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

SEGMENT BC

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ABSTRACT

The Wisconsin River from Brokaw, Wisconsin to Lake Dubay Dam has been designated as Segment BC of the Wisconsin River. Segment BC has been modeled using a finite difference water quality model known as QUAL III. QUAL III is an extensive modification of QUAL II which was developed by Water Resources Engineering, Inc. 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 model 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 twelve additional synoptic water quality surveys. The surveys covered the years 1973-1981 and generally fell in the annual low flow periods. Wasteload allocations based on modeling results have been developed for the four major dischargers on this river segment.

FORWARD

This report is the culmination of ten years of effort to develop wasteload allocations for water quality limited segments and seasons on Segment BC 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 and verification of the model, and a sensitivity analysis of the calibrated 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 model. 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

Brokaw to Lake Dubay

The Wisconsin River between Brokaw an Lake Dubay is 35 miles long and flows past the following communities: Brokaw, Wausau, Schofield, Rothschild, Weston, Mosinee, and Knowlton. This reach has been designated Segment BC of the Upper Wisconsin River (UWR). There are four hydropower dams (Wausau, Rothschild, Mosinee, and Lake Dubay) that are owned by paper companies or utility corporations in this reach. The drainage area above Lake Dubay Dam is 4,900 square miles. The general setting can be seen in Figures 1 and 2.

The Big Rib, Big Eau Pleine, Little Eau Pleine, and Eau Claire Rivers are the major tributaries discharging into this segment. These tributaries account for 1,462 square miles of drainage area or 37% of the basin above Lake Dubay Dam. In the Big Eau Pleine watershed, the Wisconsin Valley Improvement Company (WVIC) operates a 7,000-acre impoundment containing 4.5 billion cubic feet of storage. The Big Eau Pleine Reservoir is one of 21 reservoirs or raised lakes in the UWR basin that are used to provide flow augmentation and flood control of the Wisconsin River. The total summer reservoir capacity controlled by WVIC in the UWR basin is 15.6 billion cubic feet.

The river profile from Brokaw to Lake Dubay drops about two feet per mile. The river velocity is generally slow, as the result of the four mainstream impoundments. Lake Wausau and Lake Dubay are the largest impoundments and also receive the greatest amount of recreational use. The surface area and mean hydraulic retention times of these impoundments are listed in Table 1. A United Stated Geological Survey stream gaging station is located below Rothschild Dam. The drainage area above this station is 4,020 square miles. The average river flow at this site is 3,447 cfs with maximum river flow of 49,200 cfs and minimum river flow of 670 cfs. The $Q_{7,10}$ for the Rothschild site is 950 cfs.

Table 1
Impoundment Characteristics for Segment BC of the Wisconsin River

Impoundment	Surface Area (acres)	Mean Hydraulic Retention Time (days)
Wausau Flowage	304	1.0
Lake Wausau	1,918	2.0
Mosinee Flowage	1,377	1.4
Lake Dubay	7,052	9.8

The major point source pollution loading to the BC river segment results from the discharge of three pulp and paper mills (Wausau Paper Mills Company, Weyerhaeuser Company, and Mosinee Paper Corporation), one chemical industry (Reed Lignin, formerly American Can Company), and one major municipality (Wausau). One minor industrial discharge (Foremost Foods) and three small municipal sewage treatment plans (Brokaw, Rothschild and Mosinee) also discharge wastewaters to Segment BC of the Wisconsin River.

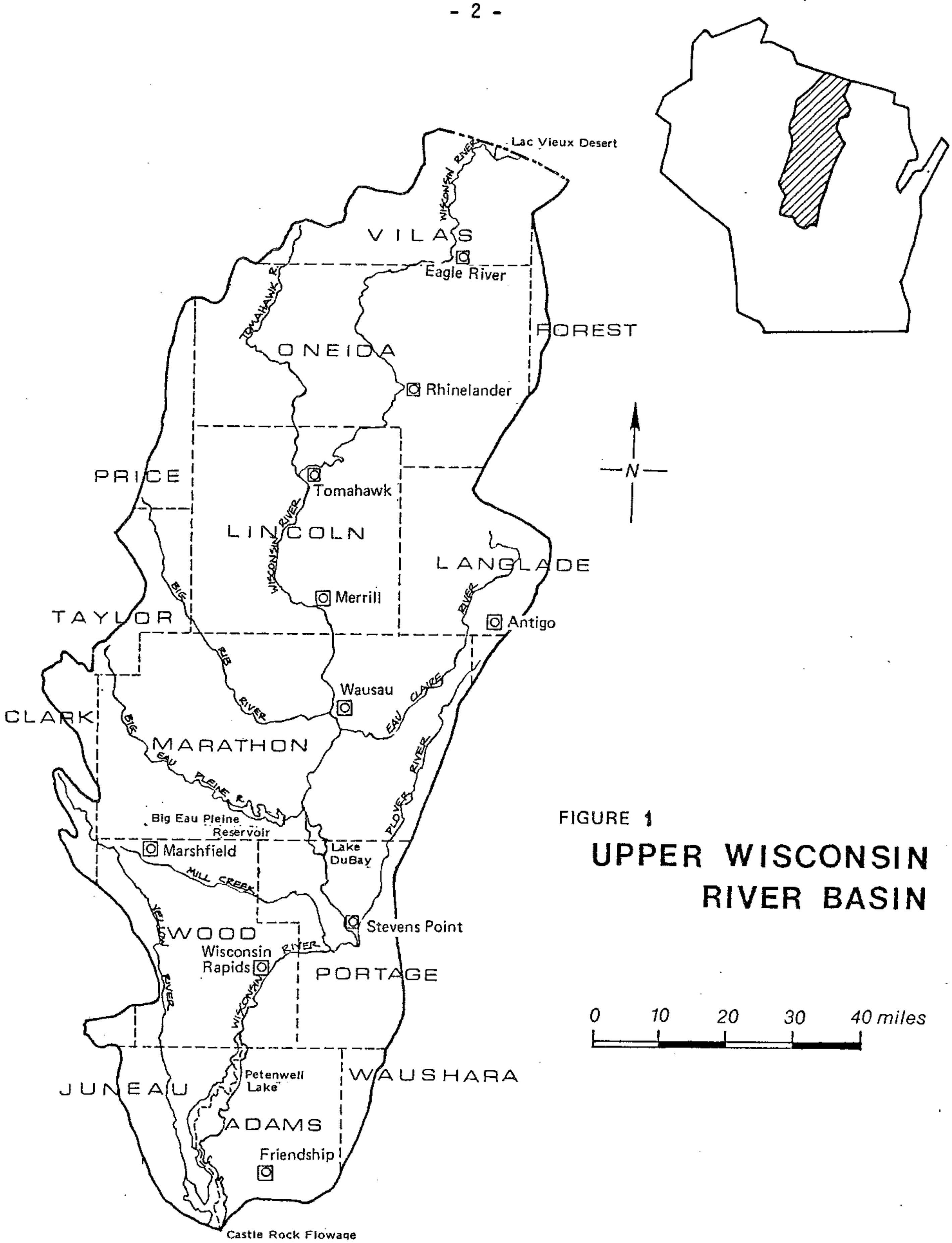


FIGURE 1

UPPER WISCONSIN RIVER BASIN

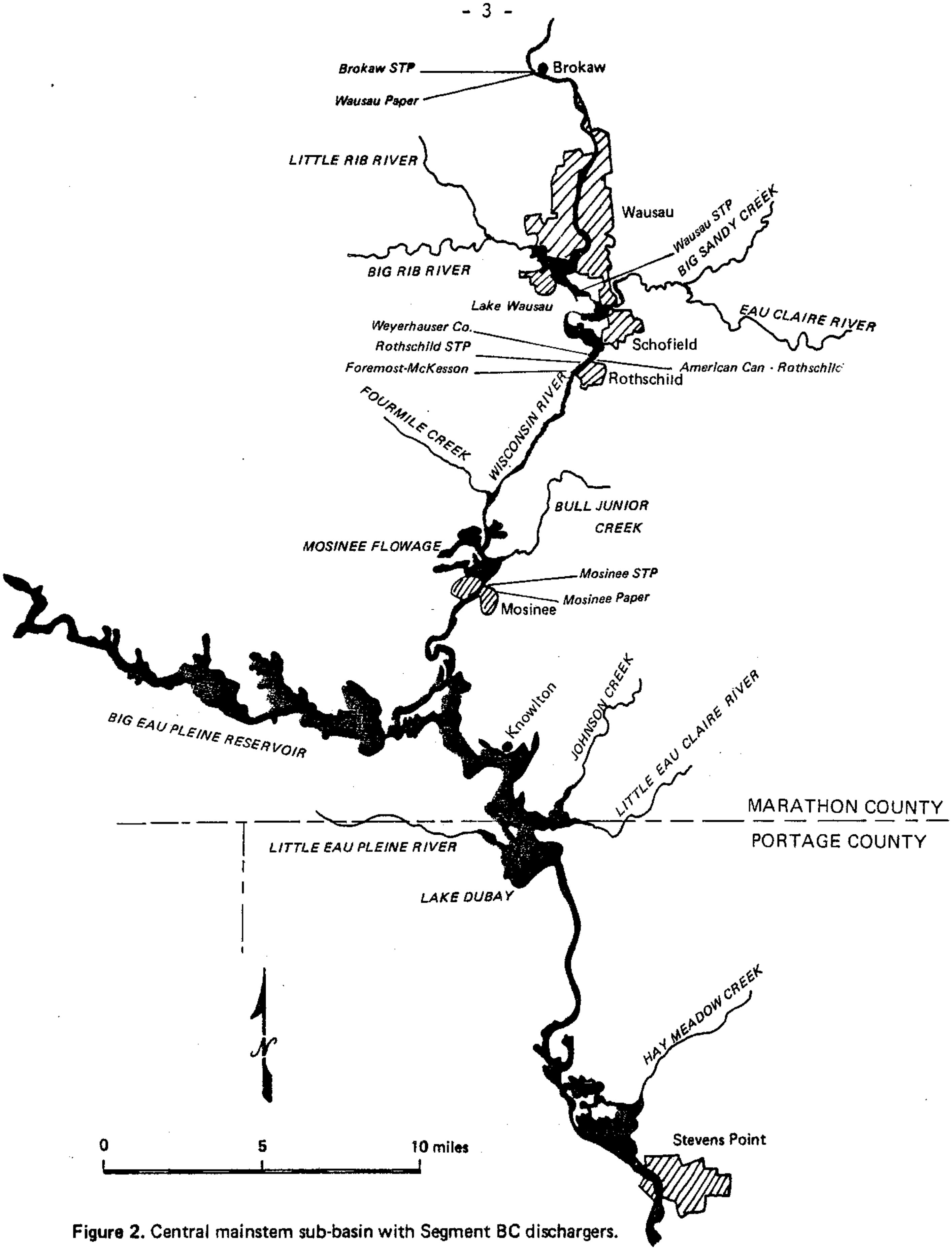


Figure 2. Central mainstem sub-basin with Segment BC dischargers.

Continuous automatic water quality monitoring stations are located at Wausau Dam, Mosinee Dam, and Lake Dubay Dam. These stations have been operating since 1972 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 above Wausau Dam, above Mosinee Dam and near the inflow to Lake Dubay.

Nonpoint source pollution may influence the water quality of the Wisconsin River during certain periods. The greatest nonpoint source pollution loading occurs during the spring, typically the high flow periods of the year. The nonpoint source pollution loading arises from large agricultural watersheds (Big Rib, Big Eau Pleine, and Eau Claire) within the BC river segment, where dairy farming and cheese making are the dominant agricultural activities. Agricultural runoff from these watersheds provides a major contribution of nitrogen and phosphorus loading to the Wisconsin River. Snowmelt runoff of oxygen demanding materials from these agricultural watersheds has been responsible for depressed dissolved oxygen levels in the Wisconsin River during some spring snowmelt periods. The Wisconsin River also receives a considerable algae loading at the inflow to Lake Dubay as a result of reservoir release from the eutrophic Big Eau Pleine Reservoir.

The major water quality problems in Segment BC are associated with depressed oxygen levels, particularly during low flow periods. Summer oxygen levels were often less than one mg/l in the river reach between Rothschild and Lake Dubay prior to categorical treatment requirements (BPT) imposed on the pulp and paper industry in 1977. Severe dissolved oxygen problems have also occurred during the winter. In the winter of 1976-1977, low flow conditions, in combination with high point source BOD loading, resulted in a massive fish kill in the Wisconsin River. An illustration of this fish kill is presented in Figure 3. By 1977, most industries had secondary treatment, and this resulted in a marked reduction in BOD and suspended solids loading to the river. Sometimes, these systems did not operate as effectively as planned, and improvements had to be made. An example was the addition of a foam trap that was placed in Weyerhaeuser's effluent channel prior to their discharge to the river in order to reduce instream foaming. An illustration of the foaming problem prior to the construction of the foam trap is also presented in Figure 3.

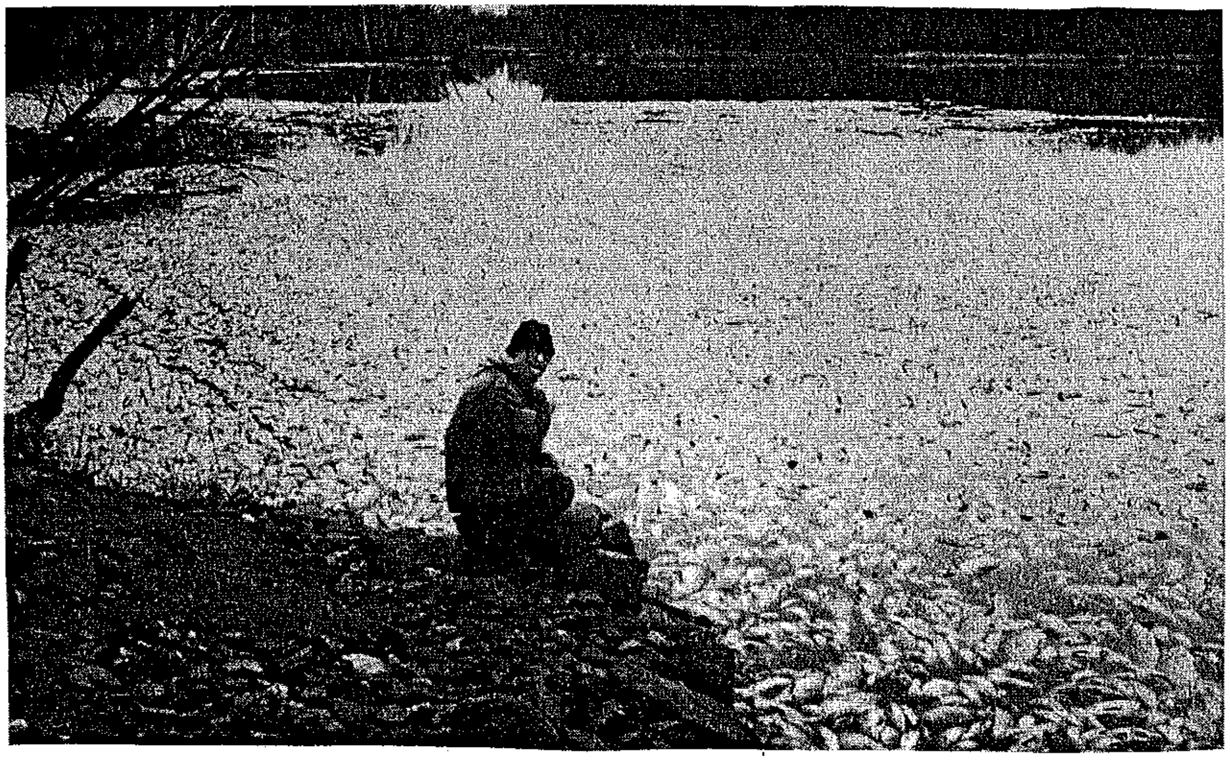
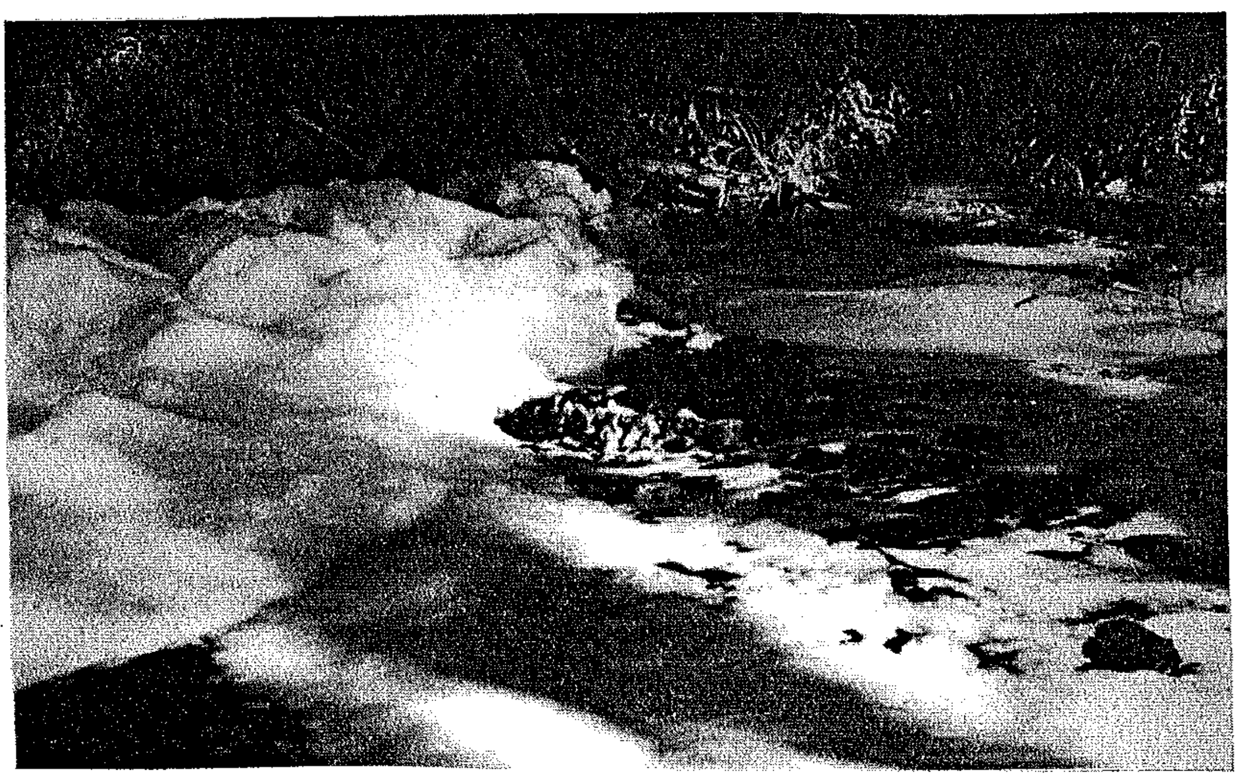


Figure 3

Past pollution problems of the Wisconsin River. Above, a fishkill during the winter of 1976-77 and, below, foaming below the Weyerhaeuser Company discharge prior to installment of a foam trap.



II. MODEL SYNTHESIS

A. Introduction

The original QUAL II model contained several problems that became apparent along the development route. These problems were painstakingly overcome before the model arrived at its present state. Because the model and its data requirements changed somewhat during the development, it is necessary to describe the kinetics the model uses in this report. A more technical account of the model kinetics can be found in the most recent QUAL III documentation called "QUAL III Water Quality Model Documentation". It is available from the Water Quality Evaluation Section of the Wisconsin DNR.

The development process took place between 1975 and 1978. During this period, data was continually being collected for use with the model. Stream surveys were taken every summer from 1973 through 1981 during the annual low flow period. Stream surveys were also made during the winters and springs of 1975, 1978 and 1979. In addition, miscellaneous data was collected including SOD using an instream bell jar technique and algae growth using a light and dark bottle technique. Effluent samples were collected for specific laboratory analysis including long-term 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

Any model by definition is a simplification of reality constructed to duplicate the most essential features of the prototype system. The QUAL III model, being no exception to this definition, 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 implies 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 in a logical fashion to arrive at a mathematical solution which matches the observed system over the range of conditions that are of interest. The reaction mechanisms are developed from research or theory and depend on our current understanding of aquatic environments.

The second point is the more difficult of the two. 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 decay rate may not be the same. 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 interpretating data but particular care must be used when dealing with measurements of rates.

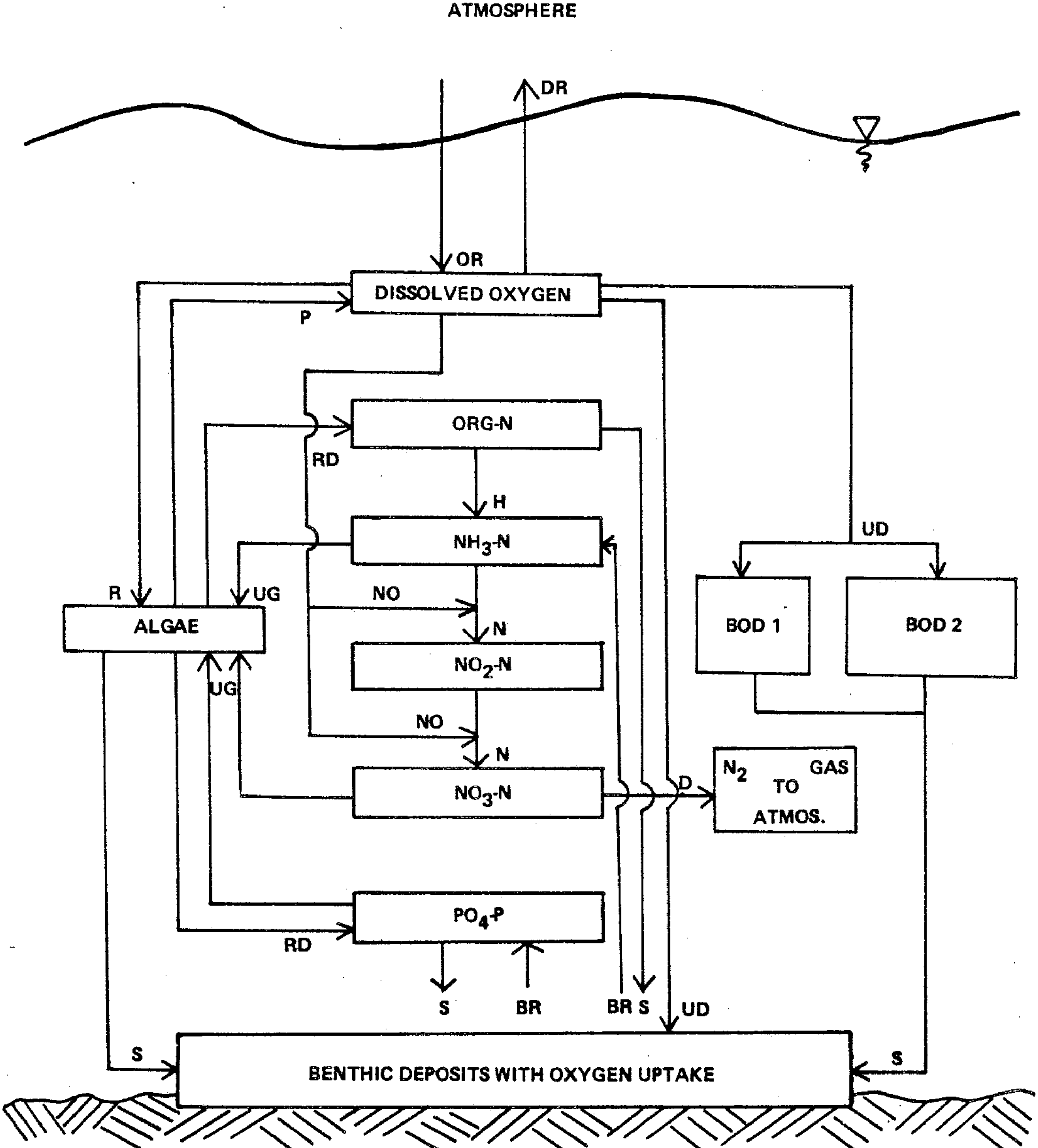
Model simulation becomes a particularly powerful tool for describing complex interactions and rates of transformation. The calibration of a model can be used to determine the rate coefficients to reproduce the observed data. If the model is calibrated to several sets of observations, the choice of coefficients 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 4 . 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 to ferrous iron ion.

Biological demand is the most prevalant 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 autotrophic bacteria feeding on the organic

FIGURE 4

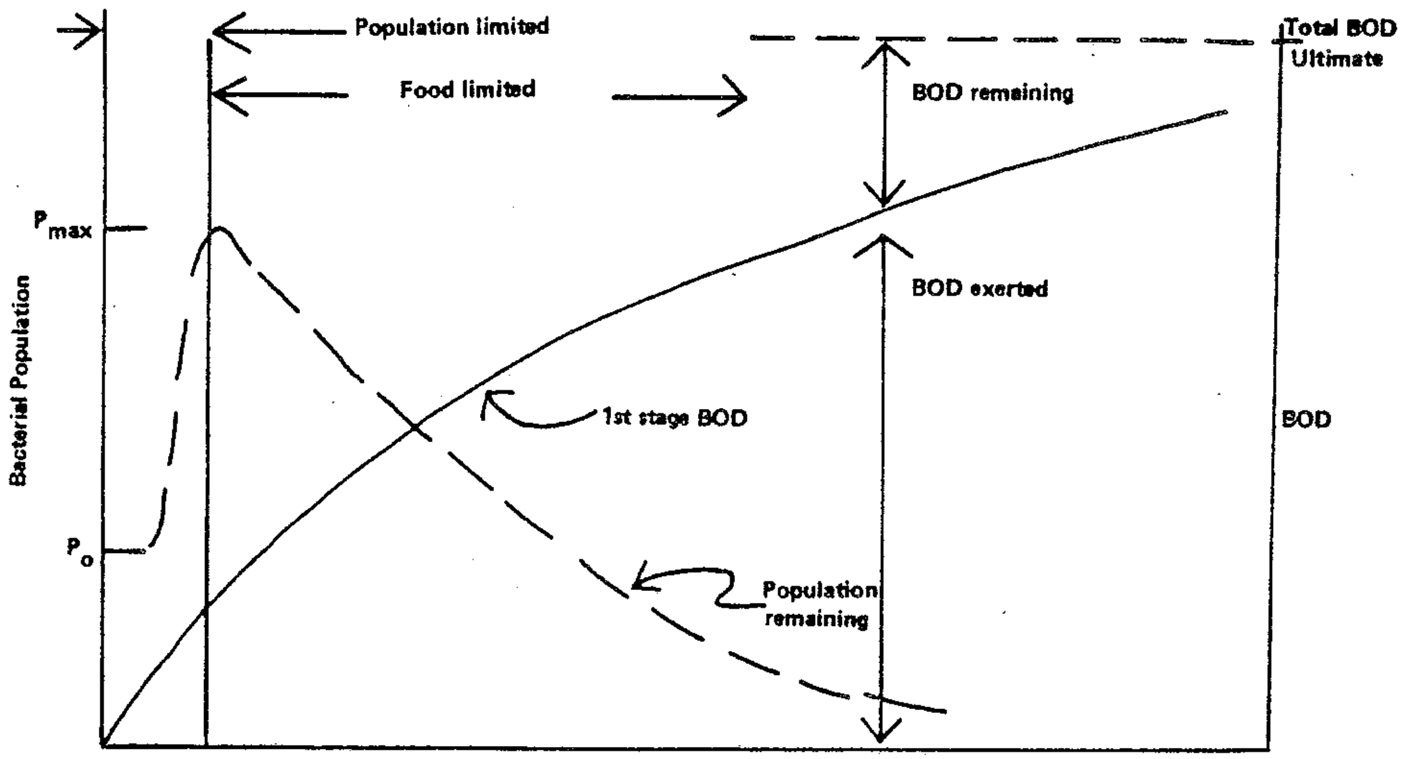


S	— Settling	UD	— Uptake of Oxygen From Decay
D	— Denitrification	UG	— Utilization for Growth
N	— Nitrification	P	— Photosynthesis
NO	— Nitrification Oxygen Uptake	R	— Respiration
BR	— Benthic Release	RD	— Release from Respiration and Mortality
OR-DR	— Oxygen Reaeration or Deaeration	H	— Hydrolysis

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.

The biological oxygen demand is determined by the rate at which a bacterial population consumes the available organic material. 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 5 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 5

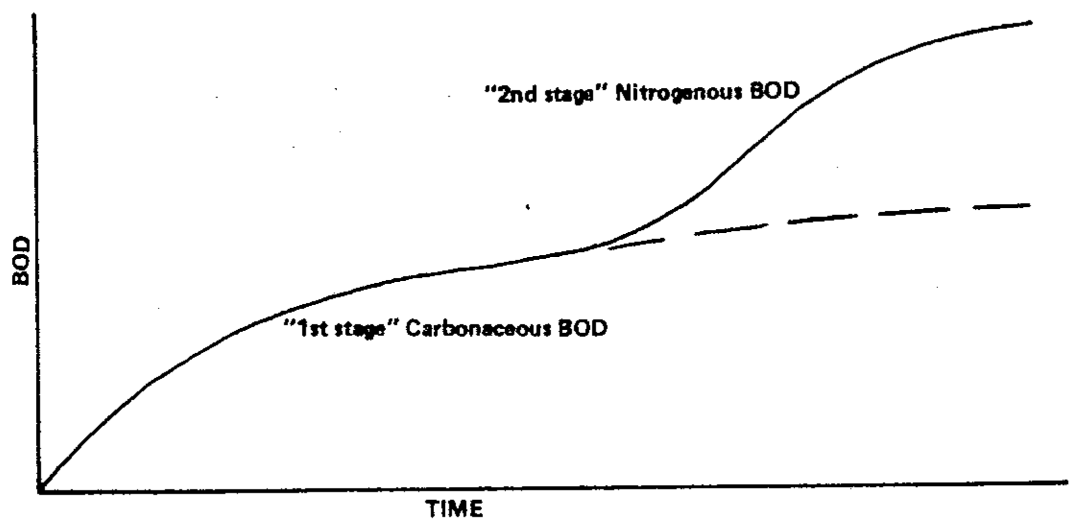


The initial population of bacteria (Po) quickly grows to the maximum population (Pmax) that the available food will allow. From that point on the remaining food determines the bacterial population.

