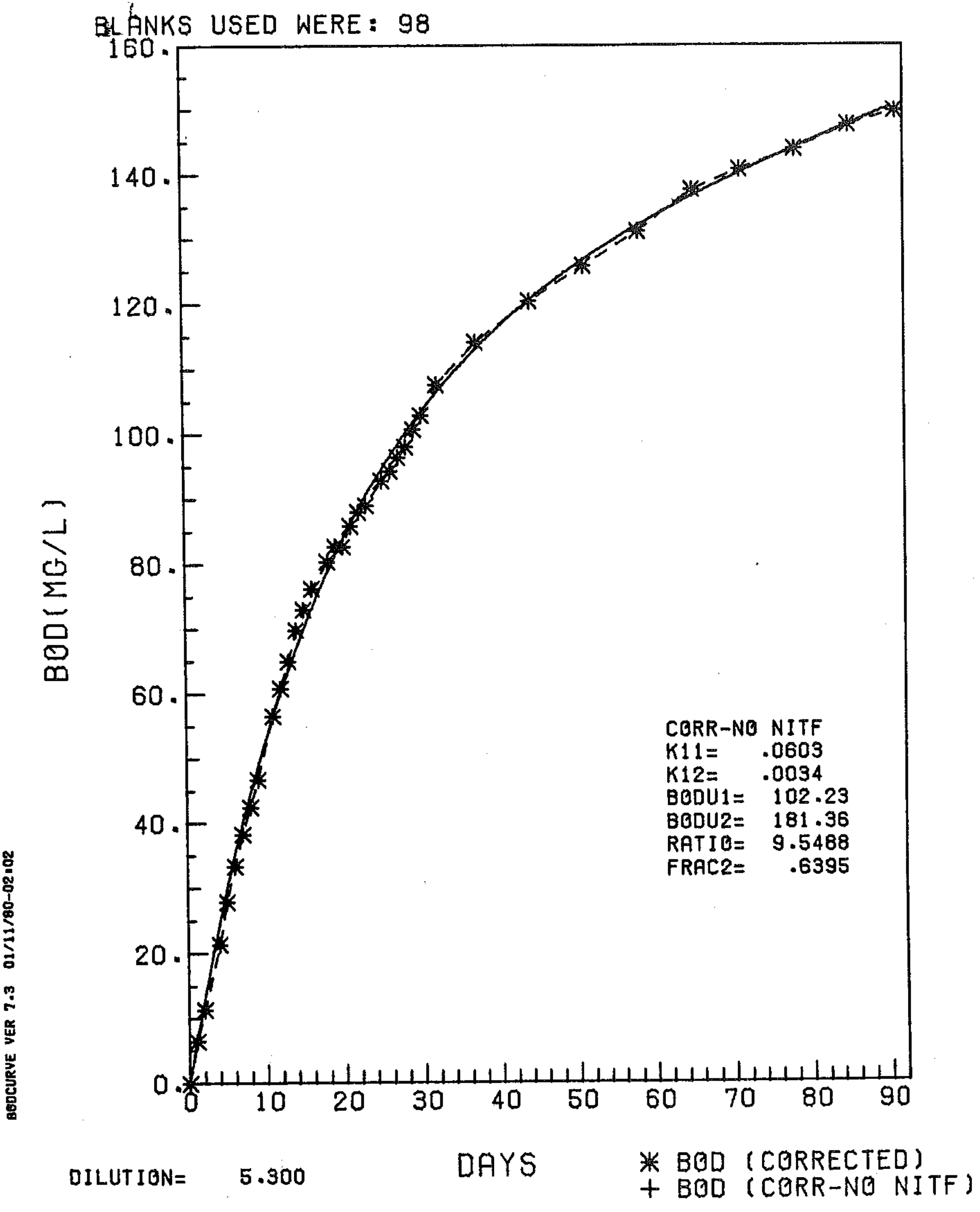

FT HOWARD - - FINAL - TOTDUP - - 4/3/79 TO 4/4/79
BLANKS USED WERE: 97
THRU DAY 20
BOD(MG/L)
0.
25.
50.
75.
100.
125.
150.
175.
200.
225.
250.
0
10
20
30
40
50
60
70
80
90
DAYS
NOD
NOD BASED ON
76.5 NO_3 Created
65.9 KN Lost
73.0 Graph
87.0 Inhibited
CORR-NO NITF
K11= .2137
K12= .0256
BODU1= 24.94
BODU2= 150.75
RATIO= 5.0903
FRAC2= .8560
DILUTION= 10.600
✳ BOD (CORRECTED)
+ BOD (CORR-NO NITF)
BODCURVE VER 7.9 01/11/80-02:02

FIGURE 8

FT HOWARD - - FINAL - INHIB - - 4/3/79 TO 4/4/79



SEDIMENT OXYGEN DEMAND

The QUAL III model assumes three sources of sediment oxygen demand. They are settling algae that carry oxygen consuming organics to the sediments, settling BOD that also carries decayable material to the sediments and a background SOD to account for any other miscellaneous sources. In the calibration process it was generally attempted to keep the background SOD at as low a level as possible by using the first two sources to account for the SOD.

The algae generated SOD is typically the most important of the first two sources for rivers with high algae levels. The model specifies a settling rate of the phytoplankton resulting in a certain quantity of algae reaching the bottom in each reach of the river. The quantity is dependent upon the concentration of algae, the depth and the velocity of the river (i.e., faster velocities allow less settling). The SOD is calculated from the mass of settled algae, the oxygen equivalent of that mass and the fraction of that mass that is readily decayable. The latter fraction is estimated by Jewell to be about 56%. The BOD generated SOD is calculated in a similar fashion. However, it is assumed that only a portion of the settled BOD is available as SOD.

When calibrating the model, BOD settling was manipulated according to the level of treatment and type of waste. An untreated waste with a high BOD solids content is allowed to settle in locations directly downstream from the point of discharge. Primary treated wastes are allowed to settle less and secondary treated wastes still less or not at all. The result of this approach is that less and less of the SOD in the model was created by point sources as treatment systems were put on line. Allowing the settling of BOD to create SOD affected the location of the exerted oxygen demand as well as quantity. This was necessary as large quantities of particulate matter were observed to have created anaerobicly decaying sludge beds at the inlet to Petenwell.

NUTRIENTS AND PHYTOPLANKTON

Phosphorus

Phosphorus is modeled in a very simplistic manner by QUAL III. The internal calculations in the model use a parameter that is equivalent to soluble available phosphorus. Any phosphorus that is used for algae growth is subtracted from this parameter and algae respiration adds back to this parameter. For output purposes, however, the amount of phosphorus contained in the algae is added to the modeled soluble phosphorus and is roughly equivalent to total phosphorus which is the typical measured quantity.

QUAL III is programmed to allow both settling of phosphorus and benthic release of phosphorus. Although both of these pathways are available, it is assumed for the Wisconsin River that the sediment phosphorus is essentially in equilibrium with the overlaying water. Therefore, neither phosphorus settling nor release were used. It must be noted that some phosphorus reaches the sediment even though direct phosphorus settling is not used. Since the algae biomass is assumed to contain some phosphorus, any algae that settle carry phosphorus (and nitrogen) to the river bottom.

Table 2
BOD Parameters Used for Steady State Modeling of Segment D of the Wisconsin River

Discharger	Parameter	July 9-10 1973	Aug. 14-15 1973	July 18 1974	Aug. 17 1975	Aug. 16-18 1976	Oct. 10-12 1976	June 29-30 1977	Aug. 17-18 1977	June 27-28 1978	Aug. 15-16 1978	July 24-26 1979	Aug. 18-19 1979	Used for WLA Runs***
Consolidated - Biron	BOD_5 (lb/day)	12,430	7,571	12,346	10,739	**	**	**	**	**	**	**	**	**
	BOD_u/BOD_5	1.7	1.7	1.7	1.7									
	Fraction in Slow Term	0.2	0.2	0.2	0.2									
Biron STP	BOD_5 (lb/day)	168	104	78	52	101	101	54	46	72	41	41	51	89
	BOD_u/BOD_5	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
	Fraction in Slow Term	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Consolidated - Kraft	BOD_5 (lb/day)	19,288	18,942	21,162	30,546	**	**	**	**	**	**	**	**	**
	BOD_u/BOD_5	1.7	1.7	1.7	1.7									
	Fraction in Slow Term	0.2	0.2	0.2	0.2									
Consolidated - Jt. Tmt.	BOD_5 (lb/day)	*	*	*	*	9,896	6,088	1,344	1,568	1,991	867	1,559	1,286	
	BOD_u/BOD_5					2.0	2.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
	Fraction in Slow Term					0.4	0.4	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Consolidated - Wis. Rapids	BOD_5 (lb/day)	4,676	4,798	10,320	11,420	**	**	**	**	**	**	**	**	**
	BOD_u/BOD_5	1.7	1.7	1.7	1.7									
	Fraction in Slow Term	0.2	0.2	0.2	0.2									
Wis. Rapids STP Bypass	BOD_5 (lb/day)	0	0	0	0	0	0	0	0	0	0	485	0	0
	BOD_u/BOD_5	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
	Fraction in Slow Term	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2

*Not yet constructed.
**Part of combined effluent: Consolidated Papers, Inc. or Nekoosa Paper Company.
***Only industries are subject to cutbacks from baseline loads.

Table 2 (continued)
BOD Parameters Used for Steady State Modeling of Segment D of the Wisconsin River

Discharger	Parameter	July 9-10 1973	Aug. 14-15 1973	July 18 1974	Aug. 17 1975	Aug. 16-18 1976	Oct. 10-12 1976	June 29-30 1977	Aug. 17-18 1977	June 27-28 1978	Aug. 15-16 1978	July 24-26 1979	Aug. 18-19 1979	Used for WLA Runs***
Wis. Rapids STP	BOD_5 (lb/day)	1,106	464	148	134	187	160	180	134	540	210	728	99	2,212
	BOD_u/BOD_5	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
	Fraction in Slow Term	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
NEPCO-Pt. Edw.	BOD_5 (lb/day)	202,885	229,000	257,541	48,233	**	**	**	**	**	**	**	**	**
	BOD_u/BOD_5	2.1	1.6	2.1	1.6	2.1	1.6	2.1	1.6					
	Fraction in Slow Term	0.4	0.2	0.4	0.2	0.4	0.2	0.4	0.2					
Pt Edwards STP	BOD_5 (lb/day)	398	81	95	81	63	63	78	71	117	107	123	173	251
	BOD_u/BOD_5	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
	Fraction in Slow Term	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
NEPCO-Jt. Tmt.	BOD_5 (lb/day)	*	*	*	*	49,897	52,789	85,789	89,702	3,873	3,873	4,099	11,064	
	BOD_u/BOD_5					1.4	1.4	1.4	1.4	6.0	6.0	6.0	6.0	6.0
	Fraction in Slow Term					0.2	0.2	0.2	0.2	0.6	0.6	0.6	0.6	0.6
NEPCO-Nekoosa	BOD_5 (lb/day)	29,201	36,372	48,159	28,268	**	**	**	**	**	**	**	**	**
	BOD_u/BOD_5	1.5	1.5	1.5	1.5									
	Fraction in Slow Term	0.2	0.2	0.2	0.2									
Nekoosa STP	BOD_5 (lb/day)	478	76	255	126	84	84	86	68	140	115	84	80	240
	BOD_u/BOD_5	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
	Fraction in Slow Term	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4

*Not yet constructed

**Part of combined effluent: Consolidated Papers, Inc. or Nekoosa Paper Company.

***Only industries are subject to cut backs from baseline loads.

Nitrogen

The nitrogen kinetics are very much more complicated. The nitrogen forms can be thought of as a series of "feed forward" transformations. Organic nitrogen can hydrolyze to ammonia with no uptake of oxygen. Ammonia decays to nitrite with a known amount of oxygen uptake. Nitrite decays to nitrate also using oxygen. Any nitrogenous oxygen demand potential from a point source effluent is modeled by these transformations using the quantity of organic nitrogen and ammonia discharged. The last two steps in this process are referred to as nitrification. The rate of nitrification is somewhat dependent on the concentration of dissolved oxygen (DO) in the system. Nitrification is slowest at very low DO levels and nearly maximum if the DO is above 2 mg/l. This effect is programmed in QUAL III. Denitrification can also occur if the DO is very low. Denitrification is the process whereby nitrate is turned into N_2 gas (with nitrite as an intermediate step) and subsequently lost from the aquatic system. Denitrification is nearly the opposite of nitrification, being at a maximum rate if the DO is zero and at a minimum when the DO is above 2 mg/l.

The nitrogen cycle is completed by the algae which utilize the inorganic nitrogen (ammonia and/or nitrate) creating organic nitrogen compounds. Thus algae growth reduces the quantities of ammonia and nitrate with algae respiration feeding back to organic nitrogen. The rate at which organic nitrogen hydrolyzes to ammonia is proportional to the amount of algae biomass present. This idea is a manifestation of the fact that whatever is responsible for organic nitrogen recycle is somewhat controlled by the algae or by the bacterial population that feeds on the algae. Organic nitrogen is also allowed to settle to the sediment.

Algae

The growth of algae biomass is dependent on four factors: 1) temperature, 2) inorganic nitrogen, 3) soluble phosphorus and 4) available light. The nitrogen and phosphorus terms are each used with a half-saturation constant to yield a fraction of maximum growth rate based on Michaelis-Menton kinetics. These terms are multiplied together to yield a nutrient limitation factor. Temperature affects the growth through an exponential temperature adjustment which is explained in a later section. The final growth limiting factor is light.

The solar radiation input to the model is averaged over the calculation period (i.e., the time step for dynamic runs and the daylight portion of the day for steady state runs) as well as averaged over the depth of each location. The sunlight is attenuated as a result of water turbidity, water color, and algae self-shading. The algae self-shading is, therefore, an internal feedback that serves to control the algae growth rate by limiting the available light.

TEMPERATURE

The QUAL III model does not currently have the capability of modeling river temperature. The temperature for each reach is specified by input data. The input temperature is the average temperature for the given location.

The temperature is used to adjust all biological rate constants. Most rates are adjusted by an exponential equation that is based on the rate at a standard temperature such as 20°C. The rate for another temperature is found from an equation of the form:

$$K_T = K_{20}\,\theta^{(T-20)}$$

where:
K_T = rate at temperature T
K_{20} = rate at 20°C
T = temperature °C
θ = constant specific for each reaction rate.

Nearly all rate constants are adjusted by an equation similar to the one above, although some variations do occur. A more complete discussion of this can be found in "QUAL III Water Quality Model Documentation", which is available from the Water Quality Evaluation Section.

DISSOLVED OXYGEN

The dissolved oxygen is affected by nearly all the terms mentioned above. Sources of dissolved oxygen include atmospheric and turbulent reaeration, algae growth, reaeration over hydraulic structures and inputs from tributaries or headwaters. Sinks of dissolved oxygen include biochemical oxygen demand (BOD), sediment oxygen demand (SOD), nitrification, algae respiration and (if the DO level is above saturation) deaeration.

The reaeration from various sources are handled differently. For most areas of the system which have typical river characteristics, the reaeration is calculated based on one of several reaeration evaluations which have been derived experimentally (usually the O'Connor-Dobbins formula). In areas that are wide and tend to be more like a flowage, reaeration is calculated from a wind driven equation. At hydraulic structures (i.e. dams) two possibilities exist. First, the water can flow over a spillway and be aerated or deaerated from the resulting turbulence. Second, the water may pass through a turbine which may be vented to add oxygen. Each dam is evaluated for these potentials and the appropriate coefficients entered.

The biochemical oxygen demand is a direct uptake of dissolved oxygen. The amount of DO consumed is directly proportional to the amount of ultimate BOD that decays in a stream segment. Nitrification works nearly the same way except that one gram of ammonia can cause 4.57 grams of oxygen uptake, if completely nitrified. Sediment oxygen demand is nearly the same as BOD in that a one to one correspondence exists between the BOD settled and amount of SOD generated. The difference lies in the fixed location where SOD is generated, and therefore exerted, which alters somewhat the location of the DO sag. The QUAL III model is programmed so the fraction of BOD which settles to create SOD is assumed to decay both aerobically and anaerobically for the Wisconsin River.

C. Model Operation

When using the model, it is necessary to be aware of the nature of the output as it is dependent on both the solution technique and the manner in which the model is run. Since QUAL III is a finite element model, it is implied that the answers are not continuous functions for all times and places. Rather, the solution is an approximation of the correct solution at only discrete times and locations.

An artifact of the numerical solution technique is an error called numerical dispersion. Numerical dispersion is analogous to real dispersion in that it tends to spread locally high concentrations of material over space. Unfortunately, numerical dispersion spreads things out even if no real dispersion is input to the equations. The numerical dispersion increases with increasing element size and time step. Thus these two factors must be chosen to limit the error while at the same time not excessively increasing the cost for the computer calculations.

When the model is run in steady state mode, the numerical dispersion error is very small and does not significantly affect the results. In dynamic mode, numerical dispersion will tend to spread slug loads or peaks faster than actually occurs. The QUAL III model attempts to eliminate numerical dispersion by reducing the calculated river dispersion by an amount equal to the numerical dispersion at each point. If the numerical dispersion exceeds the actual dispersion then the error can be reduced, but not entirely eliminated.

STEADY STATE AND DYNAMIC OPERATION

The QUAL III model can be run in two basic modes: steady state or dynamic. Steady state implies that all conditions input to the model are at nearly constant levels and the system is, therefore, at equilibrium. The solution given by the model is the equilibrium obtained if all inputs remained constant. Dynamic simulations "step through time" by changing the input values in correspondence to actual data. The results from a dynamic run are the spatial and temporal distribution of all modeled parameters based on the fluctuating input data.

When running the model in steady state mode, several assumptions must be kept in mind. The model solution will accurately represent the system only so long as the system is in equilibrium. Therefore, estimating the effect of peak loading rates which occur for only a day or two cannot accurately be simulated in steady state mode. The steady state operation is not usable for calibration or verification if the period being simulated is not near equilibrium for a sufficiently long enough time. In many cases judgment by the modeler determines whether or not the system is close enough to equilibrium to be modeled in steady state mode. Obviously, nature is never so kind as to be at true steady state conditions and thus the simulation of real data will have some local variations due to this problem.

Dynamic simulation runs can improve this situation considerably. In the dynamic mode of the QUAL III model all input parameters can be updated on a 24 hour basis. The only exception is the headwater DO which can be updated on an hourly basis. Allowing input data to be updated on a daily basis is a great improvement in attempting to match the real system. It is still possible, however, for local variations to occur because discharge values fluctuate on smaller time scales, the daily average temperature is not as accurate as instantaneous temperature and the solar radiation fluctuates greatly throughout the daylight hours whereas the model assumes an average intensity. Although the above problems exist, QUAL III in dynamic mode is capable of simulating a river system with a higher degree of accuracy than is required for practical applications.

SOLUTION TECHNIQUE

The QUAL III model uses an implicit "backward difference" technique to solve the differential equations that simulate the reactions of each of the parameters. This technique arrives at a correct solution in one iteration for dynamic simulations since all the information required for the solution at the next time step is known. However, for steady state solutions that is not the case and it is necessary to iterate to the correct solution. Several feedbacks in the model scheme make it even more difficult to arrive at a correct solution. The technique requires making a guess at the solution and then checking the internal consistency of the general solution versus the known decay and growth rates. If the solution is not consistent, a next guess is made based on the previous guess. The above procedure is repeated until the difference between successive iterations is less than an allowed error (such as .005 mg/l of DO). From experience it was found that all runs of the steady state model did not converge in the same manner. Depending upon the relative amount of algae, the solution tended to oscillate around what appeared to be the correct solution. In other words, the model would be below the solution on one iteration and above it the next without getting any closer to the correct solution. This tendency was overcome by averaging what would be the next guess with the previous solution and using the average value for the actual next guess. Furthermore, a weighting factor is applied to the averaging such that the next solution depends on a selected amount of the previous solution versus the next guess. The weighting factor is selected for each data set to minimize the number of iterations needed to get sufficient convergence of the solution. Selection of the weighting factor is generally a trial and error procedure, but it is always possible to find a weighting factor which gives a consistent answer that does not oscillate.

III. DATA REQUIREMENTS

One of the requirements of any modeling effort is the collection of pertinent information needed to calibrate and verify the model chosen. The data requirements of the QUAL III model are extensive, requiring information capable of representing the river basin's hydrology at different conditions and periods. Information is needed on the physical characteristics of the river, such as cross-sectional areas, depths, widths, and time-of-travel and dispersion measurements. In addition, information is needed on influent flow rates and characteristics. This includes the headwater flow at the beginning of the reach being modeled, flows added to the river by tributaries or distributed runoff to the mainstem, wasteload flows, and other additions or deletions to river flow such as industrial cooling water and evaporation. The water quality of these inflows must also be determined. This includes measurements of dissolved oxygen (DO), biochemical oxygen demand (BOD), temperature, algae biomass, and nutrients. Intensive synoptic river surveys are necessary to establish how these parameters affect the river's response levels under varying flow and temperature. Special studies are necessary to describe processes that are found to be important as a result of sensitivity analyses of the water quality model. These include sediment oxygen demand (SOD) investigations and algal photosynthetic measurements. A summary of the data sources used in the modeling work is described below.

Synoptic Water Quality Surveys

Synoptic water quality surveys attempt to evaluate the water quality of a specific river reach in as many places as possible in a rather short time, usually less than one or two days. From a practical stand point, this type of survey was necessary since travel time in the river reach between Biron and Castle Rock Flowage exceeds several days. Therefore, it was not possible to collect samples based on time-of-travel to various points in the river reach because of manpower limitations and some uncertainty in the determination of travel time. If the river is close to steady state conditions, the steady state model run can be used to simulate the river conditions. In addition, the QUAL III model can be run dynamically to simulate time of day measurements. Surveys were conducted during periods when the river flow was relatively stable to meet the steady state assumption, at least in terms of river flow.

Most synoptic surveys were conducted by the Department of Natural Resources and consisted of field determination of river DO, temperature, light penetration, river depth, and conductivity at up to 36 stations between Biron and Castle Rock Flowage. In addition, samples were collected at a few stations for the determination of 5-day and ultimate BOD, chlorophyll, solids, and nutrients. The Department has also received synoptic water quality survey data from one consulting firm. Most surveys were conducted during the summer period since DO levels were usually lowest during this time. However, a few surveys were conducted during the winter months to assess the impact of point source discharge for future wasteload allocation consideration during periods of ice cover. Synoptic surveys for the Biron to Castle Rock Flowage river reach are listed in Table 3. A supplementary report entitled "Water Quality Modeling of the Upper Wisconsin River for Wasteload Allocation Development - Water Quality Data" has been published by the Department. The report contains the field data collected during all synoptic surveys on the Wisconsin River and is available from the Water Quality Evaluation Section. Field data not included in that report as can be found in Appendix C of this report.

Table 3

Water Quality Synoptic Surveys for Segment D of the Upper Wisconsin River

Source	Number of Surveys	Month	Year
DNR	1	July	1973
DNR	1	August	1973
DNR	1	July	1974
DNR	1	February	1975
DNR	1	March	1975
DNR	1	August	1975
DNR	1	August	1976
CH_2M Hill*	1	August	1976
CH_2M Hill*	1	September	1976
DNR	1	June	1977
DNR	1	August	1977
DNR	2	January-March	1978
DNR	1	June	1978
DNR	1	August	1978
DNR	1	January-March	1979
DNR	2	July	1979
DNR	1	August	1979
DNR	1	August	1980

*Consulting firm

Special Studies

Much of the information needed by the model is used to define rate coefficients or other necessary parameters. Specific studies were undertaken to define these coefficients so that less emphasis had to be placed on "literature values". These special studies included: time-of-travel and dispersion studies, sediment oxygen demand and sediment characterization studies, and algae dynamics - primary production studies. The above studies were conducted by Department of Natural Resource employees and reports describing these studies are available from the Department.

Continuous Automatic Monitoring Stations

The Department of Natural Resources (DNR) operates and maintains automatic monitoring stations at six dams on the upper Wisconsin River. These stations are located at Wausau, Mosinee, DuBay, Biron, Centralia, and Petenwell Dams and have been in operation since May 1971. The DNR monitors record values of dissolved oxygen, temperature, pH, and conductivity each hour with the data sent to a computer in Madison. Wisconsin Valley Improvement Company supplies daily flow measurements at these sites on a weekly basis. These monitors are excellent sources of information for the modeling effort since they show the river's response to changing conditions on an hourly basis. In this way, the monitors are a valuable data base for verification of the QUAL III model. A summary of this data has been published by the Wisconsin Department of Natural Resources. It is entitled "Automatic Water Quality Monitoring of the Fox and Wisconsin Rivers: 1972-1981" and is available from the Water Quality Evaluation Section.

Department of Natural Resources Ambient Monitoring Network

This network consists of samples collected on a monthly basis by the DNR at eight locations in the upper Wisconsin River. These are: McNaughton Bridge (Oneida County), Hat Rapids Dam, Merrill Dam, Wausau Dam, Lake Dubay Dam, Biron Dam, Nekoosa (near sewage treatment plant), and Petenwell Dam. Water quality parameters monitored include: dissolved oxygen, pH, temperature, conductivity, nutrients, solids, and chlorophyll-a. This sampling program gives general information on changes in water quality on a seasonal and yearly basis. This information is useful for describing headwater conditions for various segments in the Department's water quality computer model at different times of the year and was used during the wasteload allocation process.

Permit Program (WPDES)

Since 1974, municipal or industrial point sources discharging to the State's waters have been controlled by Wisconsin Pollutant Discharge Elimination System (WPDES) permits. In addition to containing effluent limitations and compliance schedules, the dischargers are required to monitor their own effluent. Typical effluent parameters monitored included flow, biochemical oxygen demand (BOD), suspended solids, pH and water temperature. In addition, some permittees are required to monitor nutrients and instream water conditions, especially those who have permit limitations that are adjusted according to the flow rate and temperature of the receiving water. Most of the parameters are collected using a 24-hour composite sample. These daily results are then tabulated and sent to the Department each month. Compliance monitoring surveys are conducted by the Department at wastewater treatment plants and major industries, such as the pulp and paper industry, to ensure accurate reporting of pollutant discharges. All of the above information was used extensively during the calibration and verification phase of the QUAL III model.

United States Geological Survey

The United States Geological Survey (USGS) has a network of gaging stations in the Upper Wisconsin River Basin. This data is published yearly in "Water Resources Data for Wisconsin". Their data was relied on for determining tributary flows and mainstem flows for modeling purposes. In addition, USGS provided information describing the low-flow characteristics of gaged streams and provided relationships for estimating flows on ungaged streams. There is one station located on Segment D of the upper Wisconsin River. It was located at Centralia Dam until recently when it was moved to the Wisconsin Rapids Dam.

Wisconsin Valley Improvement Company (WVIC)

The WVIC estimates daily flow at various dams on the mainstem as well as tributaries and reservoirs of the river as part of their normal flow regulation management of the upper Wisconsin River system. Each week, WVIC sends out a reservoir report summarizing the operation of the reservoir system. Included in this report are reservoir water levels, gains or losses in storage, weekly average flow rates at Merrill, and precipitation within the system. The above information is very useful for modeling purposes and water quality monitoring because the data supplements USGS flow data and is available on a daily basis.

Other Sources of Information

In addition to the above sources of information, the following organizations have contributed additional data. A number of paper mills have supplied water quality data and have provided information on shutdown time schedules. Wisconsin Public Service Corporation has supplied a 21-year record of river temperatures at their Weston power generation station located on the upper Wisconsin River below Lake Wausau. Climatic data including wind speeds and directions, temperatures, solar radiation, and precipitation have been supplied by the State Climotologist and the National Oceanic and Atmospheric Administration (NOAA). Additional solar radiation measurements were available from the U.S. Forest Service Genetics Laboratory in Rhinelander, the University of Wisconsin - Stevens Point, a site in Mosinee, a station located in Waupaca operated by the DNR (Office of Inland Lake Renewal), and the University of Wisconsin-Madison's experimental agricultural station at Arlington.

IV. CALIBRATION OF QUAL III ON SEGMENT D OF THE UPPER WISCONSIN RIVER

The next major step in developing and using a water quality model is to calibrate the model to various particular circumstances. Calibration consists of determining the correct set of rate coefficients and assumptions so that the model duplicates the observed system when it is given the appropriate input data. With the model, the numerous rate coefficients, settling rates, growth rates, etc. are the controls available to adjust the model output into conformity with observed data. This process is repeated for each data set to be calibrated with the aim of using a fixed set of coefficients for all circumstances unless a logical reason can be given for a different choice. As stated earlier, settling rates for BOD were generally lowered with increasing treatment. In other cases as well, coefficient changes generally followed the alteration in treatment systems that went on line during the 1973 to 1978 period.

Calibration Data Sets

Eight data sets, each representing a complete dissolved oxygen profile with water quality data were used for calibration purposes. The data sets correspond to the various surveys that have been conducted from 1973 through 1977. The QUAL III model was run several times in steady state for each data set until an acceptable fit of all the parameters was obtained simultaneously. Steady state runs were compared to daily average dissolved oxygen values as adjusted from time of day measurements. Although prime emphasis was placed on matching dissolved oxygen profiles, other parameters such as nutrients and algae were matched as well. Occasionally, the calibration of one data set caused a conflict in another data set that required adjustments in an opposing direction. If no rationale was evident from careful observation of the available data as to why the conflict existed, then the model was adjusted to either split the difference or to emphasize the data set that was judged to be qualitatively better. The dates of the eight surveys are shown in Table 4.