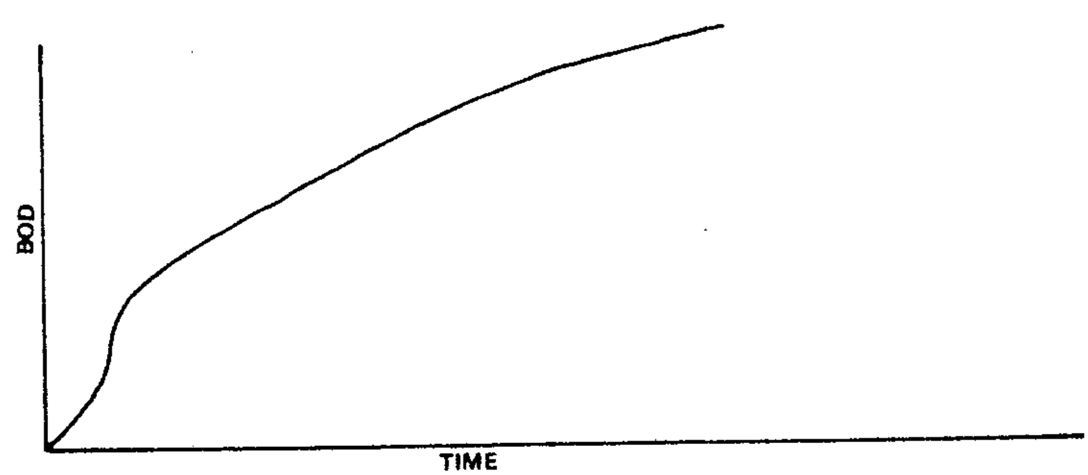
The amount of BOD in a waste stream is typically measured in a standardized five day test. The result of the test is referred to as BOD_5 and is given as a concentration of oxygen demand in milligrams per liter (same as parts per million). Most effluents are routinely measured for oxygen demand in this 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 carbonacous BOD, the latter nitrogenous BOD. Nitrogenous BOD is typically exerted after the carbonaceous portion is well under way since the autotrophic 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 autotrophic bacteria by chemical addition in the BOD test. At present, one of the best ways 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 rate. 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.

FIGURE 6



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



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 6 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 if particulate carbonaceous oxygen demanding material may be filtered out in addition to the algae.

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 that 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 a full amount of carbonaceous BOD entering the system.

The analysis of the longterm BOD curves is a multi-step procedure that typically involves an analysis of total, filtered 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. The filtered sample is used to determine the percentage of the BOD that is removed with the solids. Figures 7 to 9 are typical examples of total and inhibited longterm BODs.

Figures 7 and 8 show the total BOD curves. From the figures we can see that nitrification began on about the 8th 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 BOD equation that assumes both BOD terms are acting simultaneously. The equation representing this is of the form:

FIGURE 7

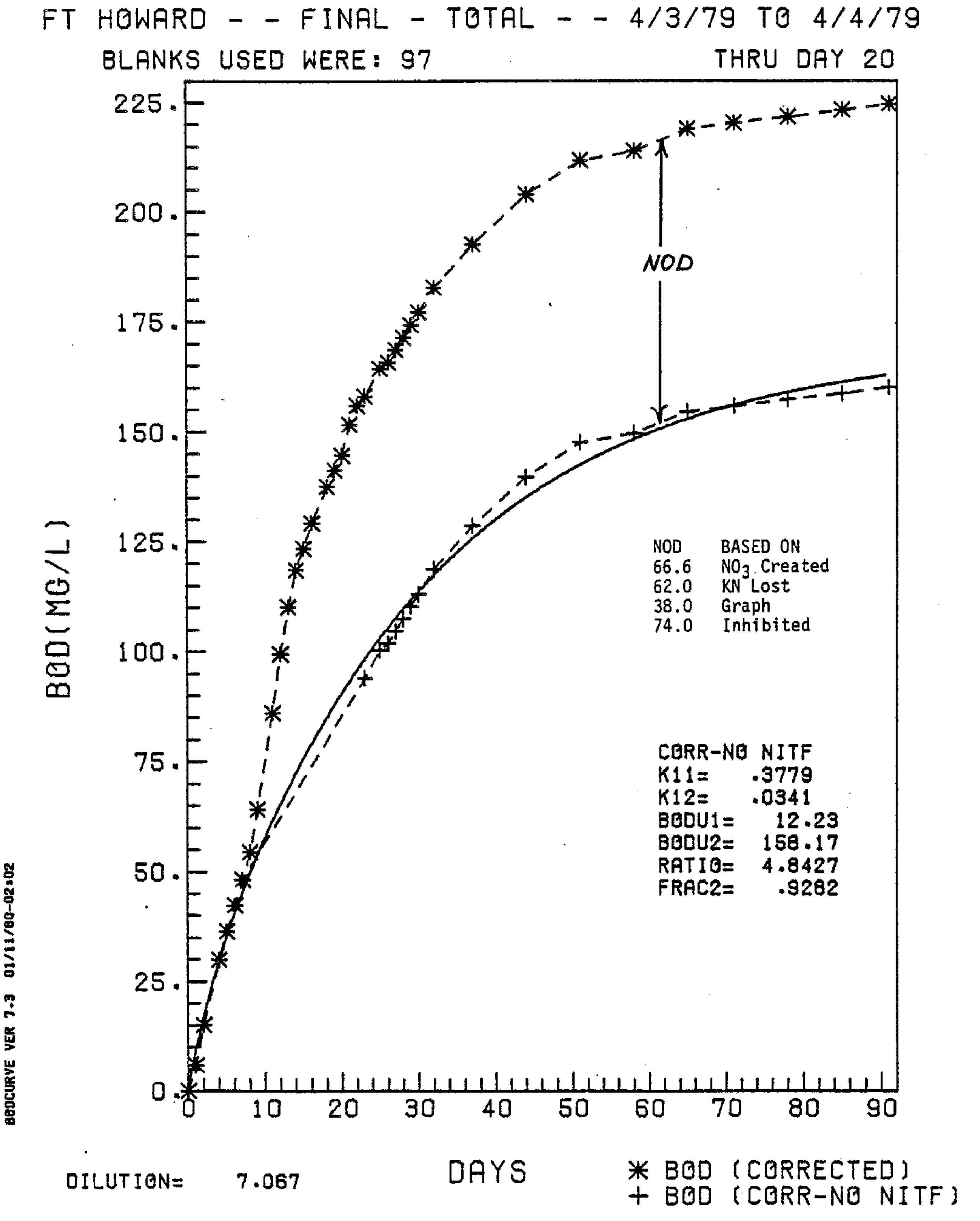

FT HOWARD - - FINAL - TOTAL - - 4/3/79 TO 4/4/79
BLANKS USED WERE: 97
THRU DAY 20
BOD(MG/L)
225.
200.
175.
150.
125.
100.
75.
50.
25.
0.
0
10
20
30
40
50
60
70
80
90
DAYS
NOD
NOD BASED ON
66.6 NO3 Created
62.0 KN Lost
38.0 Graph
74.0 Inhibited
CORR-NO NITF
K11= .3779
K12= .0341
BODU1= 12.23
BODU2= 158.17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

FIGURE 8

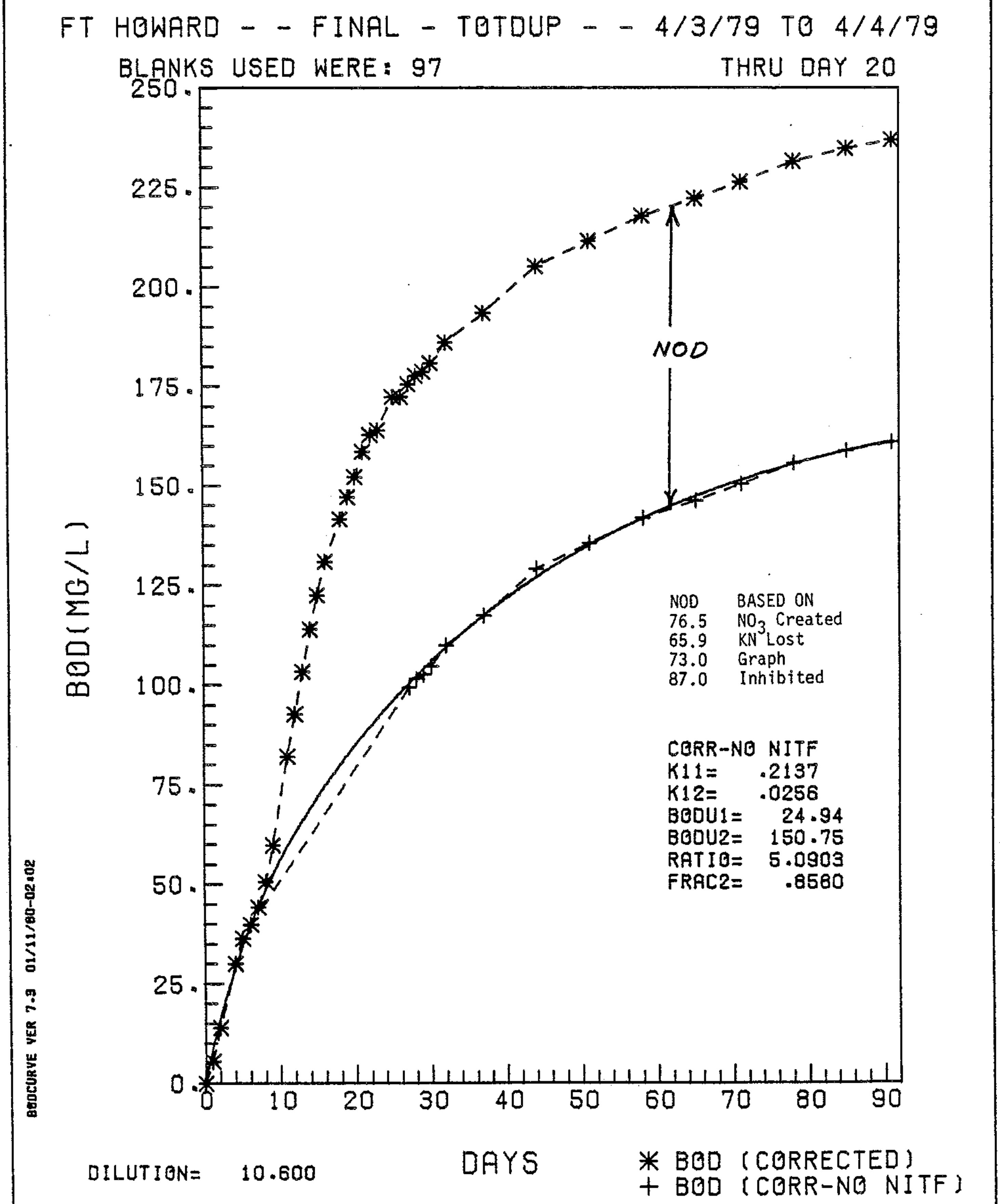
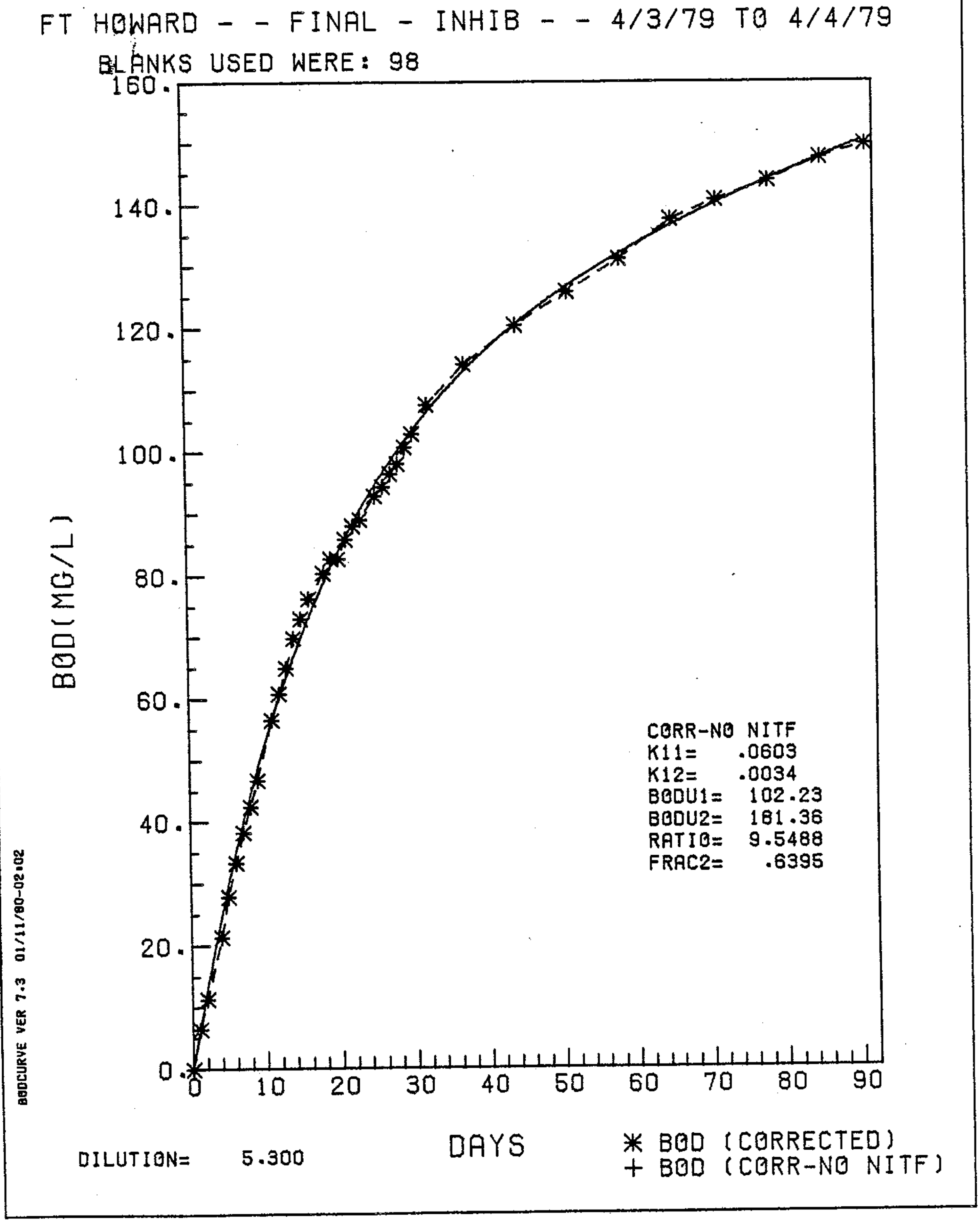

FT HOWARD - - FINAL - TOTDUP - - 4/3/79 TO 4/4/79
BLANKS USED WERE: 97
THRU DAY 20
BOD(MG/L)
250.
225.
200.
175.
150.
125.
100.
75.
50.
25.
0.
0
10
20
30
40
50
60
70
80
90
DAYS
NOD
NOD BASED ON
76.5 NO3 Created
65.9 KN Lost
73.0 Graph
87.0 Inhibited
CORR-NO NITF
K11= .2137
K12= .0256
BODU1= 24.94
BODU2= 150.75
RATIO= 5.0903
FRAC2= .8560
BODCURVE VER 7.3 01/11/80-02:02
DILUTION= 10.600
✳ BOD (CORRECTED)
+ BOD (CORR-NO NITF)

FIGURE 9


FT HOWARD - - FINAL - INHIB - - 4/3/79 TO 4/4/79
BLANKS USED WERE: 98
BOD(MG/L)
DAYS
0.
20.
40.
60.
80.
100.
120.
140.
160.
0
10
20
30
40
50
60
70
80
90
CORR-NO NITF
K11= .0603
K12= .0034
BODU1= 102.23
BODU2= 161.36
RATIO= 9.5488
FRAC2= .6395
DILUTION= 5.300
* BOD (CORRECTED)
+ BOD (CORR-NO NITF)
BODCURVE VER 7.3 01/11/80-02:02

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

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 9 is outlined in Appendix B. The three curves 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 three 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 long-term test) to the reported BOD_5, 3) the fraction of the ultimate that is in the "slow term" of the ultimate BOD 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 in Segment BC of the Wisconsin River in the model for calibration and verification purposes.

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 segment 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 all 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. Since allowing the settling of BOD to create SOD only affected the location of the exerted oxygen demand and not the quantity, the total amount of oxygen sag was not substantially affected. The model proved to be insensitive to the rate of BOD settling as will be shown in a later section.

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 phosphorus is essentially in equilibrium with the overlaying water. Therefore, neither phosphorus settling nor release were used. It must be noted that some phosphorus is allowed to reach 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 for that matter) to the river bottom.

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 decay to nitrite also uses 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.

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

Discharger	Parameter	July 11-12 1973	Aug. 23 1973	July 16-17 1974	Aug. 17 1975	Aug. 16-17 1976	Oct. 10-12 1976	June 22-24 1977	Aug. 17-18 1977	June 27-28 1978	Aug. 14-15 1978	July 16-18 1979	Aug. 6-7 1979	Aug. 27-28 1979	Used for WLA Runs**
WWausau Paper	BOD_5 (lb/day)	69,678	22,981	76,688	26,633	25,912	29,101	16,999	11,701	17,555	7,309	5,181	3,994	4814	
	BOD_u/BOD_5	1.5	1.5	1.5	1.5	1.5	1.5	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7
	Fraction in Slow Term	0.2	0.2	0.2	0.2	0.2	0.2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Wausau Paper (Disposal Well)	BOD_5 (lb/day)	0	0	963	229	796	796	116	175	31	0	0	0	0	145
	BOD_u/BOD_5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	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	0.2
Brokaw STP	BOD_5 (lb/day)	11	11	4	3	3	3	5	2	3	3	4	3	3	18
	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	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	0.4
Wausau Paper (Barrier Well)	BOD_5 (lb/day)	97	97	161	101	64	64	42	42	14	30	37	0	0	81
	BOD_u/BOD_5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	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	0.2
Wausau STP	BOD_5 (lb/day)	2508	2373	1823	1903	694	694	1402	1548	1727	961	1178	1367	1408	2303
	BOD_u/BOD_5	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
	Fraction in Slow Term	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
American Can	BOD_5 (lb/day)	*	*	*	*	*	*	*	*	997	475	473	3694	1092	
	BOD_u/BOD_5									2.0	2.0	2.0	2.0	2.0	2.0
	Fraction in Slow Term									0.4	0.4	0.4	0.4	0.4	0.4
Weyerhaeuser	BOD_5 (lb/day)	69,982	71,760	74,812	55,455	74,838	78,145	7675	7572	3358	3197	3360	6200	9213	
	BOD_u/BOD_5	1.8	1.8	1.68	1.65	1.64	1.64	9.8	8.4	11.0	11.0	11.0	11.0	11.0	11.0
	Fraction in Slow Term	0.45	0.45	0.48	0.49	0.49	0.49	0.98	0.98	0.99	0.99	0.99	0.99	0.99	0.99
Rothschild STP	BOD_5 (lb/day)	231	231	122	30	135	111	37	252	354	214	154	296	375	
	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	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	0.4

*American Can Company had a combined discharged with Weyerhaeuser Company.
**Only those industrial facilities with a baseline load greater than 600 lb/day are subject to a wasteload allocation.

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

Discharger	Parameter	July 11-12 1973	Aug. 23 1973	July 16-17 1974	Aug. 17 1975	Aug. 16-17 1976	Oct. 10-12 1976	June 22-24 1977	Aug. 17-18 1977	June 27-28 1978	Aug. 14-15 1978	July 16-18 1979	Aug. 6-7 1979	Aug. 27-28 1979	Used for WLA Runs*
Foremost Foods	BOD_5 (lb/day)	65	65	47	31	31	31	515	23	97	66	89	129	252	248
	BOD_u/BOD_5	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8
	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	0.4
Mosinee Paper	BOD_5 (lb/day)	5436	10,694	11,148	8637	15,548	14,561	6911	3691	1747	2121	2279	1502	2134	
	BOD_u/BOD_5	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	3.1	3.1	3.1	3.1	3.1	3.1
	Fraction in Slow Term	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.6	0.6	0.6	0.6	0.6	0.6
Mosinee STP	BOD_5 (lb/day)	259	259	139	41	74	74	22	29	53	57	33	33	56	137
	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	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	0.4
DuBay Foods	BOD_5 (lb/day)	401	401	100	0	0	0	0	0	0	0	0	0	0	0
	BOD_u/BOD_5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	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	0.2
Mullins Cheese	BOD_5 (lb/day)	107	107	0	0	0	0	0	0	0	0	0	0	0	0
	BOD_u/BOD_5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	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	0.2

*Only those industrial facilities with a baseline load greater than 500 lb/day are subject to a wasteload allocation.

The nitrogen cycle is completed by the algae which utilize the inorganic (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 available 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 equations 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 anaerobically, and therefore, not exert an oxygen demand. For the Wisconsin River, it was found the best calibration was obtained if BOD was not settled. In the sensitivity analysis all settled BOD created SOD.

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. The model's mathematically independent equations 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 chosen model. 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, including 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. Measurements for water quality include 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 analysis of the water quality model, such as 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 Brokaw and Lake Dubay Dam 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, then the steady state model run can be used to simulate the river conditions. In addition, the QUAL III model can be run dynamicly 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 42 stations between Brokaw and Lake Dubay Dam. In addition, samples were collected at fewer 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 two consulting firms. 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 Brokaw to Lake Dubay Dam 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 can be found in Appendix C of this report.

Table 3

Water Quality Synoptic Surveys for Segment BC 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	2	August	1979
Mid-State**	1	May	1980
Mid-State**	1	June	1980
Mid-State**	1	July	1980
Mid-State**	1	August	1980
Mid-State**	1	September	1980
Mid-State**	1	October	1980
DNR	1	April	1981
DNR	1	October	1981

*Consulting firm
**Mid-State Environmental Consulting, Inc.

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, Centrailia, 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.

Permit Program (WPDES)

Since 1974, municipal and industrial point sources discharging to the State's waters have been controlled by a Wisconsin Pollutant Discharge Elimination System (WPDES) Permit. 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 to insure accurate reporting of pollutant discharges. All of the above information is 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 used 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.

Wisconsin Valley Improvement Company (WVIC)

The WVIC collects daily flow measurements from 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 Data Sources

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, and a station located in Waupaca operated by the DNR (Office of Inland Lake Renewal).

IV. CALIBRATION OF QUAL III ON SEGMENT BC 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. The process is somewhat analogous to tuning a television by using the various controls to get a sharp clear picture on the tube. 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 having 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. The model was then run dynamically for further fine tuning. Steady state runs were compared to daily average dissolved oxygen values as adjusted from time of day measurements. Dynamic runs were compared to actual instantaneous readings taken from the river during the surveys. 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 Brokaw (cfs)	Average Temperature (°F)
July	11-12	1973	1980	72.5-77.0
August	23	1973	2067	67.1-68.9
July	16-17	1974	1869	74.8-77.0
August	17	1975	1400	70.7-74.3
August	16-17	1976	1182	70.7
October	10-12	1976	660	47.0-51.0
June	22-24	1977	1251	70.0-71.6
August	17-18	1977	1050	65.0-69.8

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 BC 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 total 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 long-term BOD analysis were also analyzed for nutrients.

Headwater concentrations were taken directly from field and laboratory data for the most upstream sampling location. Two monthly monitoring stations are located in the Segment BC reach and the several years of data at these locations were used to develop seasonal trends. Accurate flow measurements at the headwaters of Segment BC in Brokaw are not available. The headwater flow is based on flow measurements at Rothschild and at Merrill by the United States Geological Survey, flow estimates at Wausau and Rothschild Dams, and by the Wisconsin Valley Improvement Company. Normally, adjustments allowing for tributary and wasteload flow are made to both the Merrill and Rothschild flows, as measured by USGS, to determine the Brokaw flow. Temperatures in the river are derived from field observations during the survey. Solar radiation data was used from one main source; the U.S. Forest Service experimental station at Rhinelander. Wind speed was taken from either the local weather station, or estimated by the field survey crew, or based on wind measurements made by the National Oceanic and Atmospheric Administration at Marshfield.

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 determined by data collection, 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 DO swings.

During the calibration process it was not possible to calibrate the model using a single set of fast and slow term BOD decay rates. It was found to be possible to calibrate the model if two differing sets of decay rates were used. These varying sets of decay rates have been named warm water decay rates and cold water decay rates. Data sets with river temperatures below 71.5°F use the cold water decay rates while those data sets with river temperatures above 71.5°F use the warm water decay rates. For river temperatures at 71.5°F (as in wasteload allocation development) the average of the results of modeling using the warm water decay rates and the cold water decay rates is used. The only reason for the need of two sets of decay rates is that the calibration of the data sets is better.

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 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 final fine tuning runs were made dynamically. The time of day field measurements were used for comparison to the corresponding time of day values from the dynamic run. The dynamic output and time of day measurements are compared in Appendix E.

The statistics for the comparison of measured DO versus model DO are based on time of day observations. 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 ad Observed Dissolved Oxygen Values in Mg/L for Eight Segment BC Calibration Surveys in Dynamic Mode

Date	Near Wausau Dam Pred.	Near Wausau Dam Meas.	Near Mosinee Dam Pred.	Near Mosinee Dam Meas.	Near Inlet to Lake Dubay Pred.	Near Inlet to Lake Dubay Meas.	All Measurements Pred. - Meas.
Warm Water							
July 11-12, 1973	4.1	4.1	0.5	0.3	1.5	0.4	0.61±0.97
July 16-17, 1974	2.8	3.5	*	*	*	*	*
June 22-23, 1977	**	**	**	**	**	**	0.65±0.60
Cold Water							
Aug. 23, 1973	6.0	6.4	3.6	2.9	3.0	0.7	1.07±0.94
Aug. 17, 1975	4.1	3.5	4.5	1.7	3.3	1.3	2.05±1.16
Aug. 16-17, 1976	3.6	3.2	0.1	1.1	0.1	0.5	-0.81±0.86
Oct. 10-12, 1976	3.5	7.4	0.0	0.9	0.0	0.2	-0.49±2.34
Aug. 17-18, 1977	4.7	4.6	4.4	5.4	4.9	4.8	-0.54±0.57

* Time of day that field measurements were made was not recorded.
**No measurements near indicated location.

The first three sets of double columns are the selected measured and predicted values for each survey following the fine tuning of the dynamic mode. These were taken from the dynamic runs. All survey dates, except July 1974 and August 1973, were run in dynamic mode with daily variation in headwater flow, headwater dissolved oxygen (hourly variation), temperature, and point source loadings. There was insufficient daily discharge data to run the 1973 surveys with daily variation in point source loadings, although flow, dissolved oxygen, and temperature were varied. The July 1974 data set did not have the time of day recorded at which field measurements were made. Due to this, a dynamic comparison is not possible. The column headed "All Measurements" is a comparison of all measurements made during each survey.

Calibration Summary

The QUAL III model was calibrated against eight separate data sets, seven of which could be run dynamically for fine tuning against instantaneous measurements. 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 0.36 mg/l.

Appendix D contains a listing of the various coefficients determined by the calibration process. The coefficients chosen were also used for verification, sensitivity analysis 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 BC of the Wisconsin River over a wide range of conditions. The procedure followed in the calibration of the model was also followed for the verification of the model. That is, the model was run steady state and then dynamically during the days of the synoptic river surveys. Any survey data set that had not been used in the calibration process was available for verification.

Verification Data Sets

Two types of verification data sets have been used. The first type is the synoptic survey date set which is the same in format as those used in the calibration process. These data sets were run in steady state and then dynamicly in order to compare model output with time of day field measurements of the synoptic survey. The second type of verification data set is the data sets which have sufficient water chemistry data available for dynamic operation of the model but either do not have dissolved oxygen measurements made the length of the river or have dissolved oxygen measurements made but had no time recordings. Without time of day information, comparison of measured and predicted dissolved oxygen values have no statistical significance.

This second type of verification survey utilized the dissolved oxygen data collected by the automatic water quality monitors at Wausau Dam, Mosinee Dam and Lake Dubay Dam. In addition, a portable strip chart recording YSI 54 (Yellow Springs Instruments Model 54) dissolved oxygen and temperature monitors were on occasion set up at the inlet to Lake Dubay and the Rothschild 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 BC.

Five data sets of the synoptic survey type and seven dynamic surveys using the automatic monitors were run dynamicly by the QUAL III model. The dates, flows and temperatures of these surveys are listed in Table 6.

Verification Results

Results of the verification runs are located in Appendices F and G. Appendix F contains the results of the dynamic operation of the QUAL III model with comparison to the synoptic survey time-of-day dissolved oxygen measurements. Appendix G contains the results of the QUAL III model dissolved oxygen predictions and measurements made by the automatic monitors and strip chart recorders.

A statistical comparison of the field measurement versus model prediction dissolved oxygen values is given in Tables 7 and 8. Those surveys which are synoptic surveys rely on a single comparison (Table 7) while those surveys which are dynamic surveys rely on a comparison of field versus model dissolved oxygen values every four hours during the simulation period (Table 8). Table 7 is similar in nature to Table 5 and the various columns are described in the preceding chapter. The values listed in Table 8 are the average of predicted minus measured values over the specified period of time.

Table 6
Verification Data - Dates of Occurrence

Survey Date	Steady state Flow at Brokaw (cfs)	Dynamic Flow at Brokaw (cfs)	Temperature Range (°F)
June 27-28, 1978	1940	-	75.0
August 14-15, 1978	2215	-	73.0-75.0
July 16-18, 1979	2800	-	75.0
August 6-7, 1979	1940	-	75.0-77.0
August 27-28, 1979	2320	-	67.0
May 17-25, 1980	-	1196-2512	57.3-73.6
June 17-July 2, 1980	-	1540-4748	65.5-78.8
July 12-August 16, 1980*	-	1194-2809	71.8-81.7
September 2-10, 1980	-	3503-4882	66.9-71.0
October 26, November 3, 1980	-	2610-5170	38.7-47.5
October 1-27, 1981	-	1800-3406	39.1-54.4

*This is actually two data sets which have been strung together into one extra long simulation period.

Table 7
Comparison of Calculated and Observed Dissolved Oxygen Values in Mg/L for Five Segment BC Synoptic Verification Surveys in Dynamic Mode

	Near Wausau Dam		Near Mosinee Dam		Near Dubay Dam		All Measurements
Survey Date	Pred.	Meas.	Pred.	Meas.	Pred.	Meas.	Pred. - Meas.
June 27-28, 1978	5.7	5.3	4.3	3.8	7.2	6.6	0.66 ± 0.66
Aug. 14-15, 1978	7.4	7.7	6.1	6.5	7.5	6.6	0.24 ∓ 0.64
July 16-18, 1979	6.5	6.3	6.2	6.9	7.6	6.1	-0.09 ∓ 0.52
Aug. 6-7, 1979	7.9	7.6	5.3	5.6	8.4	6.7	-0.04 ∓ 0.59
Aug. 27-28, 1979	7.1	7.4	5.5	7.8	6.5	6.7	-0.77 ∓ 0.63

Table 8
Comparison of Calculated and Observed Dissolved Oxygen Values in Mg/L for Seven Segment BC Dynamic Verification Surveys in Dynamic Mode

Survey Dates	Wausau Dam	Mosinee Dam	Dubay Dam
May 17-25, 1980	*	*	*
June 17-July 2, 1980	0.50	-0.46	0.22
July 12-August 16, 1980**	-0.31	-2.38	-0.45
September 2-10, 1980	0.27	0.04	0.27
October 26-November 3, 1980	-0.97	-0.09	-0.10
October 1-27, 1981	0.11	0.30	0.21

* Hourly measurements not readily available for statistical comparison.
**Two surveys that have been combined for extended period.

The verification appendices (F and G) contain the plots of the verification data sets and modeling predictions. The plots for the synoptic survey data sets (1978 an 1979) are for the entire length of Segment BC. The plots for the dynamic survey data sets (1980 and 1981) are for dissolved oxygen at individual sites versus time over the simulation periods. The individual sites are Wausau Dam, Mosinee Dam, and Lake DuBay Dam for all survey dates with data from the automatic monitors. Some dates had data collected at the additional sites of Rothschild Dam and the inlet to Lake Dubay.

The May 1980 data set is presented in the appendix but has not had a statistical comparison done due to the unavailability of dissolved oxygen data from the automatic monitors on hard copy. The May 1980 data set and the July-August 1980 double data set were unable to accurately be predicted by the QUAL III model. These difficulties can be at least partially attributed to the discharge from Weyerhaeuser Company. During this time period Weyerhaueser Company was achieving relatively poor treatment by its wastewater treatment plant. The BOD_5 values during this period were well over 100 mg/l. The longterm BOD tests conducted on Weyerhaeuser had a BOD_5 less than 60 mg/l. A higher BOD_5 strength effluent would very likely be accompanied by a much lower ratio of ultimate to 5-day BOD. However, the actual ratio for this period was not known so the earlier determined ratio was used. A sensitivity analysis in the steady state mode on the July-August data set indicated that a 50% reduction in ultimate BOD for Weyerhaeuser would increase the predicted dissolved oxygen values at both Mosinee Dam and the inlet to Lake Dubay by 1.0 mg/l over the July to August survey date. A sensitivity analysis on the May data set indicated that a 73% reduction in ultimate BOD for Weyerhaeuser would increase the predicted dissolved oxygen values by up to 3 mg/l. No sensitivity analysis using dynamic simulation was conducted.

<u>Summary</u>

The QUAL III model for Segment BC was verified using twelve additional data sets collected during the 1978-1981 period. While a direct statistical comparison of all verification data sets is not possible due to the difference in types of verifications conducted, a comparison of key locations indicates that the verification surveys are at least as accurate as the calibration surveys. Therefore, Segment BC 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 BC of the upper Wisconsin River. One hundred nineteen runs were executed to test all parameters, headwaters and rate coefficients. The base run was selected based upon a number of factors. A rather large cutback from baseline loads was desired that could be expected to occur rather frequently. The conditions selected for the base run are those of the September wasteload allocation table with a headwater flow of 1,800 cfs and a river temperature of 63.5°F. The results of the sensitivity analysis runs are presented in Appendix H. The headwater conditions and rate coefficients for the base run are also presented.

The model shows the most sensitivity to the selection of the equation for reaeration calculations. This would be expected as long reaches of the upper Wisconsin River are wide and open. It is these stretches where wind driven reaeration is important and significantly higher than predicted by any of the other equations available. It is also the reaeration equation which is highly constrained by river characteristics. The proper reaeration coefficient must be chosen based on river characteristics and the basis of development of the reaeration equation. The second most significant parameter with respect to dissolved oxygen is the BOD decay of point source loadings. Of the fast and slow carbonaceous BOD terms, the slow portion has greater impacts. The impact is important in both the selection of decay rates and in the determination of the ultimate BOD of point source loads. Weyerhaeuser Company has a far greater impact than the other mills due to it's high fraction of slow term BOD. The third most important set of parameters is that affecting the algae. Of these, light availability causes the most diversity, either as daily solar radiation or the light extinction coefficient. Nutrient availability does not seem to affect algae growth to a great extent. This indicates that the available sunlight is the major limiting factor in algae growth. Naturally, the algae growth and respiration rates impact the algae biomass.

VII. WASTELOAD ALLOCATION PROCEDURES

Once the QUAL III model was calibrated and verified, the model was 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 prior to proceeding with WLA development. These are described below.

Policy Decisions

There are a number of policy decisions that are necessary to formulate the method of wasteload allocations for the Wisconsin River. 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 frequency of time to which a WLA permit would be enforced.

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 adjusted 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 BC, the baseline load for industrial sources is equal to the best practicable waste treatment technology categorical effluent limitation (s. 147.04(2)(a), Stats.) applied to 1979 production for point sources of less than 500 lb/day daily maximum BOD_5. For those industrial point sources with a discharge greater than 500 lb/day daily maximum BOD_5 a more complex definition of baseline loads is used. For those industries between from rivermile 271.0 to 258.5 baseline load is based on March to December 1973 average weekly production. For industries from rivermile 258.4 to 258.2 baseline load is based on 1978 BPT WPDES permit limitations. For industries from rivermile 258.19 to 249.0 baseline load is based on 1974 average weekly production plus an allowance. For rivermile 248.9 to 235.9 the baseline load is based on 1973 average weekly production plus a woodroom allowance. 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 average design flow of the treatment plants, as specified in their WPDES permits, at a BOD_5 concentration of 30 mg/l. Complete details as to the determination of baseline loads are available in Wisconsin Administrative Code Chapter NR 212. The baseline load for point sources in Segment BC is in Table 8.

Table 8
Baseline Loads for Allocation Runs*

Point Source	Q (cfs)	BOD_5 (lb/day)
Wausau Paper Mills Company	14.9	12,778
Brokaw STP	0.108	18
Wausau STP	14.23	2,303
American Can Company**	2.5	3,900
Weyerhaeuser Company	16.2	16,182
Rothschild STP	2.318	375
Foremost Foods	0.25	248
Mosinee Paper Corporation	18.3	7,260
Mosinee STP	0.847	137

* Only Wausau Paper, American Can, Weyerhaeuser, and Mosinee Paper are subject to wasteload allocation as other industries do not exceed threshold load.

**American Company has since been sold and is now known as Reed Lignin Company.

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 BC 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 BC of the Wisconsin River will not have any reserve capacity other than that allowed municipalities for residential growth.

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. These include primarily 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

An allotment for nonpoint sources of pollutants is also factored into 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.

Threshold Load

The threshold load is a level of waste discharge below which no reduction in pollutant discharge to less than categorical limits is required in a water quality limited segment. Point sources which exceed the threshold load are subject to wasteload allocation under critical conditions (low flow and high temperature) while dischargers below this level are exempt from wasteload allocation and are limited only by categorical effluent limits. The establishment of a threshold load is based on the assumption that it is more cost-effective to control major sources of pollution (i.e., those that are large and have significant impact on the river's water quality). Segment BC of the Wisconsin River has a threshold load of 500 lbs/day of BOD_5.

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 specifically 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 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 as the most stringent allocation the discharger is responsible for in the WLA table which will appear in the WPDES permit.

Flow and Temperature Matrices

The flow and temperature matrices chosen for the development of wasteload allocations were selected by a frequency of occurrence analysis of the flow and temperature data available for Segment BC of the Wisconsin River. Twenty-one years of data have been analyzed. This temperature and flow data have been provided by Wisconsin Public Service Corporation and the USGS respectively. 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 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-model distribution. At lower temperatures the bi-model 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 and changing boundary conditions, 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, September 1st to 30th, and October 1st to 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. The four 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 two periods of September and October are characterized as having decreasing temperatures, a diatom algae community, and a potential for very low flows. Boundary conditions are listed in Table 9. Evaporation from Lake Dubay is based on the river temperature. This relationship is expressed in Table 10. There are also variations in tributary flows which are related to the variations in Wisconsin River flow. These relationships which were used in the wasteload allocation are presented in Table 11.

TABLE 9

Boundary Conditions for Each Period Used
to Do Wasteload Allocation Modeling

PERIOD	HEADWATER CHLOROPHYLL-a (ug/l)	TOTAL SOLAR RADIATION (LANGLEYS)	DAYLIGHT HOURS	TARGET DISSOLVED OXYGEN* (mg/l)	HEADWATER AMMONIA (mg/l)
May-June	10.3	482.	15.15	5.55	0.052
July-August	15.2	476.	14.67	5.63	0.052
September	12.8	325.	12.34	5.43	0.052
October	12.8	274.	11.78	5.42	0.052

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	0.172	0.056	0.58	90
July-August	0.00	0.172	0.052	0.51	90
September	0.00	0.172	0.039	0.54	90
October	0.00	0.172	0.039	0.54	90

*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.

Table 10

Lake Dubay Evaporation as Function of River Temperature

River Temperature (°F)	Evaporation (cfs)
55.5	20
59.5	28
63.5	36
67.5	44
71.5	52
75.5	60
79.5	68

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 WPDGS permits issued to the allocated industries in 1982. These tables are also located in Wisconsin Administrative Code Chapter NR 212.

Table 12
Incremental and Tributary Inflow to Segment BC as Function of Headwater Flow at Brokaw

Headwater Flow at Brokaw (cfs)	Incremental Inflow (cfs/mi.)	Tributary Flows (cfs)					
		Rib River	Eau Claire River	Bull Junior Creek	Big Eau Pleine Reservoir Outflow	Johnson Cr. & Little Eau Claire R.	Little Eau Pleine River
800	0.08	27	27	7	151	23	20
1000	0.10	45	45	9	188	28	25
1200	0.13	67	67	11	226	34	30
1400	0.14	93	93	13	263	39	35
1600	0.16	123	123	14	301	45	40
1800	0.18	157	157	16	338	50	45
2000	0.20	195	195	18	376	56	50
2200	0.22	237	237	20	413	62	55
2400	0.24	282	282	21	451	67	60
2600	0.26	332	332	23	488	73	65
2800	0.28	386	386	25	526	78	70
3050	0.31	459	459	27	572	85	77
3350	0.34	555	555	30	629	94	84
3650	0.37	660	660	32	685	102	92
3950	0.40	774	774	35	741	110	99
4250	0.43	896	896	38	797	119	107
4550	0.46	1028	1028	40	854	127	114
4850	0.49	1169	1169	43	910	135	122

APPENDIX A

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

WISCONSIN RIVER ARTICLES

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.

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OTHER MODELING REFERENCES

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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 is 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

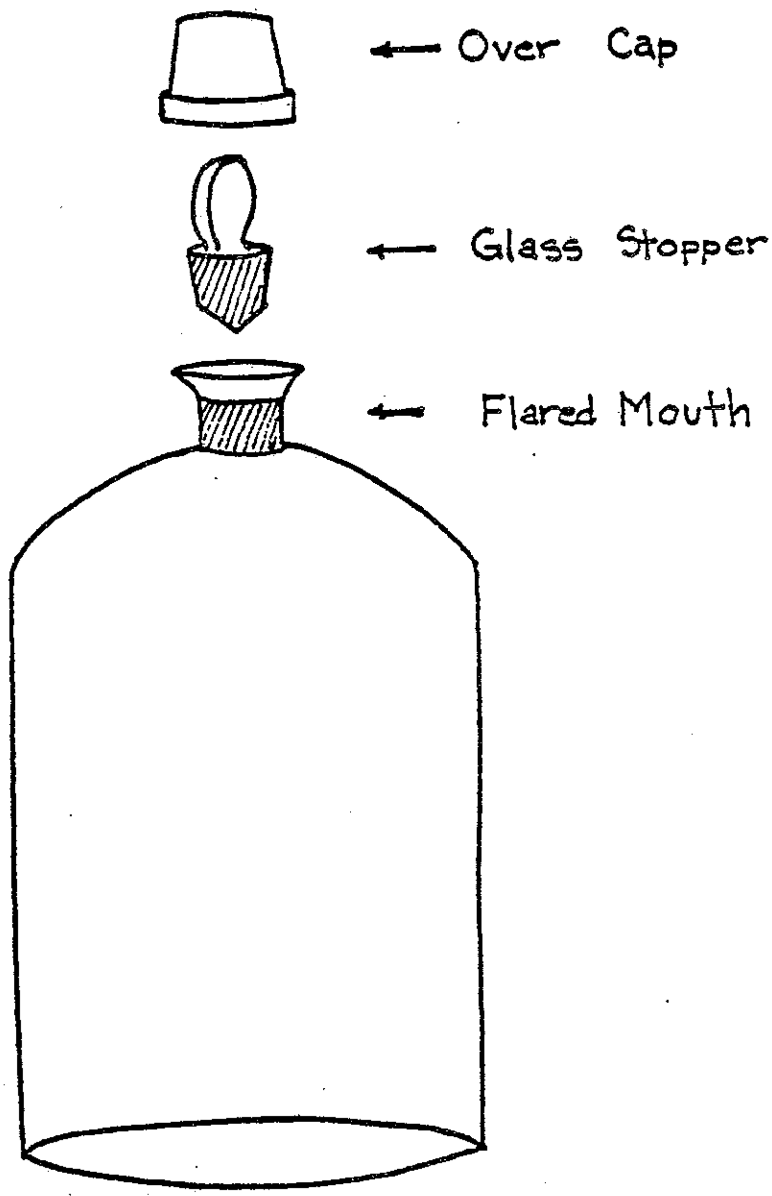
If previous tests have been done on the same effluent, the minimum time of the test can be estimated from these samples.

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 .1 mg/l. The depletion due to the dilution water is typically .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 .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, 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 .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:

$$ON \rightarrow NH^3 \rightarrow NO^2 \rightarrow NO^3$$

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 = [NO3*DIL - NO3(SAMPLE)] * 4.57

   where NO3 = mg/l nitrate in sample bottles at the end of the test. NO3 (SAMPLE) = mg/l nitrate in the sample before dilution.

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

As a rule of thumb, K11 is usually about .2 and K12 is usually about .02. Therefore,

$$BOD(\infty) = BOD(50) + 50*X \qquad X = \text{slope at 50 days}$$
$$BOD(\infty) = BOD(100) + \frac{100*X}{2} \qquad X = \text{slope at 100 days}$$

Effluents which have particularly high ratios of ultimate to 5 day BOD may have K12 = .01.

These equations for estimating ultimate BOD work well for graphical analysis if the test is run for T 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:

$$BODU = BOD(\infty) - NBOD$$

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. No correction is needed for the blank and BOD(t) = CBOD(t).

Problems in the Test

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

3. If no nutrient measurements are made after the test

   NBOD = [.3 * ON(SAMPLE) + NH3(SAMPLE) + .42 * DIL] * 4.57

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

   NH3(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 consumption.

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:

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

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

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

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.

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 criteria, 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 in 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 .06 mg/l nitrite plus nitrate.

At the end of the longterm BOD test, the nutrients in the bottled are measured to be .2 mg/l organic nitrogen, .02 mg/l ammonia, and 1.25 mg/l nitrite plus nitrate.

Calculating BOD

The cumulative DO depletion in the blank bottle is .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 .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.

Figure B-2

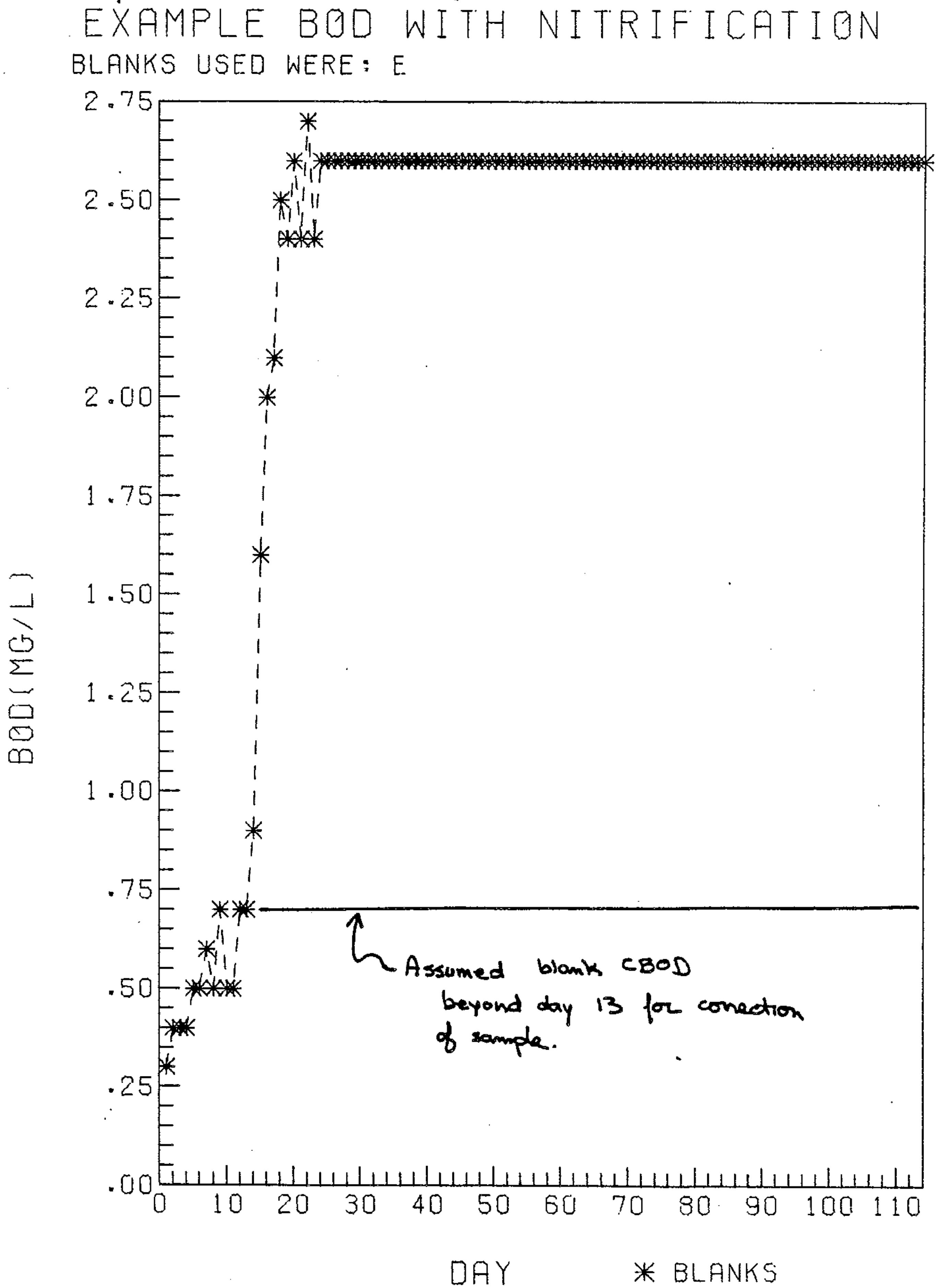
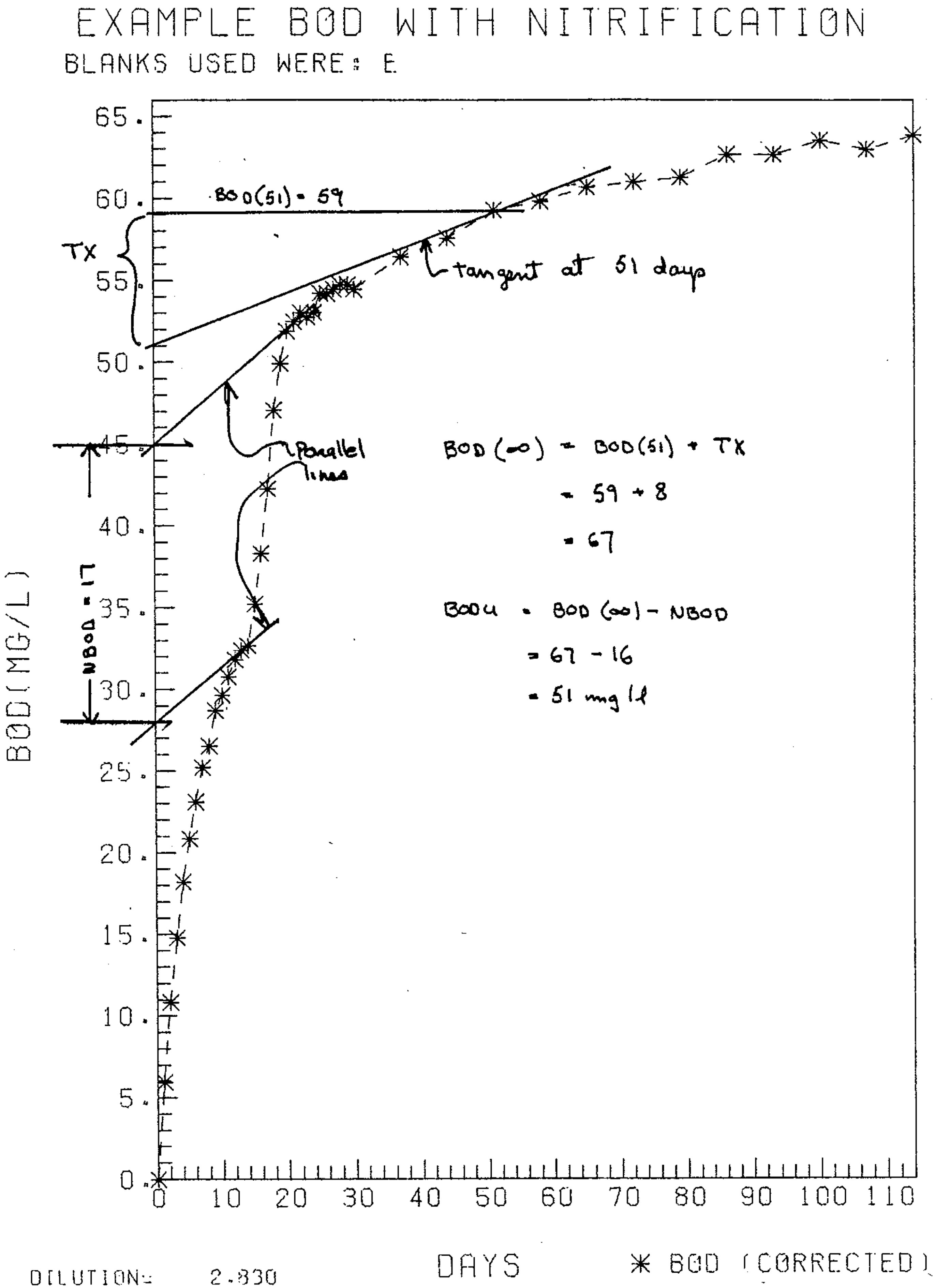

EXAMPLE BOD WITH NITRIFICATION
BLANKS USED WERE: E
BOD(MG/L)
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
.75
.50
.25
.00
0
10
20
30
40
50
60
70
80
90
100
110
DAY
BLANKS
Assumed blank CBOD beyond day 13 for correction of sample.

Figure B-3


EXAMPLE BOD WITH NITRIFICATION
BLANKS USED WERE: E
BOD(51) = 59
TX
tangent at 51 days
Parallel lines
NBOD = 17
BOD (∞) = BOD(51) + TX
= 59 + 8
= 67
BODu = BOD (∞) − NBOD
= 67 − 16
= 51 mg/l
BOD(MG/L)
DAYS
✱ BOD (CORRECTED)
DILUTION= 2.830

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.)

$$\begin{aligned} NBOD &= (1.25 * 2.83 - .06) * 4.57 \\ &= 15.9 \end{aligned}$$

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

$$\begin{aligned} NBOD &= (3 - .21 * 2.83 + .42 * 2.83) * 4.57 \\ &= 16.4 \end{aligned}$$

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

$$\begin{aligned} NBOD &= (.3 * 1.0 + 2.00 + .42 * 2.83) * 4.57 \\ &= 15.94 \end{aligned}$$

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, I suspect the 15.9 from method (2) is more accurate than 16.4 from method (3). For the following calculation I will use NBOD = 16 mg/l.

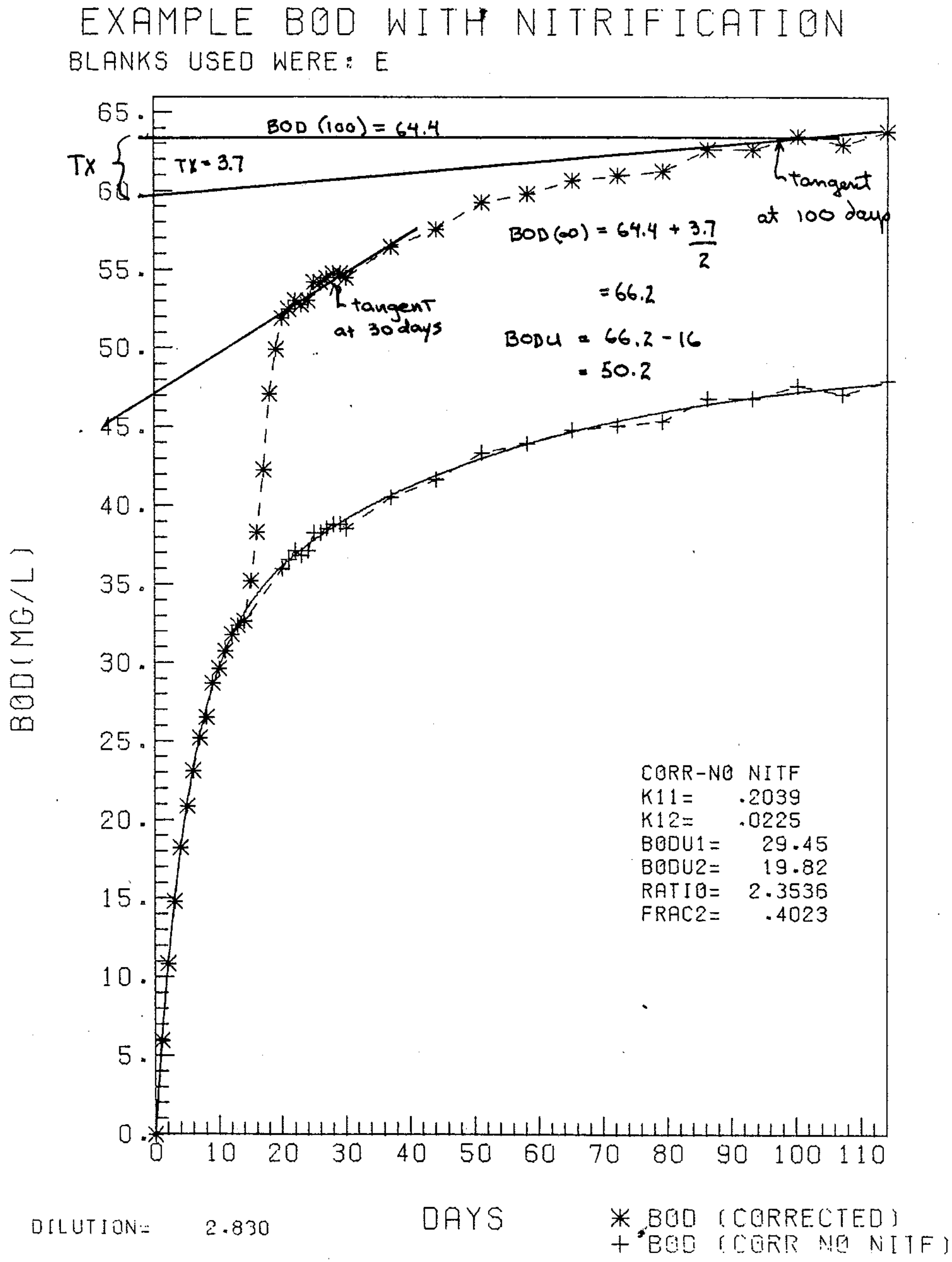
Calculating Ultimate BOD

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:

$$\begin{aligned} \text{at 51 days BODU } (\infty) &= BOD + TX \\ \text{or BODU } (\infty) &= 67.0 \\ \text{at 100 days BODU } (\infty) &= BOD + \frac{TX}{2} \\ \text{or BODU } (\infty) &= 66.2 \end{aligned}$$

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)
DAYS
DILUTION= 2.830
✳ BOD (CORRECTED)
+ BOD (CORR NO NITF)

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	$\pm$ 1.2	The plot of the
K22	=	.20	$\pm$ .01	data - NBOD and the
BODU2	=	19.8	$\pm$ .7	fitted curve follows
K12	=	.022	$\pm$ .033	
BODU	=	49.3		

FRACTION of BOD in slow term = .40

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

BODU1	=	29.9	$\pm$ 2.7
BODU2	=	21.3	$\pm$ 6.1
BODU	=	51.2	

Determination of BODU/BOD_5

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

Let's assume the measured BOD_5 of the sample was 20 as determined in the 5 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	=	.20
BODU2	=	20.	K12	=	.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 in that report, there was additional data used in the verification of the QUAL III model for Segment BC that was not contained in that report. The additional data available was collected by a continuous strip chart recording YSI 56 dissolved oxygen and temperature monitor at one or two locations. The most frequently used location was the inlet to Lake Dubay (rivermile 243.4) which is near the downstream dissolved oxygen sag point occurring between Mosinee and Dubay Dams. A second, but less frequently used location is that of the Rothschild Dam (rivermile 258.4), which is near the dissolved oxygen sag point. Table C-1 contains a list of dates for which continuous monitors were set up. Calibration notes are also contained in Table C-1. The uncorrected and corrected data are given in Tables C-2 through C-9. The corrected values are the uncorrected measurements with a linear adjustment made during the course of the survey.