Table 4
Calibration Data - Dates of Occurrence

Survey			Steady State Flow at Biron (cfs)	Average Temperature (°F)
July	9-10	1973	3341	73.5-81.1
August	14-15	1973	2931	75.7-76.8
July	18	1974	2678	77.1
August	17	1975	1732	74.0-75.7
August	16-18	1976	1738	70.4-74.6
October	10-12	1976	928	55.1-56.6
June	29-30	1977	1340	69.0-76.0
August	17-18	1977	1222	70.4-71.7

Calibration Boundary Conditions

All the data used in the calibration runs are derived from observed data taken in the field, reported from a laboratory or reported from an independent agency. When preparing a data set for entry to the model, all inputs to the river which add any quantity of a pollutant material that is routed by the model must be specified. A list of possible inputs would include such things as wasteloads, tributaries, headwaters or dispersed runoff. All these inputs are referred to as boundary conditions. The boundary conditions therefore supply the mass loading rates for each parameter routed by the model from all external locations.

The headwater of the model refers to the most upstream element in the simulation. It is necessary to quantify all parameters at this point since the solution proceeds no further upstream. Any parameter that is routed by the model must be assigned a value for the headwater. For example, the chlorophyll-a concentration that enters Segment D of the Wisconsin River for the simulation period must be specified for each run. The flow that exists in the river at that point must also be specified. In a similar manner all wasteloads or major tributaries must be quantified for each parameter.

In addition to the mass loading rate for each parameter, other information is required to complete the simulation set up. The amount of solar radiation and the wind speed for the day of the survey must be specified. The solar radiation, along with the period of daylight, define a solar radiation rate that determines a key factor in the algae growth equation. The wind speed is used to calculate the wind driven reaeration at locations where the river is wide and shallow. Finally, one set of initial conditions is specified. The temperature at all locations in the model is fixed at a representative temperature for the simulation period.

Sources for the above data are many. Wasteloads and effluent flows are primarily taken from the Self Monitoring Reports (SEMORE) filed by each discharger on a monthly basis. The SEMORE files contain daily composite values for flow and BOD_5. Discharge information for nutrients is derived from any sample analysis that can be obtained. Usually nutrient information can be found in the annual compliance monitoring report. Several major dischargers are also required to file weekly or quarterly nutrient loading rates as part of their SEMORE forms. Samples taken for longterm BOD analysis were also analyzed for nutrients.

Headwater concentrations were taken directly from field and laboratory data for the most upstream sampling location. Three monthly monitoring stations are located in the Segment D reach and the several years of data at these locations were used to develop seasonal trends. Accurate flow measurements at the headwaters of Segment D in Biron are not available. The headwater flow is based on flow measurements at Wisconsin Rapids Dam by the United States Geological Survey (USGS) and adjusted for estimated dispersed runoff. As there are no major wasteload or tributaries between the headwaters and the USGS station which cannot be accurately determined, the headwater flow is essentially that flow as measured by the USGS. The only tributary is Mosquito Creek (1-2 cfs). The only current industrial impact is the water withdrawal by Consolidated Papers, Inc. at Biron, which is reported. Temperatures in the river are derived from field observations during the survey. Solar radiation data was used from one of two main sources; the U.S. Forest Service experimental station at Rhinelander or the site in Mosinee. Wind speed was taken from either the local weather station or estimated by the field survey crew. Measured wind speeds were used for reaeration of Lake Petenwell. However, wind speeds for Biron Flowage had their direction taken into account. As Biron Flowage is long and narrow, winds along the length of the Flowage were used as measured but winds that blew across the width of the flowage needed to be reduced to better reflect actual impact upon the flowage.

Coefficient Selection

The selection of the many coefficients is the primary output of the calibration process. Although literature values or ranges can be used as a starting point for rate coefficients not able to be directly estimated from data, it is likely that the final coefficient set will be substantially altered for a river as complex as the Wisconsin. Because of the complexity involved, the calibration procedure became an iterative process involving several well defined steps. These steps were repeated every time a substantial change was made in the coefficients selected, the input data or the modeling kinetics.

The initial step was simply selecting a set of coefficients and running all calibration data sets through the QUAL III model. When the output was obtained, it was scanned to determine the qualitative fit for each parameter of each calibration data set. The choice of adjustments may not be limited to one or two possibilities. The modeler must rely on past experience and judgment in selecting the adjustment. The main factors considered in calibrating the nutrients and algae were: modeling the average level of all nutrients, modeling consistent trends, using calibration parameters consistent with expected parameter levels, and finally, modeling diurnal dissolved oxygen swings.

During the calibration process it became apparent that the depth of Lake Petenwell had a substantial impact on the instream biological community and on the model. Lake Petenwell is usually stratified during summer conditions. The lower temperature waters of the hypolimnion do not mix with the warmer waters of the epilimnion. Two separate biological communities exist in this situation.

The epilimnion has a large phytoplankton community which is active and results in near saturation dissolved oxygen values. The hypolimnion is dark and cold resulting in little photosynthetic activity. It is, however, subject to the epilimnion's community in the form of dead algae "raining" down through the hypolimnion. The dead algae decaying and the sediment oxygen demand in conjunction with little reaeration (hypolimnion water does not mix with epilimnion water) and no photosynthetic activity result in depressed dissolved oxygen levels.

The QUAL III model assumes complete mixing throughout the entire depth of the water column. Results of the model output for Lake Petenwell are hard to compare with the real world situation. The model tends to over-estimate bottom water activity while under-estimating surface water activity. Due to modeling in Lake Petenwell and instream investigations it was determined that there are two critical dissolved oxygen sag points above Petenwell Dam.

The first sag point occurs at the inlet to Lake Petenwell and its magnitude is influenced by the organic loading from point and nonpoint sources. Of these, the largest contributors are the Consolidated Papers, Inc. pulp and paper mills in Biron and Wisconsin Rapids and the Nekoosa Paper Company pulp and paper mills in Port Edwards and Nekoosa. The second sag point is located in Lake Petenwell and its magnitude is influenced the greatest by sediment oxygen demand and algae decay.

The first sag point (inlet to Lake Petenwell), while not always the location of the lowest dissolved oxygen, can be attributed to point source loadings and is considered the most critical for wasteload allocation purposes.

Several sets of BOD decay rates and BOD settling rates are used through the calibration process. The different rates are needed due to the changing characteristics of the pulp and paper mill wastes discharged into Segment D. In 1973 Consolidated Papers, Inc.'s three mills (Biron Division's pulp and paper mill, Kraft Division pulp mill in Wisconsin Rapids, and Wisconsin Rapids Division paper mill in Wisconsin Rapids) and Nekoosa Paper Company's two mills (Kraft pulp and paper mill in Nekoosa and sulfite pulp and paper mill in Port Edwards) offered no better than the equivalent of primary treatment at each of the five sites.

Starting in 1975, BOD loadings to the Wisconsin River were beginning to be reduced. Nekoosa Paper Company (NEPCO) installed evaporation/burn units at their Port Edwards facility in order to recover chemicals from their sulfite liquors. This resulted in removal of spent sulfite liquor discharge to the Wisconsin River. In 1976 Consolidated Papers, Inc. combined the effluents from their Biron facility and the two Wisconsin Rapids facilities and installed an activated sludge treatment system. NEPCO combined the effluents from their two facilities. NEPCO followed in 1977 with the installation of primary clarifiers. A completed pure oxygen activated sludge system was in operation for NEPCO in 1978. BOD_5 loadings from the five facilities dropped from over 268,000 lbs/day during the July 1973 survey to less than 5,700 lbs/day during the July 1979 verification survey.

Each of these treatment system changes resulted in different characteristics of the effluents requiring alterations of BOD decay and settling rates. In addition, the October 1976 calibration data set required some additional changes of the BOD decay rates due to low river temperatures.

Calibration Results

After the above procedure had been run several times, a final set of coefficients was determined. This set of coefficients represented the calibrated model and was used for the verification runs to check the calibration against additional data. The results of the calibration runs are presented in Appendix E. Graphs of the model output are overlaid on graphs of the observed data.

Because the model calculates daily average dissolved oxygen levels at all locations in the steady state mode, it was necessary to adjust the observed dissolved oxygen profile to be directly comparable to the model results. This adjustment was done in two steps. First, all the dissolved oxygen data collected for any cross section of the river was averaged to yield a river cross section DO at the time of measurement. It was typical to use two or three locations in a river cross section and three or more readings with depth at each location. The number of readings varied according to mixing characteristics and river depth at the cross section location. After the cross sectional average was obtained, it was further adjusted to account for the time of day the reading was taken. This was accomplished by observing the diurnal DO pattern at the closest diurnal station. The diurnal DO stations used were the Biron and Centralia automatic monitors. The DO was adjusted by an amount equal to the magnitude that the diurnal station was away from the day's average at the time the cross sectional values were observed. This adjustment could be either positive or negative depending on the time of day. The steady state output and daily average measurements are compared in Appendix E.

The statistics for the comparison of calculated versus model DO are based on daily average values. Table 5 presents the statistical comparison for each calibration run. Additional statistics on the entire river segment can be found in Appendix E.

Table 5
Comparison of Calculated and Observed Dissolved Oxygen
Values for Eight Segment D Calibration Surveys in Steady State Mode

Survey Date	All Measurements Average Difference Predicted-Measured (mg/l)
July 9-10, 1973	*
August 14-15, 1973	0.10
July 18, 1974	*
August 17, 1975	0.10
August 16-18, 1976	0.36
October 10-12, 1976	-0.11
June 29-30, 1977	0.21
August 17-18, 1977	0.27

*Daily average values not available - only time of day measurements.

The July data sets from 1973 and 1974 could not have daily average values estimated from time of day measurements as the automatic monitors were not functioning properly during the synoptic surveys. The June 1977 survey coincided with a malfunctioning automatic monitor at Centralia Dam. The average difference value for this date is the value only for the measurements which were closest to the Biron monitor.

Calibration Summary

The QUAL III model was calibrated against eight separate data sets. These data sets span the years 1973-1977. The data used to develop the model input came from several sources including SEMORE files, survey data, weather stations and others. The model was calibrated using an iteration scheme to obtain the best fit for all data sets on all parameters simultaneously. The average difference between the calibrated model dissolved oxygen predictions and the observed instantaneous dissolved oxygen values was 0.16 mg/l.

Appendix D contains a listing of the various coefficients determined by the calibration process. The final set of coefficients chosen were also used for verification, sensitivity analyses and prediction runs which are discussed later in this report.

V. MODEL VERIFICATION

The calibration discussed in the last section developed a set of coefficients that satisfies the model for Segment D of the Wisconsin River over a wide range of conditions. Two types of verifications have been done. The first is to do additional steady state modeling runs using data sets that had not been used in the calibration process. The second is to run the model dynamically for extended periods of time and compare predicted dissolved oxygen values with measured values from the automatic monitors during the extended period.

Verification Data Sets

Two types of verification data sets have been used. The first type is the synoptic survey data set which is the same in format as those used in the calibration process. The second type of verification data set are those data sets which have sufficient water chemistry data available for dynamic operation of the model to generate dissolved oxygen comparisons with the automatic monitors. These dynamic runs utilized the dissolved oxygen data collected by the automatic water quality monitors at Biron Dam, Centralia Dam and Petenwell Dam. Data collected in this manner was compared to the predicted dissolved oxygen values to determine the longterm trend modeling capabilities of the QUAL III model for Segment D.

Four data sets of the synoptic survey type and three dynamic surveys using the automatic monitors were run dynamically by the QUAL III model. The dates, flows and temperatures of these surveys are listed in Table 6. Note that two of the dynamic verification runs are developed from data sets used for steady state calibration of QUAL III for Segment D. These can still be considered verification runs as the dynamic modeling is used for longterm trend comparisons. Comparison of extended automatic monitoring data to dynamic output was not done during calibration. Thus, many days of new data are used in this comparison. In addition, diurnal dissolved oxygen swings can be observed by this comparison to supplement the longterm trend comparison.

Verification Results

Results of the verification runs are located in Appendices F and G. Appendix F contains the results of the steady state operation of the QUAL III model for comparison to the synoptic survey daily average dissolved oxygen values. Appendix G contains the results of the QUAL III model dissolved oxygen predictions and measurements made by the automatic monitors. A statistical comparison of the field measurement versus model prediction dissolved oxygen values is given in Table 7. Table 7 is similar in nature to Table 5.

Table 6
Verification Data - Dates of Occurrence

Survey Data	Steady State Flow at Biron (cfs)	Dynamic Flow at Biron (cfs)	Temperature Range (°F)
August 14-September 14, 1976	-	1130-2070	64.8-79.9
August 1-31, 1977	-	1140-1880	67.7-78.4
June 27-28, 1978	2600	-	70.4-75.6
August 15-16, 1978	2700	-	72.0-79.9
August 1-31, 1978	-	2409-15732	71.4-80.6
July 24-26, 1979	2900	-	75.0-78.8
August 18-19, 1980	-	-	57.3-73.6

Table 7
Comparison of Calculated and Observed Dissolved Oxygen Values
in Mg/L for Four Segment D Synoptic Verification Surveys in Steady State Mode

Survey Date	All Measurements Average Difference Predicted-Measured (mg/l)
June 27-28, 1978	-0.73
August 15-16, 1978	0.19
July 24-26, 1979	0.05
August 18-19, 1980	-0.38

The results of the verification runs are located in Appendices F and G. The plots for steady state comparisons to synoptic survey daily average dissolved oxygen values are in Appendix F. These plots are similar in nature to the calibration synoptic survey plots. The dynamic survey plots are for the sites of the automatic monitors: Biron Dam, Centralia Dam and Petenwell Dam. These plots are dissolved oxygen versus time for a single site on the river and found in Appendix G.

The dynamic plots for Biron and Centralia are good and the results as plotted are representative. The Centralia plot is more critical as this is the site closest to the dissolved oxygen sag point, although above Nekoosa Paper Company. The dynamic plots for Petenwell are not representative of the actual situation. While the automatic monitor at Petenwell Dam is useful for evaluating overall instream dissolved oxygen levels, it is not indicative of instream cross section average values.

A prior chapter discussed problems with the stratification of Lake Petenwell. This same condition exists up to Petenwell Dam. In conjunction with this, is the operation of the hydroelectric power plant at the dam. The Petenwell power plant is used as a peaking power plant. Thus, during high electrical demanding periods of time, large flows of water are required to be routed through the turbines. Off-peak hours result in a substantially lower volume of water being passed through the turbines.

This large fluctuation in turbine flows creates a fluctuation in flow regimes within Lake Petenwell near the dam. As previously mentioned, Lake Petenwell is stratified during summer periods. The high flow requirements of peak production hours result in the cooler, lower dissolved oxygen water of the hypolimnion being drawn through the plant. Off-peak hours with reduced flow result in a different flow regime with the warmer, higher dissolved oxygen epilimnion water being passed through the turbines.

The intake for the automatic monitor is located within the intake for the power plant. Thus, as the hypolimnion or epilimnion waters are passed through the turbines, this same varying water is sampled by the automatic monitor. The large diurnal dissolved oxygen swings at Petenwell appearing in the plots can be attributed more to the source of water that is sampled than to the photosenthetic activity of the algae within the water. It is to be expected that the Petenwell dissolved oxygen swings as predicted by the model would be less than those observed due to hypolimnion and epilimnion water passing, during periods of stratification.

Summary

The QUAL III model for Segment D of the Wisconsin River was verified in steady state using four additional synoptic data sets and dynamically simulating three month-long periods of time. The average of the absolute values of difference of the verification synoptic surveys is less than the average of the absolute values of difference of the calibration surveys. In addition, visual inspection of the dynamic month-long simulations shows that dissolved oxygen trends within the river are followed. Therefore, Segment D of the Wisconsin River is considered verified.

VI. SENSITIVITY ANALYSIS

Once the model has been calibrated and verified, a key aspect to its use is the relative sensitivity of model output to the model input coefficients and parameters. To a large degree, the calibration process is a sensitivity study. In that process, however, we are selecting rate constant changes that will alter the model output to achieve a desired response. With the model finally tuned to the observed data, it is beneficial to perform an explicit sensitivity analysis. The process usually takes the form of selecting each alterable parameter (i.e. coefficient or boundary condition) one at a time and varying its value both plus and minus a set amount or percentage while all other conditions remain constant. The model's output for both conditions are compared to the model's output for a baseline run (i.e. before any variables are altered) for each parameter of importance, such as dissolved oxygen.

A sensitivity analysis of the type described above was performed using the QUAL III model for Segment D of the upper Wisconsin River. Ninety-eight runs were executed to test all parameters, headwaters and rate coefficients. The conditions selected for the base run are those of a typical boundary condition scenario with all municipalities and industries at their baseline loads using a headwater flow of 1,500 cfs and a river temperature of 76°F. The results of the sensitivity analysis runs are presented in Appendix H. The rate coefficients for the baseline run are the same as those used from the final calibration data sets.

The model shows the most sensitivity to those parameters affecting the algae dynamics. Examples of these parameters are the maximum algal growth rate, the algal respiration rate, and available solar radiation. The second most sensitive parameters deal with the BOD loading and decay rates. The net algae growth rate has been estimated with the use of light and dark bottle tests. With the next most sensitive set of parameters dealing with BOD, a large change in the existing set of algal rates would require adjustment with BOD decay rates. Within the constraints of the algal testing (such as the light and dark bottle test), and given the known effluent loading rates for BOD for the numerous survey data sets it probably would not be possible to recalibrate the model using a substantially altered set of algae coefficients based on the altering of BOD decay rates.

The sensitivity of boundary conditions in influencing algae growth, such as solar radiation, indicates the importance of the proper selection of boundary conditions for wasteload allocation. Boundary conditions for calibration and verification are measured for each survey data set. The influence of effluent BOD loading indicates the need for a wasteload allocation for the attainment of water quality standards.

VII. WASTELOAD ALLOCATION PROCEDURES

Once the QUAL III model is calibrated and verified, the model may be used to make simulations or predictions of water quality. Of primary interest is the use of the model to determine the assimilative capacity of the water quality limited segments of the river at varying flow and temperature conditions. This information is needed to formulate effluent limitations for the point sources discharging to the river. A secondary use of the QUAL III model is the assessment of various resource management options (flow augmentation, instream aeration, dam removal, waste storage, and outfall relocation) for meeting the prescribed fish and aquatic life use standards.

Wasteload allocation (WLA) is a method of distributing the necessary reduction in an existing amount of wasteloads from industry and municipalities in an "equitable" manner such that the water quality standard for dissolved oxygen is met. Besides having a water quality model, there are a number of other considerations and data requirements needed prior to proceeding with WLA development. These needs are described below.

Policy Decisions

There are a number of policy decisions that were necessary in order to formulate the method for wasteload allocation. These decisions include determinations of: baseline loads for industry and municipalities, the method of allocation, reserve capacity, margin of safety, nonpoint source allocation, who will be included and who will be exempted from the allocation process, and the "worst case" river conditions applicable to the wasteload allocation. Most of these issues are largely dependent upon the decisions of the advisory committees made up of representatives from the municipalities, industries, and other interested groups. An exception is the application of statewide policy on the level of protection provided by a wasteload allocation.

Baseline Loads

The baseline load is a loading for a discharger to a water quality limited segment from which reductions are calculated such that the sum of the reduced loads does not exceed the assimilative capacity of the river (i.e., does not cause the water quality to fall below the 5.0 mg/l dissolved oxygen standard). The baseline load is a relevant concept only for river segments receiving multiple discharges. In the case of Segment D, the baseline load for industrial sources is equal to the best practicable waste treatment technology categorical effluent limitations (s. 147.04(2)(a), Stas.) applied to 1978 production for point sources. Baseline loads were determined based on a maximum average production level for each industry. These levels were accepted by the industries. The baseline load for municipalities is the 1978 average flow of the treatment plants at a BOD_5 concentration of 60 mg/l. Complete details as to the determination of baseline loads are available in the 208 plan for the upper Wisconsin River. The baseline for point sources in Segment D is listed in Table 8.

Table 8
Baseline Loads for Allocation Runs*

Point Source	Q (cfs)	BOD_5 (lb/day)
Biron STP	0.275	89
Consolidated Papers, Inc.	32.0	31,236
Wisconsin Rapids STP	6.835	2,211
Port Edwards STP	0.775	251
Nekoosa Paper Company	44.0	240
Nekoosa STP	0.742	30,373

* Only Consolidated Paper, Inc. and Nekoosa Paper Company are subject to cutbacks from their baseline load.

Method of Wasteload Allocation

The method of allocation refers to the procedure used to allocate the use of the river's assimilative capacity among the existing dischargers such that the total segment wasteload does not exceed the assimilative capacity of the river. The method used for Segment D was an equal percent cutback from the baseline load. Other factors must be considered before the allocation of the available assimilative capacity is made. These are discussed below.

Reserve Capacity

The reserve capacity is a portion of the river's assimilative capacity that is set aside for new or expanding point source dischargers. It is mainly a local decision of the affected communities whether or not to set aside a reserve capacity for future economic or population growth. It was decided that Segment D of the Wisconsin River will not have any reserve capacity.

Margin of Safety

The margin of safety is an allowance which may include, but is not limited to, a portion of the river's assimilative capacity to account for the uncertainties concerning the relationship between effluent limitations and water quality. Primarily, these include the technical uncertainties or limitations associated with precise modeling of a natural system. The Department of Natural Resources believes the 5.0 mg/l dissolved oxygen standard provides a sufficient margin of safety for protecting fish and aquatic life.

Nonpoint Source Allocation

Federal law requires the consideration of nonpoint sources of pollutants in the determination of the river's assimilative capacity. In its simplest form, this could mean setting a gross level of pollutant discharge which represents the nonpoint source contribution. However, the impact of nonpoint source pollution (nutrients and BOD) is addressed by using the QUAL III model which incorporates the impact of nonpoint source discharge through the routing of headwater BOD, algae, and sediment oxygen demand on the assimilative capacity of the river.

Risk Analysis

The assimilative capacity of the Wisconsin River for BOD is mainly a function of river flow and temperature. In the upper Wisconsin River, the most critical periods of low dissolved oxygen normally occur during periods of low flow and high temperature. Similarly, during these times, the point source dischargers would have their most stringent wasteload allocation. A very important policy decision is needed to determine how often our instream water quality standards would be met under a flow-temperature related permit. The present water quality standards require attainment at all times except during periods when flows are less than the average minimum seven-day low flow which occurs once in ten years ($Q_{7,10}$). However, this single factor fails to specificly account for temperature. To resolve this problem, the Department of Natural Resources has determined that dischargers with flow-temperature related permits be responsible for maintaining the dissolved oxygen standard for fish and aquatic life (5.0 mg/l) under flow-temperature conditions that are expected more frequently than one day per year (.274% risk level), as approved by the Natural Resources Board. This statistical analysis requires a sufficient flow and temperature record for the water quality limited segment. The risk analysis for a particular discharger is determined by ranking their wasteload allocations based on the historical record of river flow and temperature. The wasteload allocation that is expected to occur once per year defines the risk level. The risk level is the most stringent allocation the discharger is responsible for in the WLA table appearing in the WPDES permit.

Flow and Temperature Matrices

The flow and temperature increments chosen for the development of wasteload allocations were selected by a frequency of occurrence analysis of the flow and temperature data available for Segment D of the Wisconsin River. Twenty-one years of data have been analyzed. The flow data have been provided by the USGS. The temperature data was provided by Wisconsin Public Service Corporation's generating station at Weston. These data were adjusted for a change in location based upon the equation $T_{BIR} = 1.004 * T_{WES} + 2.43$. This equation is based upon a regression analysis of available data from Segment D and the Weston station. In addition, the period of record analyzed was for the warm temperature months (May 1 to October 31) during the 1958-1978 time period. Matrices were developed showing the correlation of flows and temperatures. Each entry in the matrix refers to a given temperature and flow range and corresponds to the number of total occurrences of that flow and temperature combination during the entire period of record.

The resulting matrices indicate that the highest temperatures and lowest flows almost never occur simultaneously. A further analysis of the calendar distribution of each box showed that most flow-temperature combinations were characterized by either a normal distribution or bi-modal distribution. At lower temperatures the bi-modal pattern was most apparent. Because of this, it was not possible to assign a "typical date of occurrence" to each flow-temperature combination. The "typical date of occurrence" would determine various other boundary conditions such as daylight hours, total solar radiation, and chlorophyll concentration in the headwater.

In light of the information from the flow-temperature analyses, it was decided to divide the year into fixed periods which would then be used to define the boundary conditions used in the model. The selected periods were May 1st to June 30th, July 1st to August 31st, and September 1st to October 31st. The flow-temperature matrices with frequency of occurrence are given in Appendix I.

Additional Boundary Conditions

A set of physical, chemical, and biological data is needed to define the characteristics of the river during a period of time, May-October, that the river is water quality limited as a result of point source discharge of BOD. The information needed includes headwater dissolved oxygen, chlorophyll-a, nutrients, BOD, solar radiation, and diurnal dissolved oxygen fluctuation. This information is needed to set up the QUAL III model for making predictions of instream dissolved oxygen levels at varying flow, temperature, and point source BOD loadings. These boundary conditions are expressed as an average of available data for a particular period or other representative values. These three periods previously noted were selected because of similar biological and physical conditions and the flow-temperature relationship. In May-June, the river temperature is rising and the algae are largely dominated by diatoms. July-August has somewhat stable temperatures, blue-green algae may become more important, and flows are low. The last period of September-October is characterized as having decreasing temperatures, a diatom algae community, and low flows. Boundary conditions are listed in Table 9.

Wasteload Allocation Tables

Wasteload allocation tables for each of the periods described in the above section on flow and temperature matrices have been developed. These tables are incorporated into the WPDES permits issued to the allocated industries in 1982. These tables are located in Wisconsin Administrative Code Chapter NR 212 as Table 1-m.

TABLE 9

Boundary Conditions for Each Period Used to Do Wasteload Allocation Modeling

PERIOD	HEADWATER CHLOROPHYLL-a (ug/l)	TOTAL SOLAR RADIATION (LANGLEY'S)	DAYLIGHT HOURS	TARGET DISSOLVED OXYGEN* (mg/l)	HEADWATER AMMONIA (mg/l)
May-June	15	500.	15.18	5.38	0.18
July-August	40	480.	14.53	5.55	0.10
Sept-Oct	20	295.	11.98	5.18	0.10

PERIOD	HEADWATER NITRITE (mg/l)	HEADWATER NITRATE (mg/l)	HEADWATER TOTAL PHOS.** (mg/l)	HEADWATER TON** (mg/l)	HEADWATER DIS. OXYGEN (% SATURATION)
May-June	0.00	0.27	0.09	0.89	***
July-August	0.00	0.17	0.07	0.60	***
Sept-Oct	0.00	0.35	0.07	0.62	***

*The target dissolved oxygen for each period is determined by the sum of the dissolved oxygen standard plus one-half of the typical diurnal fluctuation due to algae. Since the model predicts a daily average DO, it is necessary to be above the target DO to maintain the minimum DO standard. The DO standard is 5.0 mg/l.

**These items list only the portion that is <u>not</u> tied up in living algae cells.

***Based on dissolved oxygen saturation at temperature modeled and adjusted using average dissolved oxygen and temperature at the Biron Dam automatic water quality monitor.

APPENDIX A

The following list is a completion of literature sources that were used in the development of the QUAL III for Segment D of the Wisconsin River.

WISCONSIN RIVER ARTICLES

Fenske, B.A. "Water Quality Modeling for the Upper Wisconsin River for Wasteload Allocation Development - Water Quality Data. Wisconsin Department of Natural Resources. Madison, Wisconsin. August, 1982.

Mechenich, C. "Color in the Upper Wisconsin River: Sources and Effects on Primary Production." M.S. Thesis. University of Wisconsin-Stevens Point, 1980. 109 p.

Oakes, E. L. and R. D. Cottes. Water Resources of Wisconsin: Upper Wisconsin River Basin. Hydrologic Investigations Atlas HA-536, USGS. Reston, Virginia. 1975.

Schreiber, K. W. "Primary Production Studies of the Upper Wisconsin River in the Vicinity of Wisconsin Rapids." Wisconsin Department of Natural Resources. Wisconsin Rapids, Wisconsin. November, 1979.

Suchanek, A. G. "Progress Report on Petenwell SOD and Reservoir Investigation." Research sponsored by Consolidated Papers, Inc. Mid-State Environmental Consulting, Inc. Mosinee, Wisconsin. September, 1976.

Sullivan, J. F. "Phytoplankton Studies of the Upper Wisconsin River - An Information Base for the Qual-III Water Quality Model" (Unpublished Report). Upper Wisconsin River Basin, 208 Task Force, Wisconsin Department of Natural Resources. 1978. 35 p.

Sullivan, J. F. "Factors Effecting Phytoplankton Biomass and Photosynthetic Rates in the Upper Wisconsin River." (Unpublished Report) Upper Wisconsin River Basin 208 Task Force, Wisconsin Department of Natural Resources. 1980. 27 p.

Sullivan, J. F., R. Young, and J. Rogers. "Methods and Results of Field Surveys Collected in 1977 and 1978 on the Upper Wisconsin River for the Development of a Water Quality Computer Model" (Unpublished Report). Upper Wisconsin River Basin, 208 Task Force, Wisconsin Department of Natural Resources. 1978. 56 p.

United States Department of Agriculture. Water and Related Land Resources Wisconsin River Basin. Economics, Statistics and Cooperatives Service, Forest Service and Soil Conservation Service, USDA Lincoln, Nebraska. 1979.

Upper Wisconsin River 208 Task Force. Upper Wisconsin River Basin 208 Areawide Water Quality Management Plan. Wisconsin Department of Natural Resources. Rhinelander, Wisconsin. May, 1981.