Table C-1
1980 Dynamic Survey Field Data Dates and Calibration Notes

Date of Survey	Rothschild Dam	Inlet to Lake Dubay	DO Calibration Draft (mg/l)*
June 16-23, 1980		X	0.0
July 1-10, 1980		X	+0.1
July 14-23, 1980		X	+0.2
July 25-August 4, 1980		X	-0.1
August 4-13, 1980	X		+0.3
August 5-15, 1980		X	0.0
August 20-29, 1980		X	-0.3
September 2-10, 1980		X	-0.4

*Plus sign indicates final meter reading is high.

Table C-2
June 16-23, 1980 Dynamic Survey Field Data
Hourly Data - Inlet to Lake DuBay

Date	Time	Inst. DO (mg/l)	Inst. Temp. (°C)	Date	Time	Inst. DO (mg/l)	Inst. Temp. (°C)
6/16	15:00	7.1	20.7		20:00	7.5	21.7
	16:00	7.2	20.9		21:00	7.6	21.6
	17:00	7.3	21.0		22:00	7.6	21.6
	18:00	7.4	21.1		23:00	7.5	21.6
	19:00	7.4	20.9	6/18	0:00	7.5	21.6
	20:00	7.3	20.7		1:00	7.4	21.6
	21:00	7.2	20.7		2:00	7.3	21.5
	22:00	7.1	20.8		3:00	7.3	21.5
	23:00	7.1	20.8		4:00	7.2	21.5
6/17	0:00	7.0	20.8		5:00	7.1	21.5
	1:00	6.9	20.7		6:00	7.1	21.4
	2:00	6.9	20.7		7:00	7.1	21.4
	3:00	6.8	20.7		8:00	7.1	21.4
	4:00	6.7	20.7		9:00	7.0	21.4
	5:00	6.7	20.7		10:00	7.0	21.3
	6:00	6.7	20.7		11:00	7.0	21.3
	7:00	6.7	20.7		12:00	7.0	21.2
	8:00	6.7	20.8		13:00	7.0	21.0
	9:00	6.7	20.9		14:00	7.0	20.8
	10:00	6.7	21.0		15:00	7.0	20.7
	11:00	6.8	21.2		16:00	7.0	20.6
	12:00	6.9	21.5		17:00	7.1	20.4
	13:00	7.0	21.6		18:00	7.0	20.3
	14:00	7.1	21.8		19:00	7.0	20.1
	15:00	7.2	21.9		20:00	7.0	20.0
	16:00	7.4	22.0		21:00	7.0	19.8
	17:00	7.4	21.9		22:00	7.1	19.6
	18:00	7.4	21.7		23:00	7.1	19.5
	19:00	7.5	21.7				

Table C-2 (continued)
June 16-23, 1980 Dynamic Survey Field Data
Hourly Data - Inlet to Lake DuBay

Date	Time	Inst. DO (mg/l)	Inst. Temp. (°C)	Date	Time	Inst. DO (mg/l)	Inst. Temp. (°C)
6/19	0:00	7.1	19.4		12:00	9.3	18.3
	1:00	7.2	19.3		13:00	9.4	18.5
	2:00	7.2	19.0		14:00	9.4	18.7
	3:00	7.3	18.9		15:00	9.4	18.8
	4:00	7.3	18.8		16:00	9.4	19.0
	5:00	7.3	18.6		17:00	9.4	19.1
	6:00	7.3	18.6		18:00	9.4	19.1
	7:00	7.3	18.5		19:00	9.3	19.1
	8:00	7.4	18.5		20:00	9.3	19.2
	9:00	7.5	18.5		21:00	9.2	19.1
	10:00	7.5	18.5		22:00	9.1	19.0
	11:00	7.6	18.7		23:00	9.0	18.7
	12:00	7.7	18.9	6/21	0:00	9.0	18.7
	13:00	7.8	19.0		1:00	9.0	18.6
	14:00	8.0	19.3		2:00	9.0	18.4
	15:00	8.1	19.5		3:00	8.9	18.3
	16:00	8.2	19.6		4:00	8.9	18.1
	17:00	8.3	19.8		5:00	8.9	18.0
	18:00	8.3	20.0		6:00	8.9	17.9
	19:00	8.4	20.1		7:00	8.9	17.7
	20:00	8.4	20.1		8:00	8.9	17.8
	21:00	8.5	20.0		9:00	9.0	17.8
	22:00	8.5	20.0		10:00	9.0	17.9
	23:00	8.5	19.7		11:00	9.0	18.2
6/20	0:00	8.5	19.5		12:00	9.1	18.4
	1:00	8.5	19.3		13:00	9.1	18.6
	2:00	8.6	18.9		14:00	9.1	18.8
	3:00	8.6	18.7		15:00	9.0	19.0
	4:00	8.6	18.5		16:00	9.0	19.3
	5:00	8.7	18.3		17:00	9.0	19.5
	6:00	8.7	18.2		18:00	8.9	19.5
	7:00	8.9	18.0		19:00	8.9	19.7
	8:00	8.9	17.9		20:00	8.8	19.8
	9:00	9.0	17.9		21:00	8.7	19.9
	10:00	9.1	18.0		22:00	8.7	19.9
	11:00	9.2	18.2		23:00	8.6	20.0

Table C-2 (continued)
June 16-23, 1980 Dynamic Survey Field Data
Hourly Data - Inlet to Lake DuBay

Date	Time	Inst. DO (mg/l)	Inst. Temp. (°C)	Date	Time	Inst. DO (mg/l)	Inst. Temp. (°C)
6/22	0:00	8.5	20.0		18:00	8.4	20.8
	1:00	8.4	20.0		19:00	8.4	21.0
	2:00	8.3	20.0		20:00	8.3	21.0
	3:00	8.3	20.0		21:00	8.2	21.0
	4:00	8.2	20.0		22:00	8.2	21.0
	5:00	8.1	19.9		23:00	8.1	21.0
	6:00	8.0	19.8	6/23	0:00	8.0	21.1
	7:00	8.0	19.7		1:00	7.9	21.1
	8:00	8.0	19.7		2:00	7.9	21.2
	9:00	8.0	19.7		3:00	7.9	21.2
	10:00	8.1	19.8		4:00	7.8	21.2
	11:00	8.1	19.9		5:00	7.7	21.0
	12:00	8.3	20.0		6:00	7.7	20.9
	13:00	8.3	20.2		7:00	7.6	20.7
	14:00	8.4	20.4		8:00	7.6	20.6
	15:00	8.4	20.5		9:00	7.6	20.6
	16:00	8.4	20.6		10:00	7.7	20.7
	17:00	8.4	20.6		11:00	7.8	20.9

Table C-3
July 1-10, 1980 Dynamic Survey Field Data
Hourly Data - Inlet to Lake DuBay

Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)	Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)
7/1	16:00	6.9:6.9	20.7		20:00	6.7:6.7	22.5
	17:00	7.0:7.0	21.1		21:00	6.7:6.7	22.5
	18:00	7.0:7.0	21.2		22:00	6.8:6.8	22.6
	19:00	7.0:7.0	21.4		23:00	6.9:6.9	22.6
	20:00	7.0:7.0	21.4	7/3	0:00	6.9:6.9	22.7
	21:00	7.0:7.0	21.4		1:00	6.9:6.9	22.7
	22:00	7.0:7.0	21.5		2:00	6.8:6.8	22.7
	23:00	6.9:6.9	21.5		3:00	6.7:6.7	22.6
7/2	0:00	6.8:6.8	21.5		4:00	6.7:6.7	22.4
	1:00	6.8:6.8	21.4		5:00	6.7:6.7	22.3
	2:00	6.7:6.7	21.3		6:00	6.6:6.6	22.2
	3:00	6.7:6.7	21.3		7:00	6.6:6.6	22.0
	4:00	6.7:6.7	21.3		8:00	6.6:6.6	22.1
	5:00	6.6:6.6	21.2		9:00	6.7:6.7	22.1
	6:00	6.6:6.6	21.1		10:00	6.7:6.7	22.1
	7:00	6.6:6.6	21.0		11:00	6.8:6.8	22.2
	8:00	6.5:6.5	21.0		12:00	6.9:6.9	22.5
	9:00	6.6:6.6	21.1		13:00	7.1:7.1	22.7
	10:00	6.5:6.5	21.1		14:00	7.1:7.1	22.8
	11:00	6.5:6.5	21.4		15:00	7.5:7.5	23.1
	12:00	6.5:6.5	21.6		16:00	7.5:7.5	23.2
	13:00	6.6:6.6	21.8		17:00	7.5:7.5	23.2
	14:00	6.5:6.5	22.0		18:00	7.6:7.6	23.3
	15:00	6.5:6.5	22.2		19:00	7.6:7.6	23.4
	16:00	6.6:6.6	22.5		20:00	7.6:7.6	23.3
	17:00	6.7:6.7	22.5		21:00	7.7:7.7	23.3
	18:00	6.7:6.7	22.5		22:00	7.7:7.7	23.4
	19:00	6.6:6.6	22.5		23:00	7.6:7.6	23.3

*Value to right of colon is corrected reading.

Table C-3 (continued)
July 1-10, 1980 Dynamic Survey Field Data
Hourly Data - Inlet to Lake DuBay

Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)	Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)
7/4	0:00	7.6:7.6	23.4		12:00	7.7:7.7	23.7
	1:00	7.5:7.5	23.4		13:00	7.8:7.8	23.8
	2:00	7.4:7.4	23.4		14:00	8.1:8.1	24.0
	3:00	7.3:7.3	23.4		15:00	8.3:8.3	24.1
	4:00	7.3:7.3	23.4		16:00	8.5:8.5	24.3
	5:00	7.1:7.1	23.2		17:00	8.8:8.8	24.3
	6:00	7.0:7.0	23.1		18:00	8.8:8.8	24.3
	7:00	6.9:6.9	23.0		19:00	8.7:8.7	24.2
	8:00	7.0:7.0	23.1		20:00	8.4:8.4	24.0
	9:00	7.1:7.1	23.2		21:00	8.4:8.4	24.0
	10:00	7.2:7.2	23.3		22:00	8.4:8.4	23.9
	11:00	7.2:7.2	23.3		23:00	8.4:8.4	23.9
	12:00	7.3:7.3	23.4	7/6	0:00	8.3:8.3	23.8
	13:00	7.4:7.4	23.4		1:00	8.2:8.2	23.7
	14:00	7.5:7.5	23.5		2:00	8.1:8.1	23.6
	15:00	7.5:7.5	23.6		3:00	8.1:8.0	23.5
	16:00	7.5:7.5	23.6		4:00	8.0:7.9	23.3
	17:00	7.7:7.7	23.7		5:00	7.9:7.8	23.2
	18:00	8.1:8.1	24.0		6:00	7.8:7.7	23.1
	19:00	8.2:8.2	24.0		7:00	7.8:7.7	23.0
	20:00	8.5:8.5	24.2		8:00	7.8:7.7	23.0
	21:00	8.4:8.4	24.1		9:00	7.9:7.8	23.1
	22:00	8.0:8.0	24.0		10:00	8.1:8.0	23.1
	23:00	8.1:8.1	24.0		11:00	8.0:7.9	23.1
7/5	0:00	8.0:8.0	23.9		12:00	7.8:7.7	23.1
	1:00	7.9:7.9	23.8		13:00	8.0:7.9	23.2
	2:00	7.9:7.9	23.8		14:00	8.1:8.0	23.2
	3:00	7.8:7.8	23.7		15:00	8.2:8.1	23.2
	4:00	7.7:7.7	23.7		16:00	8.5:8.4	23.4
	5:00	7.6:7.6	23.5		17:00	8.6:8.5	23.4
	6:00	7.5:7.5	23.5		18:00	8.9:8.8	23.6
	7:00	7.5:7.5	23.5		19:00	9.2:9.1	23.8
	8:00	7.5:7.5	23.6		20:00	9.2:9.1	23.7
	9:00	7.6:7.6	23.7		21:00	8.9:8.8	23.7
	10:00	7.6:7.6	23.7		22:00	8.9:8.8	23.7
	11:00	7.6:7.6	23.7		23:00	8.8:8.7	23.7

*Value to right of colon is corrected reading.

Table C-3 (continued)
July 1-10, 1980 Dynamic Survey Field Data
Hourly Data - Inlet to Lake DuBay

Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)	Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)
7/7	0:00	8.7:8.6	23.7		12:00	7.2:7.1	24.7
	1:00	8.6:8.5	23.7		13:00	7.9:7.8	24.5
	2:00	8.4:8.3	23.7		14:00	7.0:6.9	24.9
	3:00	8.2:8.1	23.6		15:00	7.2:7.1	25.0
	4:00	8.0:7.9	23.5		16:00	7.4:7.3	25.2
	5:00	7.8:7.7	23.5		17:00	7.7:7.6	25.5
	6:00	7.6:7.5	23.4		18:00	8.0:7.9	25.5
	7:00	7.5:7.4	23.4		19:00	8.0:7.9	25.4
	8:00	7.5:7.4	23.4		20:00	7.9:7.8	25.5
	9:00	7.6:7.5	23.5		21:00	7.9:7.8	25.4
	10:00	7.6:7.5	23.6		22:00	7.8:7.7	25.3
	11:00	7.5:7.4	23.6		23:00	7.7:7.6	25.2
	12:00	7.5:7.4	23.6	7/9	0:00	7.6:7.5	25.2
	13:00	7.8:7.7	23.7		1:00	7.5:7.4	25.1
	14:00	7.7:7.6	23.7		2:00	7.3:7.2	25.1
	15:00	7.6:7.5	23.7		3:00	7.2:7.1	25.1
	16:00	8.0:7.9	24.0		4:00	7.1:7.0	25.0
	17:00	8.2:8.1	24.2		5:00	7.0:6.9	25.0
	18:00	8.3:8.2	24.3		6:00	7.0:6.9	24.9
	19:00	8.2:8.1	24.4		7:00	7.0:6.9	24.9
	20:00	8.2:8.1	24.4		8:00	7.0:6.9	24.9
	21:00	8.4:8.3	24.7		9:00	7.1:7.0	25.0
	22:00	8.3:8.2	24.7		10:00	7.1:7.0	24.9
	23:00	8.2:8.1	24.6		11:00	7.3:7.2	24.9
7/8	0:00	7.9:7.8	24.5		12:00	7.3:7.2	25.0
	1:00	7.9:7.8	24.5		13:00	7.5:7.4	25.1
	2:00	7.8:7.7	24.4		14:00	7.5:7.4	25.1
	3:00	7.6:7.5	24.3		15:00	7.6:7.5	25.2
	4:00	7.3:7.2	24.2		16:00	7.6:7.5	25.2
	5:00	7.1:7.0	24.1		17:00	7.8:7.7	25.4
	6:00	7.0:6.9	24.0		18:00	7.7:7.6	25.4
	7:00	7.0:6.9	24.0		19:00	7.8:7.7	25.6
	8:00	6.9:6.8	24.1		20:00	7.8:7.7	25.6
	9:00	7.1:7.0	24.2		21:00	7.7:7.6	25.6
	10:00	7.2:7.1	24.3		22:00	7.7:7.6	25.7
	11:00	7.4:7.3	24.6		23:00	7.6:7.5	25.7

*Value to right of colon is corrected reading.

Table C-3 (continued)
July 1-10, 1980 Dynamic Survey Field Data
Hourly Data - Inlet to Lake DuBay

Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)
7/10	0:00	7.4:7.3	25.6
	1:00	7.3:7.2	25.6
	2:00	7.1:7.0	25.5
	3:00	7.0:6.9	25.5
	4:00	6.8:6.7	25.4
	5:00	6.8:6.7	25.3
	6:00	6.7:6.6	25.3
	7:00	6.7:6.6	25.3
	8:00	6.7:6.6	25.4
	9:00	6.8:6.7	25.4
	10:00	6.7:6.6	25.5
	11:00	7.0:6.9	25.5
	12:00	7.2:7.1	25.7
	13:00	6.5:6.4	25.5

*Value to right of colon is corrected reading.

Table C-4
July 14-23, 1980 Dynamic Survey Field Data
Hourly Data - Inlet to Lake DuBay

Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)	Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)
7/14	14:00	5.7:5.7	25.9		19:00	6.5:6.5	27.4
	15:00	5.7:5.7	25.9		20:00	6.0:6.0	27.2
	16:00	5.7:5.7	25.9		21:00	6.2:6.2	27.2
	17:00	5.7:5.7	25.9		22:00	6.1:6.1	27.2
	18:00	5.6:5.6	25.9		23:00	6.2:6.2	27.2
	19:00	6.1:6.1	26.1	7/16	0:00	6.1:6.1	27.3
	20:00	6.2:6.2	26.1		1:00	6.0:6.0	27.3
	21:00	6.1:6.1	26.1		2:00	6.0:6.0	27.3
	22:00	5.8:5.8	26.0		3:00	6.0:6.0	27.2
	23:00	5.8:5.8	26.0		4:00	6.0:6.0	27.1
7/15	0:00	5.6:5.6	26.0		5:00	6.0:6.0	27.0
	1:00	5.6:5.6	26.1		6:00	6.0:6.0	26.7
	2:00	5.5:5.5	26.1		7:00	6.0:6.0	26.7
	3:00	5.4:5.4	26.0		8:00	5.9:5.9	26.6
	4:00	5.3:5.3	25.9		9:00	5.8:5.8	26.5
	5:00	5.2:5.2	25.9		10:00	5.9:5.9	26.6
	6:00	5.1:5.1	25.9		11:00	6.0:6.0	26.6
	7:00	5.0:5.0	25.8		12:00	6.0:6.0	26.6
	8:00	4.9:4.9	25.8		13:00	6.2:6.2	26.7
	9:00	4.8:4.8	25.7		14:00	6.6:6.6	26.8
	10:00	4.8:4.8	25.8		15:00	6.9:6.9	27.0
	11:00	4.8:4.8	25.9		16:00	7.0:7.0	27.1
	12:00	5.0:5.0	26.1		17:00	7.3:7.3	27.0
	13:00	5.3:5.3	26.3		18:00	7.2:7.2	27.0
	14:00	5.2:5.2	26.3		19:00	7.2:7.1	26.9
	15:00	6.0:6.0	27.3		20:00	7.2:7.1	26.9
	16:00	6.2:6.2	27.3		21:00	7.1:7.0	26.8
	17:00	6.2:6.2	27.4		22:00	7.3:7.2	26.7
	18:00	6.3:6.3	27.4		23:00	7.3:7.2	26.7

*Value to right of colon is corrected reading.

Table C-4 (continued)
July 14-23, 1980 Dynamic Survey Field Data
Hourly Data - Inlet to Lake DuBay

Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)	Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)
7/17	0:00	7.2:7.1	26.7		12:00	7.3:7.2	26.3
	1:00	7.1:7.0	26.6		13:00	7.1:7.0	26.2
	2:00	7.1:7.0	26.5		14:00	7.3:7.2	26.3
	3:00	7.0:6.9	26.5		15:00	7.4:7.3	26.2
	4:00	6.8:6.7	26.4		16:00	7.3:7.2	26.2
	5:00	6.7:6.6	26.3		17:00	7.2:7.1	26.1
	6:00	6.6:6.5	26.2		18:00	7.1:7.0	26.2
	7:00	6.5:6.4	26.2		19:00	7.1:7.0	26.2
	8:00	6.5:6.4	26.2		20:00	7.0:6.9	26.2
	9:00	6.7:6.6	26.3		21:00	6.8:6.7	26.0
	10:00	6.7:6.6	26.3		22:00	6.9:6.8	26.0
	11:00	7.1:7.0	26.5		23:00	6.8:6.7	26.0
	12:00	7.6:7.5	26.7	7/19	0:00	6.7:6.6	25.9
	13:00	7.9:7.8	26.9		1:00	6.6:6.5	25.8
	14:00	8.3:8.2	27.2		2:00	6.5:6.4	25.7
	15:00	7.4:7.3	26.7		3:00	6.4:6.3	25.6
	16:00	7.2:7.1	26.7		4:00	6.3:6.2	25.6
	17:00	7.4:7.3	26.7		5:00	6.0:5.9	25.5
	18:00	7.7:7.6	27.0		6:00	5.9:5.8	25.4
	19:00	8.0:7.9	27.0		7:00	5.8:5.7	25.4
	20:00	8.7:8.6	27.3		8:00	5.8:5.7	25.4
	21:00	8.2:8.1	27.0		9:00	6.2:6.1	25.6
	22:00	8.3:8.2	27.1		10:00	6.2:6.1	25.6
	23:00	7.9:7.8	27.0		11:00	6.6:6.5	25.7
7/18	0:00	7.8:7.7	26.9		12:00	6.6:6.5	25.7
	1:00	7.7:7.6	26.8		13:00	6.7:6.6	25.8
	2:00	7.7:7.6	26.8		14:00	6.7:6.6	26.0
	3:00	7.7:7.6	26.8		15:00	7.1:7.0	26.2
	4:00	7.6:7.5	26.7		16:00	6.8:6.7	26.1
	5:00	7.5:7.4	26.7		17:00	7.1:7.0	26.4
	6:00	7.4:7.3	26.6		18:00	6.9:6.8	26.4
	7:00	7.3:7.2	26.6		19:00	7.4:7.3	26.7
	8:00	7.1:7.0	26.5		20:00	7.2:7.1	26.7
	9:00	7.1:7.0	26.4		21:00	7.4:7.3	26.7
	10:00	7.0:6.9	26.3		22:00	7.1:7.0	26.7
	11:00	7.1:7.0	26.3		23:00	7.0:6.9	26.7

*Value to right of colon is corrected reading.

Table C-4 (continued)
July 14-23, 1980 Dynamic Survey Field Data
Hourly Data - Inlet to Lake DuBay

Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)	Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)
7/20	0:00	7.0:6.9	26.7		12:00	6.3:6.1	26.2
	1:00	7.0:6.9	26.7		13:00	6.3:6.1	26.3
	2:00	6.9:6.8	26.8		14:00	6.4:6.2	26.4
	3:00	6.8:6.7	26.8		15:00	6.5:6.3	26.5
	4:00	6.8:6.7	26.8		16:00	6.5:6.3	26.5
	5:00	6.6:6.5	26.9		17:00	6.5:6.3	26.5
	6:00	6.5:6.4	26.8		18:00	6.5:6.3	26.4
	7:00	6.4:6.3	26.6		19:00	6.4:6.2	26.4
	8:00	6.2:6.1	26.5		20:00	6.0:5.8	26.2
	9:00	6.5:6.4	26.4		21:00	6.2:6.0	26.2
	10:00	6.1:6.0	26.3		22:00	6.4:6.2	26.3
	11:00	6.1:6.0	26.3		23:00	6.6:6.4	26.3
	12:00	6.2:6.1	26.3	7/22	0:00	6.6:6.4	26.1
	13:00	6.4:6.3	26.4		1:00	6.6:6.4	26.1
	14:00	6.2:6.1	26.3		2:00	6.6:6.4	26.1
	15:00	6.3:6.2	26.3		3:00	6.6:6.4	26.1
	16:00	6.2:6.1	26.3		4:00	6.6:6.4	26.0
	17:00	7.0:6.9	26.5		5:00	6.5:6.3	25.9
	18:00	6.9:6.8	26.4		6:00	6.4:6.2	25.9
	19:00	7.1:7.0	26.4		7:00	6.4:6.2	25.8
	20:00	6.6:6.5	26.3		8:00	6.5:6.3	25.7
	21:00	6.4:6.3	26.2		9:00	6.5:6.3	25.7
	22:00	6.3:6.2	26.2		10:00	6.7:6.5	25.7
	23:00	6.1:6.0	26.0		11:00	6.8:6.6	25.7
7/21	0:00	6.2:6.1	26.0		12:00	7.0:6.8	25.8
	1:00	6.2:6.1	26.0		13:00	7.1:6.9	25.9
	2:00	6.2:6.1	26.0		14:00	7.2:7.0	26.0
	3:00	6.1:6.0	26.0		15:00	7.4:7.2	26.0
	4:00	5.9:5.8	26.0		16:00	7.8:7.6	25.9
	5:00	5.7:5.6	26.0		17:00	7.6:7.4	26.0
	6:00	5.6:5.4	26.0		18:00	7.8:7.6	26.0
	7:00	5.6:5.4	25.9		19:00	7.7:7.5	25.8
	8:00	5.6:5.4	25.9		20:00	7.6:7.4	25.7
	9:00	5.5:5.3	25.9		21:00	7.5:7.3	25.7
	10:00	5.7:5.5	25.9		22:00	7.6:7.4	25.6
	11:00	6.0:5.8	26.1		23:00	7.5:7.3	25.5

*Value to right of colon is corrected reading.

Table C-4 (continued)
July 14-23, 1980 Dynamic Survey Field Data
Hourly Data - Inlet to Lake DuBay

Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)
7/13	0:00	7.6:7.4	25.4
	1:00	7.5:7.3	25.4
	2:00	7.5:7.3	25.4
	3:00	7.4:7.2	25.2
	4:00	7.3:7.1	25.0
	5:00	7.2:7.0	25.0
	6:00	7.1:6.9	24.9
	7:00	7.1:6.9	24.8
	8:00	7.1:6.9	24.8
	9:00	7.4:7.2	24.9
	10:00	7.4:7.2	24.9
	11:00	7.7:7.5	25.0

*Value to right of colon is corrected reading.

Table C-5
July 25 - August 4, 1980 Dynamic Survey Field Data
Hourly Data - Inlet to Lake DuBay

Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)	Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)
7/25	13:00	7.2:7.2	25.4		19:00	7.0:7.0	24.2
	14:00	7.2:7.2	25.4		20:00	7.5:7.5	24.2
	15:00	7.1:7.1	25.4		21:00	7.8:7.8	24.3
	16:00	7.3:7.3	25.5		22:00	7.7:7.7	24.2
	17:00	7.3:7.3	25.5		23:00	7.5:7.5	24.2
	18:00	7.4:7.4	25.5	7/27	0:00	7.1:7.1	24.1
	19:00	7.3:7.3	25.4		1:00	7.2:7.2	24.0
	20:00	7.1:7.1	25.4		2:00	7.2:7.2	24.0
	21:00	7.1:7.1	25.3		3:00	7.1:7.1	24.0
	22:00	7.0:7.0	25.2		4:00	7.0:7.0	23.9
	23:00	7.0:7.0	25.2		5:00	6.9:6.9	23.8
7/26	0:00	7.0:7.0	25.0		6:00	6.9:6.9	23.7
	1:00	6.9:6.9	24.9		7:00	6.8:6.8	23.7
	2:00	6.8:6.8	24.9		8:00	6.8:6.8	23.6
	3:00	6.7:6.7	24.7		9:00	6.9:6.9	23.7
	4:00	6.6:6.6	24.5		10:00	7.4:7.4	24.0
	5:00	6.5:6.5	24.3		11:00	7.5:7.5	24.0
	6:00	6.4:6.4	24.2		12:00	7.5:7.5	24.0
	7:00	6.3:6.3	24.2		13:00	7.6:7.6	24.0
	8:00	6.3:6.3	24.0		14:00	7.5:7.5	24.0
	9:00	6.3:6.3	24.0		15:00	7.7:7.7	24.1
	10:00	6.4:6.4	23.9		16:00	7.4:7.4	24.0
	11:00	6.7:6.7	24.0		17:00	7.6:7.6	24.2
	12:00	7.0:7.0	24.0		18:00	7.4:7.4	24.3
	13:00	7.1:7.1	24.0		19:00	7.2:7.2	24.3
	14:00	7.5:7.5	24.1		20:00	7.5:7.5	24.5
	15:00	8.0:8.0	24.3		21:00	7.4:7.4	24.3
	16:00	7.4:7.4	24.3		22:00	7.4:7.4	24.5
	17:00	6.9:6.9	24.1		23:00	8.0:8.0	24.7
	18:00	6.9:6.9	24.2				

*Value to right of colon is corrected reading.

Table C-5 (continued)
July 25 - August 4, 1980 Dynamic Survey Field Data
Hourly Data - Inlet to Lake DuBay

Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)	Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)
7/28	0:00	7.9:7.9	24.6		12:00	6.6:6.6	25.3
	1:00	7.6:7.6	24.5		13:00	7.0:7.0	25.5
	2:00	7.6:7.6	24.4		14:00	7.5:7.5	25.8
	3:00	7.3:7.3	24.3		15:00	7.7:7.7	26.0
	4:00	7.0:7.0	24.3		16:00	8.0:8.0	26.2
	5:00	6.9:6.9	24.3		17:00	8.2:8.2	26.3
	6:00	6.9:6.9	24.3		18:00	8.2:8.2	26.3
	7:00	6.9:6.9	24.3		19:00	8.1:8.1	26.3
	8:00	7.1:7.1	24.4		20:00	7.7:7.7	26.1
	9:00	7.2:7.2	24.5		21:00	7.6:7.6	26.0
	10:00	7.2:7.2	24.6		22:00	7.4:7.4	26.0
	11:00	7.1:7.1	24.8		23:00	7.3:7.3	26.0
	12:00	7.5:7.5	25.0	7/30	0:00	7.3:7.3	26.0
	13:00	7.8:7.8	25.3		1:00	7.2:7.2	26.0
	14:00	7.7:7.7	25.4		2:00	7.1:7.1	26.0
	15:00	7.9:7.9	25.5		3:00	7.0:7.0	25.9
	16:00	7.8:7.8	25.5		4:00	6.9:6.9	25.8
	17:00	7.7:7.7	25.5		5:00	6.8:6.8	25.7
	18:00	7.5:7.5	25.4		6:00	6.7:6.7	25.7
	19:00	8.0:8.0	25.6		7:00	6.6:6.6	25.7
	20:00	8.5:8.5	25.6		8:00	6.5:6.5	25.6
	21:00	8.2:8.2	25.5		9:00	6.4:6.4	25.5
	22:00	7.6:7.6	25.3		10:00	6.4:6.4	25.4
	23:00	7.6:7.6	25.3		11:00	6.5:6.5	25.4
7/29	0:00	7.3:7.3	25.2		12:00	6.9:6.9	25.5
	1:00	7.3:7.3	25.1		13:00	6.9:7.0	25.4
	2:00	7.1:7.1	25.1		14:00	7.0:7.1	25.3
	3:00	6.9:6.9	25.0		15:00	7.2:7.3	25.5
	4:00	6.8:6.8	25.1		16:00	7.1:7.2	25.4
	5:00	6.8:6.8	25.0		17:00	7.6:7.7	25.5
	6:00	6.7:6.7	25.0		18:00	7.5:7.6	25.4
	7:00	6.7:6.7	25.0		19:00	7.1:7.2	25.1
	8:00	6.7:6.7	25.0		20:00	6.8:6.9	25.2
	9:00	6.7:6.7	25.1		21:00	6.7:6.8	25.1
	10:00	6.7:6.7	25.2		22:00	6.6:6.7	25.1
	11:00	6.5:6.5	25.2		23:00	6.6:6.7	25.1

*Value to right of colon is corrected reading.

Table C-5 (continued)
July 25 - August 4, 1980 Dynamic Survey Field Data
Hourly Data - Inlet to Lake DuBay

Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)	Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)
7/31	0:00	6.6:6.7	25.0		12:00	6.9:7.0	25.3
	1:00	6.5:6.6	24.9		13:00	7.1:7.2	25.5
	2:00	6.4:6.5	24.9		14:00	7.6:7.7	25.6
	3:00	6.3:6.4	24.8		15:00	8.0:8.1	25.8
	4:00	6.2:6.3	24.7		16:00	8.1:8.2	25.8
	5:00	6.1:6.2	24.6		17:00	8.2:8.3	26.0
	6:00	6.0:6.1	24.5		18:00	8.4:8.5	26.0
	7:00	5.9:6.0	24.5		19:00	8.7:8.8	26.1
	8:00	5.9:6.0	24.5		20:00	8.5:8.6	26.0
	9:00	6.0:6.1	24.5		21:00	8.2:8.3	25.9
	10:00	6.2:6.3	24.5		22:00	8.1:8.2	26.0
	11:00	6.6:6.7	24.7		23:00	8.1:8.2	26.0
	12:00	6.7:6.8	24.6	8/2	0:00	8.0:8.1	26.0
	13:00	6.6:6.7	24.7		1:00	7.9:8.0	26.0
	14:00	6.5:6.6	24.7		2:00	7.8:7.9	26.0
	15:00	7.0:7.1	25.0		3:00	7.7:7.8	26.0
	16:00	7.1:7.2	25.2		4:00	7.5:7.6	26.0
	17:00	7.5:7.6	25.5		5:00	7.3:7.1	25.8
	18:00	7.5:7.6	25.5		6:00	7.1:7.2	25.7
	19:00	7.2:7.3	25.4		7:00	6.9:7.0	25.7
	20:00	7.0:7.1	25.3		8:00	6.8:6.9	25.6
	21:00	6.8:6.9	25.3		9:00	6.7:6.8	25.6
	22:00	6.8:6.9	25.3		10:00	6.7:6.8	25.6
	23:00	6.7:6.8	25.3		11:00	6.9:7.0	25.6
8/1	0:00	6.6:6.7	25.3		12:00	7.0:7.1	25.7
	1:00	6.7:6.8	25.4		13:00	7.1:7.2	25.7
	2:00	6.7:6.8	25.4		14:00	6.7:6.8	25.6
	3:00	6.6:6.7	25.4		15:00	6.9:7.0	25.6
	4:00	6.5:6.6	25.4		16:00	6.9:7.0	25.7
	5:00	6.3:6.4	25.3		17:00	7.7:7.8	25.9
	6:00	6.3:6.4	25.2		18:00	7.9:8.0	26.0
	7:00	6.2:6.3	25.2		19:00	8.1:8.2	26.0
	8:00	6.3:6.4	25.3		20:00	8.2:8.3	26.0
	9:00	6.3:6.4	25.3		21:00	7.5:7.6	25.8
	10:00	6.4:6.5	25.3		22:00	7.3:7.4	25.6
	11:00	6.5:6.6	25.2		23:00	7.0:7.1	25.5

*Value to right of colon is corrected reading.

Table C-5 (continued)
July 25 - August 4, 1980 Dynamic Survey Field Data
Hourly Data - Inlet to Lake DuBay

Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)	Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)
8/3	0:00	6.7:6.8	25.5		19:00	6.6:6.7	25.5
	1:00	6.8:6.9	25.4		20:00	6.4:6.5	25.5
	2:00	6.6:6.7	25.4		21:00	7.0:7.1	25.5
	3:00	6.6:6.7	25.3		22:00	7.9:8.0	25.8
	4:00	6.6:6.7	25.3		23:00	7.2:7.3	25.7
	5:00	6.5:6.6	25.2	8/4	0:00	7.1:7.2	25.4
	6:00	6.4:6.5	25.2		1:00	6.7:6.8	25.3
	7:00	6.4:6.5	25.1		2:00	6.8:6.9	25.1
	8:00	6.3:6.4	25.1		3:00	6.7:6.8	25.2
	9:00	6.3:6.4	25.1		4:00	6.7:6.8	25.1
	10:00	6.5:6.6	25.2		5:00	6.7:6.8	25.2
	11:00	6.5:6.6	25.2		6:00	6.8:6.9	25.1
	12:00	6.6:6.7	25.3		7:00	6.8:6.9	25.1
	13:00	6.3:6.4	25.2		8:00	6.8:6.9	25.1
	14:00	6.5:6.6	25.4		9:00	6.8:6.9	25.0
	15:00	6.7:6.8	25.4		10:00	6.9:7.0	25.1
	16:00	6.6:6.7	25.4		11:00	6.8:6.9	25.1
	17:00	6.8:6.9	25.5		12:00	6.6:6.7	25.0
	18:00	7.1:7.2	25.5				

*Value to right of colon is corrected reading.

Table C-6
August 4-13, 1980 Dynamic Survey Field Data
Hourly Data - Rothschild Dam

Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)	Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)
8/4	12:00	7.8:7.8	23.8		18:00	9.5:9.5	24.0
	13:00	7.9:7.9	23.7		19:00	9.5:9.5	24.0
	14:00	7.9:7.9	23.7		20:00	9.5:9.5	24.0
	15:00	8.0:8.0	23.7		21:00	9.4:9.4	23.9
	16:00	8.0:8.0	23.7		22:00	9.2:9.2	23.9
	17:00	8.1:8.1	23.8		23:00	9.1:9.1	23.9
	18:00	8.2:8.2	23.8	8/6	0:00	9.1:9.0	23.8
	19:00	8.1:8.1	23.8		1:00	9.0:8.9	23.6
	20:00	8.0:8.0	23.8		2:00	8.7:8.8	23.5
	21:00	7.9:7.9	23.8		3:00	8.5:8.4	23.5
	22:00	8.0:8.0	23.7		4:00	8.4:8.3	23.4
	23:00	8.2:8.2	23.7		5:00	8.3:8.2	23.3
8/5	0:00	8.2:8.2	23.7		6:00	8.2:8.1	23.2
	1:00	8.3:8.3	23.7		7:00	8.2:8.1	23.0
	2:00	8.3:8.3	23.8		8:00	8.1:8.0	23.0
	3:00	8.3:8.3	23.7		9:00	8.2:8.1	23.1
	4:00	8.2:8.2	23.7		10:00	8.4:8.3	23.3
	5:00	8.1:8.1	23.6		11:00	8.3:8.2	23.5
	6:00	8.0:8.0	23.5		12:00	8.8:8.7	23.4
	7:00	7.9:7.9	23.5		13:00	8.9:8.8	23.5
	8:00	7.9:7.9	23.4		14:00	8.8:8.7	23.5
	9:00	8.0:8.0	23.4		15:00	8.5:8.4	23.5
	10:00	8.1:8.1	23.5		16:00	8.1:8.0	23.3
	11:00	8.3:8.3	23.5		17:00	8.2:8.1	23.4
	12:00	8.4:8.4	23.5		18:00	9.5:9.4	23.9
	13:00	8.5:8.5	23.6		19:00	8.9:8.8	23.6
	14:00	8.7:8.7	23.6		20:00	8.2:8.1	23.4
	15:00	9.0:9.0	23.7		21:00	8.3:8.2	23.4
	16:00	9.3:9.3	23.8		22:00	8.2:8.1	23.4
	17:00	9.4:9/4	24.0		23:00	8.6:8.5	23.5

*Value to right of colon is corrected reading.

Table C-6 (continued)
August 4-13, 1980 Dynamic Survey Field Data
Hourly Data - Rothschild Dam

Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)	Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)
8/7	0:00	8.8:8.7	23.6		12:00	8.7:8.6	23.7
	1:00	8.4:8.3	23.3		13:00	8.9:8.8	23.8
	2:00	8.1:8.0	23.3		14:00	9.0:8.9	23.9
	3:00	8.0:7.9	23.3		15:00	9.0:8.9	24.0
	4:00	8.1:8.0	23.3		16:00	9.1:9.0	24.0
	5:00	8.1:8.0	23.2		17:00	9.4:9.3	24.3
	6:00	8.1:8.0	23.0		18:00	9.5:9.4	24.5
	7:00	8.2:8.1	23.1		19:00	9.7:9.6	24.5
	8:00	8.2:8.1	23.0		20:00	9.6:9.5	24.5
	9:00	8.3:8.2	23.1		21:00	9.5:9.4	24.5
	10:00	8.4:8.3	23.2		22:00	9.4:9.3	24.5
	11:00	8.5:8.4	23.3		23:00	9.2:9.1	24.4
	12:00	8.6:8.5	23.4	8/9	0:00	9.0:8.8	24.3
	13:00	8.9:8.8	23.5		1:00	8.7:8.5	24.1
	14:00	9.0:8.9	23.6		2:00	8.5:8.3	24.1
	15:00	9.4:9.3	23.9		3:00	8.2:8.0	24.0
	16:00	9.6:9.5	24.0		4:00	8.1:7.9	24.0
	17:00	8.8:8.7	23.6		5:00	8.0:7.8	23.9
	18:00	8.8:8.7	23.7		6:00	8.0:7.8	23.8
	19:00	9.0:8.9	23.8		7:00	8.0:7.8	23.7
	20:00	9.1:9.0	23.9		8:00	7.9:7.7	23.7
	21:00	9.5:9.4	24.0		9:00	8.0:7.8	23.8
	22:00	9.5:9.4	24.0		10:00	8.1:7.9	23.8
	23:00	9.5:9.4	23.9		11:00	8.3:8.1	24.0
8/8	0:00	9.0:8.9	23.8		12:00	8.6:8.4	24.1
	1:00	8.7:8.6	23.7		13:00	8.7:8.5	24.1
	2:00	8.4:8.3	23.6		14:00	8.7:8.5	24.1
	3:00	8.3:8.2	23.6		15:00	8.7:8.5	24.0
	4:00	8.4:8.3	23.5		16:00	8.8:8.6	24.0
	5:00	8.3:8.2	23.5		17:00	9.3:9.1	24.2
	6:00	8.2:8.1	23.5		18:00	9.2:9.0	24.2
	7:00	8.1:8.0	23.4		19:00	8.7:8.5	24.0
	8:00	8.1:8.0	23.4		20:00	8.6:8.4	24.0
	9:00	8.1:8.0	23.4		21:00	8.5:8.3	24.0
	10:00	8.4:8.3	23.5		22:00	8.5:8.3	23.9
	11:00	8.6:8.5	23.6		23:00	8.6:8.4	23.9

*Value to right of colon is corrected reading.

Table C-6 (continued)
August 4-13, 1980 Dynamic Survey Field Data
Hourly Data - Rothschild Dam

Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)	Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)
8/10	0:00	8.6:8.4	23.8		12:00	7.8:7.6	22.8
	1:00	8.4:8.2	23.7		13:00	7.9:7.7	22.7
	2:00	8.3:8.1	23.6		14:00	8.0:7.8	22.8
	3:00	8.1:7.9	23.6		15:00	8.2:8.0	22.8
	4:00	8.1:7.9	23.5		16:00	8.4:8.2	22.9
	5:00	7.9:7.7	23.5		17:00	8.5:8.3	22.9
	6:00	7.9:7.7	23.2		18:00	8.7:8.5	23.1
	7:00	7.9:7.7	23.3		19:00	9.0:8.8	23.1
	8:00	7.8:7.6	23.3		20:00	9.1:8.9	23.0
	9:00	7.8:7.6	23.2		21:00	9.0:8.8	22.9
	10:00	7.8:7.6	23.3		22:00	9.0:8.8	22.9
	11:00	7.8:7.6	23.1		23:00	8.8:8.6	22.9
	12:00	7.9:7.7	23.2	8/12	0:00	8.5:8.2	22.8
	13:00	8.0:7.8	23.3		1:00	8.4:8.1	22.7
	14:00	8.1:7.9	23.3		2:00	8.3:8.0	22.5
	15:00	8.1:7.9	23.4		3:00	8.2:7.9	22.6
	16:00	8.0:7.8	23.2		4:00	8.1:7.8	22.5
	17:00	7.9:7.7	23.3		5:00	8.0:7.7	22.4
	18:00	7.9:7.7	23.3		6:00	7.9:7.6	22.4
	19:00	7.8:7.6	23.3		7:00	7.8:7.5	22.3
	20:00	7.9:7.7	23.3		8:00	7.7:7.4	22.2
	21:00	7.9:7.7	23.1		9:00	7.6:7.3	22.2
	22:00	7.9:7.7	23.1		10:00	7.7:7.4	22.2
	23:00	7.9:7.7	23.1		11:00	7.9:7.6	22.3
8/11	0:00	7.8:7.6	23.0		12:00	8.1:7.8	22.4
	1:00	7.8:7.6	23.0		13:00	7.9:7.6	22.4
	2:00	7.7:7.5	23.0		14:00	7.9:7.6	22.4
	3:00	7.7:7.5	23.0		15:00	7.9:7.6	22.4
	4:00	7.7:7.5	23.0		16:00	7.9:7.6	22.4
	5:00	7.7:7.5	22.9		17:00	7.9:7.6	22.5
	6:00	7.7:7.5	23.0		18:00	8.5:8.2	22.8
	7:00	7.7:7.5	22.9		19:00	8.8:8.5	22.8
	8:00	7.6:7.4	22.8		20:00	8.5:8.2	22.8
	9:00	7.7:7.5	22.7		21:00	9.0:8.7	22.8
	10:00	7.8:7.6	22.7		22:00	9.0:8.7	22.9
	11:00	7.8:7.6	22.7		23:00	9.0:8.7	22.8

*Value to right of colon is corrected reading.

Table C-6 (continued)
August 4-13, 1980 Dynamic Survey Field Data
Hourly Data - Rothschild Dam

Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)
8/13	0:00	8.2:7.9	22.5
	1:00	8.5:8.2	22.7
	2:00	8.6:8.3	22.7
	3:00	8.1:7.8	22.5
	4:00	8.0:7.7	22.3
	5:00	8.0:7.7	22.3
	6:00	7.8:7.5	22.2
	7:00	7.7:7.4	22.1
	8:00	7.6:7.3	22.0
	9:00	7.6:7.3	22.0
	10:00	7.8:7.5	22.0
	11:00	7.8:7.5	22.0

*Value to right of colon is corrected reading.

Table C-7
August 5-15, 1980 Dynamic Survey Field Data
Hourly Data - Inlet to Lake DuBay

Date	Time	Inst. DO (mg/l)	Inst. Temp. (°C)	Date	Time	Inst. DO (mg/l)	Inst. Temp. (°C)
8/5	14:00	6.4	23.7		19:00	8.7	25.2
	15:00	7.8	24.3		20:00	8.4	25.2
	16:00	6.7	24.1		21:00	8.1	25.2
	17:00	7.0	24.2		22:00	7.9	25.2
	18:00	7.3	24.2		23:00	7.8	25.2
	19:00	7.5	24.4	8/7	0:00	7.7	25.0
	20:00	7.2	24.2		1:00	7.5	25.0
	21:00	7.2	24.1		2:00	7.3	25.0
	22:00	7.3	24.1		3:00	7.2	24.8
	23:00	7.3	24.1		4:00	6.9	24.8
8/6	0:00	7.2	24.3		5:00	6.8	24.6
	1:00	7.1	24.3		6:00	6.7	24.5
	2:00	7.0	24.3		7:00	6.6	24.4
	3:00	7.0	24.2		8:00	6.6	24.4
	4:00	6.9	24.1		9:00	6.5	24.3
	5:00	6.8	24.1		10:00	7.2	24.2
	6:00	6.6	24.1		11:00	7.3	24.3
	7:00	6.5	24.0		12:00	7.3	24.5
	8:00	6.5	24.0		13:00	7.3	24.5
	9:00	6.9	24.0		14:00	7.5	24.5
	10:00	7.0	24.2		15:00	8.7	24.7
	11:00	7.2	24.2		16:00	8.2	25.0
	12:00	7.4	24.3		17:00	8.1	24.9
	13:00	7.8	24.5		18:00	7.9	24.9
	14:00	8.5	24.7		19:00	7.6	24.8
	15:00	8.6	24.9		20:00	7.6	24.7
	16:00	8.4	25.0		21:00	7.6	24.6
	17:00	8.2	25.0		22:00	7.6	24.6
	18:00	8.7	25.3		23:00	7.4	24.6

Table C-7 (continued)
August 5-15, 1980 Dynamic Survey Field Data
Hourly Data - Inlet to Lake DuBay

Date	Time	Inst. DO (mg/l)	Inst. Temp. (°C)	Date	Time	Inst. DO (mg/l)	Inst. Temp. (°C)
8/8	0:00	7.4	24.5		12:00	7.8	24.4
	1:00	7.3	24.5		13:00	7.9	24.6
	2:00	7.1	24.5		14:00	8.0	24.5
	3:00	6.9	24.4		15:00	8.1	24.6
	4:00	6.8	24.4		16:00	8.1	24.6
	5:00	6.6	24.3		17:00	8.1	24.6
	6:00	6.5	24.1		18:00	8.2	24.6
	7:00	6.4	24.1		19:00	8.2	24.6
	8:00	6.3	24.0		20:00	8.2	24.5
	9:00	6.4	24.1		21:00	8.0	24.5
	10:00	6.5	24.2		22:00	7.8	24.4
	11:00	6.6	24.1		23:00	7.7	24.4
	12:00	6.7	24.2	8/10	0:00	7.5	24.3
	13:00	6.7	24.2		1:00	7.3	24.2
	14:00	6.8	24.3		2:00	7.2	24.2
	15:00	7.0	24.3		3:00	7.2	24.1
	16:00	7.1	24.4		4:00	7.1	24.1
	17:00	7.2	24.4		5:00	7.0	24.0
	18:00	7.4	24.5		6:00	6.9	24.0
	19:00	7.5	24.5		7:00	6.9	23.9
	20:00	7.6	24.6		8:00	6.8	23.8
	21:00	7.5	24.5		9:00	6.8	23.8
	22:00	7.3	24.5		10:00	6.8	23.8
	23:00	7.3	24.5		11:00	6.8	23.8
8/9	0:00	7.3	24.5		12:00	7.0	23.7
	1:00	7.1	24.4		13:00	7.3	23.8
	2:00	7.0	24.4		14:00	7.5	23.9
	3:00	6.9	24.3		15:00	7.4	23.7
	4:00	6.8	24.3		16:00	7.2	23.6
	5:00	6.8	24.2		17:00	7.4	23.7
	6:00	6.8	24.2		18:00	7.3	23.7
	7:00	6.8	24.0		19:00	7.4	23.6
	8:00	6.8	24.0		20:00	7.3	23.6
	9:00	7.1	24.0		21:00	7.2	23.6
	10:00	7.2	24.1		22:00	7.1	23.5
	11:00	7.5	24.3		23:00	7.1	23.4

Table C-7 (continued)
August 5-15, 1980 Dynamic Survey Field Data
Hourly Data - Inlet to Lake DuBay

Date	Time	Inst. DO (mg/l)	Inst. Temp. (°C)	Date	Time	Inst. DO (mg/l)	Inst. Temp. (°C)
8/11	0:00	7.0	23.4		12:00	7.6	23.2
	1:00	6.9	23.4		13:00	7.9	23.4
	2:00	6.9	23.3		14:00	8.4	23.6
	3:00	6.8	23.3		15:00	8.7	23.8
	4:00	6.7	23.2		16:00	9.3	24.1
	5:00	6.6	23.2		17:00	9.4	24.3
	6:00	6.6	23.2		18:00	9.4	24.3
	7:00	6.6	23.1		19:00	9.4	24.1
	8:00	6.6	23.0		20:00	8.7	23.9
	9:00	6.6	23.0		21:00	8.3	23.7
	10:00	6.6	23.0		22:00	8.3	23.7
	11:00	6.6	23.1		23:00	8.3	23.7
	12:00	6.6	23.1	8/13	0:00	8.3	23.6
	13:00	6.6	23.1		1:00	8.2	23.6
	14:00	6.8	23.2		2:00	8.1	23.5
	15:00	6.9	23.2		3:00	8.0	23.5
	16:00	7.0	23.3		4:00	7.9	23.5
	17:00	7.3	23.5		5:00	7.6	23.4
	18:00	7.2	23.4		6:00	7.5	23.2
	19:00	7.2	23.4		7:00	7.4	23.2
	20:00	7.3	23.3		8:00	7.3	23.2
	21:00	7.2	23.3		9:00	7.2	23.2
	22:00	7.2	23.3		10:00	7.3	23.2
	23:00	7.2	23.4		11:00	7.4	23.1
8/12	0:00	7.1	23.3		12:00	7.4	23.2
	1:00	7.1	23.3		13:00	7.4	23.1
	2:00	7.0	23.3		14:00	7.5	23.2
	3:00	6.9	23.2		15:00	7.6	23.2
	4:00	6.8	23.1		16:00	7.6	23.2
	5:00	6.7	22.9		17:00	7.5	23.2
	6:00	6.6	22.9		18:00	7.5	23.1
	7:00	6.5	22.8		19:00	7.3	23.1
	8:00	6.6	22.8		20:00	7.3	23.0
	9:00	6.8	22.8		21:00	7.2	23.0
	10:00	7.0	23.0		22:00	7.2	23.0
	11:00	7.3	23.2		23:00	7.0	22.9

Table C-7 (continued)
August 5-15, 1980 Dynamic Survey Field Data
Hourly Data - Inlet to Lake DuBay

Date	Time	Inst. DO (mg/l)	Inst. Temp. (°C)	Date	Time	Inst. DO (mg/l)	Inst. Temp. (°C)
8/14	0:00	6.9	22.9		20:00	7.8	23.3
	1:00	6.8	22.8		21:00	7.7	23.2
	2:00	6.6	22.8		22:00	7.6	23.1
	3:00	6.5	22.6		23:00	7.7	23.2
	4:00	6.4	22.5	8/15	0:00	7.7	23.2
	5:00	6.3	22.5		1:00	7.7	23.2
	6:00	6.2	22.4		2:00	7.6	23.2
	7:00	6.1	22.3		3:00	7.5	23.1
	8:00	6.1	22.3		4:00	7.4	23.2
	9:00	6.3	22.4		5:00	7.4	23.1
	10:00	6.5	22.4		6:00	7.3	23.0
	11:00	6.5	22.4		7:00	7.2	23.0
	12:00	6.7	22.5		8:00	7.3	22.9
	13:00	6.9	22.7		9:00	7.4	23.0
	14:00	7.4	23.2		10:00	7.6	23.1
	15:00	7.6	23.3		11:00	7.9	23.3
	16:00	7.6	23.3		12:00	8.3	23.5
	17:00	7.9	23.3		13:00	8.6	23.7
	18:00	8.1	23.5		14:00	8.7	23.7
	19:00	8.0	23.4		15:00	8.8	23.7

Table C-8
August 20-29, 1980 Dynamic Survey Field Data
Hourly Data - Inlet to Lake DuBay

Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)	Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)
8/20	13:00	8.7:8.7	24.0		19:00	8.4:8.4	23.6
	14:00	9.0:9.0	24.1		20:00	8.3:8.3	23.5
	15:00	9.1:9.1	24.3		21:00	8.2:8.2	23.6
	16:00	9.3:9.3	24.5		22:00	8.1:8.1	23.5
	17:00	9.4:9.4	24.6		23:00	8.0:8.0	23.5
	18:00	9.1:9.1	24.5	8/22	0:00	7.8:7.9	23.6
	19:00	8.5:8.5	24.2		1:00	7.7:7.8	23.6
	20:00	8.2:8.2	24.0		2:00	7.6:7.7	23.5
	21:00	8.1:8.1	24.0		3:00	7.6:7.7	23.4
	22:00	8.0:8.0	23.8		4:00	7.5:7.6	23.3
	23:00	7.9:7.9	23.7		5:00	7.4:7.5	23.2
8/21	0:00	7.7:7.7	23.5		6:00	7.3:7.4	23.0
	1:00	7.5:7.5	23.5		7:00	7.3:7.4	22.9
	2:00	7.3:7.3	23.5		8:00	7.3:7.4	22.8
	3:00	7.1:7.1	23.5		9:00	7.3:7.4	22.7
	4:00	7.0:7.0	23.5		10:00	7.4:7.5	22.7
	5:00	7.0:7.0	23.4		11:00	7.6:7.7	22.7
	6:00	7.1:7.1	23.3		12:00	7.8:7.9	22.8
	7:00	7.1:7.1	23.0		13:00	8.0:8.1	23.0
	8:00	7.2:7.2	22.9		14:00	8.2:8.3	23.3
	9:00	7.2:7.2	22.7		15:00	8.4:8.5	23.5
	10:00	7.4:7.4	22.7		16:00	8.4:8.5	23.6
	11:00	7.5:7.5	22.8		17:00	8.6:8.7	23.7
	12:00	7.7:7.7	22.9		18:00	8.8:8.9	23.8
	13:00	7.9:7.9	23.0		19:00	8.7:8.8	23.9
	14:00	8.0:8.0	23.1		20:00	8.7:8.8	23.9
	15:00	8.2:8.2	23.2		21:00	8.6:8.7	23.9
	16:00	8.3:8.3	23.4		22:00	8.5:8.6	23.9
	17:00	8.4:8.4	23.6		23:00	8.3:8.4	23.9
	18:00	8.4:8.4	23.6				

*Value to right of colon is corrected reading.

Table C-8 (continued)
August 20-29, 1980 Dynamic Survey Field Data
Hourly Data - Inlet to Lake DuBay

Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)	Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)
8/23	0:00	8.2:8.3	23.8		12:00	6.8:6.9	22.3
	1:00	8.0:8.1	23.7		13:00	7.0:7.1	22.5
	2:00	7.9:8.0	23.6		14:00	7.2:7.3	22.8
	3:00	7.8:7.9	23.5		15:00	7.5:7.6	22.9
	4:00	7.7:7.8	23.4		16:00	7.1:7.2	22.5
	5:00	7.5:7.6	23.4		17:00	7.0:7.1	22.3
	6:00	7.4:7.5	23.3		18:00	6.9:7.0	22.2
	7:00	7.3:7.4	23.2		19:00	6.9:7.0	22.3
	8:00	7.3:7.4	23.1		20:00	6.7:6.8	22.3
	9:00	7.3:7.4	23.0		21:00	6.6:6.7	22.3
	10:00	7.4:7.5	23.0		22:00	6.5:6.6	22.3
	11:00	7.4:7.5	23.0		23:00	6.4:6.6	22.2
	12:00	7.6:7.7	23.0	8/25	0:00	6.4:6.6	22.1
	13:00	7.7:7.8	23.1		1:00	6.3:6.5	22.0
	14:00	7.8:7.9	23.2		2:00	6.3:6.5	22.0
	15:00	7.8:7.9	23.2		3:00	6.3:6.5	22.0
	16:00	7.8:7.9	23.2		4:00	6.2:6.4	21.9
	17:00	7.9:8.0	23.0		5:00	6.1:6.3	22.0
	18:00	8.0:8.1	23.2		6:00	6.1:6.3	21.9
	19:00	7.9:8.0	23.1		7:00	6.1:6.3	21.9
	20:00	7.9:8.0	23.1		8:00	6.0:6.2	21.8
	21:00	7.8:7.9	23.1		9:00	6.1:6.3	21.7
	22:00	7.8:7.9	23.0		10:00	6.1:6.3	21.7
	23:00	7.7:7.8	23.0		11:00	6.1:6.3	21.8
8/24	0:00	7.6:7.7	23.0		12:00	6.2:6.4	21.9
	1:00	7.5:7.6	22.9		13:00	6.3:6.5	22.0
	2:00	7.4:7.5	22.8		14:00	6.4:6.6	22.0
	3:00	7.3:7.4	22.7		15:00	6.5:6.7	22.2
	4:00	7.2:7.3	22.7		16:00	6.8:7.0	22.4
	5:00	7.1:7.2	22.6		17:00	7.0:7.2	22.5
	6:00	7.0:7.1	22.5		18:00	7.3:7.5	22.6
	7:00	6.4:6.5	22.5		19:00	7.1:7.3	22.6
	8:00	6.8:6.9	22.4		20:00	6.6:6.8	22.4
	9:00	6.8:6.9	22.4		21:00	6.4:6.6	22.3
	10:00	6.7:6.8	22.3		22:00	6.2:6.4	22.5
	11:00	6.7:6.8	22.2		23:00	6.2:6.4	22.5

*Value to right of colon is corrected reading.