Weckwerth, H.W., B.A. Fenske. Automatic Water Quality Monitoring of the Fox and Wisconsin Rivers: 1972-1981. Wisconsin Department of Natural Resources. Madison, Wisconsin. November 1982.

OTHER MODELING REFERENCES BY THE DEPARTMENT OF NATURAL RESOURCES

Fenske, B.A., D.J. Patterson, J.W. Rogers, J.F. Sullivan. "Water Quality Modeling of the Upper Wisconsin River for Wasteload Allocation Development - Segment A." Wisconsin Department of Natural Resources. Madison, Wisconsin. September 1981.

Fenske, B.A. and S.A. Skavroneck. "Water Quality Modeling of the Rock River for Wasteload Allocation Development." Wisconsin Department of Natural Resources. Madison, Wisconsin. April, 1982.

Fenske, B.A., J.W. Rogers, and J.F. Sullivan. Water Quality Modeling of the Upper Wisconsin River for Wasteload Allocation Development - Segment BC. Wisconsin Department of Natural Resources. Madison, Wisconsin. April, 1983.

Patterson, D.J. "Water Quality Modeling of the Lower Fox River for Wasteload Allocation Development." Wisconsin Department of Natural Resources. Madison, Wisconsin. January, 1980.

Wisconsin Department of Natural Resources. "QUAL III Water Quality Model Documentation." Water Quality Evaluation Section. Madison, Wisconsin. Revised November, 1979.

Wisconsin Department of Natural Resources. "QUAL*TTY.BODCURVE - Longterm BOD Analysis Program User's Manual." Water Quality Evaluation Section. Madison, Wisconsin. November, 1981.

APPENDIX B
LONGTERM BOD PROCEDURES AND ANALYSIS

The method referenced in this report for measuring longterm biochemical oxygen demand was developed at the Wisconsin State Laboratory of Hygiene. The procedure involves using an oversize BOD bottle (2120 ml) that is equipped with a normal BOD bottle flange and ground glass stopper. Figure B-1 shows a diagram of the special BOD bottle. A detailed list of the exact step by step procedure used by the laboratory are available from the Wisconsin State Laboratory of Hygiene, University of Wisconsin Center for Health Sciences, Environmental Science Section.

Analysis of Longterm BOD Data

The Wisconsin Department of Natural Resources has been using the results of longterm BOD tests in its water quality modeling of both large and small rivers across the state. This discussion summarizes the methods used to analyze the results of these longterm BOD tests.

During the test, DO in the bottle is measured every day or as necessary to assure the DO in the bottle does not drop too low before the next measurement. When the DO in the bottle is approximately 2 mg/l, the sample is aerated and the DO before and after aeration is recorded. These measurements yield the cumulative DO depletion for the sample.

The test is run at least until the estimated ultimate BOD (BODU) is relatively constant from one measurement to another. The BODU is estimated from the equation:

BODU = SAMPLE (t) + tX, where
BODU = estimated ultimate BOD in sample bottle
SAMPLE(t) = cumulative DO depletion in the sample bottle after t days
X = average change in DO in the sample bottle per day after time t

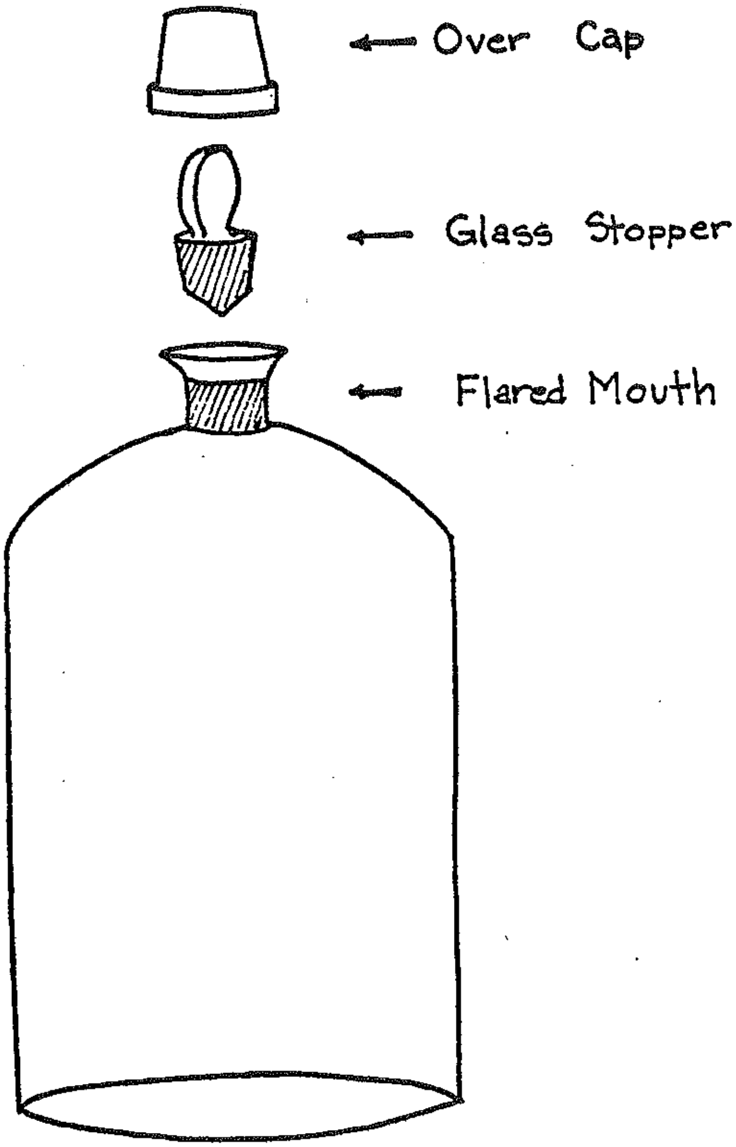
If previous tests have been done on the same effluent, the minimum time of the test can be estimated from these samples.

As a rule of thumb, most samples should be run more than 50 days, and samples that are highly treated which may have high ratios of ultimate to 5 day BOD should be run more than 100 days.

Calculating BOD

The DO depletion on the test bottle is due to carbonaceous BOD in the sample, the dilution water and the stream seed, and nitrification in the sample and dilution water. The depletion due to stream seed is very small, typically less than 0.1 mg/l. The depletion due to the dilution water is typically 0.6 mg/l after about 10 days and unchanged from then on. However, the total depletion in the dilution water can vary anywhere from about 0.2 to 3 mg/l.

FIGURE B-1



DIMENSIONS
Volume 2120 mL
Diameter 13 cm
Height 28 cm

The DO depletion in the blank bottle is due to BOD in the dilution water and the seed, and nitrogen added in the nutrients. Since the majority of the blank depletion is due to the dilution water, the blank correction is a function of the dilution of the sample. For the blank correction, the DO depletion without nitrification is used. To get this, the point at which nitrification starts in the blank must be determined. It is then assumed that the blank DO depletion remains constant from this point on. The correction for the nutrients in the blank is made automatically when the depletion due to the nutrients in the sample is subtracted.

Calculation of BOD in the sample after t days:

$$\text{BOD(t)} = \left[\text{SAMPLE (t)} - \left(1 - \frac{1}{\text{DIL}}\right)\text{Blank (t)}\right] * \text{DIL}$$

$$= \text{SAMPLE (t)} * \text{DIL} - (\text{DIL}-1) * \text{BLANK(t)}$$

Where DIL = dilution factor = $\frac{\text{Bottle Volume}}{\text{Sample Volume}}$

BLANK(t) = cumulative depletion in blank bottle after correcting for nitrification

The ammonia added to the blank and to the sample bottles is 0.42 mg/l which causes a DO depletion of 1.92 mg/l. If the assumption that most of the blank depletion is due to dilution water is wrong, the maximum error in BOD(t) due to this assumption will be BLANK(t).

Calculating NBOD

The nitrogenous BOD (NBOD) can be calculated in several ways as listed below. The NBOD is due to the oxidation of organic nitrogen and ammonia (Kjeldahl nitrogen) to nitrite and nitrate consuming 4.57 mg of oxygen per mg of nitrogen. The reaction sequence is:

$$\text{ON} \rightarrow NH_3 \rightarrow NO_2 \rightarrow NO_3$$

Nitrification in the sample bottle comes from nitrogen in the sample and ammonia added in the nutrients. Usually when nitrification occurs, all of the ammonia and 30% of the organic nitrogen are oxidized to nitrate.

The methods for determining NBOD are as follows:

1. NBOD = $[NO_3 * \text{DIL} - NO_3(\text{SAMPLE})] * 4.57$

   where NO_3 = mg/l nitrate in sample bottles at the end of the test.
   NO_3 (SAMPLE) = mg/l nitrate in the sample before dilution.

2. NBOD = [KN(SAMPLE) - KN * DIL + 0.42 * DIL] * 4.57

   where KN = kjeldahl nitrogen in the sample bottle at the end of the test. KN(SAMPLE) = mg/l kjeldahl nitrogen in the sample before dilution.

3. If no nutrient measurements are made after the test

   NBOD = [0.3 * ON(SAMPLE) + NH_3(SAMPLE) + 0.42 * DIL] * 4.57

   where ON(SAMPLE) = mg/l organic nitrogen in the sample before dilution.
   NH_3(SAMPLE) = mg/l ammonia in the sample before dilution.

4. Judgment from the BOD(t) curve as to when and how much nitrification has occurred. This is the least accurate method.

5. A modification of 4, where different amounts of NBOD are assumed and the value which results in the best statistical fit is used.

Finally, the CBOD(t) = BOD(t) - NBOD after nitrification has occurred and CBOD(t) = BOD(t) before nitrification.

Determination of Ultimate BOD

We assume that the CBOD(t) curve can be represented as the sum of two BOD curves which decay exponetially to an ultimate oxygen demand.

CBOD(t) = BODU1 [1-EXP(-K11*T)] + BODU2 [1-EXP(-K12*T)]

BODU1 = ultimate oxygen uptake for the first term;
K11 = decay rate for the first term;
BODU2 = ultimate oxygen uptake for the second term;
K12 = decay rate for the second term;
T = time in days

A. Graphical Determination of Ultimate BOD

If the two decay rates K11 and K12 are significantly different (perhaps K11 $<$ 3*K12) then:

$$BOD(\infty) = BOD(T) + TX \ldots\ldots\ldots\ldots (1)$$

where BOD (∞) = ultimate BOD (including NBOD)
X = the slope of the BOD(t) curve at time T (change in BOD per day)
T = 1/K12

or

$$BOD(\infty) = BOD(T) + \frac{TX}{2} \ldots\ldots\ldots\ldots (2)$$

where T = 2/K12.

Equations 1 and 2 can be used to estimate BOD if the CBOD(t) curve can be represented by the two term equation above. Equation 1 will not over estimate the true ultimate by more than 14%. Equation 2 will not over estimate the true value by more than 2%. For most samples, these estimates will be much closer.

As a rule of thumb, K11 is usually about 0.2 and K12 is usually about 0.02. Therefore,

$$\text{BOD }(\infty) = \text{BOO}(50) + 50*X \qquad X = \text{slope at 50 days}$$

$$\text{BOD }(\infty) = \text{BOD}(100) + \frac{100*X}{2} \qquad X = \text{slope at 100 days}$$

Effluents which have particularly high ratios of ultimate to 5 day BOD may have K12 = 0.01.

These equations for estimating ultimate BOD work well for graphical analysis if the test is run for $T \approx 1/K12$. The term TX is the difference between BOD(T) and intercept of a line tangent to the BOD curve at time T and the BOD axis of a plot of BOD(t).

The amount of BOD due to faster decaying compounds can be approximately estimated by finding where a tangent line to the BOD curve at 30 days meets the BOD axis.

The ultimate BOD of the sample then is:

$$\text{BODU} = \text{BOD}(\infty) - \text{NBOD}$$

B. Statistical Determination of BODU

The ultimate BOD of a sample can also be estimated by a DNR designed computer program using nonlinear least squares to get the best statistical fit of BODU1, K11, BODU2 and K12 for the measurement of CBOD(t).

In order to use the program one needs information on when nitrification begins and ends and the value of NBOD. The program then calculates CBOD(t) from BOD(t) and converges to a best fit.

The output from the program includes the final parameters with estimated errors and a plot of residuals to evaluate how well the program was able to fit the data.

The value of ultimate BOD, the ratio of ultimate to 5 day BOD for the fitted curve and the fraction of BOD in the slow and fast term come directly from the output.

Inhibited BODs

When the longterm BODs are inhibited, the analyses above are the same except the inhibitor is added to both the sample and the blank bottle. In both cases the NBOD can be ignored.

Problems in the Test

Some problems which make the test results difficult to interpret are listed below.

a. Sampling error, lab error, time lag between sampling and the beginning of the test.

b. Nitrogen does not balance. Some samples seem to lose nitrogen during the test. However, the analysis will be different if ammonia or nitrate is lost.

c. Often the nitrification portion of the curve has two humps. The first and bigger one corresponds to ammonia oxidizing to nitrite and the second is nitrite oxidizing to nitrate.

d. Oxygen consumption in the bottle may lag by a day or two.

e. The test may not be run long enough to get a good value for ultimate BOD.

f. Some samples have curves which do not appear to be first order exponential decay curves. While very generally these curves follow the model proposed, the sample may decrease its oxygen consumption for a while, then increase again.

g. The inhibitor, if used, may breakdown or appear to stop working between 50 and 100 days.

h. A small number of curves fit no general pattern.

Adequacy of the Test

If the BOD curve is generally understandable, one additional criterium, the depletion in the bottle, must be used to assess the value of the test.

In general, the greater the cumulative depletion in the sample bottle, not counting nitrification, the more accurate the results. However, if the sample is not diluted enough, it is likely to go anaerobic between readings, and it will need aeration more often. Since the effects of more frequent aeration in the sample bottle on the calculation of ultimate BOD is not known, these situations should be avoided.

Calculation of BODU/BOD$_5$

It is often necessary to estimate the ultimate BOD from reported BOD$_5$ values using the ratio of BODU to BOD$_5$. BODU can be determined from the longterm BOD test. The value of BOD$_5$ can come from several sources. With a sample from a papermill, for example, the BOD$_5$ value might be: 1) the BOD$_5$ from a split sample measured by the mill, 2) BOD$_5$ measured in the state lab, 3) BOD after 5 days in the longterm bottle, 4) BOD$_5$ from an equation fit to the data, or 5) BOD$_5$ reported on a discharge monitoring report for the time the sample was collected. These are listed approximately on their preferred order. Often judgment is needed to decide what is the best value of BOD$_5$ or BODU when calculating BODU/BOD$_5$.

Analysis and Calculation of Ultimate BOD

(An Example)

As an example of how longterm BOD data are analyzed, a step by step procedure follows for one sample. Note, however, this was an ideal sample and the test ran well with no complications.

-The Test-

The sample comes to the lab and the estimated five day BOD of the sample is 20. The sample volume used in the longterm test is:

$$\frac{15{,}000}{20} = 750 \text{ ml}$$

The dilution factor (DIL) for the sample is:

$$\frac{\text{bottle volume}}{\text{sample volume}} = \frac{2{,}120}{750} = 2.826666.. \text{ or } 2.83$$

750 ml of sample is added to the test bottle. Stream seed, nutrient solutions, and distilled water are then added to fill the bottle. A blank is also started with the seed, nutrients and distilled water but no sample.

DO measurements are taken on the sample and blank each day and recorded.

From previous samples of this effluent we know that the test must be run at least 50 days. In this example, the test is run for 114 days. After the first 30 days, the DO in the bottle is measured only once per week.

The tests of the sample show 1.0 mg/l organic nitrogen, 2.00 mg/l ammonia (or 3.0 mg/l Kjeldahl nitrogen), and 0.06 mg/l nitrite plus nitrate.

At the end of the longterm BOD test, the nutrients in the bottled are measured to be 0.2 mg/l organic nitrogen, 0.02 mg/l ammonia, and 1.25 mg/l nitrite plus nitrate.

Calculating BOD

The cumulative DO depletion in the blank bottle is 0.7 mg/l on day 13 before nitrification appears to have started. It is, therefore, assumed that without nitrification the blank depletion would have remained at 0.7 mg/l for the remainder of the test. This level is shown on the plot of the blank. (Figure B-2).

The BOD of the sample can now be calculated from the depletion of the sample and the blank for each day.

The BOD at day t can be calculated using BOD(t) = SAMPLE(t) * 2.83 - BLANK(t) * 1.83 where 2.83 = the dilution factor (DIL) and 1.83 = DIL-1. The plot of the corrected BOD is shown in Figure B-3.

Calculating Nitrification

The NBOD in the sample can be calculated several ways:

1. By measurement of the graph of BOD - For this sample the beginning and end of nitrification are fairly clear. Drawing two parallel lines tangent to the BOD curve before and after nitrification occurs, the approximate NBOD is the vertical distance between the two lines, in this case 17 mg/l (see Figure B-3).

2. From the nitrate measurements - Usually the measurement of nitrite plus nitrate measures mostly nitrate. (Assume it is all nitrate.)

$$\begin{aligned} NBOD &= (1.25 * 2.83 - 0.06) * 4.57 \\ &= 15.9 \end{aligned}$$

3. From the Kjeldahl nitrogen (ammonia plus organic nitrogen):

$$\begin{aligned} NBOD &= (3.0 - 0.21 * 2.83 + 0.42 * 2.83) * 4.57 \\ &= 16.4 \end{aligned}$$

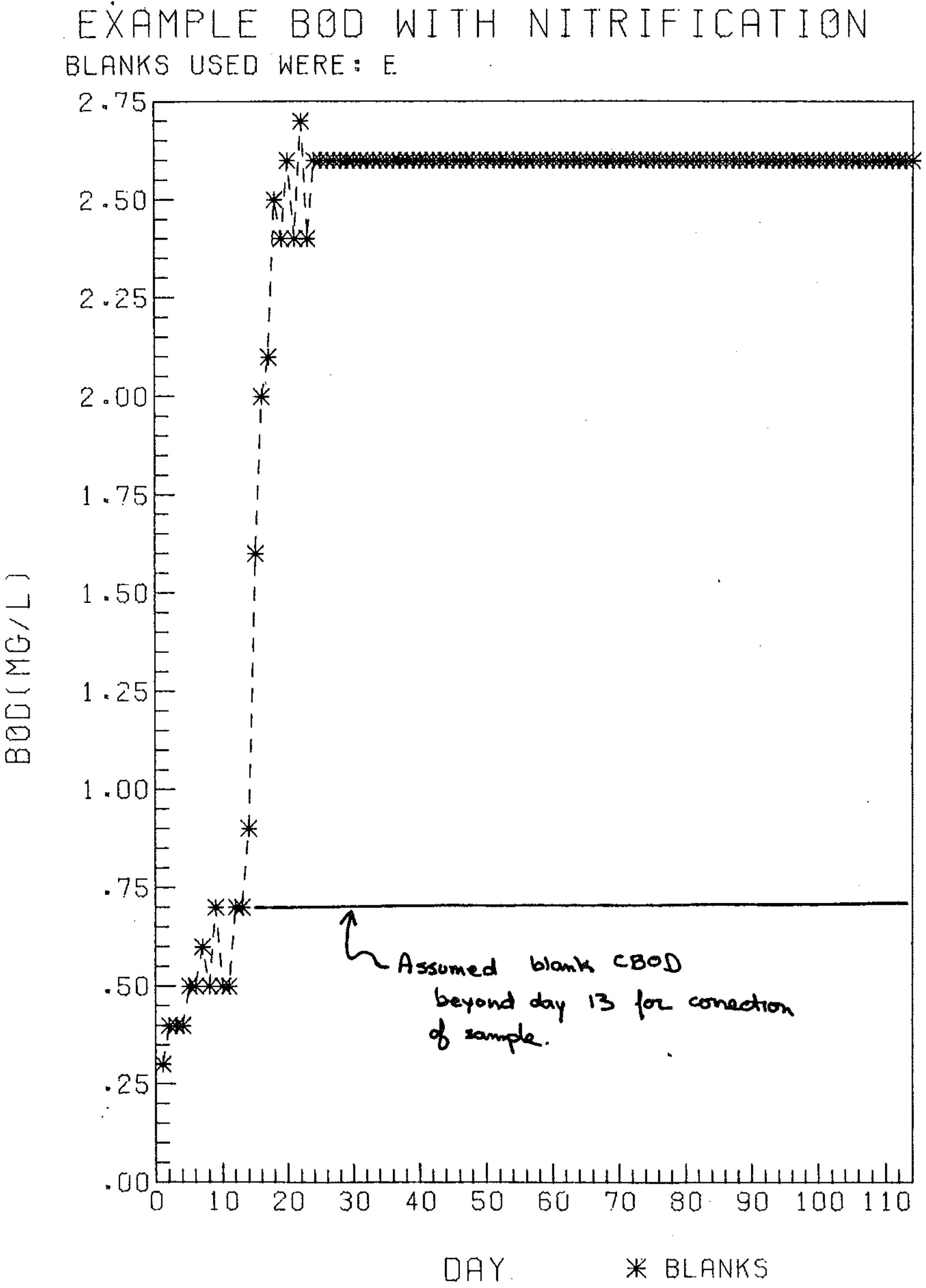
4. Ignoring the final nutrient measurements and assuming 30% of the organic nitrogen is oxidized:

$$\begin{aligned} NBOD &= (0.3 * 1.0 + 2.00 + 0.42 * 2.83) * 4.57 \\ &= 15.94 \end{aligned}$$

5. If an inhibited sample is run, the difference between the total BOD and inhibited BOD at the end of the test can be used.

Since the nitrogen measurements are consistent (i.e., decrease in KN (1.27) = increase in nitrate (1.23) within the accuracy of measurement) I will use them as a basis for defining the NBOD. Since the nitrate measurements are more accurate, the 15.9 from method (2) is suspected as more accurate than 16.4 from method (3). For the following calculation NBOD = 16 mg/l.

Figure B-2

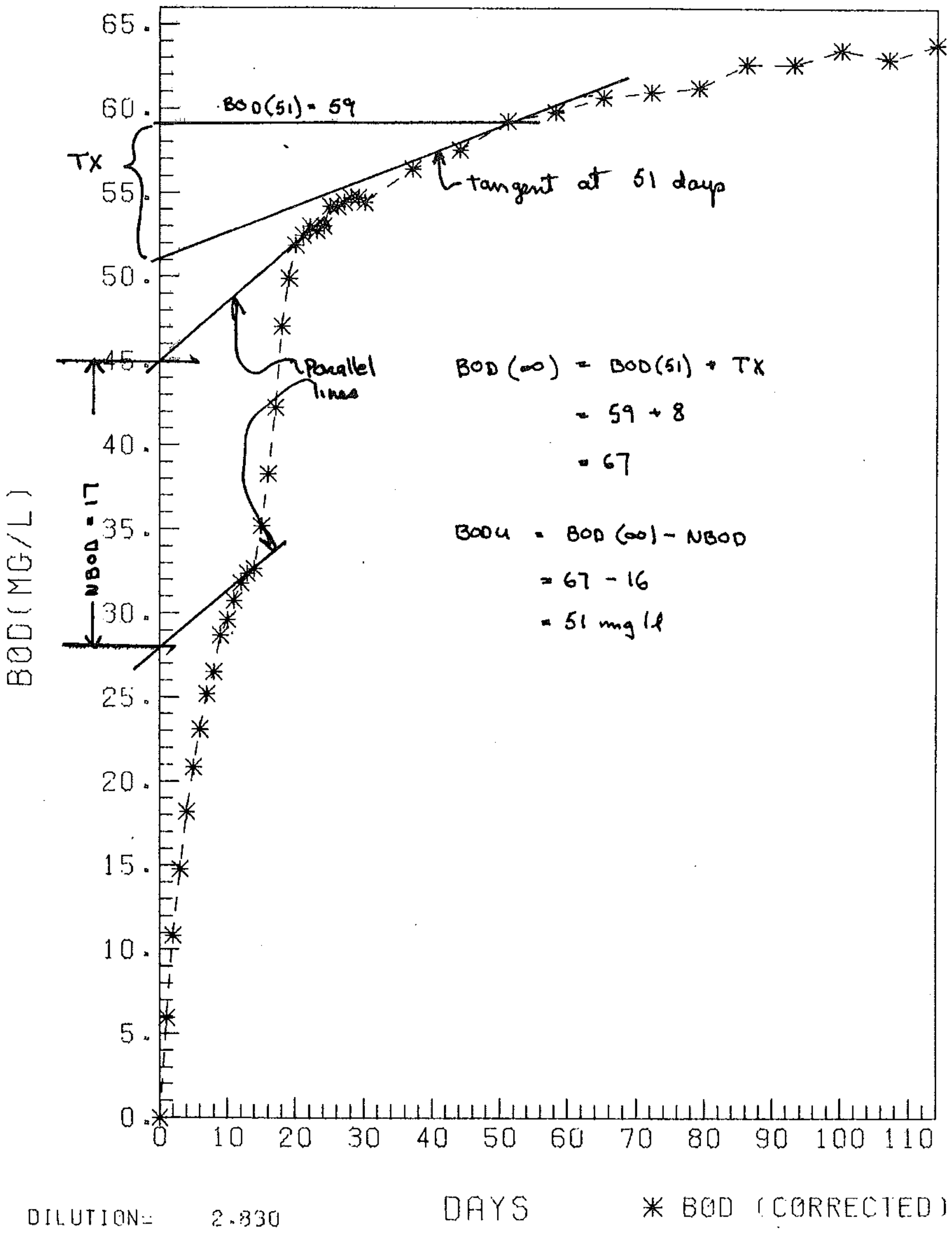


Assumed blank CBOD beyond day 13 for correction of sample.

Figure B-3

EXAMPLE BOD WITH NITRIFICATION

BLANKS USED WERE: E



BOD (∞) = BOD(51) + TX
= 59 + 8
= 67

BODu = BOD (∞) − NBOD
= 67 − 16
= 51 mg/l

Calculating Ultimate BOD

The ultimate BOD in the sample can be calculated from the graph or statistically.

(a) For the graphical method (Figure B-4), a tangent line to the BOD curve is extended to the BOD axis. The difference between the BOD where the axis and the tangent intersect, and the BOD of the curve at the tangent point equals TX, the product of the slope at the tangent point and the number of days to that point. Two examples are shown, for 51 days and 100 days. Using the rule of thumb:

at 51 days $\mathrm{BODU}(\infty) = \mathrm{BOD} + \mathrm{TX}$
or $\mathrm{BODU}(\infty) = 67.0$
at 100 days $\mathrm{BODU}(\infty) = \mathrm{BOD} + \frac{\mathrm{TX}}{2}$

or $\mathrm{BODU}(\infty) = 66.2$

The carbonaceous BODU is calculated by subtracting the NBOD from the total ultimate BOD.

The amount of BOD due to the faster decaying compounds can be estimated by drawing a line tangent to the BOD curve at about 30 days. The point where it intersects the BOD axis gives the appropriate value. For this sample about 47 mg/l BOD is due to faster decaying compounds of which about 16 mg/l is NBOD.

(b) Statistical fit - One can also use a program which uses nonlinear least squares to fit two BOD terms to the data. The following equation is used in the fit.