Table C-8 (continued)
August 20-29, 1980 Dynamic Survey Field Data
Hourly Data - Inlet to Lake DuBay

Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)	Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)
8/26	0:00	6.2:6.4	22.5		12:00	7.1:7.3	20.9
	1:00	6.3:6.5	22.5		13:00	7.2:7.4	21.0
	2:00	6.2:6.4	22.5		14:00	7.2:7.4	21.0
	3:00	6.2:6.4	22.5		15:00	7.3:7.5	20.9
	4:00	6.3:6.5	22.4		16:00	7.3:7.5	20.8
	5:00	6.5:6.7	22.4		17:00	7.3:7.5	20.8
	6:00	6.5:6.7	22.4		18:00	7.5:7.7	20.8
	7:00	6.5:6.7	22.4		19:00	7.5:7.7	20.8
	8:00	6.5:6.7	22.4		20:00	7.4:7.6	20.8
	9:00	6.6:6.8	22.5		21:00	7.6:7.8	20.8
	10:00	6.6:6.8	22.5		22:00	7.6:7.8	20.9
	11:00	6.5:6.7	22.6		23:00	7.7:8.0	20.9
	12:00	6.5:6.7	22.7	8/28	0:00	7.6:7.9	20.9
	13:00	6.5:6.7	22.7		1:00	7.6:7.9	20.8
	14:00	6.5:6.7	22.8		2:00	7.6:7.9	20.7
	15:00	6.5:6.7	22.8		3:00	7.6:7.9	20.7
	16:00	6.6:6.8	22.9		4:00	7.6:7.9	20.6
	17:00	6.5:6.7	22.8		5:00	7.7:8.0	20.5
	18:00	6.5:6.7	22.8		6:00	7.7:8.0	20.5
	19:00	6.5:6.7	22.8		7:00	7.8:8.1	20.4
	20:00	6.4:6.6	22.7		8:00	7.8:8.1	20.2
	21:00	6.4:6.6	22.6		9:00	7.8:8.1	20.1
	22:00	6.4:6.6	22.6		10:00	7.9:8.2	20.0
	23:00	6.4:6.6	22.5		11:00	7.9:8.2	20.0
8/27	0:00	6.4:6.6	22.4		12:00	8.0:8.3	20.0
	1:00	6.5:6.7	22.3		13:00	8.0:8.3	20.0
	2:00	6.5:6.7	22.1		14:00	8.1:8.4	20.1
	3:00	6.5:6.7	22.0		15:00	8.1:8.4	20.1
	4:00	6.4:6.6	21.9		16:00	8.1:8.4	20.1
	5:00	6.5:6.7	21.8		17:00	8.1:8.4	20.0
	6:00	6.4:6.6	21.6		18:00	8.1:8.4	20.0
	7:00	6.5:6.7	21.5		19:00	8.1:8.4	20.0
	8:00	6.5:6.7	21.4		20:00	8.1:8.4	20.0
	9:00	6.5:6.7	21.3		21:00	8.1:8.4	20.0
	10:00	6.6:6.8	21.1		22:00	8.1:8.4	19.9
	11:00	6.7:6.9	21.0		23:00	8.1:8.4	19.9

*Value to right of colon is corrected value.

Table C-8 (continued)
August 20-29, 1980 Dynamic Survey Field Data
Hourly Data - Inlet to Lake DuBay

Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)
8/29	0:00	8.1:8.4	19.9
	1:00	8.1:8.4	19.8
	2:00	8.1:8.4	19.7
	3:00	8.1:8.4	19.6
	4:00	8.1:8.4	19.6
	5:00	8.0:8.3	19.6
	6:00	8.0:8.3	19.5
	7:00	8.0:8.3	19.5
	8:00	8.0:8.3	19.5
	9:00	8.0:8.3	19.4
	10:00	8.0:8.3	19.5

*Value to right of colon is corrected reading.

Table C-9
September 2-10, 1980 Dynamic Survey Field Data
Hourly Data - Inlet to Lake DuBay

Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)	Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)
9/2	13:00	8.2:8.2	19.1		19:00	8.3:8.4	19.7
	14:00	8.3:8.3	19.2		20:00	8.3:8.4	19.8
	15:00	8.3:8.3	19.3		21:00	8.4:8.5	19.9
	16:00	8.3:8.3	19.5		22:00	8.3:8.4	19.9
	17:00	8.3:8.3	19.6		23:00	8.2:8.3	19.9
	18:00	8.3:8.3	19.8	9/4	0:00	8.2:8.3	19.9
	19:00	8.3:8.3	19.7		1:00	8.2:8.3	19.8
	20:00	8.3:8.3	19.7		2:00	8.2:8.3	19.8
	21:00	8.2:8.2	19.8		3:00	8.1:8.2	19.7
	22:00	8.2:8.2	19.8		4:00	8.1:8.2	19.6
	23:00	8.1:8.1	19.8		5:00	8.1:8.2	19.6
9/3	0:00	8.1:8.1	19.8		6:00	8.1:8.2	19.5
	1:00	8.1:8.1	19.8		7:00	8.1:8.2	19.4
	2:00	8.0:8.0	19.7		8:00	8.1:8.2	19.4
	3:00	8.0:8.0	19.6		9:00	8.1:8.2	19.3
	4:00	8.0:8.0	19.5		10:00	8.1:8.2	19.3
	5:00	8.0:8.0	19.4		11:00	8.1:8.2	19.3
	6:00	8.1:8.1	19.3		12:00	8.2:8.3	19.4
	7:00	8.1:8.1	19.3		13:00	8.2:8.3	19.5
	8:00	8.1:8.1	19.1		14:00	8.3:8.4	19.6
	9:00	8.2:8.2	19.1		15:00	8.3:8.4	19.7
	10:00	8.2:8.2	19.0		16:00	8.4:8.5	19.8
	11:00	8.2:8.2	19.0		17:00	8.4:8.5	20.0
	12:00	8.3:8.3	18.9		18:00	8.5:8.6	20.0
	13:00	8.3:8.4	18.9		19:00	8.4:8.5	20.0
	14:00	8.3:8.4	19.0		20:00	8.4:8.5	20.1
	15:00	8.3:8.4	19.3		21:00	8.4:8.5	20.0
	16:00	8.3:8.4	19.4		22:00	8.4:8.5	20.0
	17:00	8.4:8.5	19.5		23:00	8.4:8.5	20.0
	18:00	8.4:8.5	19.6				

*Value to right of colon is corrected reading.

Table C-9 (continued)
September 2-10, 1980 Dynamic Survey Field Data
Hourly Data - Inlet to Lake DuBay

Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)	Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)
9/5	0:00	8.4:8.5	19.9		12:00	8.7:8.9	19.3
	1:00	8.3:8.4	19.8		13:00	8.7:8.9	19.4
	2:00	8.3:8.4	19.6		14:00	8.7:8.9	19.5
	3:00	8.3:8.4	19.5		15:00	8.7:8.9	19.7
	4:00	8.3:8.4	19.4		16:00	8.7:8.9	20.0
	5:00	8.3:8.4	19.3		17:00	8.7:8.9	20.1
	6:00	8.2:8.3	19.1		18:00	8.7:8.9	20.2
	7:00	8.2:8.3	18.9		19:00	8.7:8.9	20.3
	8:00	8.3:8.4	18.8		20:00	8.7:8.9	20.4
	9:00	8.3:8.4	18.7		21:00	8.7:8.9	20.3
	10:00	8.3:8.4	18.7		22:00	8.7:8.9	20.3
	11:00	8.4:8.5	18.8		23:00	8.6:8.8	20.3
	12:00	8.4:8.5	18.8	9/7	0:00	8.6:8.8	20.2
	13:00	8.5:8.7	19.0		1:00	8.5:8.7	20.2
	14:00	8.4:8.6	19.0		2:00	8.5:8.7	20.2
	15:00	8.4:8.6	19.3		3:00	8.5:8.7	20.1
	16:00	8.3:8.5	19.4		4:00	8.4:8.6	20.0
	17:00	8.5:8.7	19.5		5:00	8.4:8.6	19.9
	18:00	8.6:8.8	19.7		6:00	8.4:8.6	19.8
	19:00	8.7:8.9	19.9		7:00	8.4:8.6	19.6
	20:00	8.7:8.9	20.0		8:00	8.4:8.6	19.5
	21:00	8.7:8.9	20.0		9:00	8.4:8.6	19.5
	22:00	8.6:8.8	20.0		10:00	8.4:8.6	19.5
	23:00	8.6:8.8	19.9		11:00	8.4:8.6	19.5
9/6	0:00	8.6:8.8	19.8		12:00	8.4:8.6	19.5
	1:00	8.6:8.8	19.6		13:00	8.5:8.8	19.7
	2:00	8.5:8.7	19.5		14:00	8.5:8.8	19.8
	3:00	8.5:8.7	19.5		15:00	8.6:8.9	20.0
	4:00	8.5:8.7	19.4		16:00	8.6:8.9	20.1
	5:00	8.5:8.7	19.2		17:00	8.7:9.0	20.2
	6:00	8.5:8.7	19.0		18:00	8.7:9.0	20.4
	7:00	8.5:8.7	18.9		19:00	8.7:9.0	20.5
	8:00	8.5:8.7	18.8		20:00	8.7:9.0	20.5
	9:00	8.6:8.8	18.8		21:00	8.7:9.0	20.5
	10:00	8.6:8.8	19.0		22:00	8.6:8.9	20.6
	11:00	8.6:8.8	19.0		23:00	8.5:8.8	20.5

*Value to right of colon is corrected reading.

Table C-9 (continued)
September 2-10, 1980 Dynamic Survey Field Data
Hourly Data - Inlet to Lake DuBay

Date	Time	Inst. DO* (mg/l)	Inst. Temp. (°C)
9/8	0:00	8.5:8.8	20.5
	1:00	8.4:8.7	20.6
	2:00	8.4:8.7	20.6
	3:00	8.4:8.7	20.5
	4:00	8.3:8.6	20.4
	5:00	8.3:8.6	20.2
	6:00	8.3:8.6	20.0
	7:00	8.3:8.6	19.9
	8:00	8.3:8.6	19.8
	9:00	8.3:8.6	19.8
	10:00	8.3:8.6	19.9
	11:00	8.3:8.6	20.0
	12:00	8.4:8.7	20.1
	13:00	8.4:8:8	20.2
	14:00	8.4:8.8	20.4
	15:00	8.4:8.8	20.6
	16:00	8.4:8.8	20.8
	17:00	8.4:8.8	21.0
	18:00	8.4:8.8	21.2
	19:00	8.4:8.8	21.4
	20:00	8.3:8.7	21.5
	21:00	8.3:8.7	21.5
	22:00	8.3:8.7	21.6
	23:00	8.2:8.6	21.6
9/9	0:00	8.2:8.6	21.6
	1:00	8.2:8.6	21.6
	2:00	8.2:8.6	21.6
	3:00	8.2:8.6	21.6
	4:00	8.1:8.5	21.5
	5:00	8.0:8.4	21.4
	6:00	7.9:8.3	21.3
	7:00	7.9:8.3	20.9
	8:00	7.9:8.3	20.7
	9:00	8.0:8.4	20.5
	10:00	8.0:8.4	20.4
	11:00	8.1:8.5	20.3
	12:00	8.2:8.6	20.2
	13:00	8.3:8.7	20.2
	14:00	8.4:8.8	20.3
	15:00	8.2:8.6	20.5
	16:00	8.6:9.0	20.6
	17:00	8.7:9.1	20.8
	18:00	8.7:9.1	21.0
	19:00	8.6:9.0	21.0
	20:00	8.6:9.0	20.9
	21:00	8.6:9.0	20.8
	22:00	8.5:8.9	20.7
	23:00	8.5:8.9	20.5
9/10	0:00	8.4:8.8	20.4
	1:00	8.4:8.8	20.2
	2:00	8.4:8.8	20.1
	3:00	8.4:8.8	20.0
	4:00	8.4:8.8	19.8
	5:00	8.5:8.9	19.7
	6:00	8.5:8.9	19.5
	7:00	8.5:8.9	19.4
	8:00	8.5:8.9	19.3
	9:00	8.6:9.0	19.3
	10:00	8.6:9.0	19.3
	11:00	8.7:9.1	19.4

*Value to right of colon is corrected reading.

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 BC of the Wisconsin River. Some of the rate coefficients when set are constant for the entire segment, while others are variable by reach (even if the same as surrounding reaches). The constant rate coefficients are given in Table D-1. Table D-3 contains the settings of the reach variable rate 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 in 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 $K_2=Q^b$, 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 BC 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	= 1.70 mg O_2/mg algae
Oxygen Uptake by Algae Respiration	= 1.70 mg O_2/mg algae
Nitrogen Content of Algae	= 0.10 mg N/mg algae
Phosphorus Content of Algae	= 0.008 mg P/mg algae
Nitrogen Half-Saturation Constant	= 0.02 mg/l
Phosphorus Half-Saturation Constant	= 0.005 mg/l
Fraction of Settled Algae Biomass that Decays for Oxygen Consumption	= 0.56
Saturating Light Level for Algae Growth	= 0.55 langleys/minute

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

Number	Name	Upstream Mile Point	Downstream Mile Point
1	Brokaw	271.4	270.9
2	Sewage Treatment Plant Island	270.9	269.9
3	County Hwy W	269.9	267.9
4	Wausau Flowage I	267.9	266.3
5	Wausau Flowage II	266.3	265.7
6	Wausau Flowage III	265.7	265.6
7	Hammond Park	265.6	264.7
8	Hospital	264.7	264.1
9	Lake Wausau I	264.1	263.2
10	Lake Wausau II	263.2	262.3
11	Lake Wausau III	262.3	261.4
12	Lake Wausau IV	261.4	260.8
13	Lake Wausau V	260.8	260.2
14	Lake Wausau VI	260.2	259.6
15	Lake Wausau VII	259.6	258.8
16	Lake Wausau VIII	258.8	258.4
17	Below Rothschild Dam	258.4	258.2
18	East of Mosinee Hill	258.2	257.4
19	Cedar Creek	257.4	256.4
20	Electrical SUbstation	256.4	255.6
21	East of Gravel Pit	255.6	254.6
22	Four-mile Creek	254.6	252.6
23	Mosinee Flowage I	252.6	251.2
24	Mosinee Flowage II	251.2	250.7
25	Mosinee Flowage III	250.7	250.0
26	Mosinee Flowage IV	250.0	249.4
27	Mosinee Flowage V	249.4	249.2
28	Mosinee FLowage VI	249.2	248.9
29	Below Mosinee Dam	248.9	248.7
30	Large Island	248.7	247.9
31	Hog Creek	247.9	245.9
32	Inlet to Lake DuBay	245.9	244.3
33	Lake DuBay I	244.3	243.4
34	Lake DuBay II	243.4	242.6
35	Lake DuBay III	242.6	242.1
36	Lake DuBay IV	242.1	240.8
37	Lake DuBay V	240.8	240.1
38	Lake DuBay VI	240.1	239.3
39	Lake DuBay VII	239.3	238.2
40	Lake DuBay VIII	238.2	237.0
41	Lake DuBay IX	237.0	236.6
42	Lake DuBay X	236.6	235.5
43	Lake DuBay XI	235.5	235.4

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

	Warm Water		Cold Water			
Reach	Fast Term BOD Decay Rate (1/day)	Slow Term BOD Decay Rate (1/day)	Fast Term BOD Decay Rate (1/day)	Slow Term BOD Decay Rate (1/day)	Formula Used	BOD Settling (ft/day)
1	1.70	0.55	1.00	0.50	3	0.00
2	1.70	0.55	1.00	0.50	3	0.00
3	1.70	0.55	1.70	0.50	3	0.00
4	0.50	0.20	1.70	0.50	3	0.00
5	0.50	0.20	1.70	0.50	3	0.00
6	0.50	0.20	1.70	0.50	3 or 8	0.00
7	0.80	0.20	1.70	0.50	3	0.00
8	0.80	0.20	1.70	0.50	3	0.00
9	0.80	0.20	1.70	0.05	3	0.00
10	0.80	0.20	1.70	0.05	3	0.00
11	0.80	0.20	1.70	0.05	8	0.00
12	0.80	0.20	1.70	0.05	3 or 8	0.00
13	0.80	0.20	1.70	0.05	8	0.00
14	0.80	0.20	1.70	0.05	3 or 8	0.00
15	0.80	0.20	1.70	0.05	8	0.00
16	0.80	0.20	1.70	0.05	8	0.00
17	0.90	0.50	0.90	0.55	3	0.00
18	0.90	0.50	0.90	0.55	3	0.00
19	0.90	0.50	0.90	0.55	3	0.00
20	0.90	0.50	0.90	0.55	3	0.00
21	0.90	0.50	0.90	0.55	3	0.00
22	0.90	0.50	0.90	0.55	3	0.00
23	0.90	0.50	0.90	0.55	3	0.00
24	0.90	0.50	0.90	0.55	3	0.00
25	0.90	0.50	0.90	0.55	3	0.00
26	0.90	0.50	0.90	0.55	3 or 8	0.00
27	0.90	0.50	0.90	0.55	3	0.00
28	0.90	0.50	0.90	0.55	3	0.00
29	1.70	0.40	1.70	0.40	3	0.00
30	1.70	0.40	1.70	0.40	3	0.00
31	1.70	0.40	1.70	0.40	3	0.00
32	1.70	0.40	1.70	0.40	3	0.00
33	1.70	0.40	1.70	0.40	3	0.00
34	1.70	0.40	1.70	0.40	3	0.00
35	1.70	0.03	1.70	0.03	3 or 8	0.00
36	1.70	0.03	1.70	0.03	3 or 8	0.00
37	1.70	0.03	1.70	0.03	8	0.00
38	1.70	0.03	1.70	0.03	8	0.00
39	1.70	0.03	1.70	0.03	8	0.00
40	1.70	0.03	1.70	0.03	8	0.00
41	1.70	0.03	1.70	0.03	8	0.00
42	1.70	0.03	1.70	0.03	8	0.00
43	1.70	0.03	1.70	0.03	8	0.00

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

Reach	Algae Settling (ft/day)	ORG-N Settling (ft/day)	ORG-N Recycle Algae Dep.	Light Extinction Coef. (1/day)	Maximum Algae Growth Rate (1/day)	Algae Respiration Rate (1/day)
1	0.25	0.80	0.004	0.80	2.70	0.10
2	0.25	0.80	0.004	0.80	2.70	0.10
3	0.25	0.80	0.004	0.80	2.70	0.10
4	0.25	0.80	0.004	0.80	2.70	0.10
5	0.25	0.80	0.004	0.80	2.70	0.10
6	0.25	0.80	0.004	0.80	2.70	0.10
7	0.25	0.80	0.004	0.80	2.70	0.10
8	0.25	0.80	0.004	0.80	2.70	0.10
9	0.25	0.80	0.004	0.80	2.70	0.10
10	0.25	0.80	0.004	0.80	2.70	0.10
11	0.25	0.80	0.004	0.80	2.70	0.10
12	0.25	0.80	0.004	0.80	2.70	0.10
13	0.25	0.80	0.004	0.80	2.70	0.10
14	0.25	0.80	0.004	0.80	2.70	0.10
15	0.25	0.80	0.004	0.80	2.70	0.10
16	0.25	0.80	0.004	0.80	2.70	0.10
17	0.25	0.80	0.004	0.80	2.70	0.10
18	0.25	0.80	0.004	0.80	2.70	0.10
19	0.25	0.80	0.004	0.80	2.70	0.10
20	0.25	0.80	0.004	0.80	2.70	0.10
21	0.25	0.80	0.004	0.80	2.70	0.10
22	0.25	0.80	0.004	0.80	2.70	0.10
23	0.25	0.80	0.004	0.80	2.70	0.10
24	0.25	0.80	0.004	0.80	2.70	0.10
25	0.25	0.80	0.004	0.80	2.70	0.10
26	0.25	0.80	0.004	0.80	2.70	0.10
27	0.25	0.80	0.004	0.80	2.70	0.10
28	0.25	0.80	0.004	0.80	2.70	0.10
29	0.25	0.80	0.004	0.80	2.70	0.10
30	0.25	0.80	0.004	0.80	2.70	0.10
31	0.25	0.80	0.004	0.80	2.70	0.10
32	0.25	0.80	0.004	0.80	2.70	0.10
33	0.25	0.80	0.004	0.80	2.70	0.10
34	0.25	0.80	0.004	0.80	2.70	0.10
35	0.25	0.80	0.004	0.80	2.70	0.10
36	0.25	0.80	0.004	0.80	2.70	0.10
37	0.25	0.80	0.004	0.80	2.70	0.10
38	0.25	0.80	0.004	0.80	2.70	0.10
39	0.25	0.80	0.004	0.80	2.70	0.10
40	0.25	0.80	0.004	0.80	2.70	0.10
41	0.25	0.80	0.004	0.80	2.70	0.10
42	0.25	0.80	0.004	0.80	2.70	0.10
43	0.25	0.80	0.004	0.80	2.70	0.10

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

Reach	CHL-A Algae (ug/mg)	NH3-N Decay (1/day)	NO2-N Decay (1/date)	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	0.05	10.0	0	0	0.5
2	6.50	0.05	10.0	0	0	0.5
3	6.50	0.05	10.0	0	0	0.5
4	6.50	0.05	10.0	0	0	0.5
5	6.50	0.05	10.0	0	0	0.5
6	6.50	0.05	10.0	0	0	0.5
7	6.50	0.10	10.0	0	0	0.5
8	6.50	0.10	10.0	0	0	0.5
9	6.50	0.10	10.0	0	0	0.5
10	6.50	0.10	10.0	0	0	0.5
11	6.50	0.10	10.0	0	0	0.5
12	6.50	0.10	10.0	0	0	0.5
13	6.50	0.10	10.0	0	0	0.5
14	6.50	0.10	10.0	0	0	0.5
15	6.50	0.10	10.0	0	0	0.5
16	6.50	0.10	10.0	0	0	0.5
17	6.50	0.35	10.0	0	0	0.5
18	6.50	0.35	10.0	0	0	0.5
19	6.50	0.35	10.0	0	0	0.5
20	6.50	0.35	10.0	0	0	0.5
21	6.50	0.35	10.0	0	0	0.5
22	6.50	0.35	10.0	0	0	0.5
23	6.50	0.35	10.0	0	0	0.5
24	6.50	0.35	10.0	0	0	0.5
25	6.50	0.35	10.0	0	0	0.5
26	6.50	0.35	10.0	0	0	0.5
27	6.50	0.35	10.0	0	0	0.5
28	6.50	0.35	10.0	0	0	0.5
29	6.50	0.20	10.0	0	0	0.5
30	6.50	0.20	10.0	0	0	0.5
31	6.50	0.20	10.0	0	0	0.5
32	6.50	0.20	10.0	0	0	0.5
33	6.50	0.20	10.0	0	0	0.5
34	6.50	0.20	10.0	0	0	0.5
35	6.50	0.20	10.0	100	0	0.5
36	6.50	0.20	10.0	100	0	0.5
37	6.50	0.20	10.0	100	0	0.5
38	6.50	0.20	10.0	100	0	0.5
39	6.50	0.20	10.0	100	0	0.5
40	6.50	0.20	10.0	100	0	0.5
41	6.50	0.20	10.0	100	0	0.5
42	6.50	0.20	10.0	100	0	0.5
43	6.50	0.20	10.0	100	0	0.5

Appendix E

This appendix contains the results of the calibration runs. For a discussion of these graphs refer to Chapter IV of the text. Each dissolved oxygen data set from a synoptic survey is shown with the corresponding dynamic output of the QUAL III model. A statistical comparison between the observed time of day data and calculated results is presented for the dissolved oxygen profiles in Tables C-1 and C-2. All plots have the dynamic model output represented by the solid line and the observed time of day data by the black circle.

Table E-1

Calibration Warm Water Dissolved Oxygen Comparison

Survey Date	Differences (mg/l)	Mean Absolute Differences (mg/l)
July 11-12, 1973	0.61 ± 0.97	0.91 ± 0.67
July 16-17, 1974	*	*
June 22-24, 1977	0.65 ± 0.60	0.72 ± 0.49

*Insufficient data for dynamic comparisons to be made.

Table E-2

Calibration Cold Water Dissolved Oxygen Comparison

Survey Date	Differences (mg/l)	Mean Absolute Differences (mg/l)
August 23, 1973	1.07 ± 0.94	1.19 ± 0.78
August 17, 1975	2.05 ∓ 1.16	2.06 ∓ 1.13
August 16-17, 1976	-0.81 ∓ 0.86	0.92 ∓ 0.72
October 11-12, 1976	-0.49 ∓ 2.34	1.77 ∓ 1.58
August 17-18, 1977	-0.54 ∓ 0.57	0.66 ∓ 0.42

Figure E-1

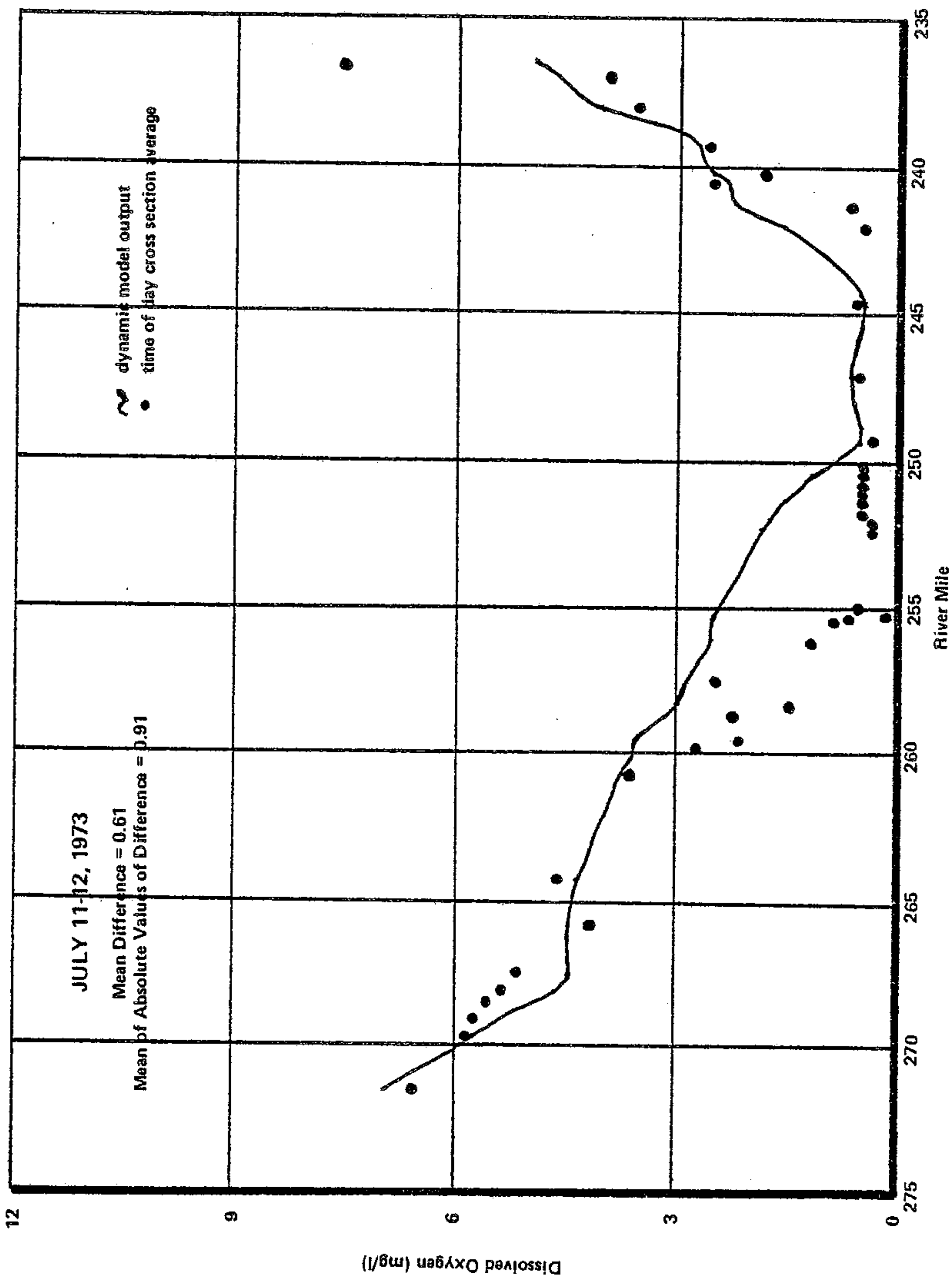

JULY 11-12, 1973
Mean Difference = 0.61
Mean of Absolute Values of Difference = 0.91
dynamic model output
time of day cross section average
River Mile
Dissolved Oxygen (mg/l)
275
270
265
260
255
250
245
240
235
0
3
6
9
12

Figure E-2

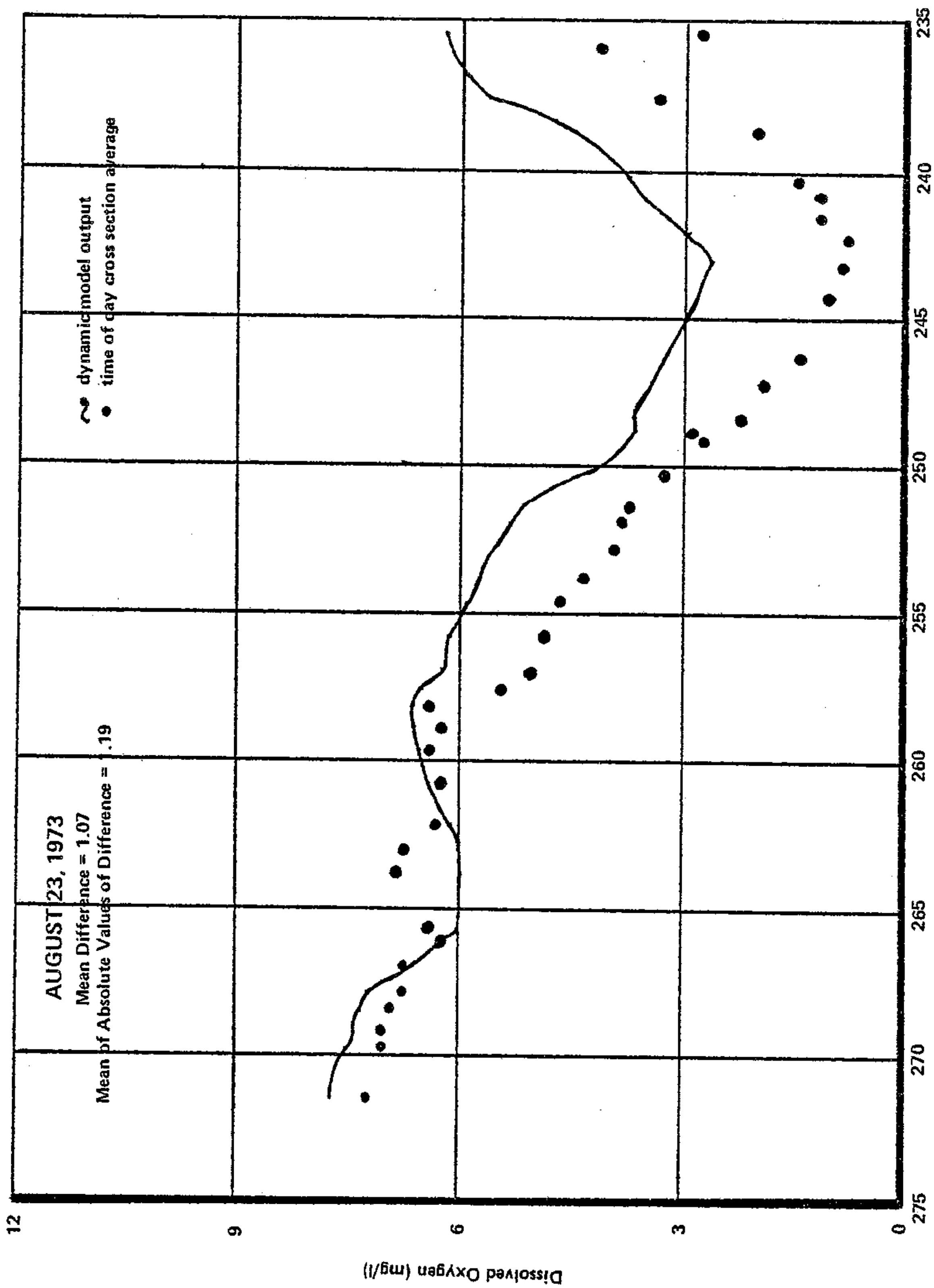

AUGUST 23, 1973
Mean Difference = 1.07
Mean of Absolute Values of Difference = 1.19
dynamic model output
time of day cross section average
River Mile
Dissolved Oxygen (mg/l)
0
3
6
9
12
275
270
265
260
255
250
245
240
235

Figure E-3

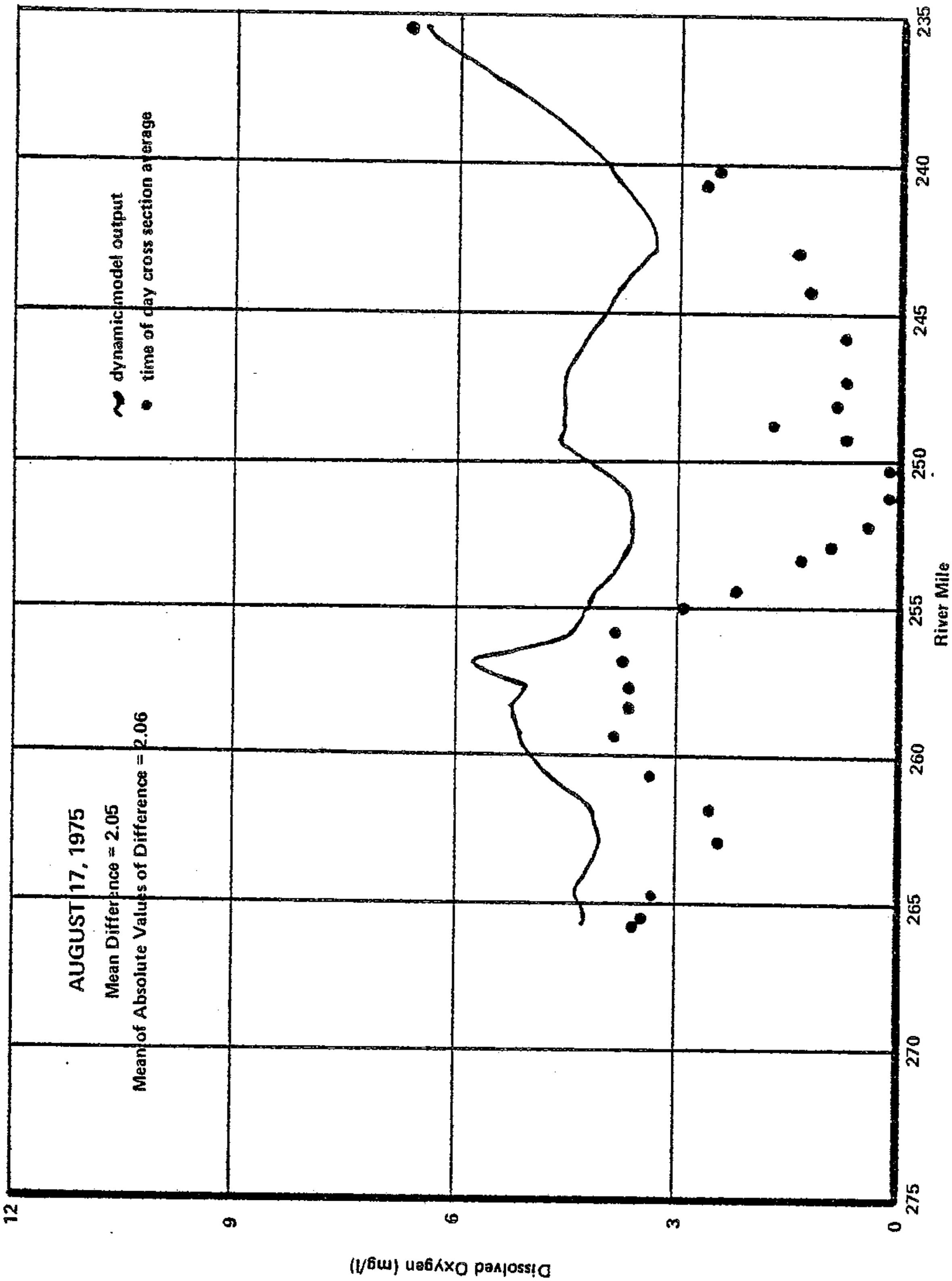

AUGUST 17, 1975
Mean Difference = 2.05
Mean of Absolute Values of Difference = 2.06
dynamic model output
time of day cross section average
River Mile
Dissolved Oxygen (mg/l)
0
3
6
9
12
275
270
265
260
255
250
245
240
235

Figure E-4

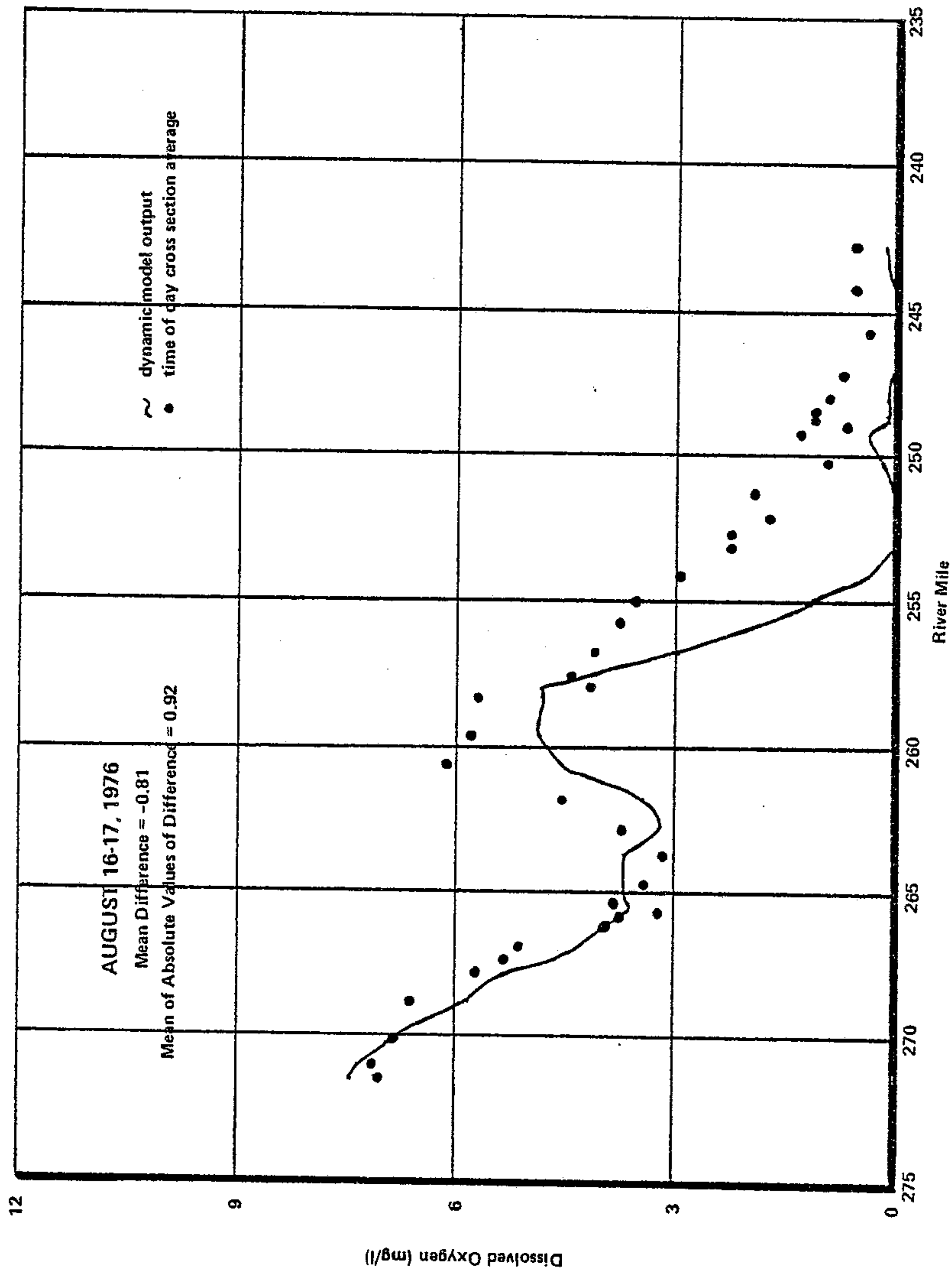

AUGUST 16-17, 1976
Mean Difference = -0.81
Mean of Absolute Values of Difference = 0.92
~ dynamic model output
• time of day cross section average
River Mile
235
240
245
250
255
260
265
270
275
Dissolved Oxygen (mg/l)
0
3
6
9
12

Figure E-5

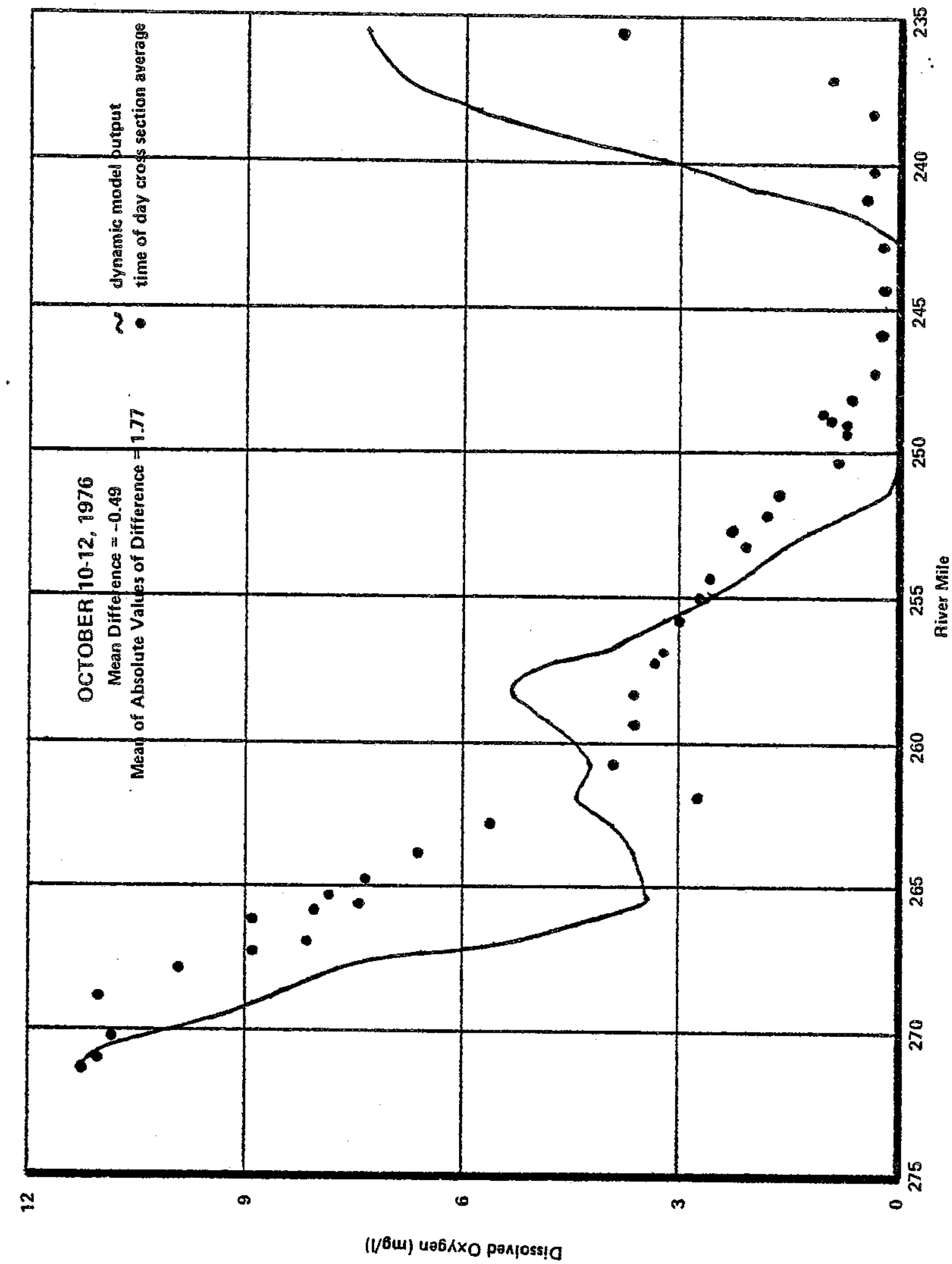

OCTOBER 10-12, 1976
Mean Difference = -0.49
Mean of Absolute Values of Difference = 1.77
dynamic model output
time of day cross section average
Dissolved Oxygen (mg/l)
River Mile
12
9
6
3
0
275
270
265
260
255
250
245
240
235

Figure E-6

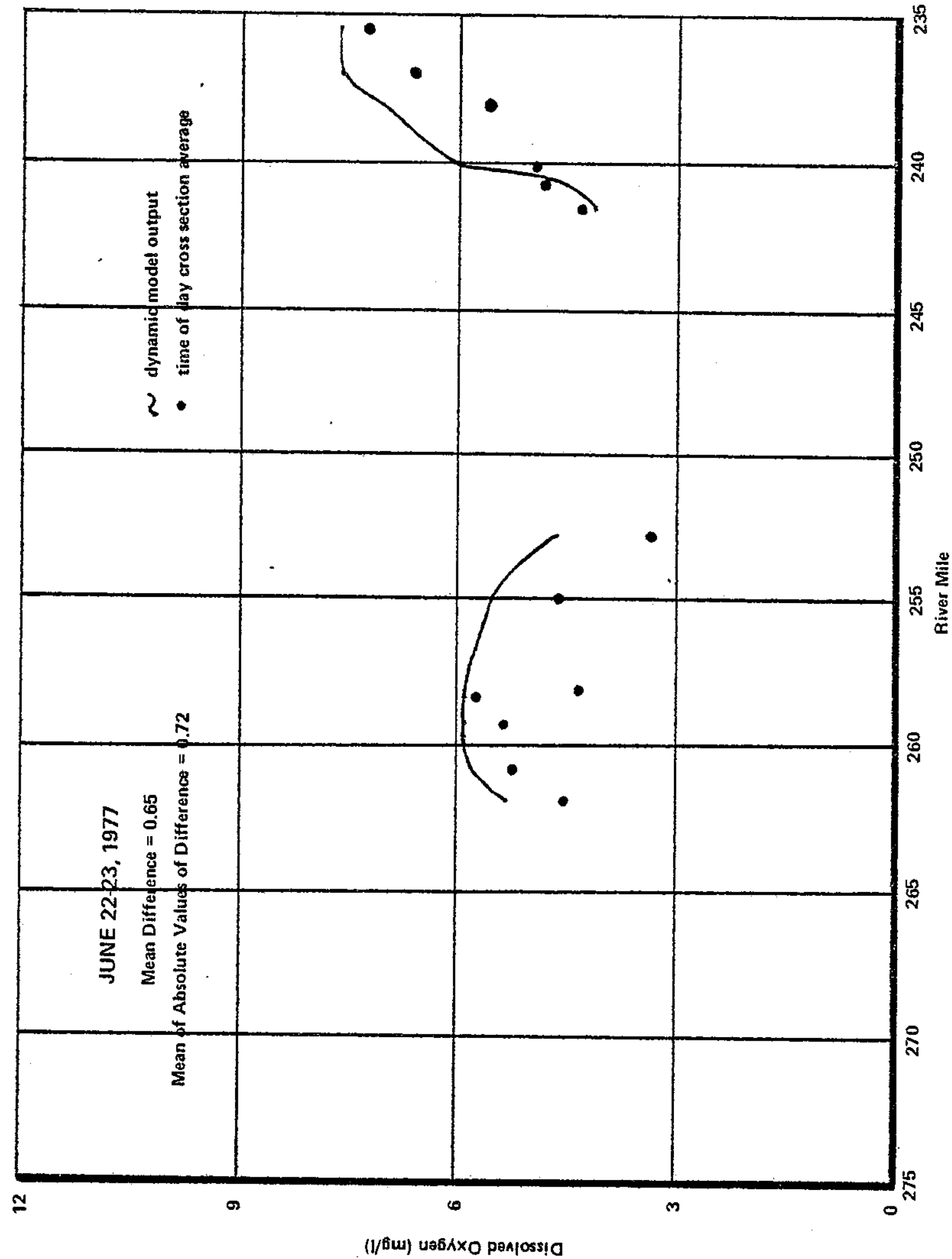
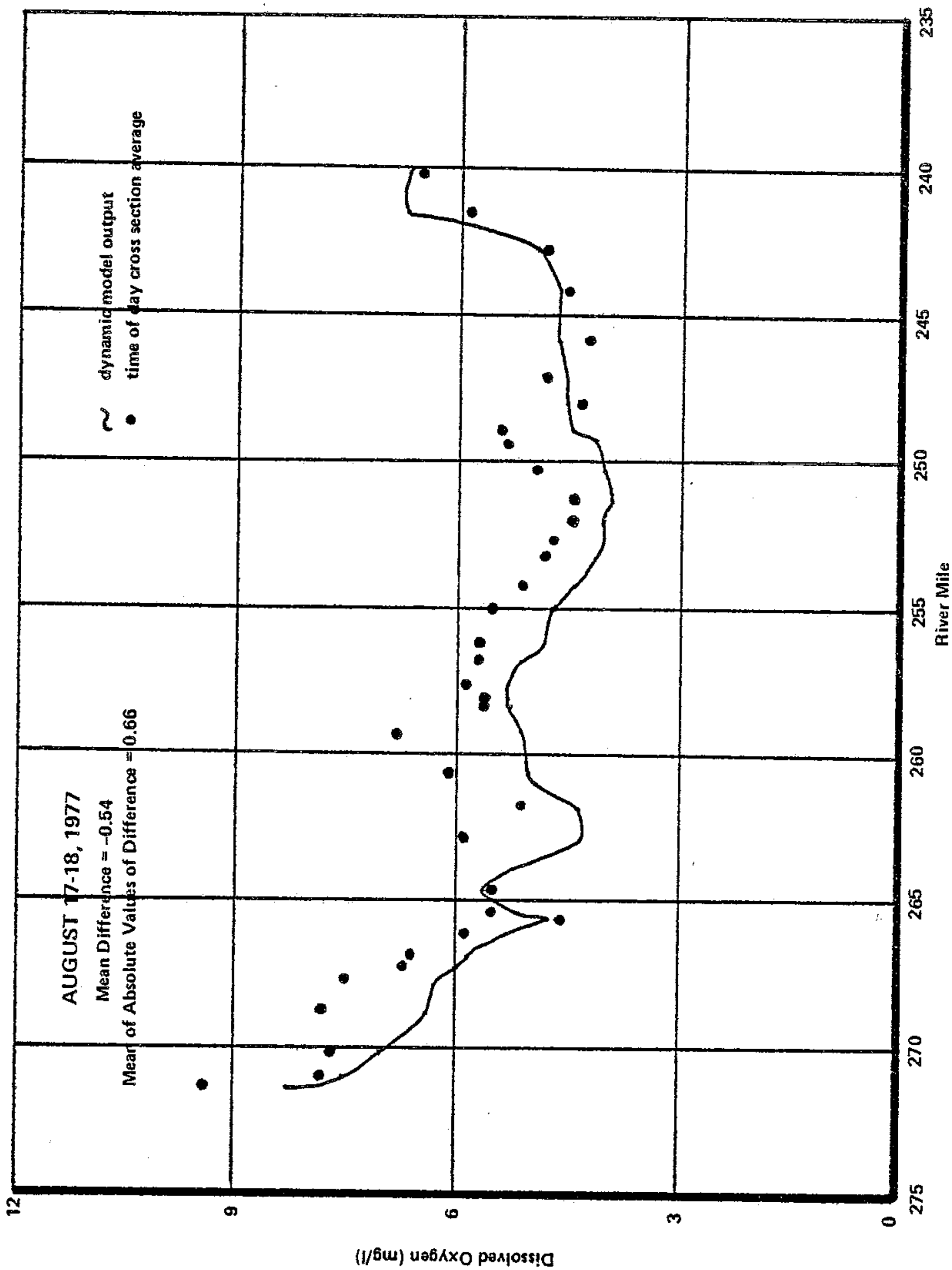

JUNE 22-23, 1977
Mean Difference = 0.65
Mean of Absolute Values of Difference = 0.72
dynamic model output
time of day cross section average
Dissolved Oxygen (mg/l)
River Mile
0
3
6
9
12
235
240
245
250
255
260
265
270
275

Figure E-7


AUGUST 17-18, 1977
Mean Difference = -0.54
Mean of Absolute Values of Difference = 0.66
dynamic model output
time of day cross section average
Dissolved Oxygen (mg/l)
River Mile
0
3
6
9
12
275
270
265
260
255
250
245
240
235

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 dynamic output of the QUAL III model. A statistical comparison between the observed time of day data and calculated results is presented in Tables D-1 and D-2. All plots have the dynamic model output represented by the solid line and the observed time of day data by the black circle.

Table F-1

Verification Warm Water Dissolved Oxygen Comparison

Survey Date	Mean Differences (mg/l)	Mean Absolute Differences (mg/l)
June 27-28, 1978	0.66 ± 0.66	0.73 ± 0.56
August 14-15, 1978	0.24 ∓ 0.64	0.58 ∓ 0.34
July 16-18, 1979	-0.09 ∓ 0.52	0.42 ∓ 0.32
August 6-7, 1979	-0.04 ± 0.59	0.40 ± 0.43

Table

Verification Cold Water Dissolved Oxygen Comparison

Survey Date	Mean Differences (mg/l)	Mean Absolute Differences (mg/l)
August 27-28, 1979	-0.77 ± 0.63	0.79 ± 0.60

Figure F-1

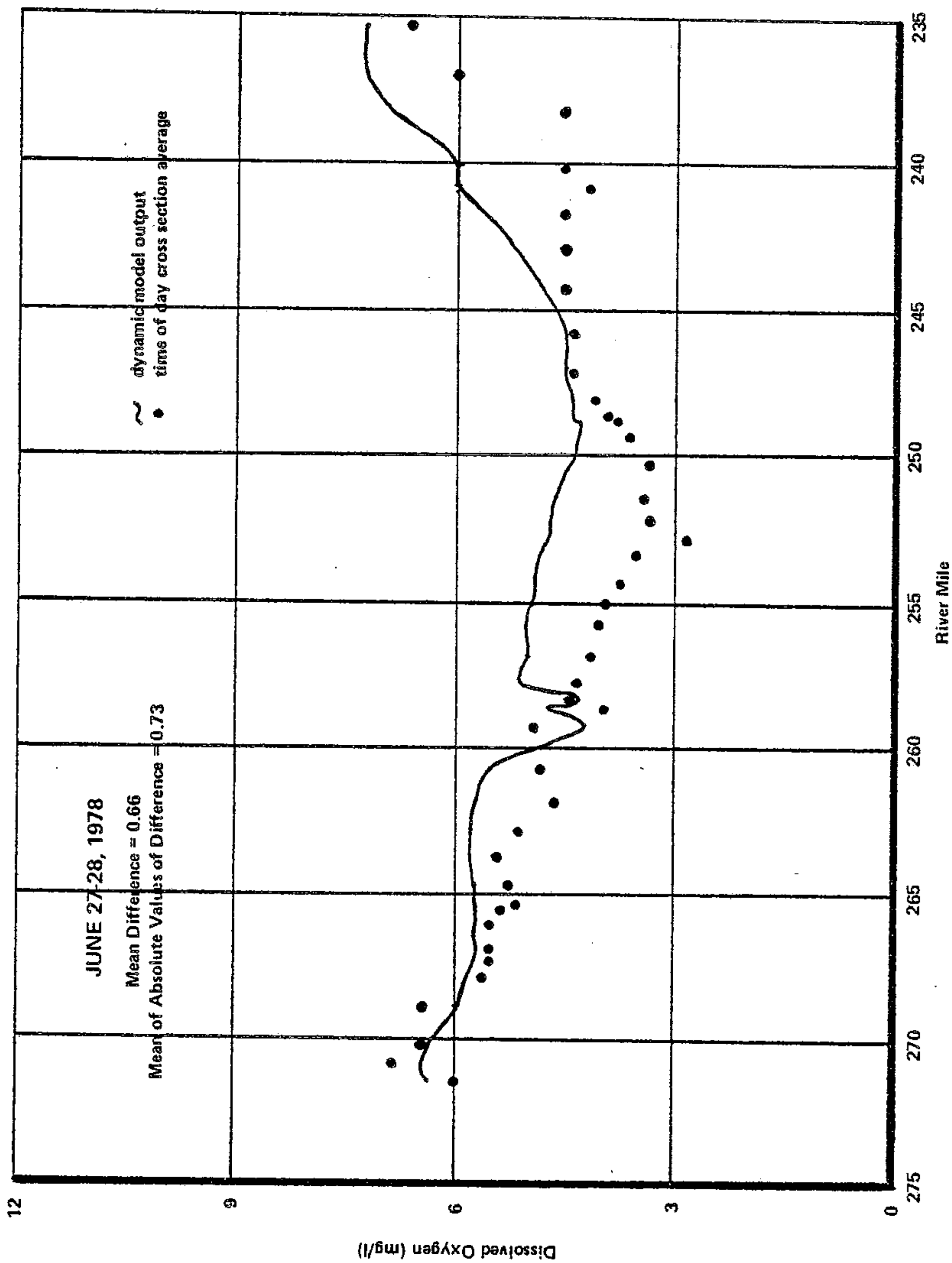

JUNE 27-28, 1978
Mean Difference = 0.66
Mean of Absolute Values of Difference = 0.73
dynamic model output
time of day cross section average
River Mile
Dissolved Oxygen (mg/l)
235
240
245
250
255
260
265
270
275
0
3
6
9
12