BOD (T) = BODU1 * (1-EXP(-K11 * T)) + BODU2 * (1-EXP(-K12 * T))

The program needs information on where nitrification begins and ends, NBOD, and initial estimates of the parameters from which it converges to a solution. Using this program, where nitrification occurs between day 15 and day 19 and NBOD is 15.9, the fitted values are:

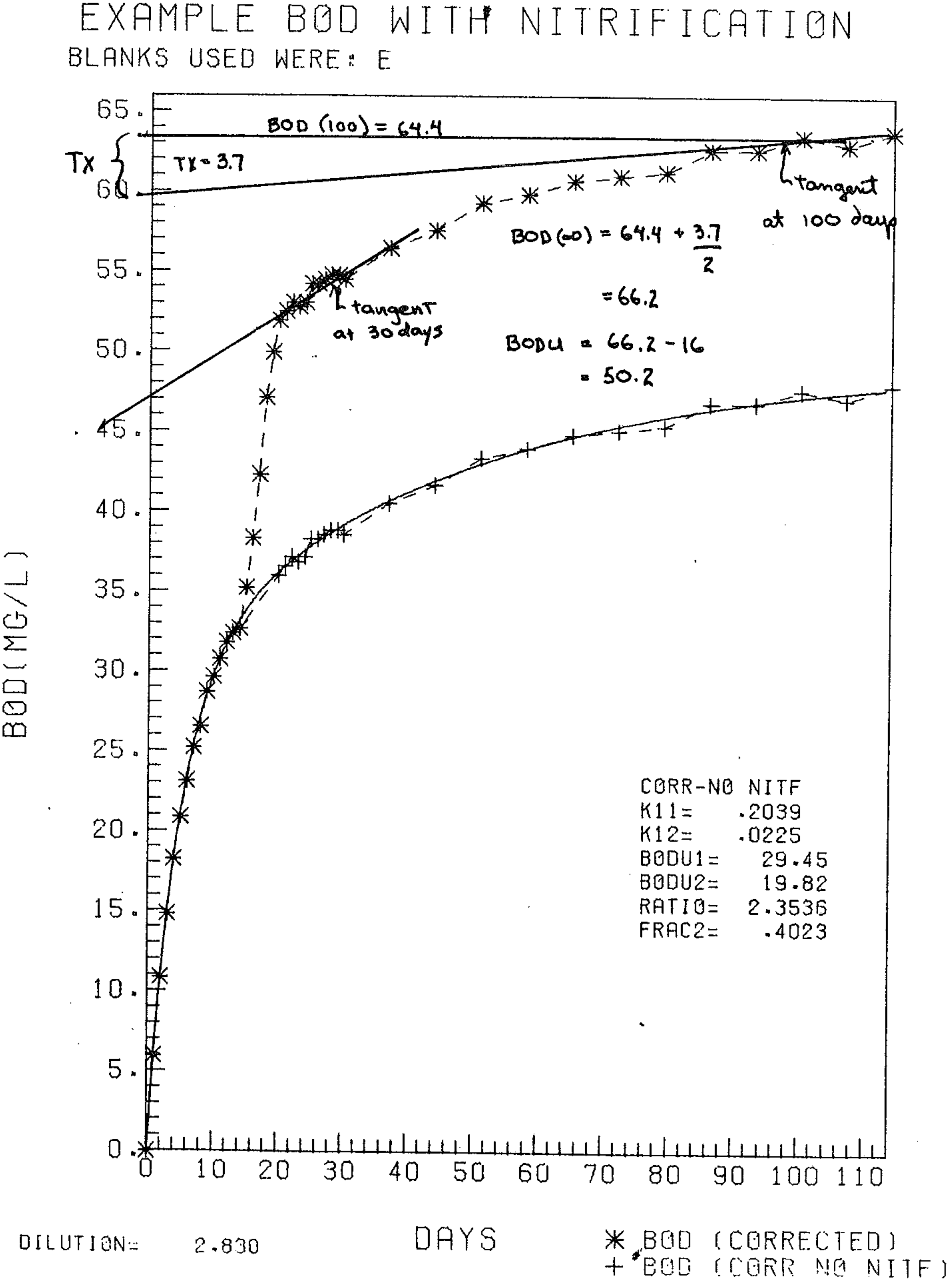
BODU1 = 29.5 ± 1.2
K22 = 0.20 ± 0.01
BODU2 = 19.8 ± 0.7
K12 = 0.022 ± 0.033
BODU = 49.3
FRACTION of BOD in slow term = 0.40

The plot of the data - NBOD and the fitted curve follows

If only data from the first 51 days is used, the fitted values are:

BODU1 = 29.9 ± 2.7
BODU2 = 21.3 ± 6.1
BODU = 51.2

Figure B-4


EXAMPLE BOD WITH NITRIFICATION
BLANKS USED WERE: E
BOD (100) = 64.4
Tx
TX = 3.7
tangent at 100 days
BOD(60) = 64.4 + 3.7/2
= 66.2
tangent at 30 days
BODu = 66.2 - 16
= 50.2
CORR-NO NITF
K11= .2039
K12= .0225
BODU1= 29.45
BODU2= 19.82
RATIO= 2.3536
FRAC2= .4023
BOD(MG/L)
0. 5. 10. 15. 20. 25. 30. 35. 40. 45. 50. 55. 60. 65.
0 10 20 30 40 50 60 70 80 90 100 110
DAYS
DILUTION= 2.830
✳ BOD (CORRECTED)
+ BOD (CORR NO NITF)

Determination of $BODU/BOD_5$

From the statistical and graphical analysis, BODU appears to be between 49 and 51. Assume that BODU = 50.

Assume the measured BOD_5 of the sample was 20 as determined in the five day BOD test.

Then $$\frac{BODU}{BOD_5} = \frac{50}{20} = 2.50$$

For the statistically fitted curve the ratio was 2.35.

More about the Sample

The sample which was analyzed here was a theoretical curve with:

$BODU1 = 30.$ $K11 = 0.20$
$BODU2 = 20.$ $K12 = 0.02$
$\frac{BODU}{BOD_5} = 2.50$ and $NBOD = 15.94$

This analysis demonstrates typical accuracy of a BOD test in which everything works well. The curve was meant to portray a typical situation.

Appendix C

This appendix is supplementary to the document "Water Quality Modeling of the Upper Wisconsin River for Wasteload Allocation Development - Water Quality Data." While synoptic survey data is contained on that report, there was additional data that can be used in the verification of the QUAL III model for Segment D that was not contained in that report. This data is from August 1980. Additional data was collected in July 1981 to be further used in quantifying diurnal dissolved oxygen variations during warm weather. The additional data available was collected by a Montodoro Whitney DOR1B dissolved oxygen and temperature probe with an Esterline-Angus Model 602 recorder (August 1980) or a continuous strip chart recording YSI 56 dissolved oxygen and temperature monitor (July 1981) at two locations. One location was the inlet to Lake Petenwell (rivermile 188.5) which is near the downstream dissolved oxygen sag point occurring at the inlet to Lake Petenwell. A second location is near the Nekoosa STP (rivermile 192.2). Calibration notes are contained in Table C-1. The uncorrected data are given in Tables C-2 and C-3. The corrected values are the uncorrected measurements with a linear adjustment made during the course of the survey.

Table C-1

Calibration Notes for 1980 and 1981 Continuous DO Monitoring

Date	Time	DO Calibration Drift (mg/l)	Comments
8/18/80	11:00	--	Probe set-up and calibrated
	15:15	0.0	
8/20/80	15:00	-1.0	Probe cleaned
8/21/80	11:00	0.0	
7/23/81	9:15	--	Probe set-up and calibrated
7/31/81	11:30	-0.3	

Table C-2
August 18-22, 1980 Dynamic Survey Field Data
Hourly Data - Near Nekoosa STP

Date	Time	Inst. DO** (mg/l)	Inst. Temp. (°C)
8/18	11:00	7.0	21.2
	12:00	7.0	21.6
	13:00	7.0	21.8
	14:00	7.4	21.9
	15:00	8.3	21.9
	16:00	8.1:8.1	21.7
	17:00	7.7:7.7	21.6
	18:00	7.4:7.5	21.5
	19:00	7.6:7.7	21.8
	20:00	7.6:7.7	21.9
	21:00	7.8:7.9	21.9
	22:00	7.8:7.9	22.0
	23:00	8.0:8.2	22.0
8/19	0:00	7.7:7.9	22.0
	1:00	7.2:7.4	21.9
	2:00	7.1:7.3	21.9
	3:00	7.0:7.3	21.9
	4:00	7.0:7.3	21.9
	5:00	6.9:7.2	21.8
	6:00	6,8:7.1	21.7
	7:00	7.0:7.3	21.6
	8:00	6.7:7.1	21.7
	9:00	7.3:7.7	22.0
	10:00	7.3:7.7	22.2
	11:00	7.3:7.7	22.6
	12:00	7.4:7.8	22.8
	13:00	7.2:7.7	22.8
	14:00	7.1:7.6	22.9
	15:00	6.4:6.9	22.9
	16:00	6.7:7.2	23.0
	17:00	7.3:7.8	22.9
	18:00	7.7:8.3	22.8
	19:00	7.5:8.1	22.9
	20:00	7.6:8.2	22.9
	21:00	7.5:8.1	22.9
	22:00	7.6:8.2	22.9
	23:00	7.2:7.9	22.9
8/20	0:00	7.0:7.7	22.8
	1:00	6.9:7.6	22.8
	2:00	6.8:7.5	22.9
	3:00	6.7:7.5	23.0
	4:00	6.6:7.4	22.9
	5:00	6.8:7.6	22.9
	6:00	6.5:7.3	22.8
	7:00	6.4:7.2	22.7
	8:00	6.3:7.2	22.6
	9:00	6.4:7.3	22.6
	10:00	*	*
	11:00	*	*
	12:00	*	*
	13:00	*	*
	14:00	*	*
	15:00	6.0	24.5
	16:00	*	24.8
	17:00	*	25.0
	18:00	6.9	25.0
	19:00	6.6	25.0
	20:00	6.6	24.8
	21:00	6.3	24.4
	22:00	6.3	24.1
	23:00	6.3	24.2

* Pen failed to mark on paper.
**Value to right of colon is corrected reading.

Table C-2 (continued)
August 18-22, 1980 Dynamic Survey Field Data
Hourly Data - Near Nekoosa STP

Date	Time	Inst. DO (mg/l)	Inst. Temp. (°C)	Date	Time	Inst. DO (mg/l)	Inst. Temp. (mg/l)
8/21	0:00	6.2	24.2		18:00	7.7	24.6
	1:00	6.0	24.1		19:00	7.4	24.6
	2:00	5.8	24.0		20:00	7.6	24.5
	3:00	5.6	24.0		21:00	7.4	24.5
	4:00	5.6	24.0		22:00	7.6	24.5
	5:00	5.5	24.0		23:00	7.4	24.3
	6:00	5.4	23.8	8/22	0:00	7.2	24.3
	7:00	5.3	23.7		1:00	*	24.2
	8:00	5.5	23.7		2:00	*	24.1
	9:00	5.7	23.7		3:00	*	24.0
	10:00	5.8	23.9		4:00	*	24.0
	11:00	5.9	24.0		5:00	*	23.9
	12:00	7.6	24.2		6:00	*	23.8
	13:00	7.7	24.2		7:00	*	23.7
	14:00	7.7	24.3		8:00	*	23.7
	15:00	7.8	24.3		9:00	*	23.7
	16:00	7.8	24.4		10:00	*	23.7
	17:00	7.8	24.6		11:00	*	23.7

*DO probe failed.

Table C-3
July 23-31, 1981 Diurnal Survey Field Data
Hourly Data - Inlet to Lake Petenwell

Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)	Date	Time	Inst. DO* (mg/l)	Inst. Temp. (mg/l)
7/23	10:00	7.9:7.9	24.5		17:00	9.6:9.6	25.5
	11:00	8.0:8.0	24.5		18:00	9.7:9.7	25.5
	12:00	8.1:8.1	24.5		19:00	9.6:9.6	25.5
	13:00	8.2:8.2	25.0		20:00	9.5:9.5	25.0
	14:00	8.1:8.1	24.5		21:00	9.0:9.0	25.0
	15:00	8.0:8.0	24.5		22:00	8.9:8.9	25.0
	16:00	8.3:8.3	24.5		23:00	8.8:8.9	25.0
	17:00	8.7:8.7	24.5	7/25	0:00	8.6:8.7	25.0
	18:00	8.9:8.9	24.5		1:00	8.5:8.6	25.0
	19:00	8.8:8.8	24.5		2:00	8.3:8.4	25.0
	20:00	8.5:8.5	24.5		3:00	8.2:8.3	24.5
	21:00	8.4:8.4	24.5		4:00	8.0:8.1	24.5
	22:00	8.2:8.2	24.5		5:00	7.8:7.9	24.5
	23:00	8.0:8.0	24.0		6:00	7.7:7.8	24.5
7/24	0:00	7.9:7.9	24.0		7:00	7.6:7.7	24.5
	1:00	7.8:7.8	24.0		8:00	7.7:7.8	24.5
	2:00	7.8:7.8	24.0		9:00	7.8:7.9	24.5
	3:00	7.7:7.7	24.0		10:00	7.8:7.9	24.5
	4:00	7.6:7.6	24.0		11:00	8.1:8.2	24.5
	5:00	7.5:7.5	24.0		12:00	8.5:8.6	25.0
	6:00	7.4:7.4	24.0		13:00	8.6:8.7	25.0
	7:00	7.4:7.4	24.0		14:00	8.6:8.7	25.5
	8:00	7.4:7.4	24.0		15:00	8.6:8.7	25.0
	9:00	7.5:7.5	24.0		16:00	9.0:9.1	25.5
	10:00	7.7:7.7	24.0		17:00	9.0:9.1	25.5
	11:00	8.0:8.0	24.5		18:00	9.2:9.3	25.5
	12:00	8.5:8.5	25.0		19:00	9.3:9.4	25.5
	13:00	8.9:8.9	25.0		20:00	8.8:8.9	25.0
	14:00	9.1:9.1	25.0		21:00	8.7:8.8	25.0
	15:00	9.2:9.2	25.0		22:00	8.7:8.8	25.0
	16:00	9.4:9.4	25.0		23:00	8.7:8.8	25.0

*Value to right of colon is corrected reading.

Table C-3 (continued)
July 23-31, 1981 Diurnal Survey Field Data
Hourly Data - Inlet to Lake Petenwell

Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)	Date	Time	Inst. DO* (mg/l)	Inst. Temp. (mg/l)
7/26	0:00	8.5:8.6	25.0		12:00	8.8:8.9	23.0
	1:00	8.4:8.5	25.0		13:00	8.9:9.0	23.0
	2:00	8.4:8.5	25.0		14:00	9.1:9.2	23.0
	3:00	8.2:8.3	25.0		15:00	9.1:9.2	23.0
	4:00	8.1:8.2	24.5		16:00	9.0:9.1	23.0
	5:00	8.0:8.1	24.5		17:00	9.3:9.4	23.0
	6:00	8.0:8.1	24.5		18:00	9.3:9.4	23.0
	7:00	7.8:7.9	24.5		19:00	9.3:9.4	23.0
	8:00	7.7:7.8	24.5		20:00	9.2:9.3	23.0
	9:00	7.8:7.9	24.5		21:00	9.1:9.2	23.0
	10:00	8.1:8.2	24.0		22:00	9.1:9.2	23.0
	11:00	8.1:8.2	24.0		23:00	9.0:9.1	22.5
	12:00	8.2:8.3	24.0	7/28	0:00	8.8:9.0	22.5
	13:00	8.2:8.3	24.0		1:00	8.7:8.9	22.5
	14:00	8.5:8.6	24.0		2:00	8.6:8.8	22.5
	15:00	8.6:8.7	24.0		3:00	8.5:8.7	22.5
	16:00	8.6:8.7	24.0		4:00	8.4:8.6	22.5
	17:00	9.0:9.1	24.0		5:00	8.3:8.5	22.5
	18:00	8.9:9.0	24.0		6:00	8.2:8.4	22.5
	19:00	8.8:8.9	24.0		7:00	8.1:8.3	22.0
	20:00	9.0:9.1	24.0		8:00	8.0:8.2	22.0
	21:00	9.1:9.2	24.0		9:00	8.1:8.3	22.0
	22:00	9.1:9.2	24.0		10:00	8.2:8.4	22.0
	23:00	8.9:9.0	23.5		11:00	8.2:8.4	22.0
7/27	0:00	8.7:8.8	23.5		12:00	8.5:8.7	22.0
	1:00	8.6:8.7	23.5		13:00	8.6:8.8	22.0
	2:00	8.5:8.6	23.5		14:00	8.9:9.1	22.0
	3:00	8.4:8.5	23.0		15:00	9.0:9.2	22.5
	4:00	8.2:8.3	23.0		16:00	9.5:9.7	23.0
	5:00	8.1:8.2	23.0		17:00	9.7:9.9	23.0
	6:00	8.0:8.1	23.0		18:00	9.4:9.6	23.0
	7:00	7.9:8.0	23.0		19:00	9.7:9.9	23.0
	8:00	7.9:8.0	22.5		20:00	9.4:9.6	23.0
	9:00	7.9:8.0	22.5		21:00	9.0:9.2	22.5
	10:00	8.1:8.2	23.0		22:00	8.9:9.1	22.5
	11:00	8.5:8.6	23.0		23:00	9.1:9.3	22.5

*Value to right of colon is corrected reading.

Table C-3 (continued)
July 23-31, 1981 Diurnal Survey Field Data
Hourly Data - Inlet to Lake Petenwell

Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)
7/29	0:00	9.0: 9.2	22.5
	1:00	8.9: 9.1	22.5
	2:00	8.8: 9.0	22.5
	3:00	8.8: 9.0	22.5
	4:00	8.6: 8.8	22.5
	5:00	8.5: 8.7	22.0
	6:00	8.4: 8.6	22.0
	7:00	8.3: 8.5	22.0
	8:00	8.2: 8.4	22.0
	9:00	8.3: 8.5	22.5
	10:00	8.7: 8.9	23.0
	11:00	9.3: 9.5	22.5
	12:00	9.1: 9.3	22.5
	13:00	9.0: 9.2	23.0
	14:00	9.1: 9.3	23.0
	15:00	9.4: 9.6	23.0
	16:00	9.5: 9.7	23.0
	17:00	9.3: 9.5	23.0
	18:00	9.6: 9.8	24.0
	19:00	**: **	24.0
	20:00	**: **	24.0
	21:00	**: **	23.5
	22:00	**: **	23.5
	23:00	10.0:10.2	23.5
7/30	0:00	9.8:10.0	23.5
	1:00	9.7: 9.9	23.5
	2:00	9.6: 9.8	23.5
	3:00	9.5: 9.7	23.5
	4:00	9.3: 9.5	23.0
	5:00	9.1: 9.4	23.0
	6:00	9.0: 9.3	23.0
	7:00	9.0: 9.3	23.0
	8:00	8.8: 9.1	23.0
	9:00	8.9: 9.2	23.0
	10:00	9.0: 9.3	23.0
	11:00	8.9: 9.2	23.0
	12:00	8.7: 9.0	23.0
	13:00	8.8: 9.1	23.0
	14:00	9.1: 9.4	23.0
	15:00	9.7:10.0	23.5
	16:00	9.8:10.1	23.5
	17:00	9.6: 9.9	23.5
	18:00	**: **	24.0
	19:00	**: **	24.0
	20:00	**: **	24.0
	21:00	9.9:10.2	23.5
	22:00	9.6: 9.9	23.5
	23:00	9.3: 9.6	23.5
7/31	0:00	9.2: 9.5	23.0
	1:00	9.1: 9.4	23.0
	2:00	9.1: 9.4	23.0
	3:00	9.0: 9.3	23.0
	4:00	8.8: 9.1	23.0
	5:00	8.6: 8.9	22.5
	6:00	8.4: 8.7	22.5
	7:00	8.1: 8.4	22.5
	8:00	8.1: 8.4	22.5
	9:00	8.2: 8.5	22.5
	10:00	8.3: 8.6	22.5
	11:00	8.4: 8.7	22.5

* Value to right of colon is corrected reading.

**DO greater than 10 mg/l. Scale set on 0-10 mg/l and pen went off the chart.

Appendix D

The following tables present the coefficients used for the calibration, verification, sensitivity analysis and prediction runs using the QUAL III model for Segment D of the Wisconsin River. Some of the rate coefficients are constant for the entire segment, while others are variable by reach (even if the same as adjacent reaches). Still other coefficients are varied by time to reflect different waste characteristics, indicative of improved treatment. The constant rate coefficients are given in Table D-1. Table D-3 contains the settings of the reach variable rate coefficients. Table D-4 has the time variable coefficients. A listing of the reach mileages is given in Table D-2 for use in identifying reaches in Table D-3. In addition to the reach mileage, a reach name is also given to aid in identification. Reaeration equation identification is as follows: 1-read in values of K_2, 2-Churchill, 3-O'Connor and Dobbins, 4-Owens and Gibbs, 5-Thackston and Krenkel, 6-Langbien and Durum, 7-use equation $K_2=aQ^b$, and 8-K_2 based on wind velocity. For further clarification of the reaeration equations see "QUAL III Water Quality Model Documentation" available from the Water Quality Evaluation Section.

Table D-1

Rate Coefficients that are fixed for Entire Segment D of the Wisconsin River

Oxygen Uptake by Ammonia Nitrification = 3.43 mg/O_2/mg N
Oxygen Uptake by Nitrite Nitrification = 1.14 mg O_2/mg N
Maximum Denitrification Rate = 0.40 1/day
Fixed Portion of Organic Nitrogen Hydrolysis Rate = 0.00 1/day
Oxygen Production by Algae Growth = 1.60 mg O_2/mg algae
Oxygen Uptake by Algae Respiration = 1.50 mg O_2/mg algae
Nitrogen Content of Algae = 0.09 mg N/mg algae
Phosphorus Content of Algae = 0.012 mg P/mg algae
Nitrogen Half-Saturation Constant = 0.02 mg/l
Phosphorus Half-Saturation Constant = 0.010 mg/l
Fraction of Settled Algae Biomass that Decays for Oxygen Consumption = 0.56
Saturating Light Level for Algae Growth = 0.55 langleys/minute
Fraction of Settled BOD that Decays with Oxygen Consumption = 0.02
Organic Nitrogen Decay that is Independent of Chlorophyll - A = 0.01

Table D-2
Reach Identification for Segment D of the Wisconsin River

Number	Name	Upstream Mile Point	Downstream Mile Point
1	Biron Flowage I	208.9	208.1
2	Biron Flowage II	208.1	207.0
3	Biron Flowage III	207.0	206.4
4	Biron Flowage IV	206.4	205.3
5	Village of Biron	205.3	204.5
6	Big Island	204.5	202.8
7	Forest Hill Cemetery	202.8	202.2
8	CPI Dam - Wisconsin Rapids	202.2	201.9
9	Howe School	201.9	201.4
10	Belle Island	201.4	200.5
11	Garrison & Edwards Islands	200.5	199.3
12	Centralia Dam	199.3	199.2
13	Centralia Dam Tailrace	199.2	199.0
14	West of Airport	199.0	197.9
15	Port Edwards Dam Tailrace I	197.9	197.4
16	Port Edwards Dam Tailrace II	197.4	197.0
17	Nekoosa Junction	197.0	195.0
18	Riverside Park	195.0	194.0
19	Above NEPCO Dam	194.0	193.4
20	Nekoosa	193.4	193.1
21	Cranberry Bog	193.1	191.1
22	East of Grass Lake	191.1	189.1
23	West of Ross Lake	189.1	187.1
24	Inlet to Lake Petenwell	187.1	186.0
25	Petenwell Flowage I	186.0	185.0
26	Petenwell Flowage II	185.0	184.4
27	Petenwell Flowage III	184.4	182.4
28	Petenwell Flowage IV	182.4	180.4
29	Petenwell Flowage V	180.4	179.6
30	Petenwell Flowage VI	179.6	177.6
31	Petenwell Flowage VII	177.6	175.6
32	Petenwell Flowage VIII	175.6	173.7
33	Petenwell Flowage IX	173.7	172.5
34	Petenwell Flowage X	172.5	172.0
35	Petenwell Flowage XI	172.0	171.9
36	Petenwell Rock	171.9	170.8
37	Strong's Prairie	170.8	169.7
38	Inlet to Castle Rock Flowage	169.7	167.7
39	Castle Rock Flowage I	167.7	166.6
40	Castle Rock Flowage II	166.6	165.5
41	Castle Rock Flowage III	165.5	163.5
42	Castle Rock Flowage IV	163.5	162.7
43	Castle Rock Flowage V	162.7	161.2
44	Castle Rock Flowage VI	161.2	159.2

Table D-3
Rate Coefficients that are Reach Variable for Segment D of the Wisconsin River

Reach	Algae Settling (ft/day)	ORG-N Settling (ft/day)	ORG-N Recycle Algae Dep.	Recreation Formula Used	Maximum Algae Growth Rate (1/day)	Algae Respiration Rate (1/day)
1	0.05	0.05	0.0030	8	2.40	0.30
2	0.05	0.05	0.0030	8	2.40	0.25
3	0.05	0.05	0.0030	8	2.40	0.15
4	0.05	0.05	0.0030	8	2.40	0.12
5	0.05	0.05	0.0030	3	2.40	0.30
6	0.05	0.05	0.0030	3	2.40	0.30
7	0.05	0.05	0.0030	3	2.40	0.30
8	0.05	0.05	0.0030	3	2.40	0.30
9	0.05	0.05	0.0060	3	2.40	0.30
10	0.05	0.05	0.0060	3	2.40	0.30
11	0.05	0.05	0.0060	3	2.40	0.30
12	0.05	0.05	0.0060	3	2.40	0.30
13	0.05	0.05	0.0030	3	2.40	0.30
14	0.05	0.05	0.0030	3	2.40	0.30
15	0.05	0.05	0.0030	3	2.40	0.30
16	0.05	0.05	0.0030	3	2.40	0.22
17	0.05	0.05	0.0030	3	2.40	0.22
18	0.05	0.05	0.0030	3	2.40	0.22
19	0.05	0.05	0.0030	3	2.40	0.22
20	0.05	0.05	0.0030	3	2.40	0.22
21	0.05	0.05	0.0030	3	2.40	0.22
22	0.05	0.05	0.0030	3	2.40	0.22
23	0.05	0.05	0.0030	3	2.40	0.22
24	0.05	0.05	0.0030	3	2.40	0.15
25	0.05	0.05	0.0022	8	2.20	0.13
26	0.05	0.05	0.0022	8	2.20	0.13
27	0.05	0.05	0.0022	8	2.20	0.13
28	0.05	0.05	0.0022	8	1.25	0.10
29	0.05	0.05	0.0022	8	1.25	0.10
30	0.05	0.05	0.0022	8	1.25	0.10
31	0.05	0.05	0.0022	8	1.25	0.10
32	0.05	0.05	0.0022	8	1.25	0.10
33	0.05	0.05	0.0022	8	1.25	0.10
34	0.05	0.05	0.0022	8	1.25	0.10
35	0.05	0.05	0.0022	8	1.25	0.10
36	0.05	0.05	0.0022	3	2.40	0.18
37	0.05	0.05	0.0022	3	2.40	0.18
38	0.05	0.05	0.0022	3	2.40	0.18
39	0.05	0.05	0.0022	3	2.40	0.18
40	0.05	0.05	0.0022	8	2.40	0.18
41	0.05	0.05	0.0022	8	2.40	0.18
42	0.05	0.05	0.0022	8	2.40	0.18
43	0.05	0.05	0.0022	8	2.40	0.18
44	0.05	0.05	0.0022	8	2.40	0.18

Table D-3 (continued)
Rate Coefficients that are Reach Variable for Segment D of the Wisconsin River

Reach	CHL-A Algae (ug/mg)	NO2-N Decay (1/day)	Sediment Source for NH3-N (mg/M^2/day)	Sediment Source for PO4-P (mg/M^2/day)	Background Sediment Oxygen Demand (mg/m^2/day)
1	6.50	2.50	0	0	0.0
2	6.50	2.50	0	0	0.0
3	6.50	2.50	0	0	0.0
4	6.50	2.50	0	0	0.0
5	6.50	2.50	0	0	0.0
6	6.50	2.50	0	0	0.0
7	6.50	2.50	0	0	0.0
8	6.50	2.50	0	0	0.0
9	6.50	2.50	0	0	0.0
10	6.50	2.50	0	0	0.0
11	6.50	2.50	0	0	0.0
12	6.50	2.50	0	0	0.0
13	6.50	2.50	0	0	0.0
14	6.50	2.50	0	0	0.0
15	6.50	2.50	0	0	0.0
16	6.50	2.50	0	0	0.0
17	6.50	2.50	0	0	0.0
18	6.50	2.50	0	0	0.0
19	6.50	2.50	0	0	0.0
20	6.50	2.50	0	0	0.0
21	6.50	2.50	0	0	0.0
22	6.50	2.50	0	0	0.0
23	6.50	2.50	0	0	0.0
24	6.50	2.50	0	0	0.0
25	6.50	2.50	0	0	0.0
26	6.50	2.50	0	0	0.0
27	6.50	2.50	0	0	0.0
28	6.50	2.50	0	0	0.0
29	6.50	2.50	0	0	0.0
30	6.50	2.50	0	0	0.0
31	6.50	2.50	0	0	0.0
32	6.50	2.50	0	0	0.0
33	6.50	2.50	0	0	0.0
34	6.50	2.50	0	0	0.0
35	6.50	2.50	0	0	0.0
36	6.50	2.50	0	0	0.0
37	6.50	2.50	0	0	0.0
38	6.50	2.50	0	0	0.0
39	6.50	2.50	0	0	0.0
40	6.50	2.50	0	0	0.0
41	6.50	2.50	0	0	0.0
42	6.50	2.50	0	0	0.0
43	6.50	2.50	0	0	0.0
44	6.50	2.50	0	0	0.0

Table D-4
Rate Coefficients that are Time Variable for Segment D of the Wisconsin River 1973-1974

Reach	Fast Term BOD Decay (1/day)	Slow Term BOD Decay (1/day)	BOD Settling (ft/day)	Light Extinction Coef. (1/ft)	NH3-N Decay (1/day)
1	0.05	0.02	0.0	0.6	0.70
2	0.05	0.02	0.0	0.6	0.70
3	0.05	0.02	0.0	0.6	0.70
4	0.05	0.02	0.0	0.6	0.70
5	1.50	0.02	1.0	0.6	0.70
6	1.50	0.10	1.0	0.6	0.70
7	1.50	0.10	1.0	0.6	0.70
8	1.50	0.10	1.0	0.6	0.70
9	1.50	0.10	1.0	0.6	0.70
10	1.50	0.10	1.0	0.6	0.70
11	1.50	0.10	1.0	0.6	0.70
12	1.50	0.10	0.0	0.6	0.70
13	1.50	0.10	0.0	0.6	0.70
14	1.50	0.10	0.0	0.6	0.70
15	1.50	0.10	0.0	0.6	0.70
16	0.30	0.05	10.0	0.6	0.70
17	0.30	0.05	10.0	0.6	0.70
18	0.30	0.05	10.0	0.6	0.70
19	0.30	0.05	10.0	0.6	0.70
20	0.30	0.05	10.0	0.6	0.70
21	0.30	0.05	10.0	0.6	0.70
22	0.30	0.05	10.0	0.6	0.70
23	0.30	0.05	10.0	0.6	0.70
24	0.30	0.05	8.0	0.6	0.70
25	0.30	0.02	8.0	0.6	0.70
26	0.30	0.02	5.0	0.6	0.25
27	0.30	0.02	5.0	0.6	0.25
28	0.20	0.02	0.0	0.6	0.25
29	0.20	0.02	0.0	0.6	0.25
30	0.20	0.02	0.0	0.6	0.25
31	0.20	0.02	0.0	0.6	0.70
32	0.20	0.02	0.0	0.6	0.25
33	0.20	0.02	0.0	0.6	0.25
34	0.20	0.02	0.0	0.6	0.25
35	0.20	0.02	0.0	0.6	0.25
36	0.20	0.02	0.0	0.6	0.10
37	0.20	0.02	0.0	0.6	0.10
38	0.20	0.02	0.0	0.6	0.10
39	0.20	0.02	0.0	0.6	0.10
40	0.20	0.02	0.0	0.6	0.10
41	0.20	0.02	0.0	0.6	0.10
42	0.20	0.02	0.0	0.6	0.10
43	0.20	0.02	0.0	0.6	0.10
44	0.20	0.02	0.0	0.6	0.10

Table D-4 (continued)
Rate Coefficients that are Time Variable for Segment D of the Wisconsin River
1975

Reach	Fast Term BOD Decay (1/day)	Slow Term BOD Decay (1/day)	BOD Settling (ft/day)	Light Extinction Coef. (1/ft)	NH3-N Decay (1/day)
1	0.05	0.02	0.0	0.6	0.70
2	0.05	0.02	0.0	0.6	0.70
3	0.05	0.02	0.0	0.6	0.70
4	0.05	0.02	0.0	0.6	0.70
5	1.50	0.02	1.0	0.6	0.70
6	1.50	0.10	1.0	0.6	0.70
7	1.50	0.10	1.0	0.6	0.70
8	1.50	0.10	1.0	0.6	0.70
9	1.50	0.10	1.0	0.6	0.70
10	1.50	0.10	1.0	0.6	0.70
11	1.50	0.10	1.0	0.6	0.70
12	1.50	0.10	0.0	0.6	0.70
13	1.50	0.10	0.0	0.6	0.70
14	1.50	0.10	0.0	0.6	0.70
15	1.50	0.10	0.0	0.6	0.70
16	0.30	0.05	5.0	0.6	0.70
17	0.30	0.05	5.0	0.6	0.70
18	0.30	0.05	5.0	0.6	0.70
19	0.30	0.05	5.0	0.6	0.70
20	0.30	0.05	5.0	0.6	0.70
21	0.30	0.05	5.0	0.6	0.70
22	0.30	0.05	5.0	0.6	0.70
23	0.30	0.05	5.0	0.6	0.70
24	0.30	0.05	8.0	0.6	0.70
25	0.30	0.02	8.0	0.6	0.70
26	0.30	0.02	5.0	0.6	0.25
27	0.30	0.02	5.0	0.6	0.25
28	0.20	0.02	0.0	0.6	0.25
29	0.20	0.02	0.0	0.6	0.25
30	0.20	0.02	0.0	0.6	0.25
31	0.20	0.02	0.0	0.6	0.25
32	0.20	0.02	0.0	0.6	0.25
33	0.20	0.02	0.0	0.6	0.25
34	0.20	0.02	0.0	0.6	0.25
35	0.20	0.02	0.0	0.6	0.25
36	0.20	0.02	0.0	0.6	0.10
37	0.20	0.02	0.0	0.6	0.10
38	0.20	0.02	0.0	0.6	0.10
39	0.20	0.02	0.0	0.6	0.10
40	0.20	0.02	0.0	0.6	0.10
41	0.20	0.02	0.0	0.6	0.10
42	0.20	0.02	0.0	0.6	0.10
43	0.20	0.02	0.0	0.6	0.10
44	0.20	0.02	0.0	0.6	0.10

Table D-4 (continued)
Rate Coefficients that are Time Variable for Segment D of the Wisconsin River
Summer 1976

Reach	Fast Term BOD Decay (1/day)	Slow Term BOD Decay (1/day)	BOD Settling (ft/day)	Light Extinction Coef. (1/ft)	NH3-N Decay (1/day)
1	0.05	0.02	0.0	0.6	0.70
2	0.05	0.02	0.0	0.6	0.70
3	0.05	0.02	0.0	0.6	0.70
4	0.05	0.02	0.0	0.6	0.70
5	0.05	0.02	0.0	0.6	0.70
6	0.05	0.02	0.0	0.6	0.70
7	0.05	0.02	0.0	0.6	0.70
8	0.80	0.05	0.0	0.6	0.70
9	0.80	0.05	0.0	0.3	0.70
10	0.80	0.05	0.0	0.3	0.70
11	0.80	0.05	0.0	0.3	0.70
12	0.80	0.05	0.0	0.3	0.70
13	0.80	0.05	0.0	0.6	0.70
14	0.80	0.05	0.0	0.6	0.70
15	0.80	0.05	0.0	0.6	0.70
16	0.80	0.05	0.0	0.6	0.70
17	0.30	0.05	0.0	0.6	0.70
18	0.30	0.05	0.0	0.6	0.70
19	0.30	0.08	2.0	0.6	0.70
20	0.30	0.08	2.0	0.6	0.70
21	0.30	0.08	2.0	0.6	0.70
22	0.30	0.08	2.0	0.6	0.70
23	0.30	0.08	2.0	0.6	0.70
24	0.30	0.08	2.0	0.6	0.70
25	0.30	0.08	2.0	0.6	0.70
26	0.30	0.08	2.0	0.6	0.25
27	0.30	0.08	2.0	0.6	0.25
28	0.20	0.04	0.0	0.6	0.25
29	0.20	0.04	0.0	0.6	0.25
30	0.20	0.02	0.0	0.6	0.25
31	0.20	0.02	0.0	0.6	0.25
32	0.20	0.02	0.0	0.6	0.25
33	0.20	0.02	0.0	0.6	0.25
34	0.20	0.02	0.0	0.6	0.25
35	0.20	0.01	0.0	0.6	0.25
36	0.20	0.01	0.0	0.6	0.10
37	0.20	0.01	0.0	0.6	0.10
38	0.20	0.01	0.0	0.6	0.10
39	0.20	0.01	0.0	0.6	0.10
40	0.20	0.01	0.0	0.6	0.10
41	0.20	0.01	0.0	0.6	0.10
42	0.20	0.01	0.0	0.6	0.10
43	0.20	0.01	0.0	0.6	0.10
44	0.20	0.01	0.0	0.6	0.10

Table D-4 (continued)
Rate Coefficients that are Time Variable for Segment D of the Wisconsin River
Autumn 1976

Reach	Fast Term BOD Decay (1/day)	Slow Term BOD Decay (1/day)	BOD Settling (ft/day)	Light Extinction Coef. (1/ft)	NH3-N Decay (1/day)
1	0.05	0.02	0.0	0.6	0.30
2	0.05	0.02	0.0	0.6	0.30
3	0.05	0.02	0.0	0.6	0.30
4	0.05	0.02	0.0	0.6	0.30
5	0.05	0.02	0.0	0.6	0.30
6	0.05	0.02	0.0	0.6	0.30
7	0.05	0.02	0.0	0.6	0.30
8	0.80	0.05	0.0	0.6	0.30
9	0.80	0.05	0.0	0.3	0.30
10	0.80	0.05	0.0	0.3	0.30
11	0.80	0.05	0.0	0.3	0.30
12	0.80	0.05	0.0	0.3	0.30
13	0.80	0.05	0.0	0.6	0.30
14	0.80	0.05	0.0	0.6	0.30
15	0.80	0.05	0.0	0.6	0.30
16	0.20	0.05	0.0	0.6	0.30
17	0.20	0.05	0.0	0.6	0.30
18	0.20	0.05	0.0	0.6	0.30
19	0.20	0.05	2.0	0.6	0.30
20	0.20	0.05	2.0	0.6	0.30
21	0.20	0.05	2.0	0.6	0.30
22	0.20	0.05	2.0	0.6	0.30
23	0.20	0.05	2.0	0.6	0.30
24	0.20	0.05	2.0	0.6	0.30
25	0.20	0.05	2.0	0.6	0.30
26	0.20	0.05	2.0	0.6	0.30
27	0.20	0.05	2.0	0.6	0.30
28	0.20	0.04	0.0	0.6	0.30
29	0.20	0.04	0.0	0.6	0.30
30	0.20	0.02	0.0	0.6	0.30
31	0.20	0.02	0.0	0.6	0.30
32	0.20	0.02	0.0	0.6	0.30
33	0.20	0.02	0.0	0.6	0.30
34	0.20	0.02	0.0	0.6	0.30
35	0.20	0.01	0.0	0.6	0.10
36	0.20	0.01	0.0	0.6	0.10
37	0.20	0.01	0.0	0.6	0.10
38	0.20	0.01	0.0	0.6	0.10
39	0.20	0.01	0.0	0.6	0.10
40	0.20	0.01	0.0	0.6	0.10
41	0.20	0.01	0.0	0.6	0.10
42	0.20	0.01	0.0	0.6	0.10
43	0.20	0.01	0.0	0.6	0.10
44	0.20	0.01	0.0	0.6	0.10

Table D-4 (continued)
Rate Coefficients that are Time Variable for Segment D of the Wisconsin River
1977

Reach	Fast Term BOD Decay (1/day)	Slow Term BOD Decay (1/day)	BOD Settling (ft/day)	Light Extinction Coef. (1/ft)	NH3-N Decay (1/day)
1	0.05	0.02	0.0	0.45	0.70
2	0.05	0.02	0.0	0.45	0.70
3	0.05	0.02	0.0	0.45	0.70
4	0.05	0.02	0.0	0.45	0.70
5	0.05	0.02	0.0	0.45	0.70
6	0.05	0.02	0.0	0.45	0.70
7	0.05	0.02	0.0	0.45	0.70
8	0.80	0.05	0.0	0.45	0.70
9	0.80	0.05	0.0	0.45	0.70
10	0.80	0.05	0.0	0.45	0.70
11	0.80	0.05	0.0	0.45	0.70
12	0.80	0.05	0.0	0.45	0.70
13	0.80	0.05	0.0	0.60	0.70
14	0.80	0.05	0.0	0.60	0.70
15	0.80	0.05	0.0	0.60	0.70
16	0.80	0.05	0.0	0.60	0.70
17	0.30	0.05	0.0	0.60	0.70
18	0.30	0.08	0.0	0.60	0.70
19	0.30	0.08	1.0	0.60	0.70
20	0.30	0.08	1.0	0.60	0.70
21	0.30	0.08	1.0	0.60	0.70
22	0.30	0.08	1.0	0.60	0.70
23	0.30	0.08	1.0	0.60	0.70
24	0.30	0.08	1.0	0.60	0.70
25	0.30	0.08	1.0	0.60	0.70
26	0.30	0.08	1.0	0.60	0.25
27	0.30	0.08	1.0	0.60	0.25
28	0.20	0.04	0.0	0.60	0.25
29	0.20	0.04	0.0	0.60	0.25
30	0.20	0.02	0.0	0.60	0.25
31	0.20	0.02	0.0	0.60	0.25
32	0.20	0.02	0.0	0.60	0.25
33	0.20	0.02	0.0	0.60	0.25
34	0.20	0.02	0.0	0.60	0.25
35	0.20	0.01	0.0	0.60	0.25
36	0.20	0.01	0.0	0.60	0.10
37	0.20	0.01	0.0	0.60	0.10
38	0.20	0.01	0.0	0.60	0.10
39	0.20	0.01	0.0	0.60	0.10
40	0.20	0.01	0.0	0.60	0.10
41	0.20	0.01	0.0	0.60	0.10
42	0.20	0.01	0.0	0.60	0.10
43	0.20	0.01	0.0	0.60	0.10
44	0.20	0.01	0.0	0.60	0.10

Table D-4 (continued)
Rate Coefficients that are Time Variable for Segment D of the Wisconsin River 1978 - Wasteload Allocation

Reach	Fast Term BOD Decay (1/day)	Slow Term BOD Decay (1/day)	BOD Settling (ft/day)	Light Extinction Coef. (1/ft)	NH3-N Decay (1/day)
1	0.05	0.02	0.0	0.45	0.50
2	0.05	0.02	0.0	0.45	0.50
3	0.05	0.02	0.0	0.45	0.50
4	0.05	0.02	0.0	0.45	0.50
5	0.05	0.02	0.0	0.45	0.50
6	0.05	0.02	0.0	0.45	0.50
7	0.05	0.02	0.0	0.45	0.50
8	0.80	0.05	0.0	0.45	0.50
9	0.80	0.05	0.0	0.45	0.50
10	0.80	0.05	0.0	0.45	0.50
11	0.80	0.05	0.0	0.45	0.50
12	0.80	0.05	0.0	0.45	0.50
13	0.80	0.05	0.0	0.45	0.50
14	0.80	0.05	0.0	0.45	0.50
15	0.80	0.05	0.0	0.45	0.50
16	0.80	0.05	0.0	0.45	0.50
17	0.20	0.05	0.0	0.45	0.50
18	0.20	0.04	0.0	0.45	0.50
19	0.20	0.04	0.0	0.45	0.50
20	0.20	0.04	0.0	0.45	0.50
21	0.20	0.04	0.0	0.45	0.50
22	0.20	0.04	0.0	0.45	0.50
23	0.20	0.02	0.0	0.45	0.50
24	0.20	0.02	0.0	0.45	0.50
25	0.20	0.02	0.0	0.45	0.50
26	0.20	0.02	0.0	0.45	0.25
27	0.20	0.02	0.0	0.60	0.25
28	0.20	0.02	0.0	0.60	0.25
29	0.20	0.02	0.0	0.60	0.25
30	0.20	0.02	0.0	0.60	0.25
31	0.20	0.02	0.0	0.60	0.25
32	0.20	0.02	0.0	0.60	0.25
33	0.20	0.02	0.0	0.60	0.25
34	0.20	0.02	0.0	0.60	0.25
35	0.20	0.01	0.0	0.60	0.10
36	0.20	0.01	0.0	0.60	0.10
37	0.20	0.01	0.0	0.60	0.10
38	0.20	0.01	0.0	0.60	0.10
39	0.20	0.01	0.0	0.60	0.10
40	0.20	0.01	0.0	0.60	0.10
41	0.20	0.01	0.0	0.60	0.10
42	0.20	0.01	0.0	0.60	0.10
43	0.20	0.01	0.0	0.60	0.10
44	0.20	0.01	0.0	0.60	0.10

Appendix E

This appendix contains the results of the steady state calibration runs. For a discussion of these graphs refer to Chapter IV of the text. Each dissolved oxygen data set for a synoptic survey is shown with the corresponding steady state output of the QUAL III model. A statistical comparison between the observed daily average (as determined from time of day) survey data and calculated results is presented for the dissolved oxygen profiles in Table E-1. All plots have the model output represented by the solid line and the daily average survey data by the black circle.

Table E-1

Steady State Calibration Dissolved Oxygen Comparison

Survey Date	Differences (mg/l)	Mean Absolute Differences (mg/l)
July 9-10, 1973	*	*
August 14-15, 1973	0.10 ± 0.67	0.52 ± 0.42
July 18, 1974	*	*
August 17, 1975	0.10 ± 1.10	0.85 ± 0.64
August 16-18, 1976	0.36 ± 0.62	0.54 ± 0.46
October 10-12, 1976	-0.11 ± 0.36	0.29 ± 0.22
June 29-30, 1977	0.21 ± 1.11	0.56 ± 0.97
August 17-18, 1977	0.27 ± 0.97	0.76 ± 0.64

*Insufficient data from automatic monitors to adjust time of day dissolved oxygen measurements to daily average values.

Figure E-1

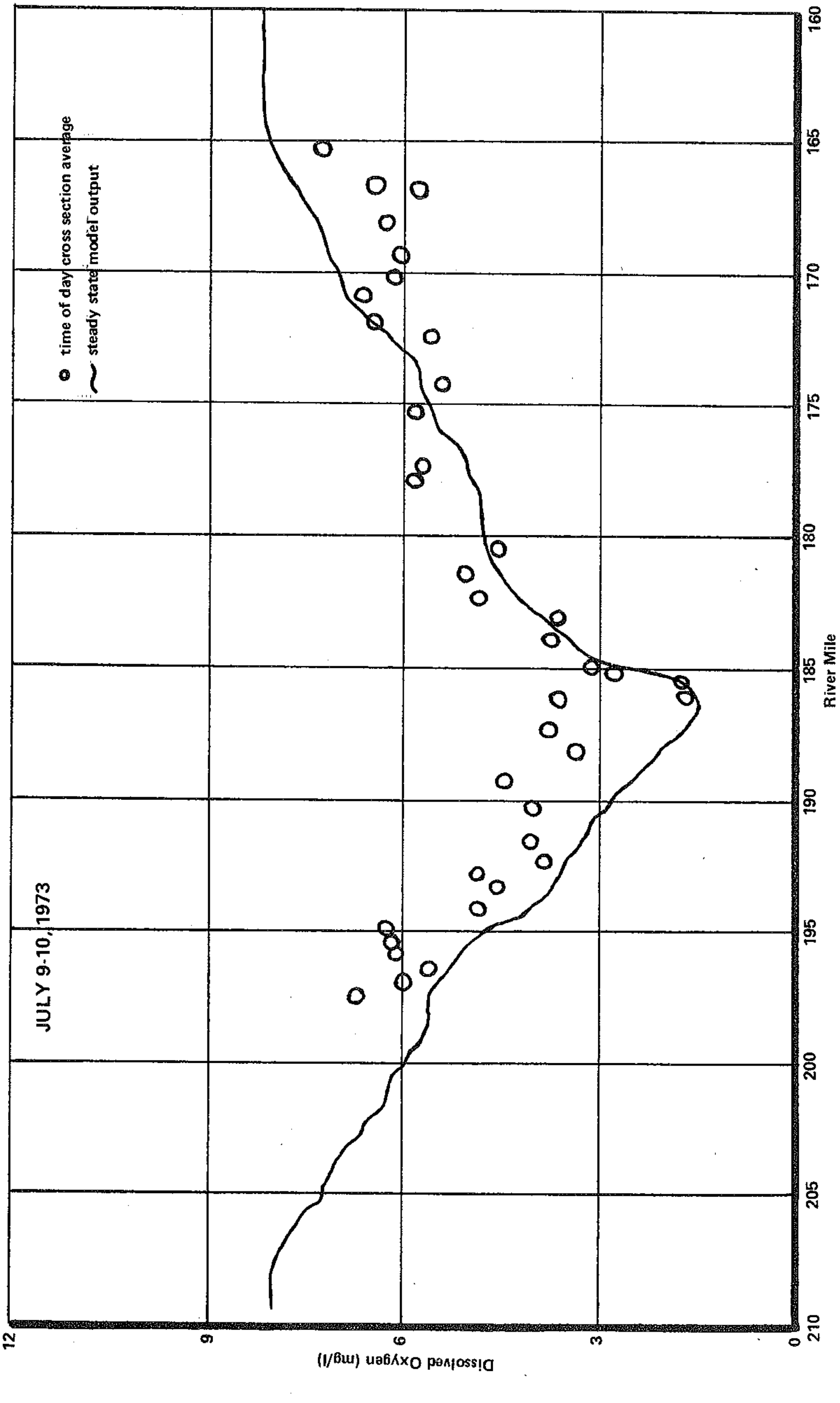

JULY 9-10, 1973
○ time of day cross section average
~ steady state model output
Dissolved Oxygen (mg/l)
0
3
6
9
12
River Mile
160
165
170
175
180
185
190
195
200
205
210

Figure E-2

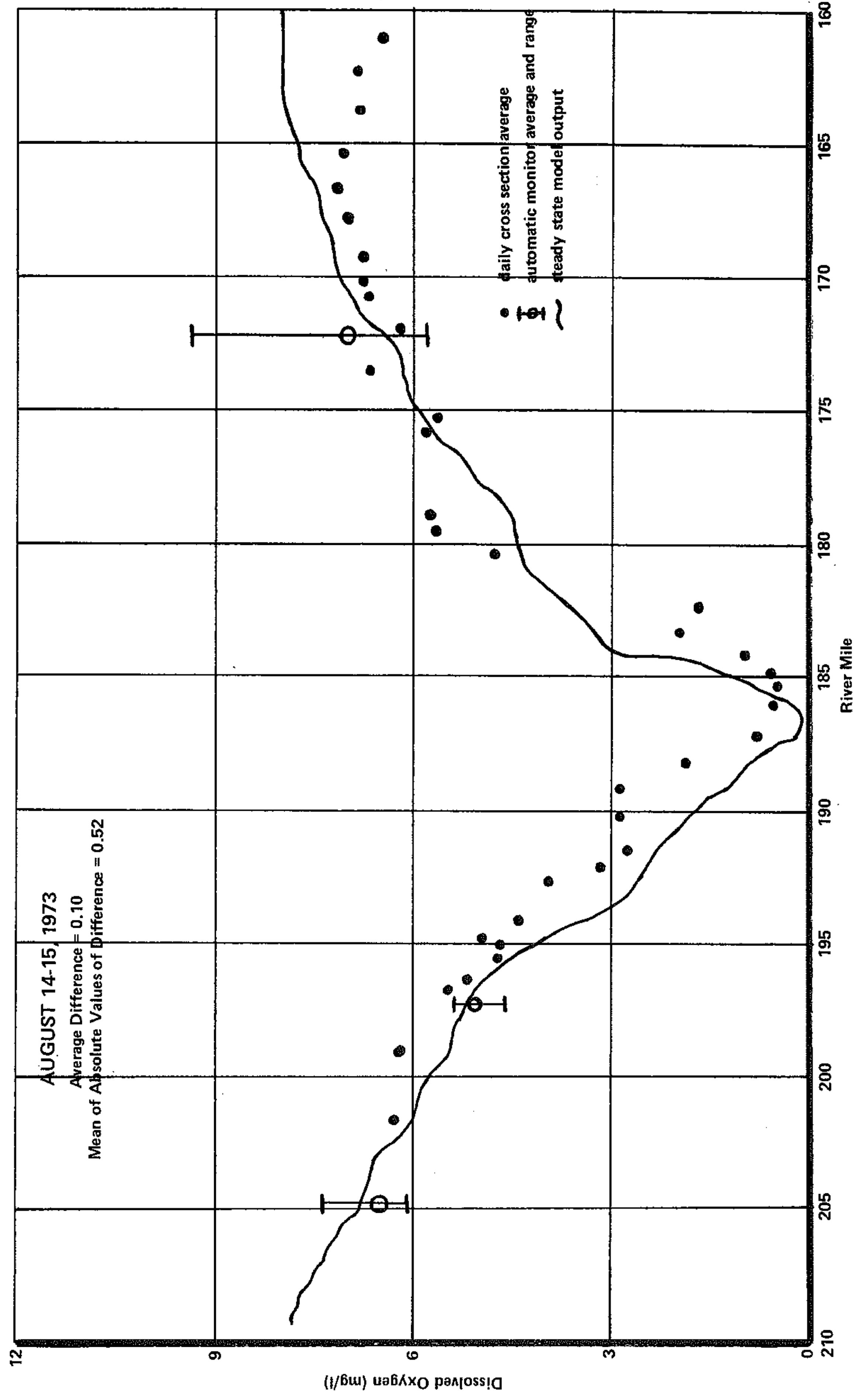

AUGUST 14-15, 1973
Average Difference = 0.10
Mean of Absolute Values of Difference = 0.52
daily cross section average
automatic monitor average and range
steady state model output
Dissolved Oxygen (mg/l)
12
9
6
3
0
River Mile
160
165
170
175
180
185
190
195
200
205
210

Figure E-3

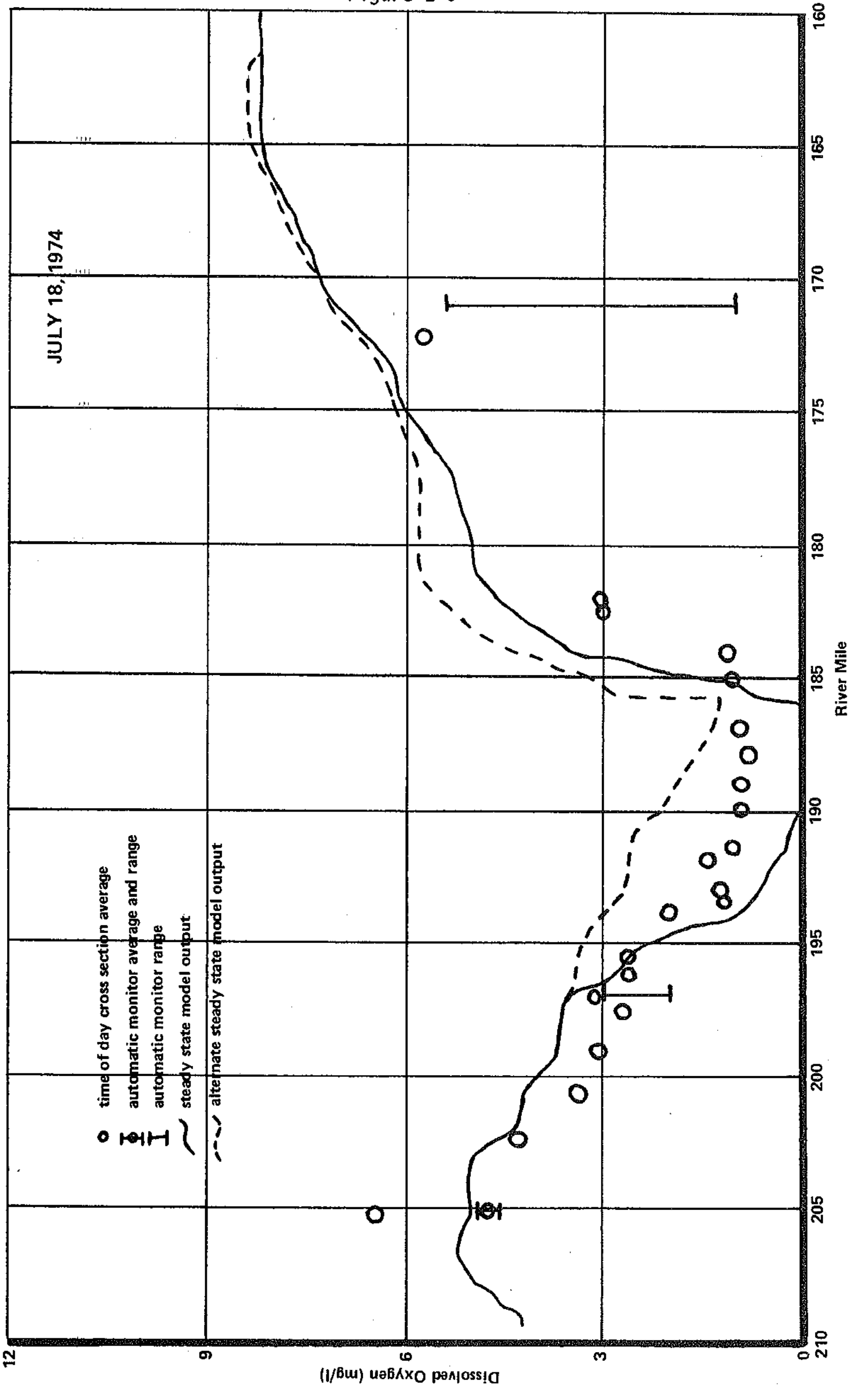

JULY 18, 1974
o time of day cross section average
automatic monitor average and range
automatic monitor range
steady state model output
alternate steady state model output
Dissolved Oxygen (mg/l)
0
3
6
9
12
River Mile
210
205
200
195
190
185
180
175
170
165
160

Figure E-4

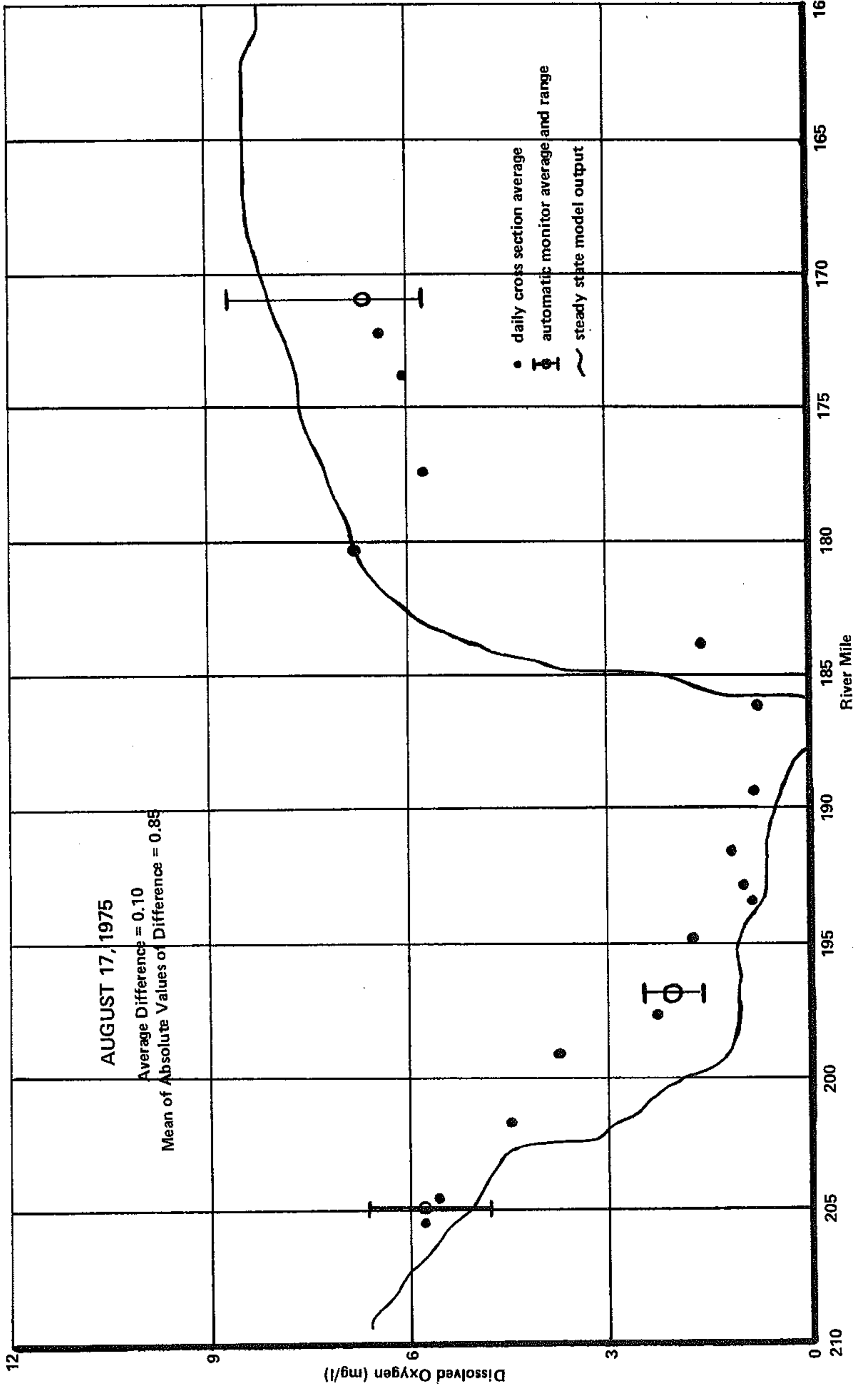

AUGUST 17, 1975
Average Difference = 0.10
Mean of Absolute Values of Difference = 0.85
● daily cross section average
automatic monitor average and range
~ steady state model output
Dissolved Oxygen (mg/l)
0
3
6
9
12
River Mile
210
205
200
195
190
185
180
175
170
165
160

Figure E-5

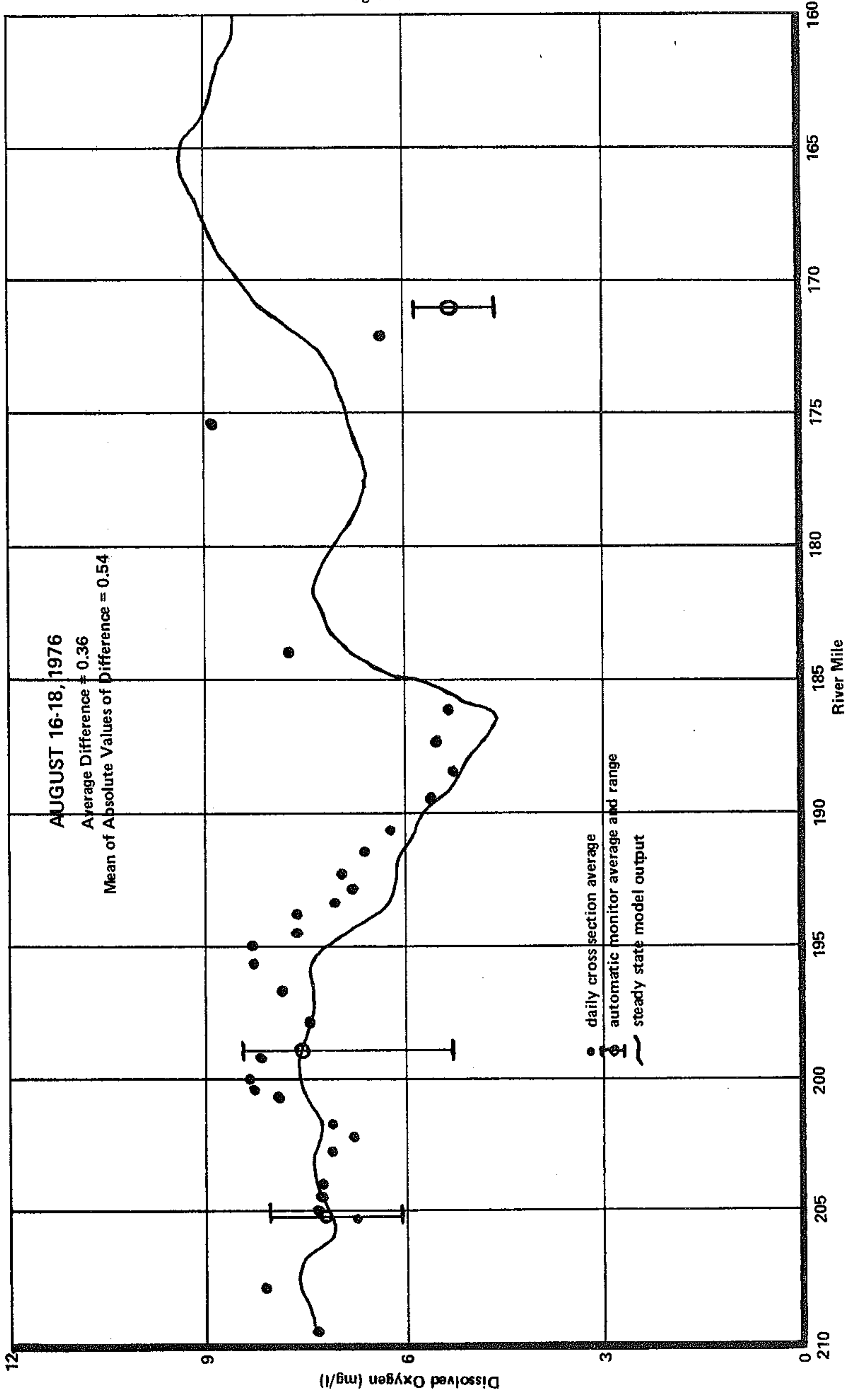

AUGUST 16-18, 1976
Average Difference = 0.36
Mean of Absolute Values of Difference = 0.54
daily cross section average
automatic monitor average and range
steady state model output
Dissolved Oxygen (mg/l)
0
3
6
9
12
River Mile
210
205
200
195
190
185
180
175
170
165
160

Figure E-6

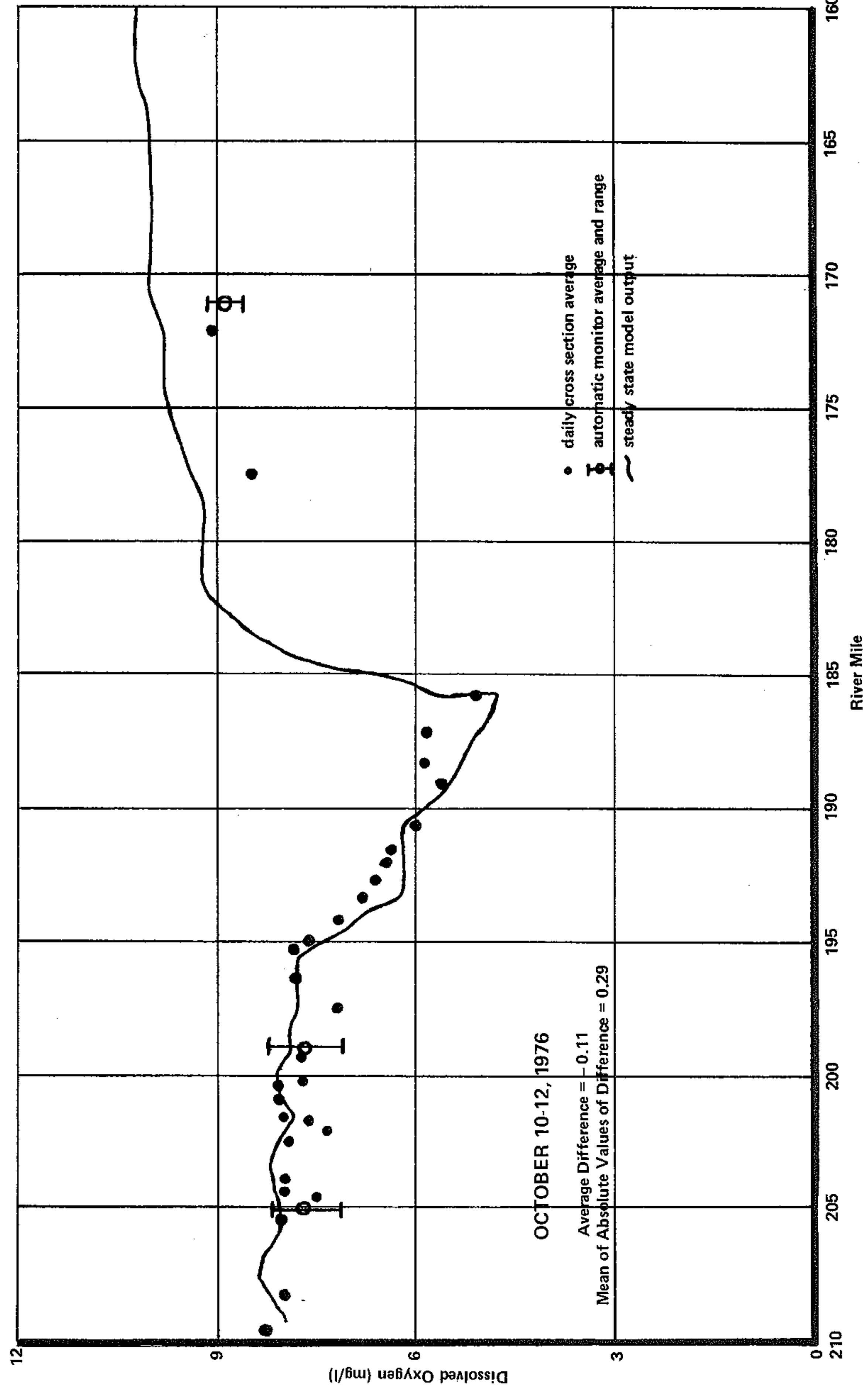

12
9
6
3
0
Dissolved Oxygen (mg/l)
210
205
200
195
190
185
180
175
170
165
160
River Mile
● daily cross section average
automatic monitor average and range
steady state model output
OCTOBER 10-12, 1976
Average Difference = −0.11
Mean of Absolute Values of Difference = 0.29

Figure E-7

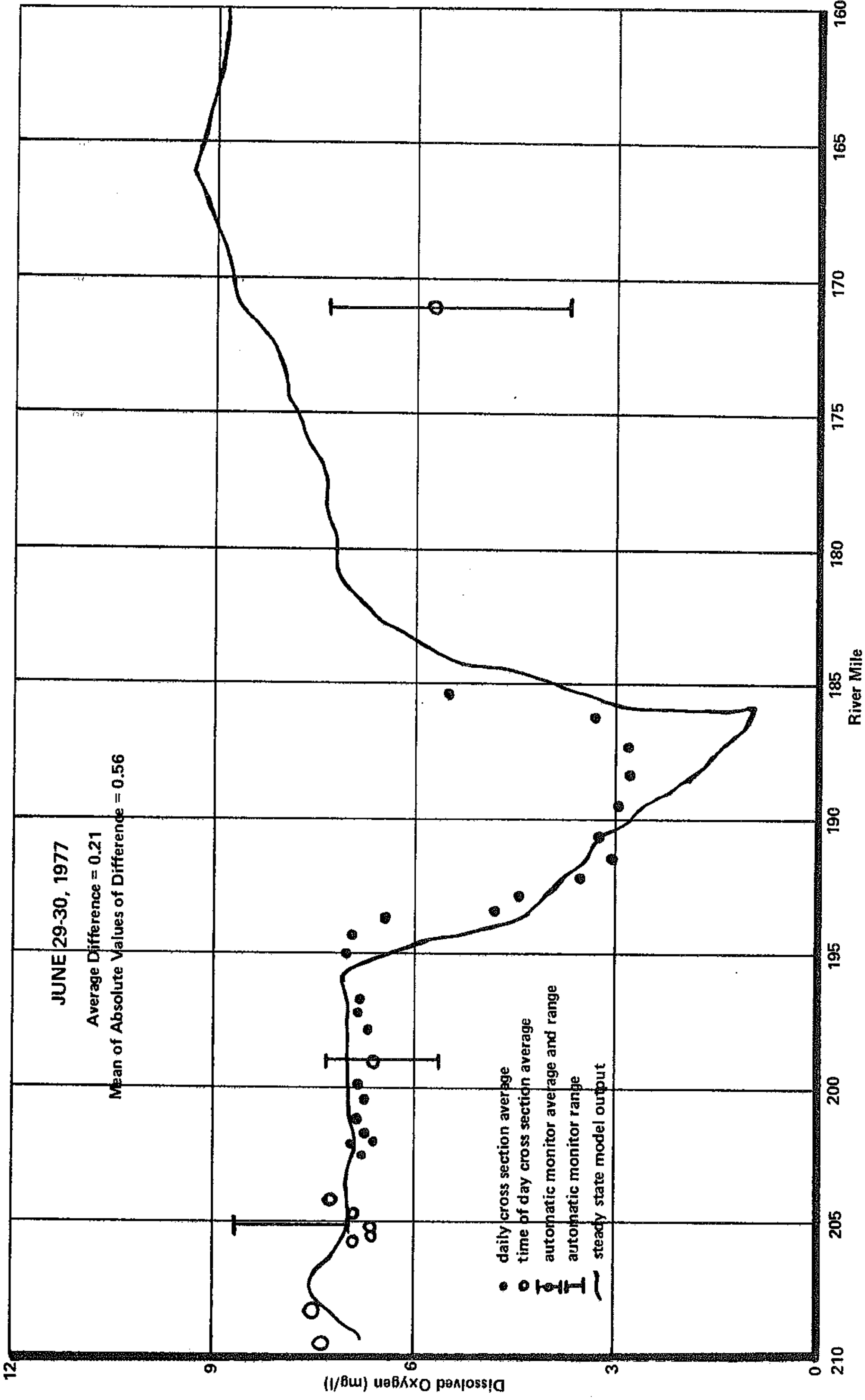
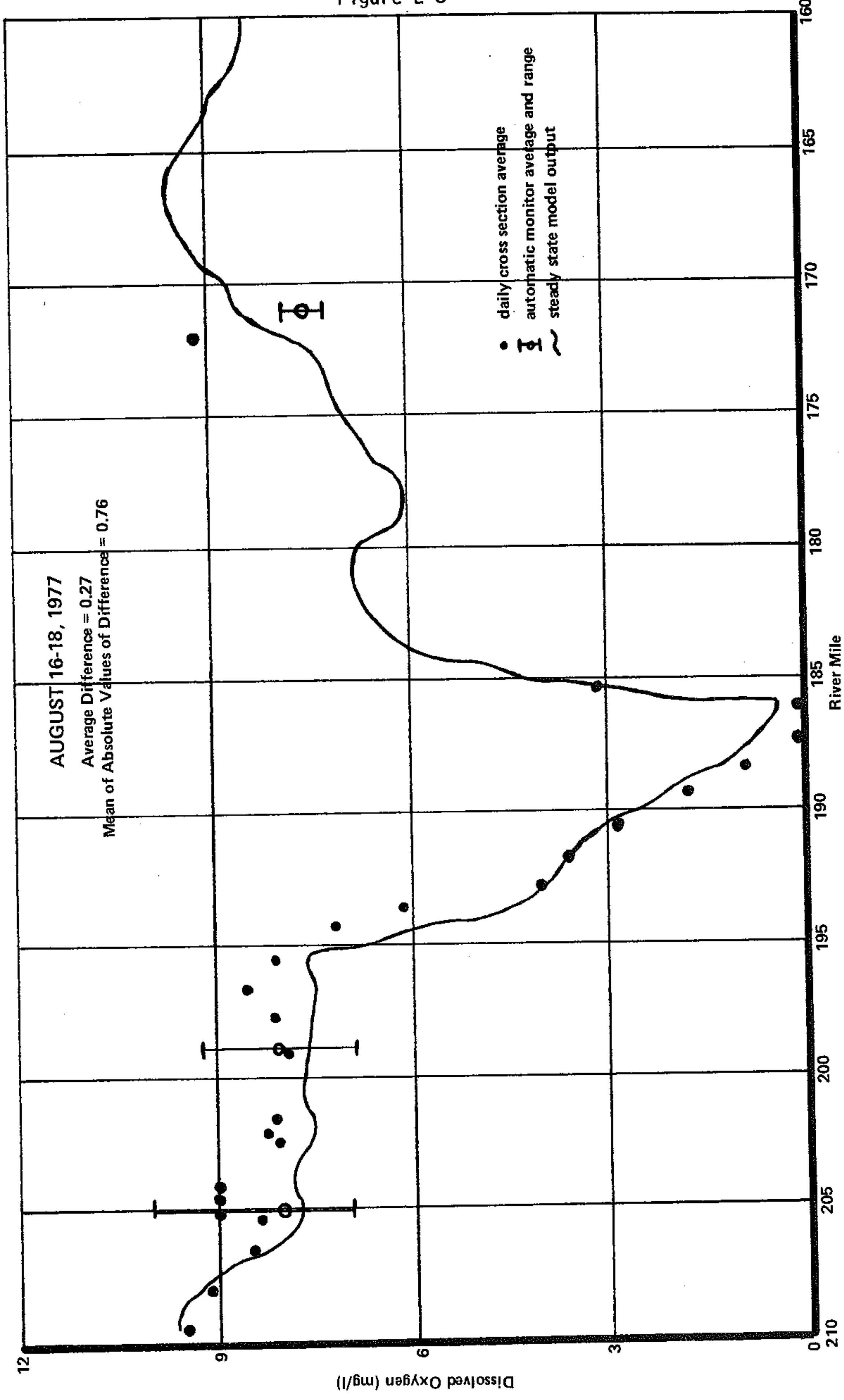

JUNE 29-30, 1977
Average Difference = 0.21
Mean of Absolute Values of Difference = 0.56
● daily cross section average
o time of day cross section average
automatic monitor average and range
automatic monitor range
steady state model output
Dissolved Oxygen (mg/l)
12
9
6
3
0
River Mile
210
205
200
195
190
185
180
175
170
165
160

Figure E-8


AUGUST 16-18, 1977
Average Difference = 0.27
Mean of Absolute Values of Difference = 0.76
● daily cross section average
automatic monitor average and range
~ steady state model output
Dissolved Oxygen (mg/l)
12
9
6
3
0
River Mile
210
205
200
195
190
185
180
175
170
165
160

Appendix F

This appendix contains the results of the verification runs. For a discussion of these graphs refer to Chapter V of the text. Each dissolved oxygen data set from a synoptic survey is shown with the corresponding steady state output of the QUAL III model. A statistical comparison between the daily average (as determined from time of day) survey data and calculated results is presented in Table F-1. All plots have the model output represented by the solid line and the daily average survey data by the black circle.

Table F-1

Steady State Verification Dissolved Oxygen Comparison

Survey Date	Mean Differences (mg/l)	Mean Absolute Differences (mg/l)
June 27-28, 1978	-0.73 ± 0.52	0.78 ± 0.43
August 15-16, 1978	0.19 ± 0.28	0.28 ± 0.19
July 24-26, 1979	0.05 ± 0.41	0.36 ± 0.19
August 6-7, 1980	-0.38 ± 0.54	0.62 ± 0.21

Figure F-1

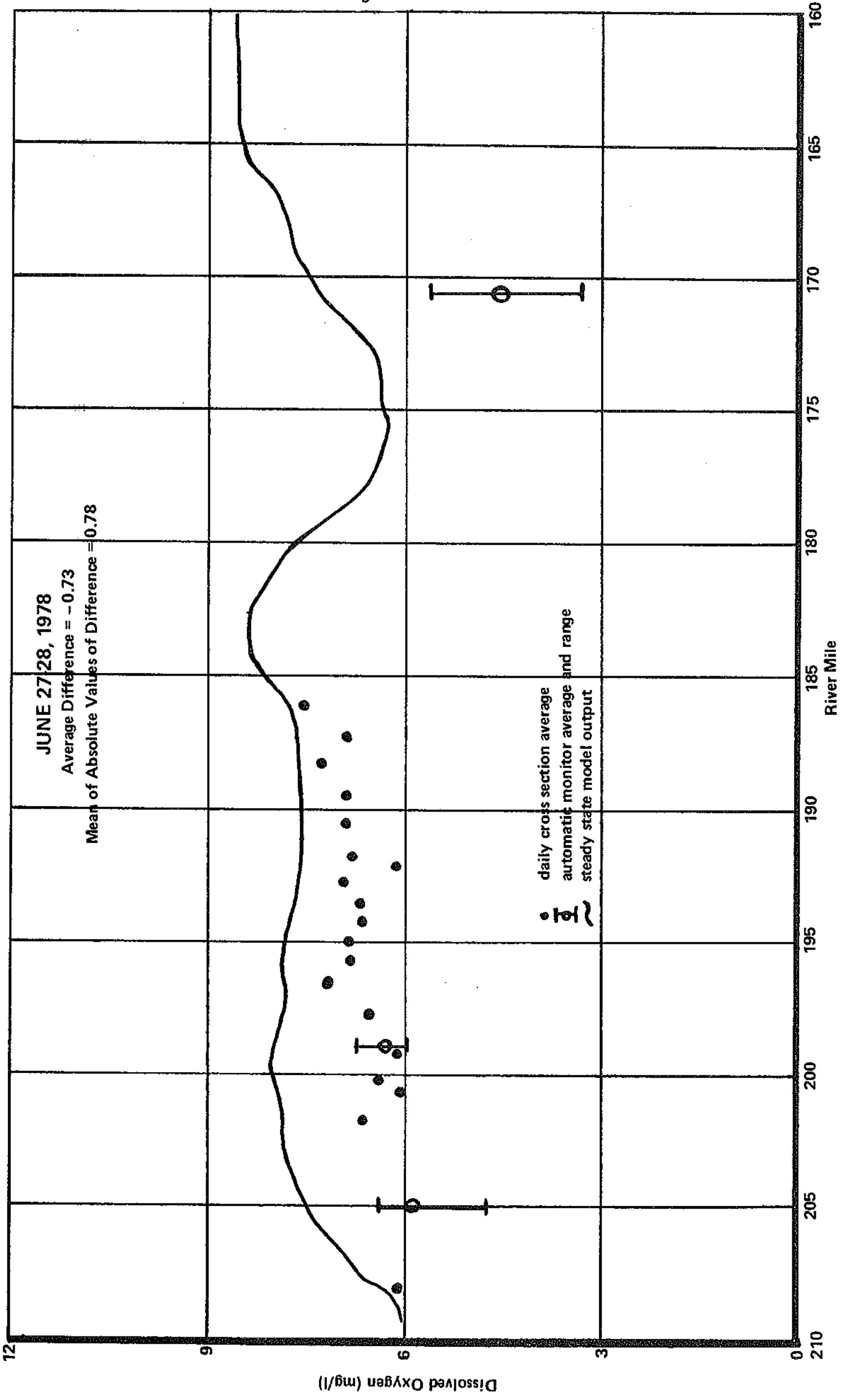

JUNE 27-28, 1978
Average Difference = −0.73
Mean of Absolute Values of Difference = 0.78
● daily cross section average
Ȯ automatic monitor average and range
~ steady state model output
Dissolved Oxygen (mg/l)
12
9
6
3
0
River Mile
210
205
200
195
190
185
180
175
170
165
160

Figure F-2

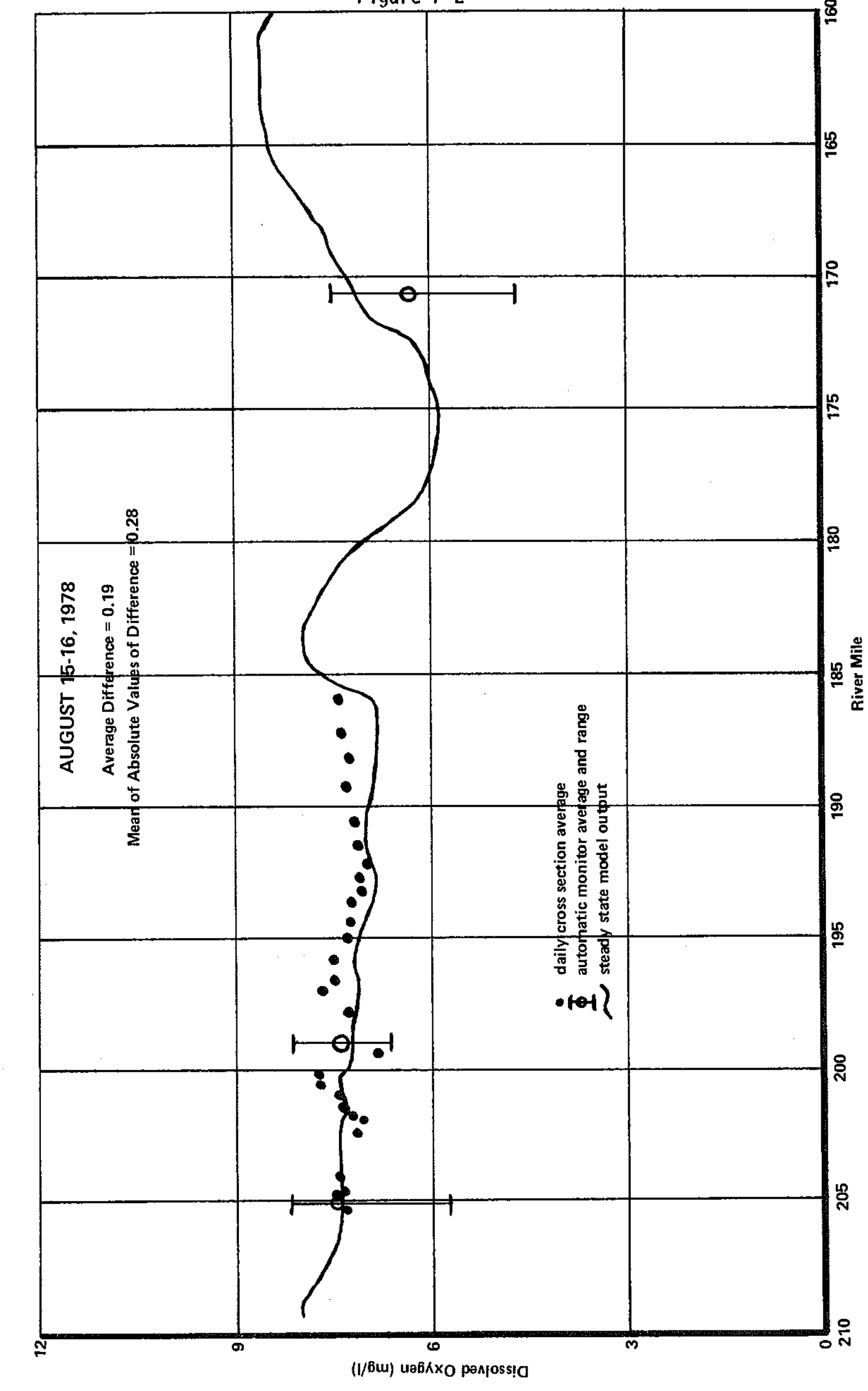

AUGUST 15-16, 1978
Average Difference = 0.19
Mean of Absolute Values of Difference = 0.28
• daily cross section average
automatic monitor average and range
steady state model output
Dissolved Oxygen (mg/l)
0
3
6
9
12
River Mile
210
205
200
195
190
185
180
175
170
165
160

Figure F-3

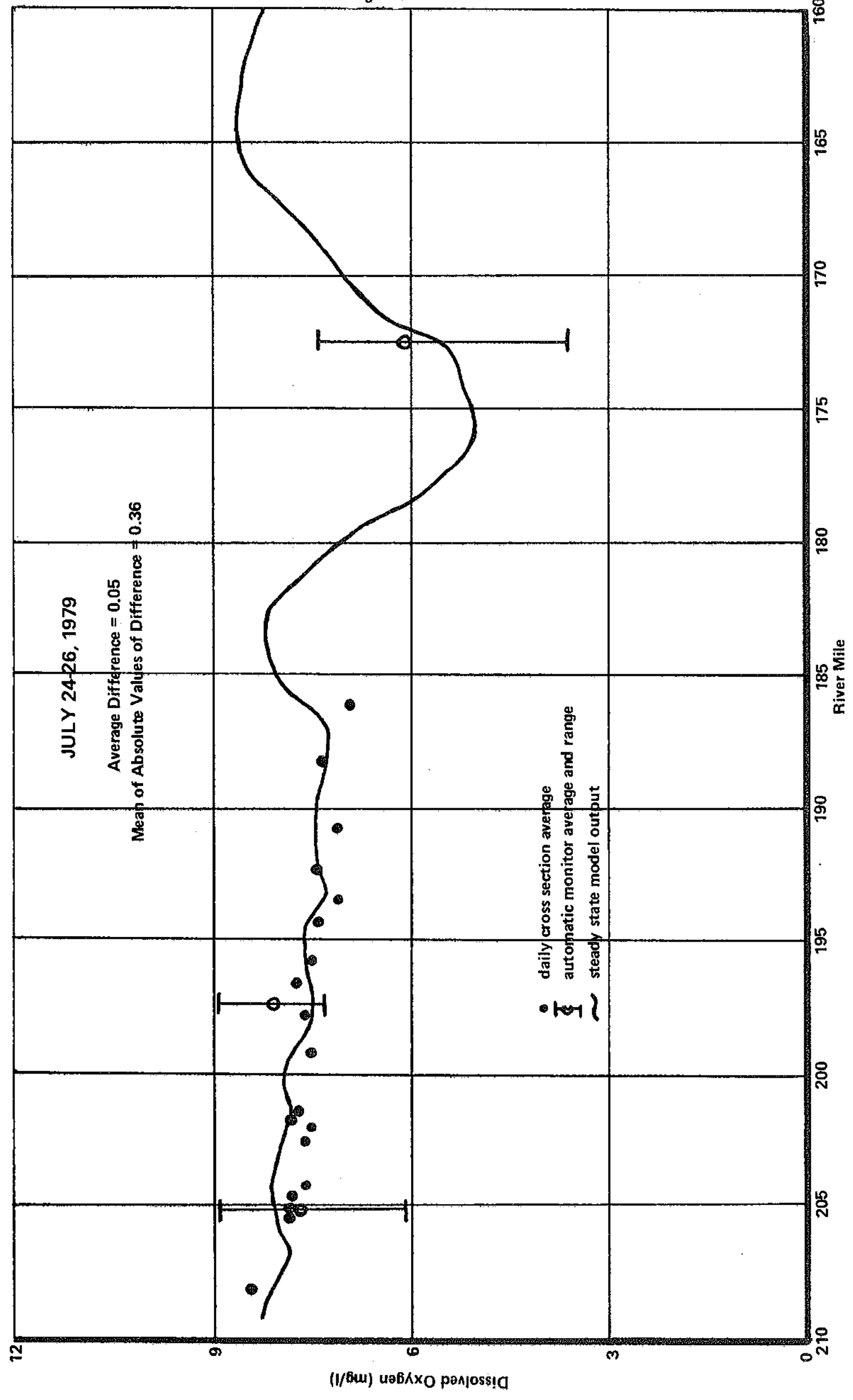
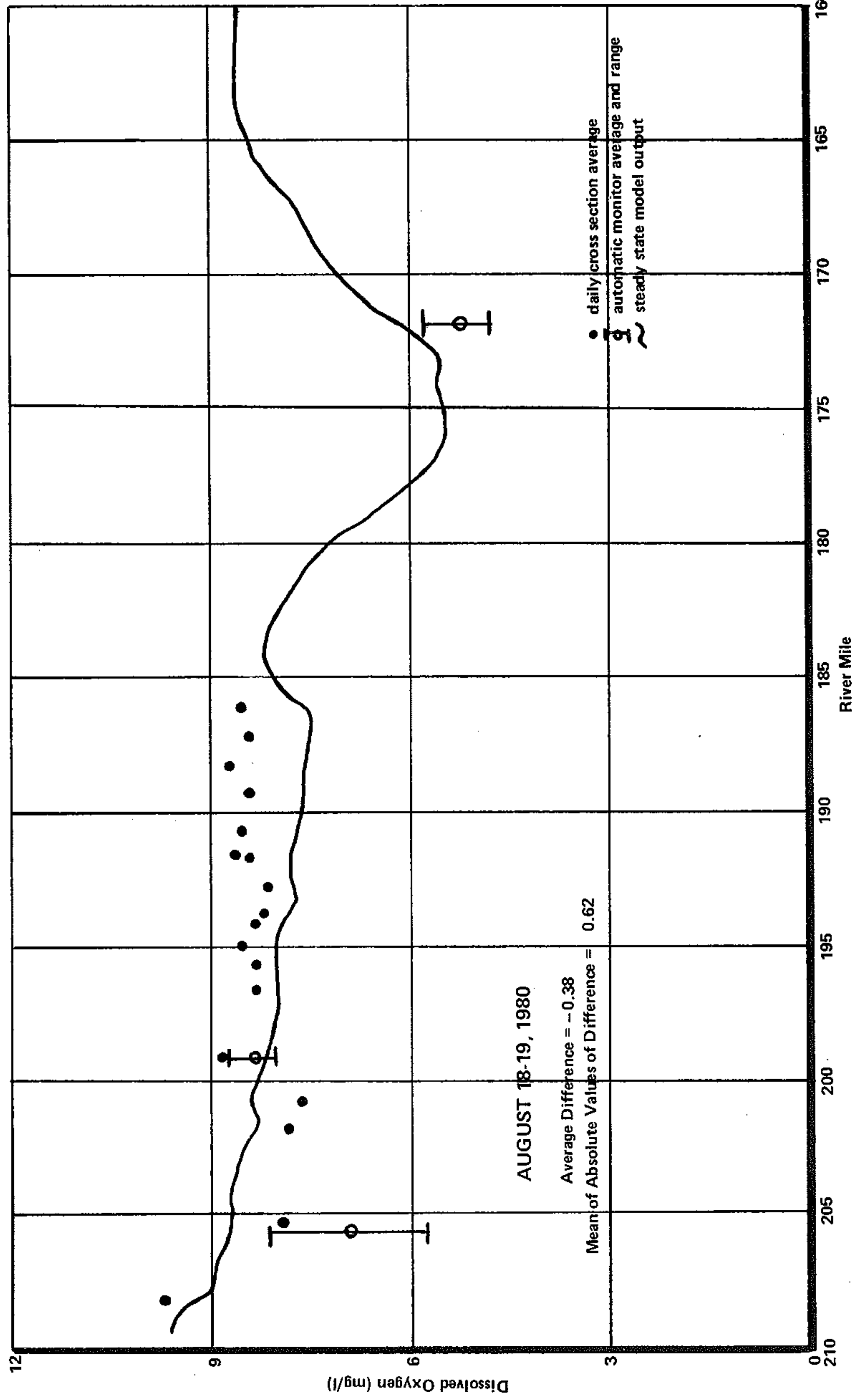

JULY 24-26, 1979
Average Difference = 0.05
Mean of Absolute Values of Difference = 0.36
● daily cross section average
automatic monitor average and range
~ steady state model output
Dissolved Oxygen (mg/l)
River Mile
12
9
6
3
0
210
205
200
195
190
185
180
175
170
165
160

Figure F-4


• daily cross section average
automatic monitor average and range
~ steady state model output
AUGUST 18-19, 1980
Average Difference = – 0.38
Mean of Absolute Values of Difference = 0.62
Dissolved Oxygen (mg/l)
12
9
6
3
0
River Mile
210
205
200
195
190
185
180
175
170
165
160

Appendix G

This appendix contains the results of dynamic verification runs for month-long simulations from 1976, 1977, 1978. The plots are for sites of Biron Dam, Centralia Dam, and Petenwell Dam. No correction for calibration drift has been applied to the plots. Calibration notes made by field personnel are provided in Table G-1.

Table G-1
Calibration for Segment D Dynamic Survey Sites

Monitor	Date	Reading Before Maintenance	Reading After Maintenance	Actual Reading*
Biron	7/23/76	5.7	7.3	7.2
	8/19/76	6.8	6.9	6.8
	9/03/76	4.6	7.0	7.0
	9/17/76	8.0	7.9	7.8
	8/01/77	7.3	6.8	6.8
	8/17/77	8.1	6.7	6.7
	9/01/77	6.0	6.3	6.3
	7/25/78	6.1	7.4	7.4
	8/09/78	5.1	7.8	7.7
	8/25/78	6.0	6.7	6.7
	9/07/78	0.0	8.1	8.1
Centralia	7/26/76	5.2	5.7	5.6
	8/12/76	6.1	6.0	6.0
	8/30/76	6.0	6.3	6.3
	9/13/76	6.9	7.5	7.5
	7/27/77	6.6	6.3	6.3
	8/09/77	5.7	5.7	5.7
	8/25/77	7.7	8.2	8.2
	9/12/77	6.4	6.8	6.8
	7/20/78	--	7.6	7.4
	8/09/78	7.3	7.4	7.3
	8/14/78	7.6	7.5	7.6
	8/30/78	8.4	8.3	8.2
	9/05/78	7.8	7.9	9.0
Petenwell	7/29/76	5.7	6.0	6.0
	8/19/76	6.0	6.2	6.4
	9/03/76	6.4	6.3	6.4
	9/14/76	7.1	7.4	7.4
	7/26/77	7.4	6.9	6.9
	8/11/77	6.4	6.4	6.3
	8/29/77	7.1	7.3	7.3
	9/23/77	6.9	7.2	7.3
	7/18/78	4.4	4.7	4.5
	8/08/78	5.4	5.0	5.0
	8/17/78	7.0	6.8	6.8
	8/29/78	5.5	6.4	6.2
	9/15/78	7.0	7.1	7.1

*As measured by a YSI 54 dissolved oxygen probe carried by field personnel.

Figure G-1

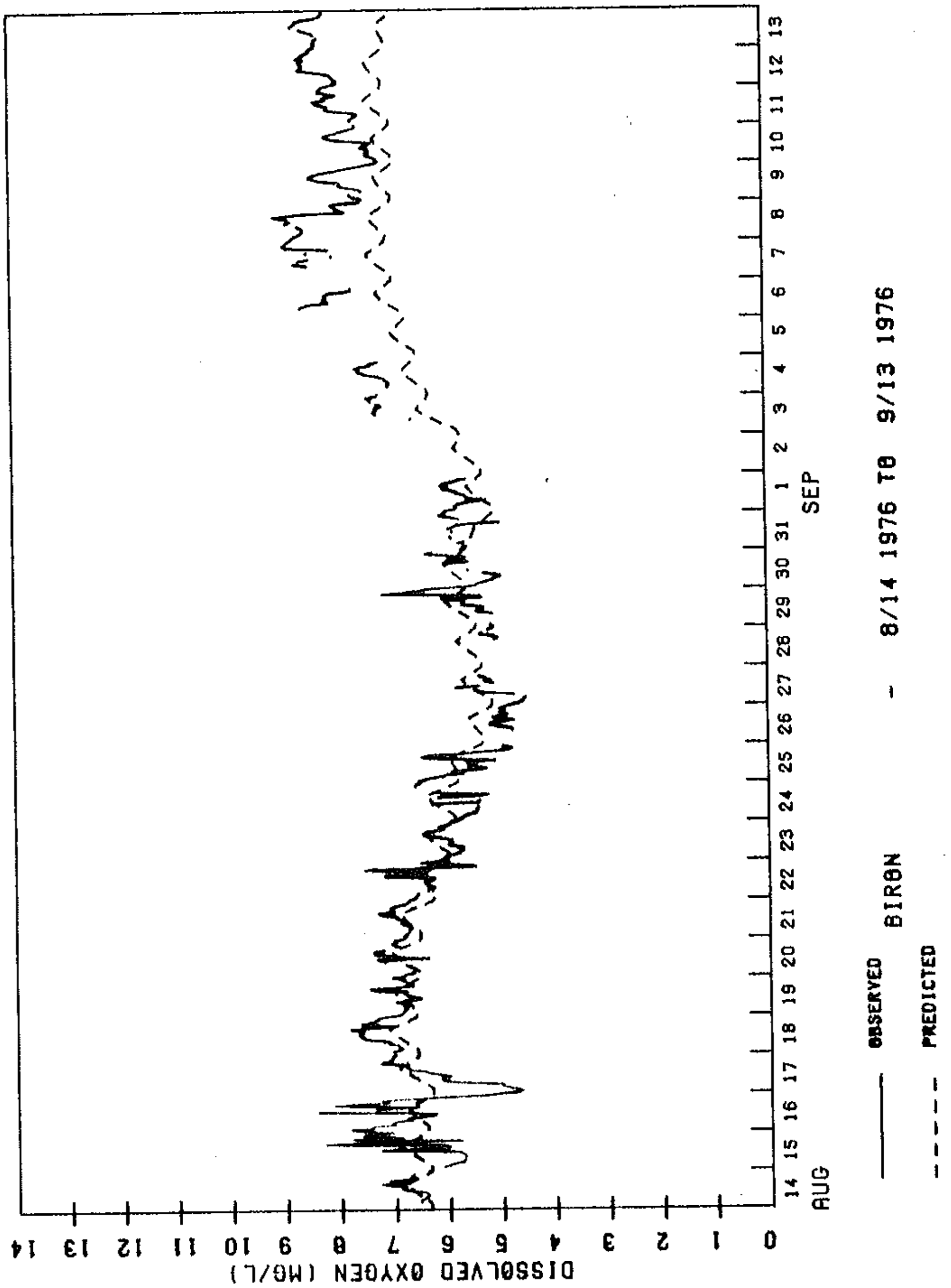

DISSOLVED OXYGEN (MG/L)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
AUG
1
2
3
4
5
6
7
8
9
10
11
12
13
SEP
BIRON - 8/14 1976 TO 9/13 1976
OBSERVED
PREDICTED

Figure G-2

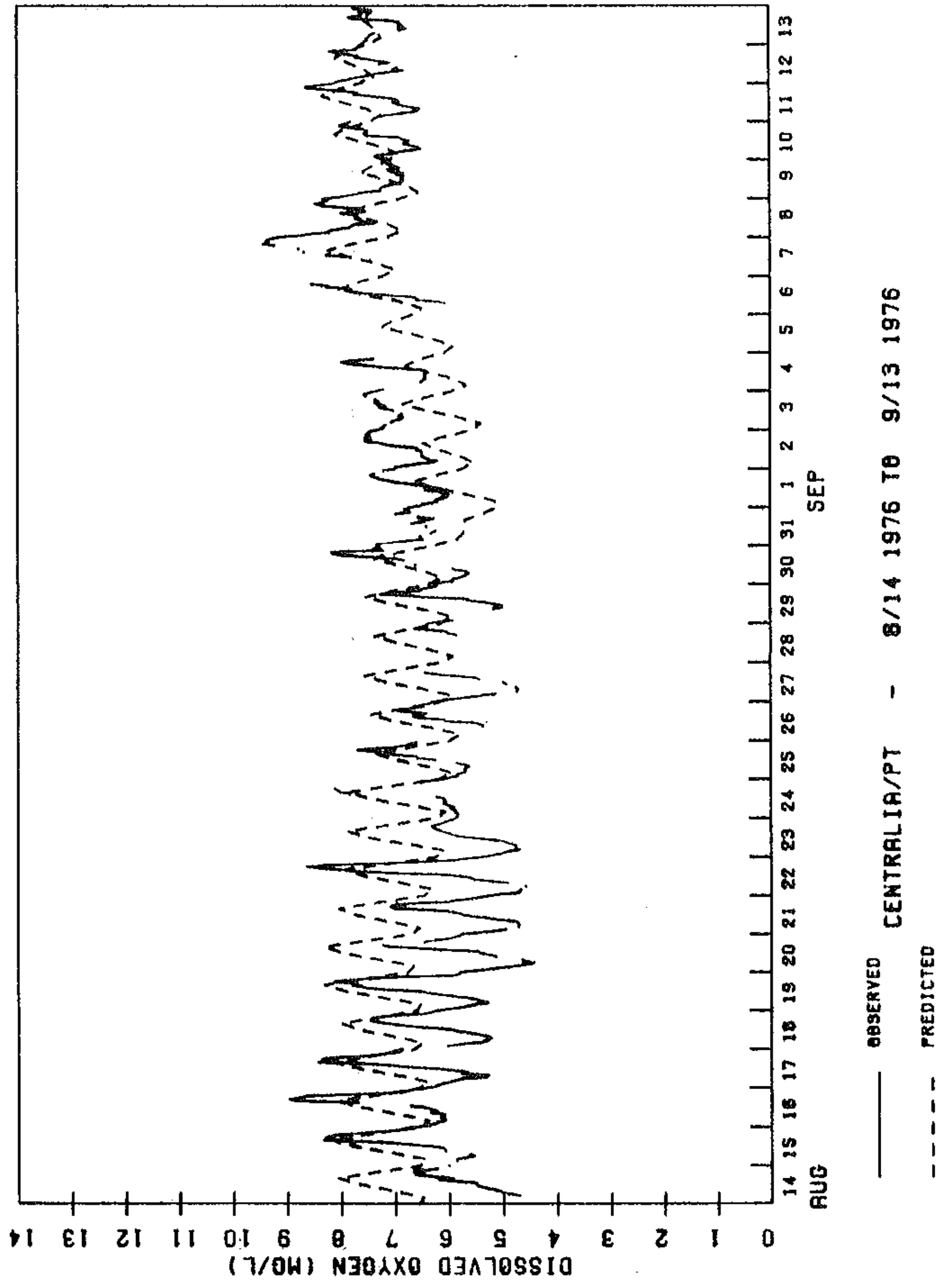

DISSOLVED OXYGEN (MG/L)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
AUG
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
SEP
1
2
3
4
5
6
7
8
9
10
11
12
13
OBSERVED
PREDICTED
CENTRALIA/PT - 8/14 1976 TO 9/13 1976

Figure G-3

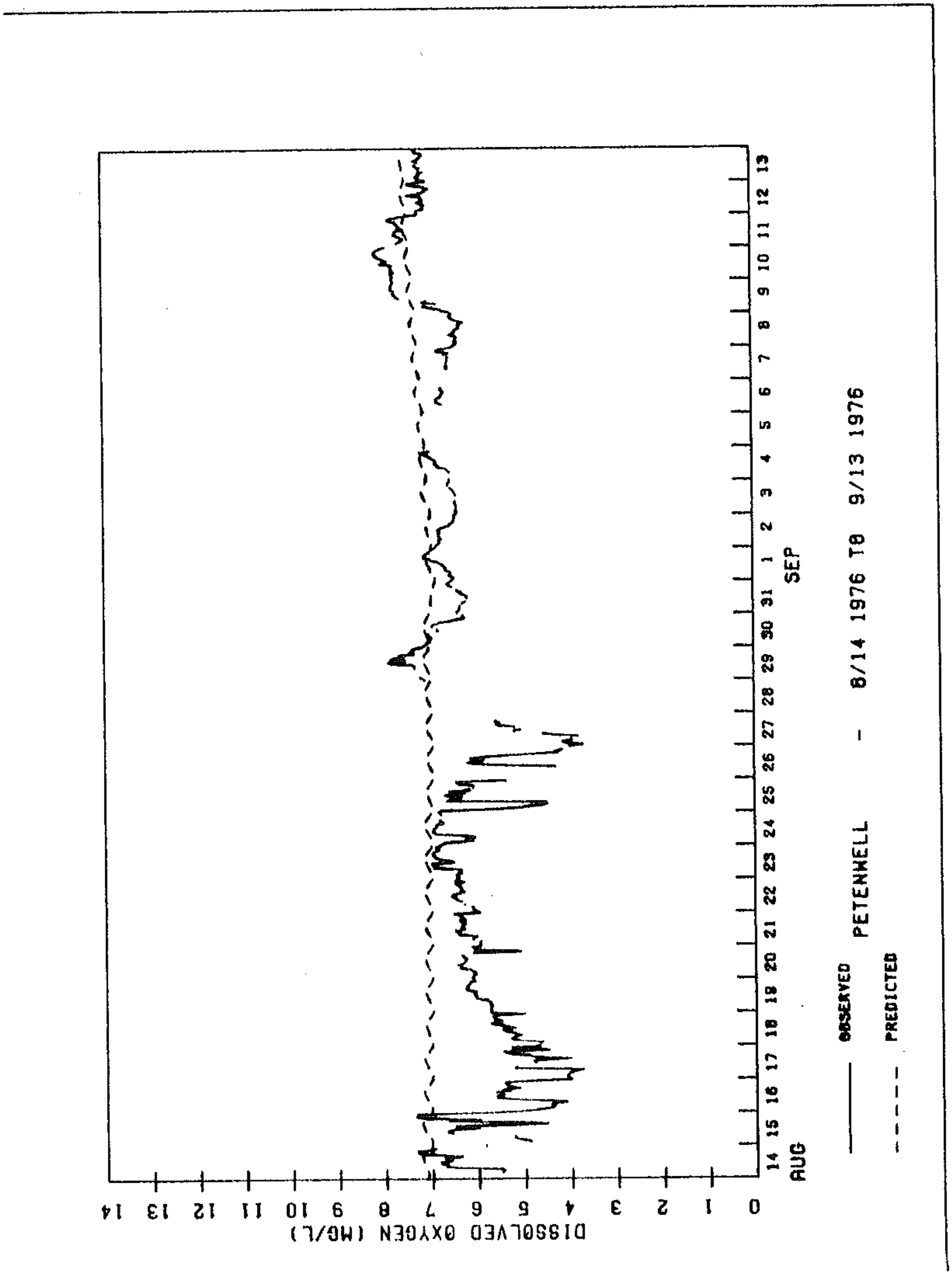

DISSOLVED OXYGEN (MG/L)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
AUG
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
SEP
1
2
3
4
5
6
7
8
9
10
11
12
13
OBSERVED
PREDICTED
PETENWELL - 8/14 1976 TO 9/13 1976

Figure G-4

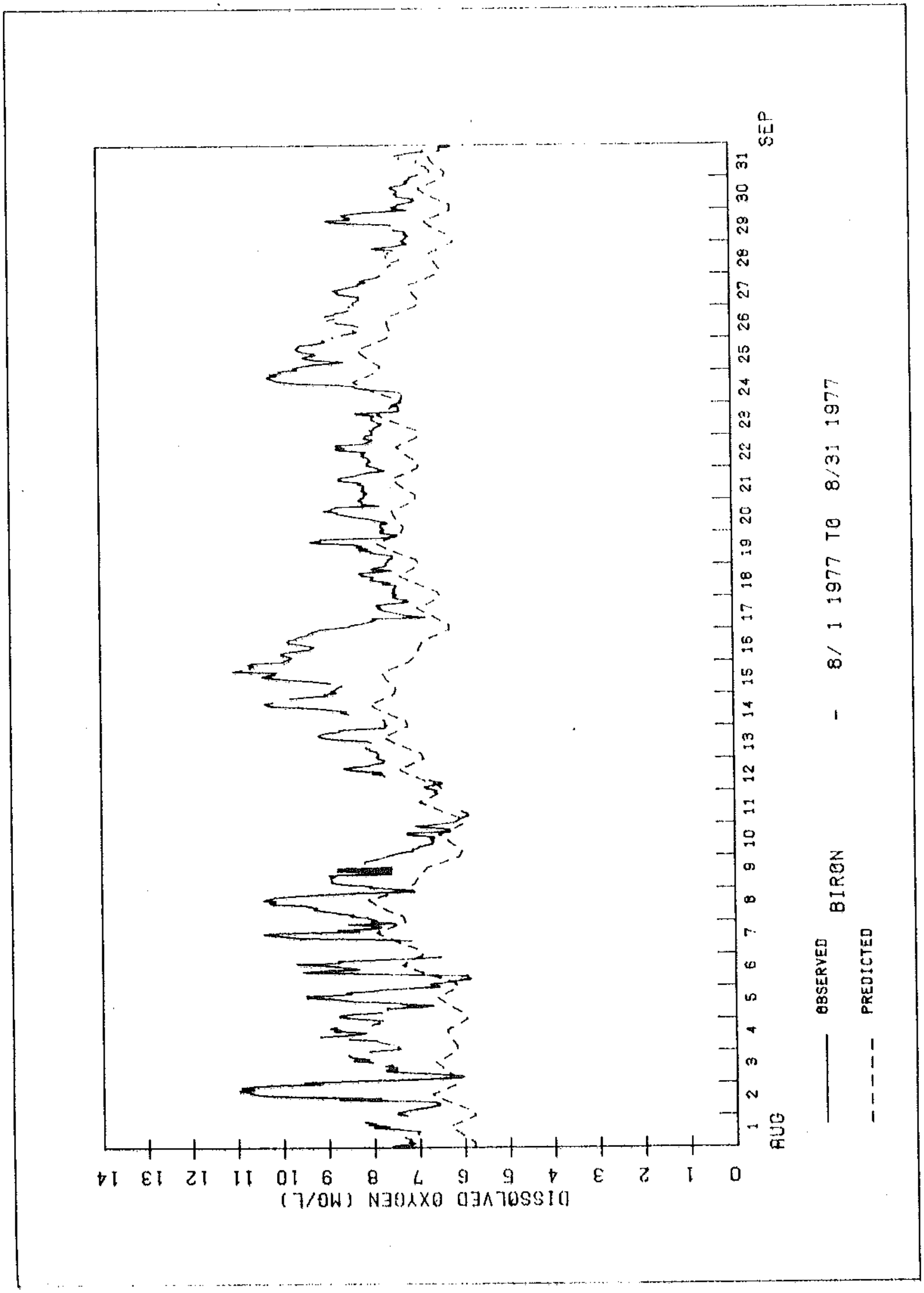
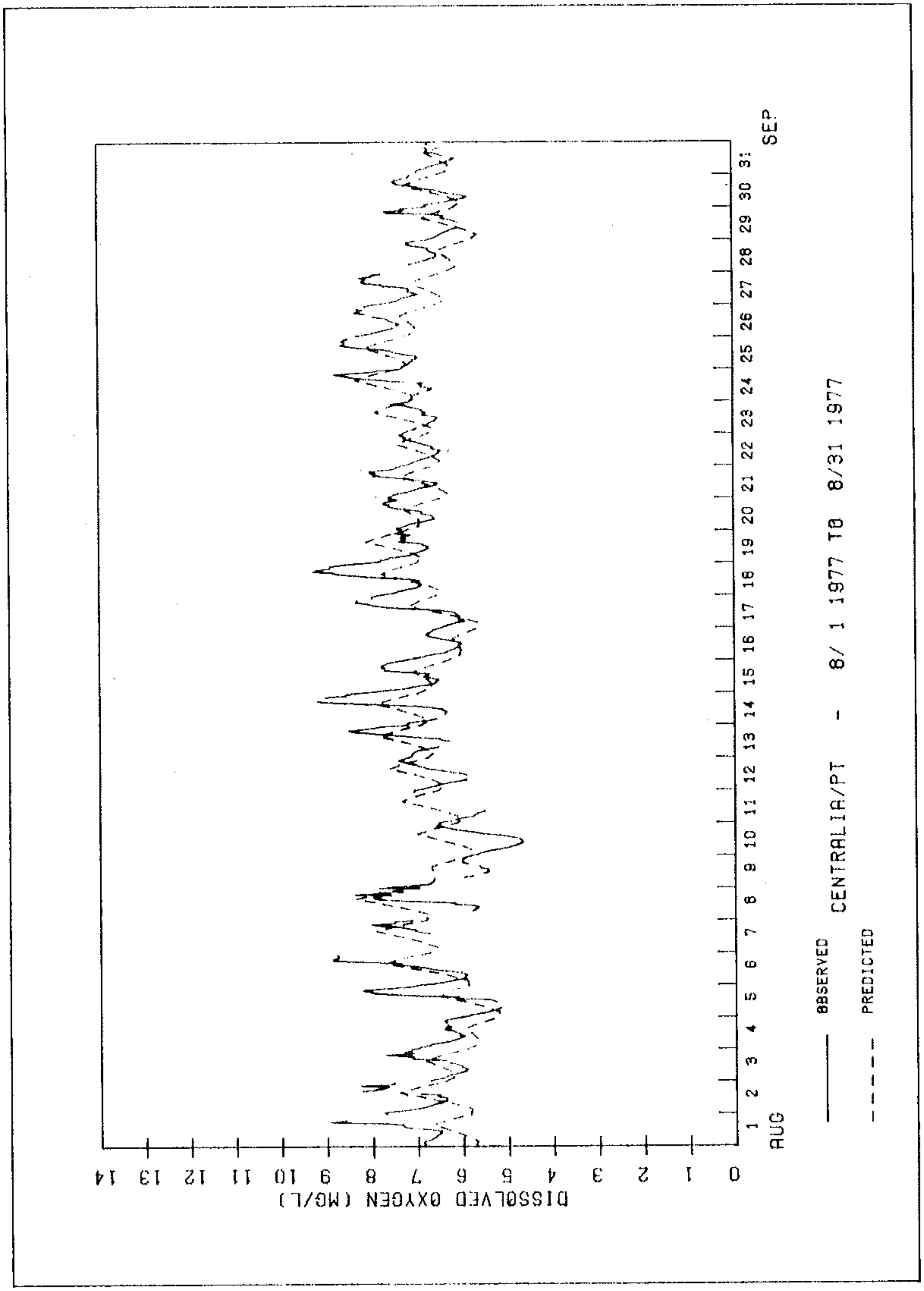

DISSOLVED OXYGEN (MG/L)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
AUG
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
SEP
OBSERVED
PREDICTED
BIRON
- 8/ 1 1977 TO 8/31 1977

Figure G-5


DISSOLVED OXYGEN (MG/L)
0
1
2
3
4
5
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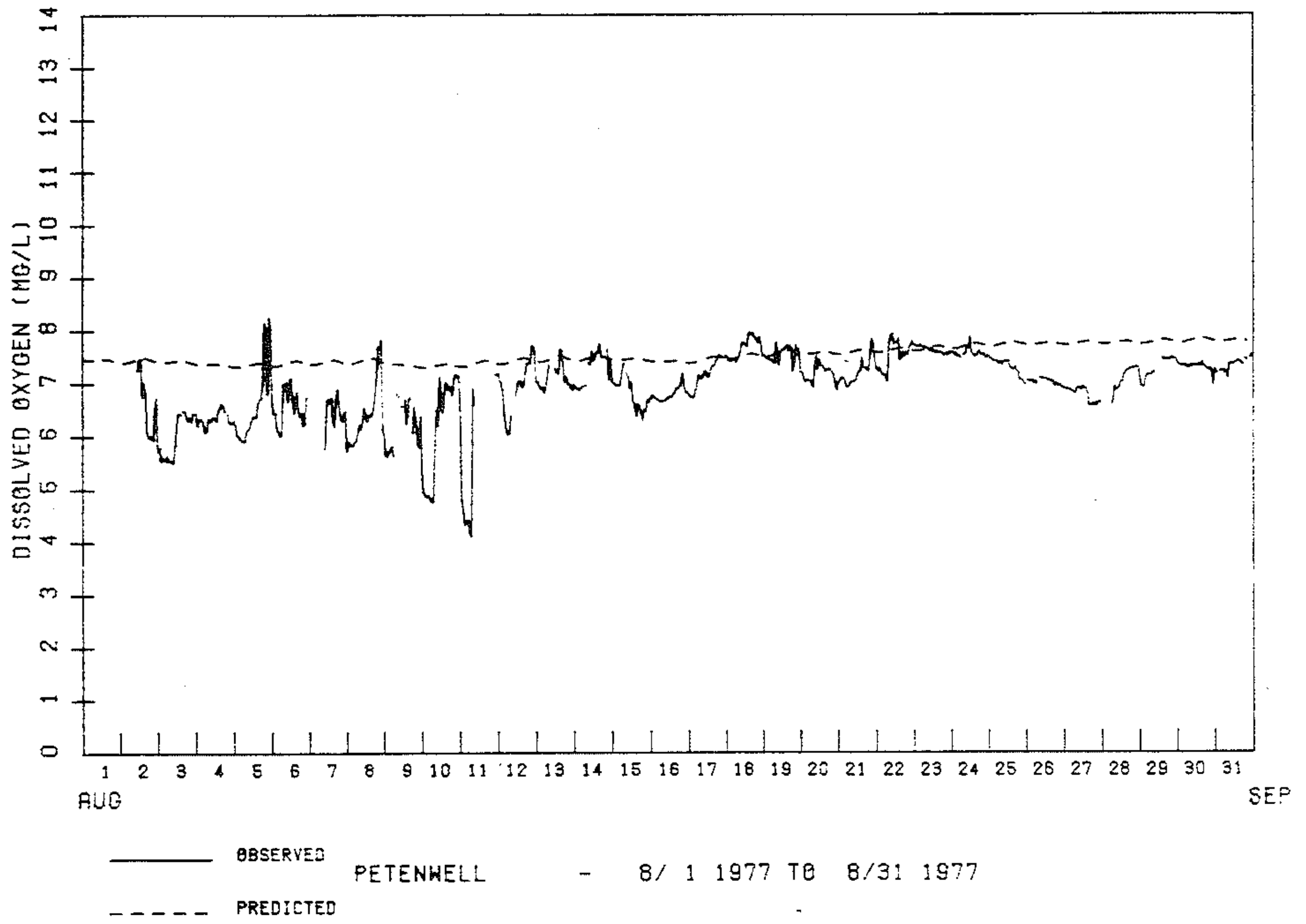
31
SEP
OBSERVED
PREDICTED
CENTRALIA/PT - 8/ 1 1977 TO 8/31 1977

Figure G-6


DISSOLVED OXYGEN (MG/L)
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14
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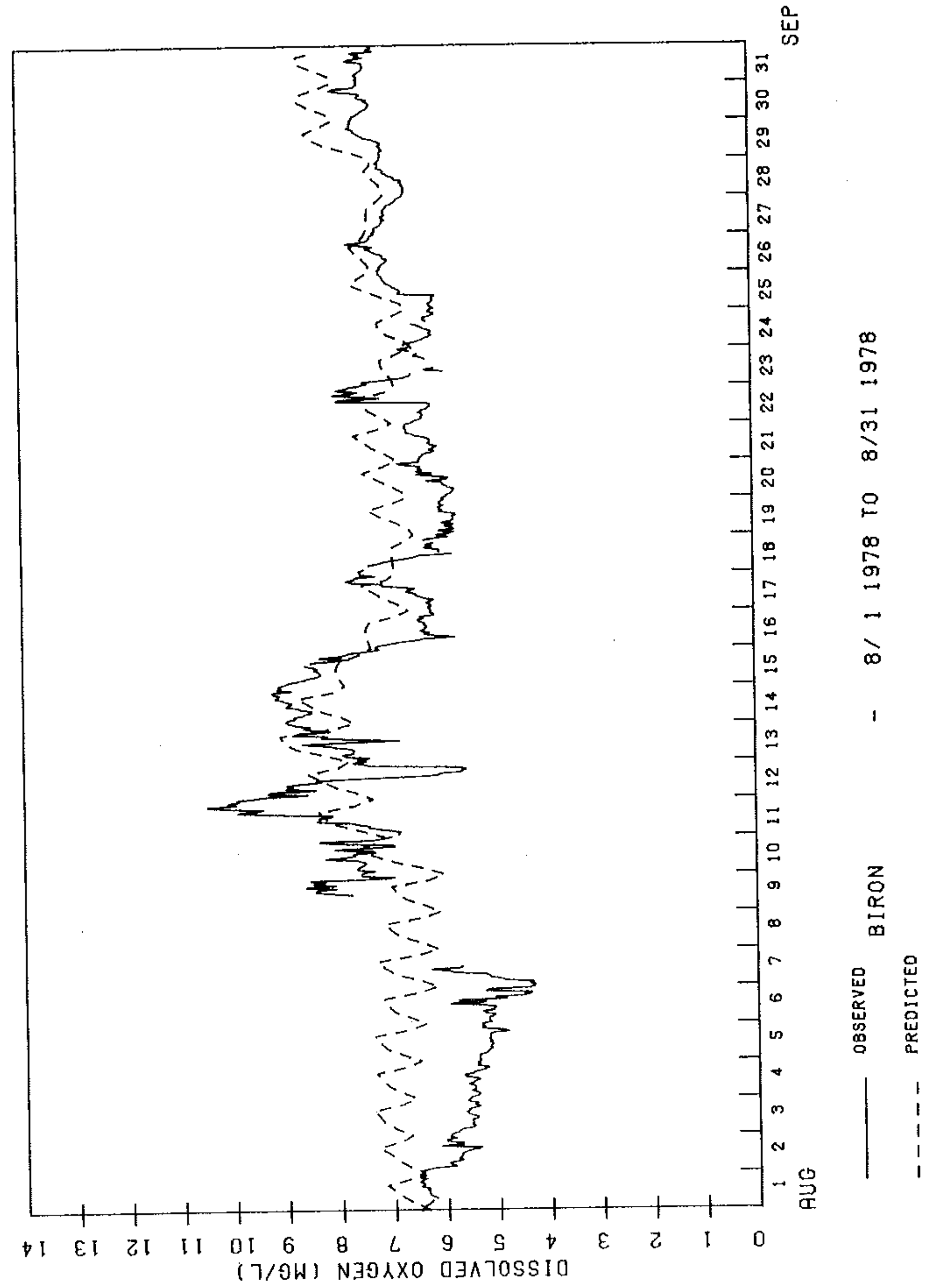
AUG
SEP
OBSERVED
PREDICTED
PETENWELL - 8/ 1 1977 TO 8/31 1977

Figure G-7


DISSOLVED OXYGEN (MG/L)
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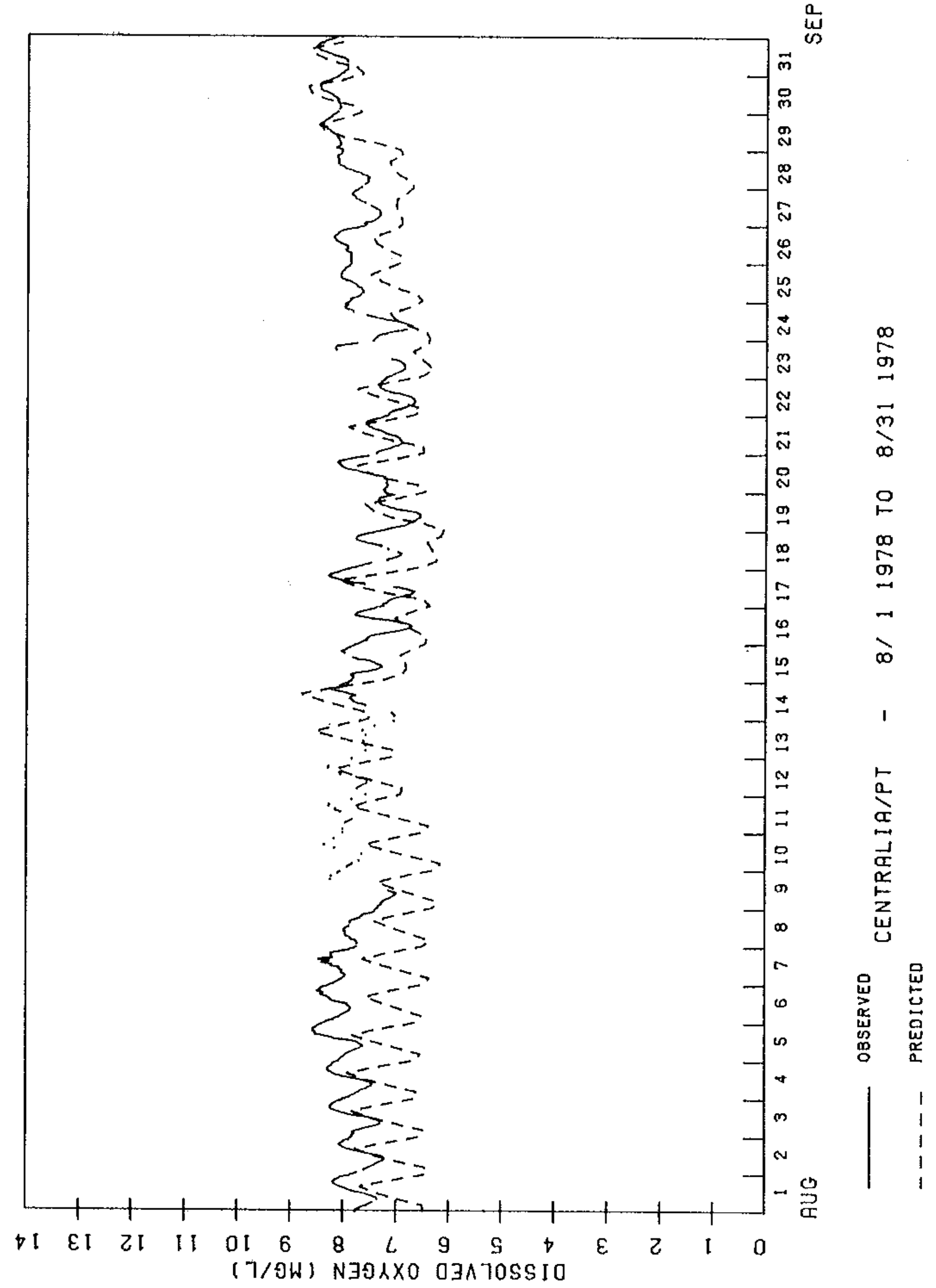
SEP
OBSERVED
PREDICTED
BIRON - 8/ 1 1978 TO 8/31 1978

Figure G-8


DISSOLVED OXYGEN (MG/L)
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AUG
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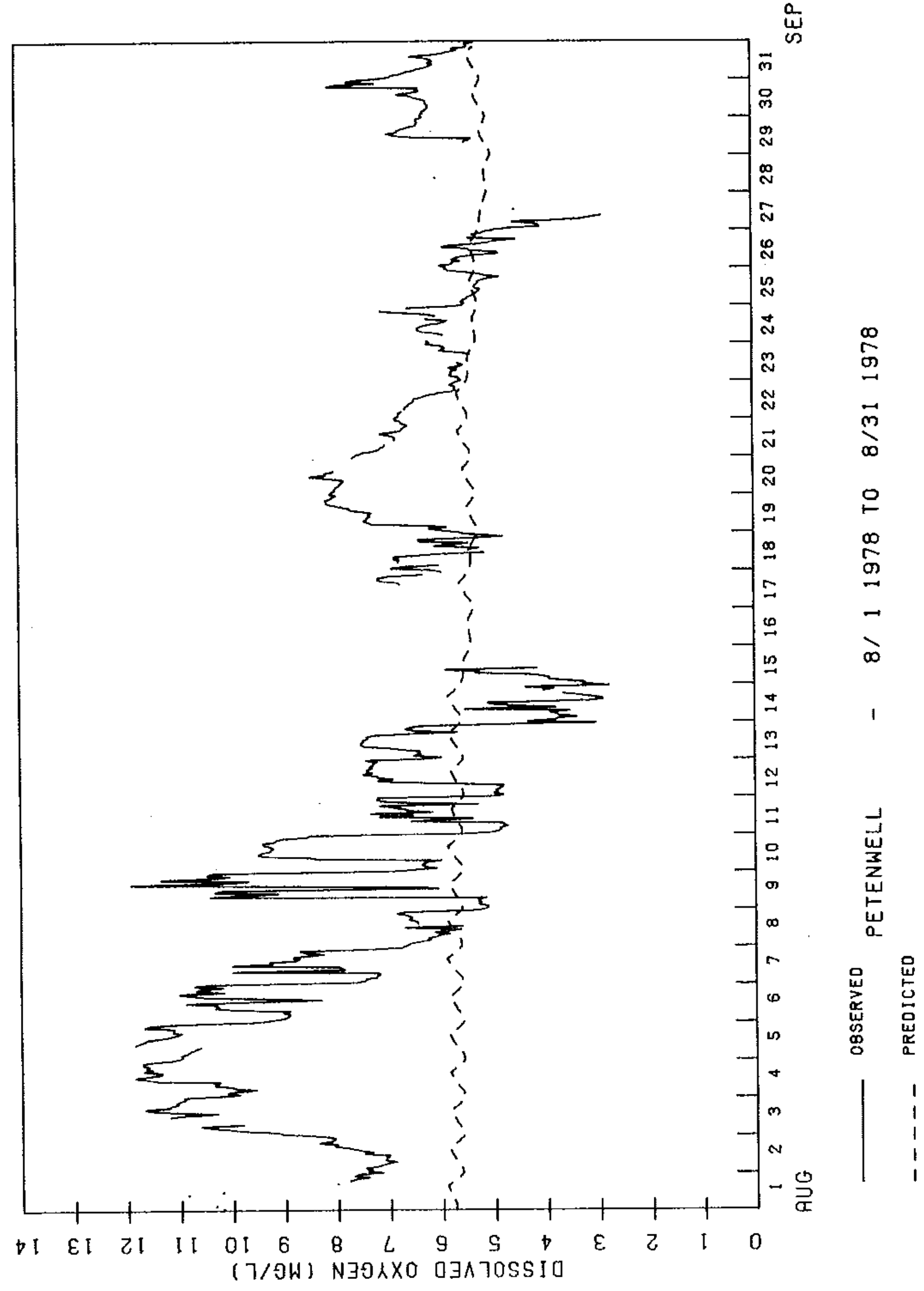
SEP
OBSERVED
PREDICTED
CENTRALIA/PT - 8/ 1 1978 TO 8/31 1978

Figure G-9


DISSOLVED OXYGEN (MG/L)
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AUG
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SEP
PETENWELL - 8/ 1 1978 TO 8/31 1978
OBSERVED
PREDICTED

Appendix H

This appendix presents the results of the sensitivity analyses on Segment D of the upper Wisconsin River. A typical set of conditions was chosen for the base run. These are the conditions occurring with a headwater flow of 1,500 cfs and a river temperature of 76.0 degrees Fahrenheit. All wastewater dischargers were discharging at their baseline loads. The set of rate coefficients in the sensitivity analysis is that set which was determined during the calibration process and used for the wasteload allocation. The boundary conditions are listed below in Table H-1. The model was run in the steady state mode.

A discussion of the results of the sensitivity analysis is given in the sixth chapter. It should be pointed out that changes in some parameters drive the dissolved oxygen to zero. This is noted by an asterisk. In these instances, the maximum change in the parameters may not be the maximum change which would have occurred if the dissolved oxygen had not gone to zero. Also, as the maximum change in a parameter is listed, the listed changes do not necessarily occur at the same location in the river. The interpretation of the sensitivity analysis is not straight forward. Each parameter was normally varied by a set percentage of its value (± 20%). A parameter that shows a large change in dissolved oxygen to a change in that parameter's value usually will be a parameter that is highly constrained by the calibration of the model to the data sets. For example, the maximum growth rate of algae if varied by 20% will cause a maximum change in dissolved oxygen of at least 0.93 mg/l. Use of this greatly increased algae maximum growth could only be accomplished by altering many other parameters to compensate for the difference. Such attempts would probably drive other parameters outside of their accepted range. Results of the sensitivity analysis are found in Table H-2.

Table H-1

Boundary Condition Settings for Base Run of Sensitivity Analysis

Headwater (Biron Flowage) Flow = 1500 cfs
Wisconsin River Temperature = 76.0 °F
Headwater Algae = 20 ug/l
Headwater Phosphorus (Not in Algae) = 0.02 mg/l
Headwater Organic Nitrogen (Not in Algae) = 0.66 mg/l
Headwater Ammonia = 0.04 mg/l
Headwater Nitrite = 0.011 mg/l
Headwater Nitrate = 0.20 mg/l
Headwater Dissolved Oxygen = 8.3 mg/l
Incremental Runoff = 1.02-15.81 cfs/mile
Lake Petenwell Evaporation = -340 cfs
Solar Radiation = 450 langleys
Hours of Daylight = 14.0 hours

Table H-2

Sensitivity Analysis Results

Maximum Change in Parameter

Parameter Altered	Change in Parameter	DO (mg/l)	BOD_5 (mg/l)	Ammonia (mg/l)	Nitrate (mg/l)	Chl-A (ug/l)
Oxygen Production by Algae	-20%*	-0.80	+0.01	+0.02	-0.03	- 0.2
	+20%	+1.00	+0.01	-0.02	+0.03	+ 0.3
Oxygen Respiration by Algae	-20%	+0.73	+0.01	+0.02	+0.03	+ 0.3
	+20%*	-0.69	+0.01	+0.02	-0.03	- 0.3
Nitrogen Content of Algae	-20%	+0.07	+0.01	+0.03	+0.04	+ 1.5
	+20%	-0.12	+0.01	-0.03	-0.03	- 2.1
Phosphorus Content of Algae	-20%	0.00	+0.01	0.00	0.00	0.0
	+20%	-0.01	+0.01	0.00	0.00	0.0
Maximum Denitrification Rate	-20%	+0.05	+0.01	+0.01	+0.02	+ 0.7
	+20%	-0.04	+0.01	-0.01	-0.01	- 0.5
Nitrogen Half-Saturation Constant	-20%	+0.09	+0.01	-0.01	-0.01	+ 1.1
	+20%	-0.09	+0.01	+0.01	+0.01	- 0.9
Phosphorus Half-Saturation Constant	-20%	+0.13	+0.01	-0.01	-0.01	+ 1.7
	+20%	-0.13	+0.01	+0.01	+0.01	- 1.5
Light Half-Saturation Content	-20%	+0.60	+0.01	-0.03	-0.03	+ 5.9
	+20%*	-0.37	+0.01	+0.03	+0.03	- 5.5
Chlorophyll-A Content of Algae	-20%	+0.20	0.00	-0.04	-0.04	+ 3.9
	+20%	-0.21	0.00	+0.03	+0.03	- 4.6
Fast Term BOD Decay Rate	-20%	+0.47	+0.17	-0.01	+0.02	+ 0.1
	+20%*	-0.41	-0.13	+0.01	-0.02	+ 0.1
Slow Term BOD Decay Rate	-20%	+0.62	+0.53	-0.02	+0.02	+ 0.2
	+20%*	-0.60	-0.43	+0.02	-0.02	+ 0.1
Light Extinction Coef. Indep. of Algae	-20%	+0.71	+0.01	-0.04	-0.04	+ 6.9
	+20%*	-0.45	+0.01	+0.04	+0.04	- 6.6
Maximum Algae Growth Rate	-20%**	-0.64	+0.01	+0.06	+0.05	-10.2
	+20%*	+0.93	+0.01	-0.05	-0.04	+ 8.3

*Maximum charge may be limited by instream dissolved oxygen going to zero.

**Steady state solution not fully converged.

Table H-2 (continued)

Sensitivity Analysis Results

Maximum Change in Parameter

Parameter Altered	Change in Parameter	DO (mg/l)	BOD$_5$ (mg/l)	Ammonia (mg/l)	Nitrate (mg/l)	Chl-A (ug/l)
Algae Death Rate	-20%*	+2.19	+0.01	-0.06	-0.08	+49.2
	+20%**	-0.51	+0.01	+0.02	+0.04	- 8.4
Organic Nitrogen Settling Rate	-20%	-0.01	+0.01	0.00	0.00	+ 0.1
	+20%	-0.01	+0.01	0.00	0.00	- 0.1
Organic Nitrogen Recycle Rate Per Algae	-20%*	-0.67	+0.01	+0.21	+0.28	+ 1.7
	+20%	-0.06	+0.01	+0.03	+0.02	+ 1.1
Organic Nitrogen Recycle Rate Indep. of Algae	-20%	+0.01	+0.01	0.00	0.00	- 0.1
	+20%	0.00	+0.01	0.00	0.00	+ 0.1
Ammonia Nitrification Rate	-20%	+0.07	+0.01	+0.02	-0.01	+ 0.5
	+20%	-0.08	+0.01	-0.02	+0.01	- 0.4
Nitrite Nitrification Rate	-20%	-0.01	+0.01	0.00	0.00	0.0
	+20%	-0.01	+0.01	0.00	0.00	+ 0.1
Headwater DO	-20%	-1.27	0.00	0.00	-0.01	- 0.1
	+20%	+1.27	0.00	0.00	+0.01	+ 0.1
Headwater Slow Term BOD5	-20%	+0.06	-0.12	0.00	0.00	0.00
	+20%	-0.06	+0.12	0.00	0.00	0.00
Headwater Algae	-20%	+0.11	0.00	-0.01	+0.01	- 3.9
	+20%	-0.12	0.00	+0.01	-0.01	+ 3.8
Headwater Ammonia	-20%	+0.01	0.00	0.00	0.00	0.0
	+20%	-0.01	0.00	0.00	0.00	0.0

*Maximum change may be limited by instream dissolved oxygen going to zero.

**Steady state solution not fully converged.

Table H-2 (continued)

Sensitivity Analysis Results

Maximum Change in Parameter

Parameter Altered	Change in Parameter	DO (mg/l)	BOD_5 (mg/l)	Ammonia (mg/l)	Nitrate (mg/l)	Chl-A (ug/l)
Headwater Nitrite	-20%	0.00	0.00	0.00	0.00	0.0
	+20%	0.00	0.00	0.00	0.00	0.0
Headwater Nitrate	-20%	0.00	0.00	0.00	-0.03	-0.1
	+20%	0.00	0.00	0.00	+0.03	+0.1
Headwater Organic Nitrogen	-20%	+0.08	0.00	-0.02	-0.02	-1.3
	+20%	-0.07	0.00	+0.02	+0.02	+1.0
Headwater Phosphorus	-20%	-0.11	0.00	+0.01	+0.01	-0.9
	+20%	+0.10	0.00	0.00	-0.01	+0.8
Solar Radiation	300 langleys*	-0.72	+0.01	+0.06	+0.06	-11.7
	400 langleys	-0.26	+0.01	+0.02	+0.02	-3.5
	500 langleys	+0.29	+0.01	-0.02	-0.01	+3.0
	600 langleys**	+0.77	+0.01	-0.05	-0.03	+7.2
Algae Settling Rate	-20%	0.00	+0.01	0.00	0.00	+0.3
	+20%	-0.02	+0.01	0.00	0.00	-0.2
Tributary & Runoff DO	-20%	-0.02	0.00	0.00	0.00	0.0
	+20%	+0.03	0.00	0.00	0.00	0.0
Tributary & Runoff Phosphorus	-20%	0.00	0.00	0.00	0.00	0.0
	+20%	0.00	0.00	0.00	0.00	0.0
Tributary & Runoff Organic Nitrogen	-20%	0.00	0.00	0.00	0.00	0.0
	+20%	0.00	0.00	0.00	0.00	0.0
Tributary & Runoff Nitrate	-20%	-0.03	0.00	0.00	-0.01	-0.4
	+20%	+0.03	0.00	0.00	+0.01	+0.3
Tributary & Runoff Ammonia	-20%	0.00	0.00	0.00	0.00	0.0
	+20%	0.00	0.00	0.00	0.00	0.0
Tributary & Runoff Flow	-20%	-0.07	+0.05	0.00	-0.01	-0.3
	+20%	+0.05	-0.04	0.00	+0.01	-0.2 to +0.2

* Maximum change may be limited by instream dissolved oxygen going to zero.

**Steady state solution not fully converged.

Table H-2 (continued)

Sensitivity Analysis Results

Maximum Change in Parameter

Parameter Altered	Change in Parameter	DO (mg/l)	BOD_5 (mg/l)	Ammonia (mg/l)	Nitrate (mg/l)	Chl-A (ug/l)
Tributary & Runoff BOD5	-20%	+0.02	-0.01	0.00	0.00	0.0
	+20%	-0.02	+0.01	0.00	0.00	0.0
Tributary & Runoff Algae	-20%	0.00	0.00	0.00	0.00	-0.1
	+20%	0.00	0.00	0.00	0.00	+0.1
Consolidated Papers Phosphorus	-20%	-0.02	+0.01	0.00	0.00	-0.2
	+20%	+0.01	+0.01	0.00	0.00	+0.2
Consolidated Papers Organic Nitrogen	-20%	-0.01	+0.01	0.00	0.00	0.0
	+20%	-0.01	+0.01	0.00	0.00	0.0
Consolidated Papers Nitrate	-20%	-0.01	+0.01	0.00	0.00	0.0
	+20%	-0.01	+0.01	0.00	0.00	0.0
Consolidated Papers Ammonia	-20%	0.00	+0.01	-0.01	0.00	0.0
	+20%	-0.02	+0.01	+0.01	0.00	+0.1
Consolidated Papers BOD	-20%	+0.68	-1.13	-0.02	+0.02	+0.2
	+20%	-0.68	+1.13	+0.02	-0.02	-0.2
Nekoosa Paper Company Phosphorus	-20%	-0.06	+0.01	0.00	0.00	-0.6
	+20%	+0.05	+0.01	0.00	0.00	+0.6
Nekoosa Paper Company Organic Nitrogen	-20%	-0.01	+0.01	0.00	0.00	0.0
	+20%	-0.01	+0.01	0.00	0.00	+0.1
Nekoosa Paper Company Nitrate	-20%	-0.01	+0.01	0.00	0.00	+0.1
	+20%	-0.01	+0.01	0.00	0.00	+0.1
Nekoosa Paper Company Ammonia	-20%	+0.01	+0.01	-0.02	-0.01	-0.1
	+20%	-0.03	+0.01	+0.03	+0.01	+0.4
Nekoosa Paper Company BOD	-20%	+0.70	-0.83	-0.02	+0.02	+0.2
	+20%*	-0.57	+0.84	+0.02	-0.02	-0.1

*Maximum change may be limited by instream dissolved oxygen going to zero.

Appendix I

This appendix contains the flow-temperature matrices (tables I-2 through I-4) described in the seventh chapter. The horizontal row at the top is the flow boundaries while the vertical column at the left is the temperature boundaries. All of the matrices are for measurements just below the Wisconsin Rapids Dam. The years of data are 1958-1978. The flow data was obtained from the United States Geological Survey's flow gaging station. The temperature data was obtained from a regression equation developed to convert data from Weston Power near Rothschild to equivalent values at Biron. The entries in each matrix are the percentage of time that particular range of flow and temperature conditions occurred during the indicated months. The total number of observations are listed in Table I-1.

Table I-1

Total Observations by Period for 1958-1978

Month	Number*
May-June	1251
July-August	1234
September-October	1240

*Thirty, sixty-eight, and forty-one days omitted due to artificial low flows brought on by mill shutdown and resultant storage in Lake DuBay and Biron Flowage.

Table I-2
Segment D Flow-Temperature
Percentage of Time occurring at Centralia Dam
May-June 1958-1978

Flow Range	0- 999	1000 1199	1200 1499	1500 1999	2000 2499	2500 2999	3000 3999	4000 More
Temp. Range								
69.0-89.0	.0	.0	.5	3.4	3.3	6.8	12.7	12.9
65.0-68.9	.0	.0	.0	.7	1.4	1.0	5.0	11.1
61.0-64.9	.0	.0	.0	.1	1.0	.8	3.3	10.9
57.0-60.9	.0	.0	.0	.0	.2	.6	1.6	8.3
53.0-56.9	.0	.0	.0	.0	.1	.6	1.0	7.9
49.0-52.9	.0	.0	.0	.0	.1	.0	.1	3.8
30.0-48.9	.0	.0	.0	.0	.0	.0	.0	1.0

Table I-3
Segment D Flow-Temperature
Percentage of Time occurring at Centralia Dam
July-August 1958-1978

Flow Range	0- 999	1000 1199	1200 1499	1500 1999	2000 2499	2500 2999	3000 3999	4000 More
Temp. Range								
77.0-89.9	.0	.0	1.0	5.3	9.2	7.9	7.4	3.5
73.0-76.9	.0	.2	1.0	4.9	7.9	10.5	12.7	4.4
69.0-72.9	.0	.2	2.2	2.2	2.6	3.7	3.4	1.5
65.0-68.9	.0	.1	.1	.7	.3	.4	.4	.4
61.0-64.9	.0	.0	.0	.0	.0	.0	.0	.2
30.0-60.9	.0	.0	.0	.0	.0	.0	.0	.0

Table I-4
Segment D Flow-Temperature
Percentage of Time occurring at Centralia Dam
September-October 1958-1978

Flow Range	0- 999	1000 1199	1200 1499	1500 1999	2000 2499	2500 2999	3000 3999	4000 More
Temp. Range								
73.0-89.9	.0	.0	.0	.2	.5	.7	1.2	2.3
69.0-72.9	.0	.0	.5	.8	1.5	1.9	3.1	2.1
65.0-68.9	.0	.6	.4	1.2	3.5	2.9	2.8	3.5
61.0-64.9	.0	.4	.0	2.5	2.5	2.6	3.2	5.9
57.0-60.9	.0	1.0	.0	.2	3.4	1.9	4.7	4.3
53.0-56.9	.0	.7	.0	6.6	3.1	2.4	4.7	4.7
49.0-52.9	.0	.2	.0	.2	2.0	3.0	3.9	3.1
45.0-48.9	.1	.6	.0	.2	.6	1.6	1.3	2.0
30.0-44.9	.0	.4	.0	.0	.4	.8	.6	1.1