Figure F-2

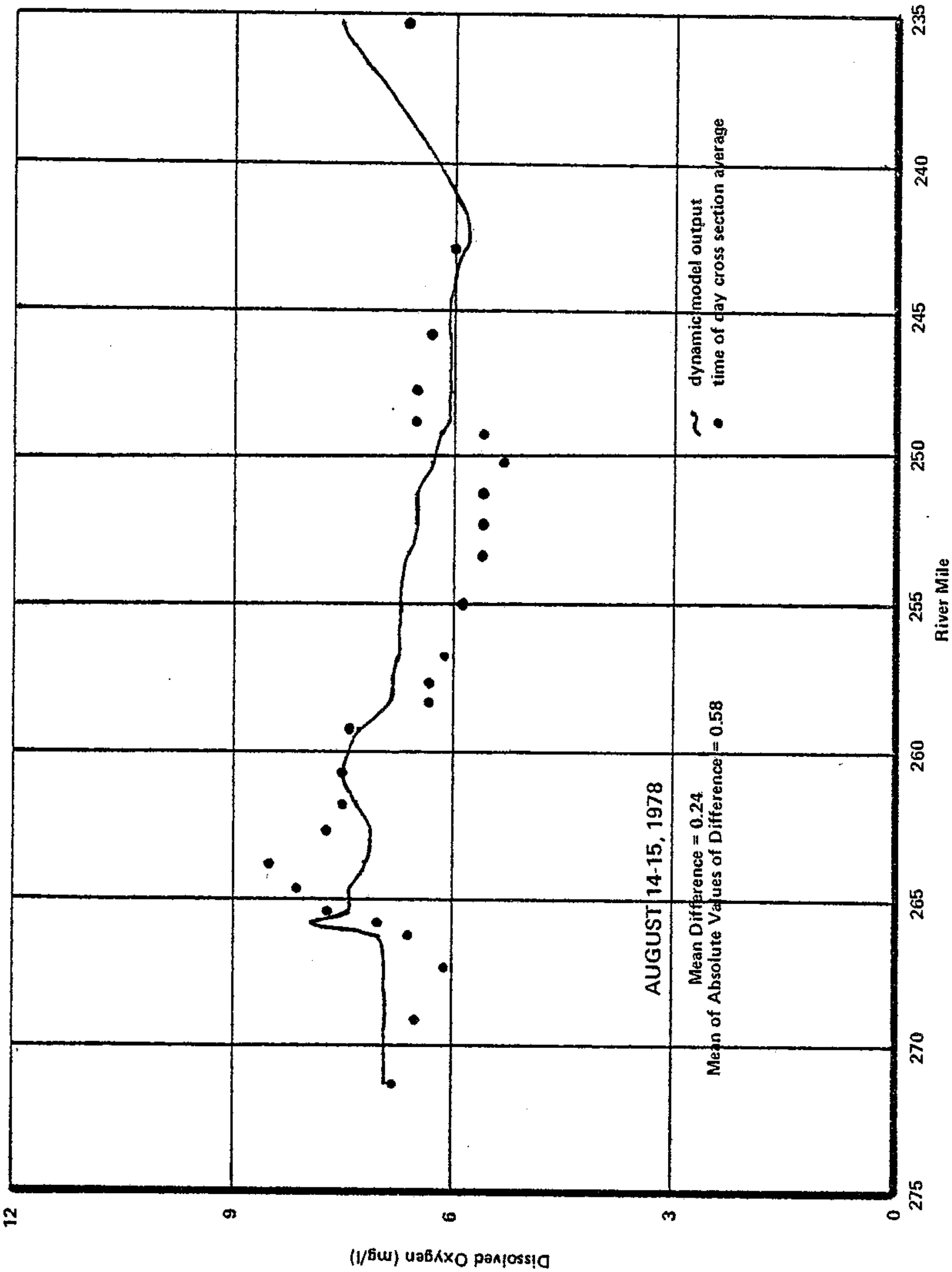

AUGUST 14-15, 1978
Mean Difference = 0.24
Mean of Absolute Values of Difference = 0.58
dynamic model output
time of day cross section average
River Mile
235
240
245
250
255
260
265
270
275
Dissolved Oxygen (mg/l)
0
3
6
9
12

Figure F-3

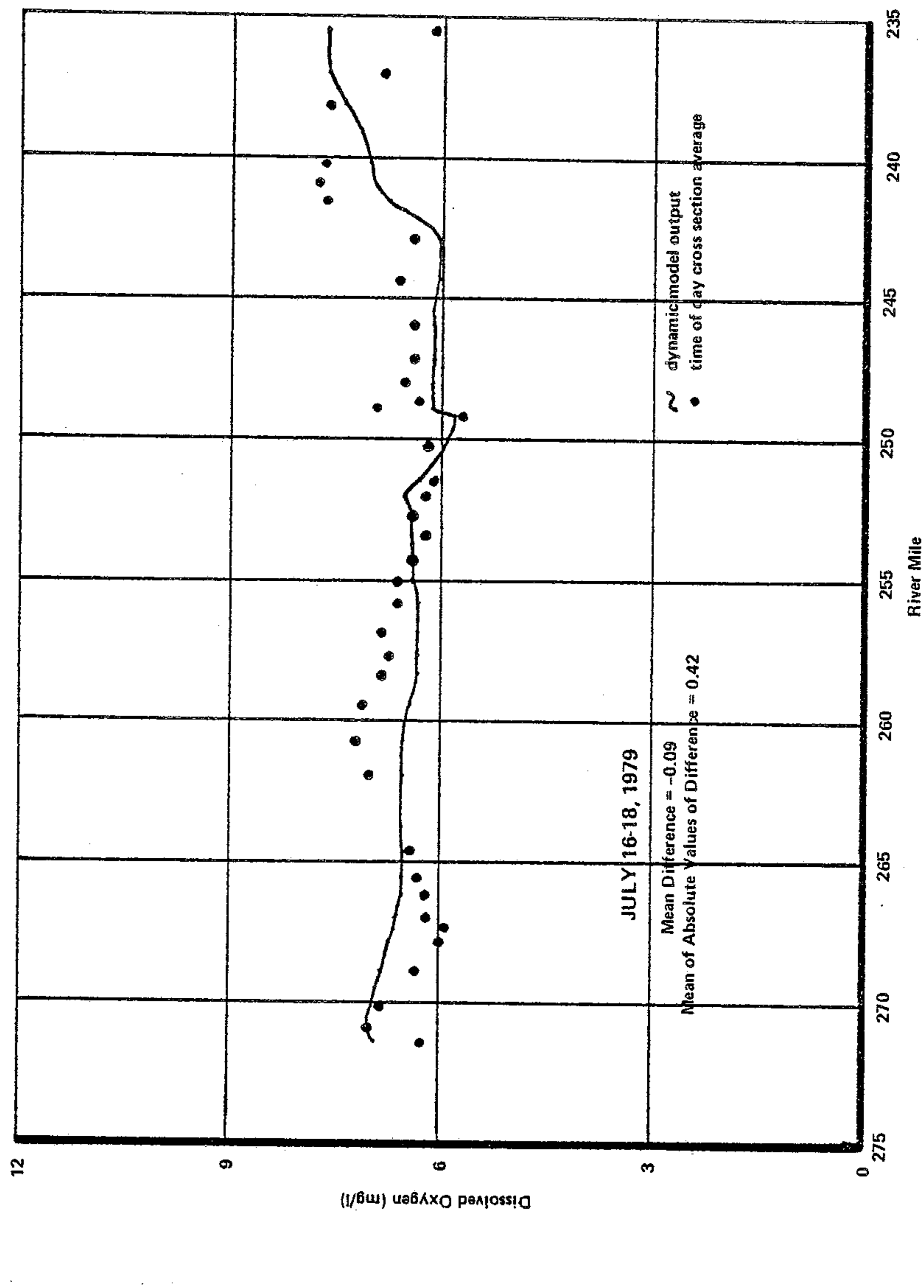
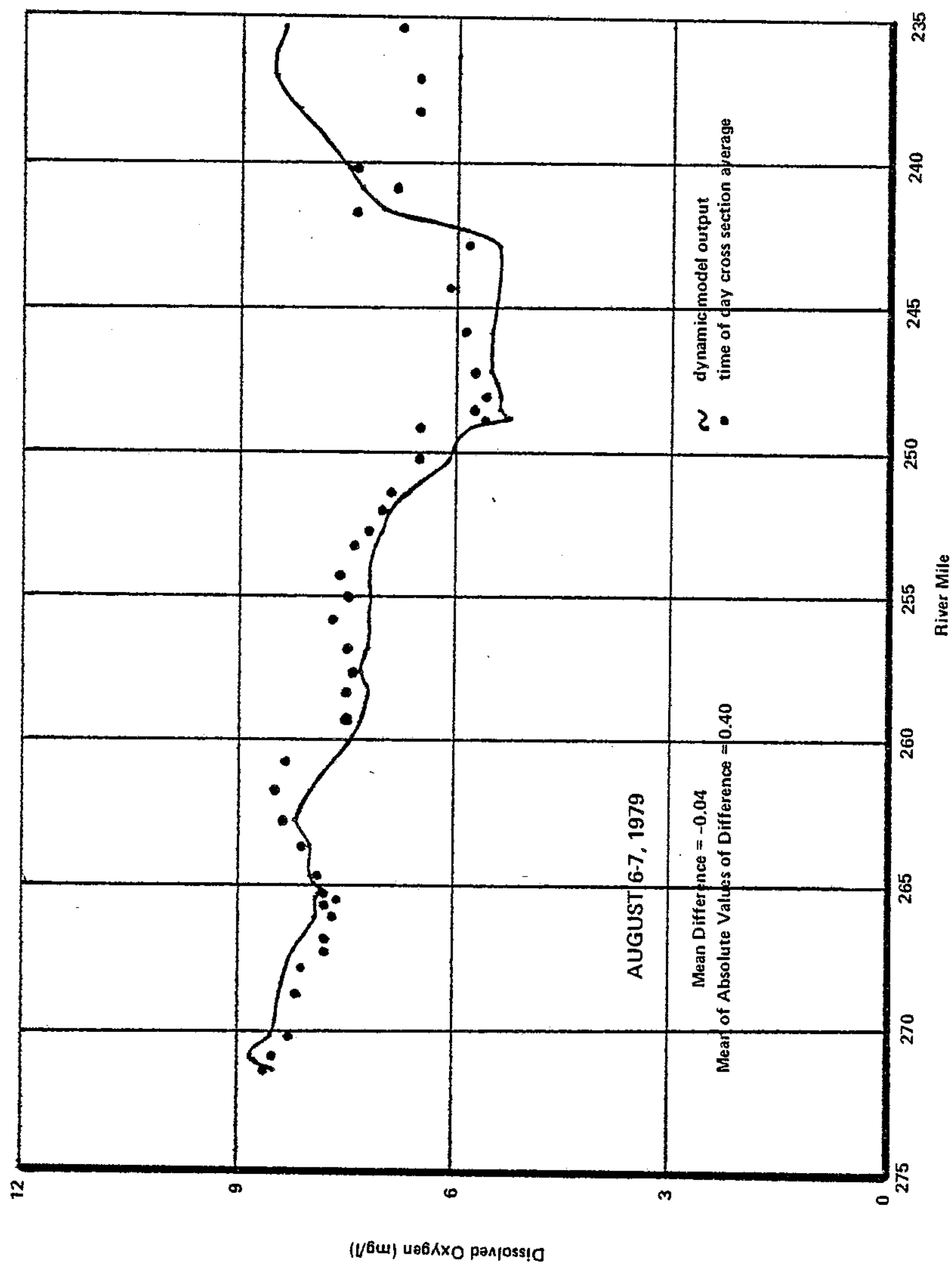
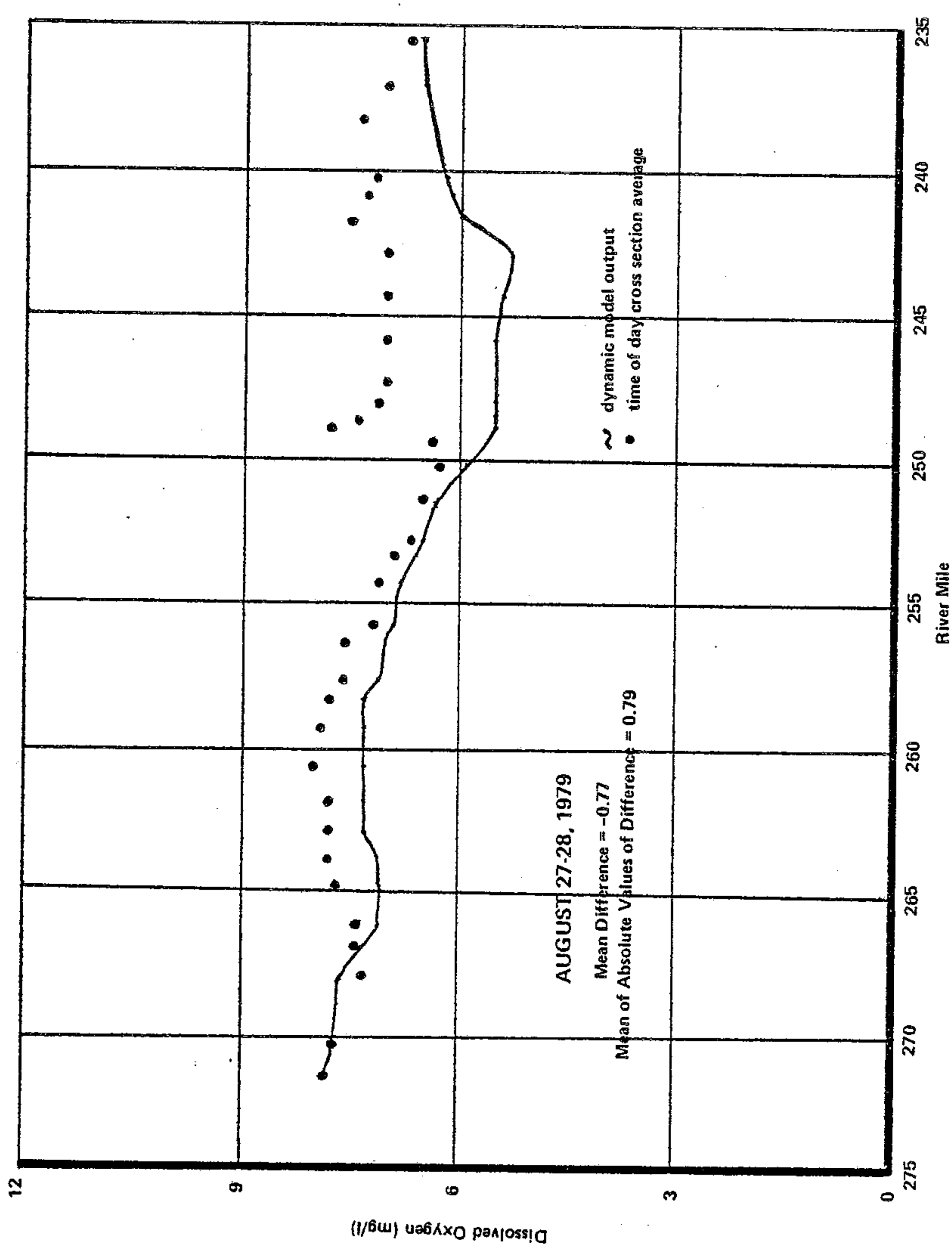

JULY 16-18, 1979
Mean Difference = -0.09
Mean of Absolute Values of Difference = 0.42
dynamic model output
time of day cross section average
River Mile
235
240
245
250
255
260
265
270
275
Dissolved Oxygen (mg/l)
0
3
6
9
12

Figure F-4



Dissolved Oxygen (mg/l)
0
3
6
9
12
River Mile
275
270
265
260
255
250
245
240
235
AUGUST 6-7, 1979
Mean Difference = -0.04
Mean of Absolute Values of Difference = 0.40
dynamic model output
time of day cross section average

Figure F-5


AUGUST 27-28, 1979
Mean Difference = -0.77
Mean of Absolute Values of Difference = 0.79
dynamic model output
time of day cross section average
River Mile
Dissolved Oxygen (mg/l)
235
240
245
250
255
260
265
270
275
12
9
6
3
0

Appendix G

This appendix contains the results of dynamic verification runs for 1980-81 data sets. The plots are for sites at Wausau Dam, Rothschild Dam, Mosinee Dam, the inlet to Lake Dubay and Lake Dubay Dam. The plots are measured and predicted dissolved oxygen versus time. No correction for calibration drift has been applied to the plots. Calibration notes made by field personnel are provided in Table G-1. A statistical analysis of the predictive accuracy has been done on each of the five sites and is presented in Table G-2. A correction for calibration drift was done in these analyses. The method applied assumed a linear drift with time between station visitations.

Table G-1
Calibration Records for Segment BC Dynamic Survey Sites

Monitor	Date	Reading Before Maintenance	Reading After Maintenance	Actual Reading*	Code**
Wausau	5/12/80	9.0	9.3	9.2	1
	6/04/80	7.2	6.8	6.8	1
	6/20/80	7.5	7.5	7.4	1
	6/30/80	6.1	6.8	6.7	2
	7/15/80	5.8	6.1	6.0	1
	7/28/80	6.8	7.9	7.8	1
	8/14/80	6.4	7.1	7.1	1
	8/29/80	6.6	7.1	7.1	1
	9/15/80	7.9	8.2	8.1	1
	10/15/80	9.9	9.9	9.8	1
	11/06/80	11.0	11.6	11.8	2
	9/21/81	8.9	9.0	9.0	2
	10/05/81	9.3	9.8	9.7	2
	10/14/81	12.2	9.5	9.6	2
	10/27/81	12.7	12.0	12.0	1
Rothschild	8/04/80	-	7.8	7.8	3
	8/13/80	7.8	-	7.5	-
Mosinee	5/12/80	8.6	8.6	8.6	1
	6/04/80	5.5	5.8	5.6	1
	6/20/80	8.0	8.2	8.1	2
	6/30/80	6.8	6.7	6.6	1
	7/15/80	4.6	5.2	5.1	1
	7/28/80	6.0	6.3	6.5	1
	8/01/80	6.6	6.8	6.7	1
	8/14/80	6.2	6.5	6.5	1
	8/29/80	7.0	7.0	7.0	1
	9/15/80	8.4	8.6	8.4	2
	10/23/80	10.0	9.9	9.9	1
	10/31/80	11.7	11.8	11.7	1
	11/06/80	10.8	11.0	11.0	2
	9/30/81	8.5	8.6	8.5	2
	10/14/81	8.5	8.5	8.5	2
	10/27/81	10.9	11.1	11.0	2

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

**1= Probe Calibration Checked, 2=Probe Membrane Changed, Influent Line Cleaned, and Calibration Checked, 3=Battery Changed.

Table G-1 (continued)
Calibration Records for Segment BC Dynamic Survey Sites

Monitor	Date	Reading Before Maintenance	Reading After Maintenance	Actual Reading*	Code**
Inlet to	6/16/80	-	7.1	7.1	3
Lake DuBay	6/23/80	7.8	-	7.8	-
	7/01/80	-	7.0	7.0	3
	7/10/80	6.5	-	6.4	-
	7/14/80	-	5.7	5.7	3
	7/23/80	7.7	-	7.5	-
	7/25/80	-	7.2	7.2	3
	8/04/80	6.6	-	6.7	-
	8/05/80	-	6.4	6.4	3
	8/15/80	8.8	-	8.8	-
	8/20/80	-	8.7	8.7	3
	8/29/80	8.0	-	8.3	-
	9/02/80	-	8.2	8.2	3
	9/10/80	8.7	-	9.1	-
	10/01/81	-	9.4	9.4	3
	10/05/81	8.1	8.1	8.3	2
	10/09/81	8.7	9.2	9.2	3
	10/14/81	8.2	8.2	8.2	2
	10/21/81	10.1	10.2	10.3	3
	10/28/81	11.1	-	11.0	-
DuBay	5/13/80	9.4	9.8	9.6	2
	5/23/80	14.5	13.0	13.0	1
	6/04/80	3.5	4.1	4.1	1
	6/12/80	6.4	6.5	6.4	1
	6/26/80	9.7	7.7	7.9	1
	6/30/80	7.3	6.8	6.9	1
	7/02/80	9.5	8.2	8.7	1
	7/08/80	10.2	10.0	9.8	1
	7/15/80	10.0	10.8	11.1	1
	7/28/80	7.0	10.3	10.5	2
	8/14/80	5.3	6.6	6.6	2
	8/29/80	4.3	5.4	5.4	1
	9/08/80	10.0	8.0	8.0	1
	9/22/80	8.9	8.3	8.3	2
	10/15/80	10.1	10.0	9.9	1
	10/29/80	11.6	11.5	11.4	1
	10/31/80	11.8	12.0	12.0	1
	11/17/80	Out of Order	12.0	12.0	1
	9/24/81	10.8	9.8	9.8	1
	10/14/81	9.6	9.2	9.2	1
	10/27/81	11.9	11.0	11.0	1

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

**1= Probe Calibration Checked, 2=Probe Membrane Changed, Influent Line Cleaned, and Calibration Checked, 3=Battery Changed.

Table G-2

Verification Warm and Cold Water Dissolved Oxygen Comparison
Mean Difference of Predicted Minus Measured Dissolved Oxygen (mg/l)

Survey Dates	Wausau Dam RM 265.6	Rothschild Dam RM 258.4	Mosinee Dam RM 248.9	Inlet to Lake DuBay RM 243.4	Lake DuBay Dam RM 235.4
Warm Water:					
July 12-Aug. 16, 1980*	-0.31±0.54	-1.80±0.70	-2.38±0.97	-2.30±0.97	-0.45±1.5
Cold Water:					
May 17-25, 1980	**	-	**	-	**
June 17-July 2, 1980	0.50±0.33	-	-0.46±0.84	-1.16±0.84	0.22±0.85
Sept. 2-10, 1980	0.27±0.18	-	0.04±0.19	-1.12±0.29	0.27±1.23
Oct. 26-Nov. 3, 1980	-0.97±0.21	-	-0.09±0.35	-	-0.10±0.33
Oct. 1-27, 1981	0.11±0.48	-	0.30±0.36	0.05±0.41	0.21±0.59

*This is actually two data sets joined together for an extra long simulation period.

**Hourly automatic monitoring data not readily available for statistical comparison. Plots are provided in Figures G6 - G8.

Figure G-1

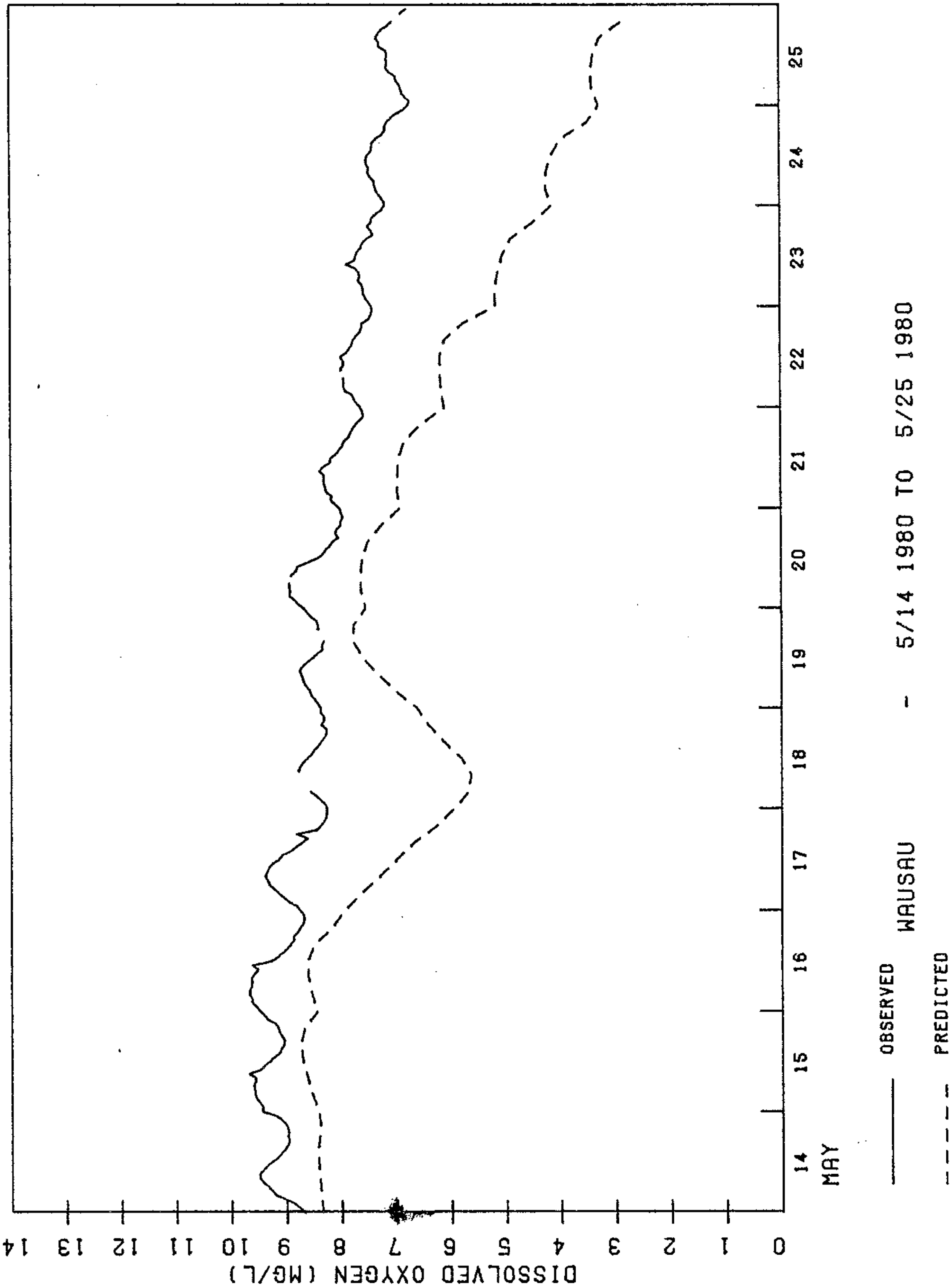

DISSOLVED OXYGEN (MG/L)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
MAY
14 15 16 17 18 19 20 21 22 23 24 25
WAUSAU - 5/14 1980 TO 5/25 1980
OBSERVED
PREDICTED

Figure G-2

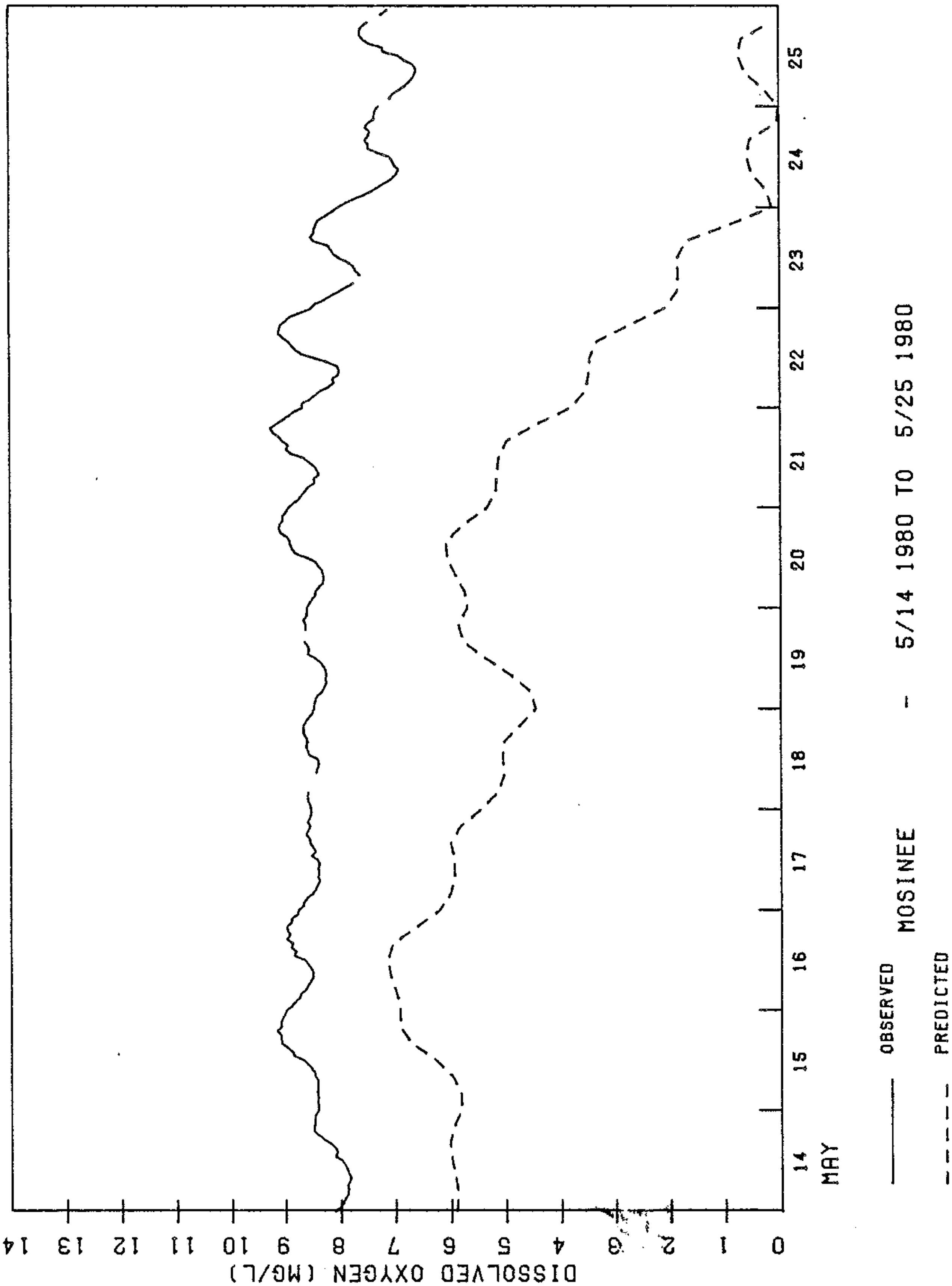

DISSOLVED OXYGEN (MG/L)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
MAY
14
15
16
17
18
19
20
21
22
23
24
25
OBSERVED
PREDICTED
MOSINEE - 5/14 1980 TO 5/25 1980

Figure G-3

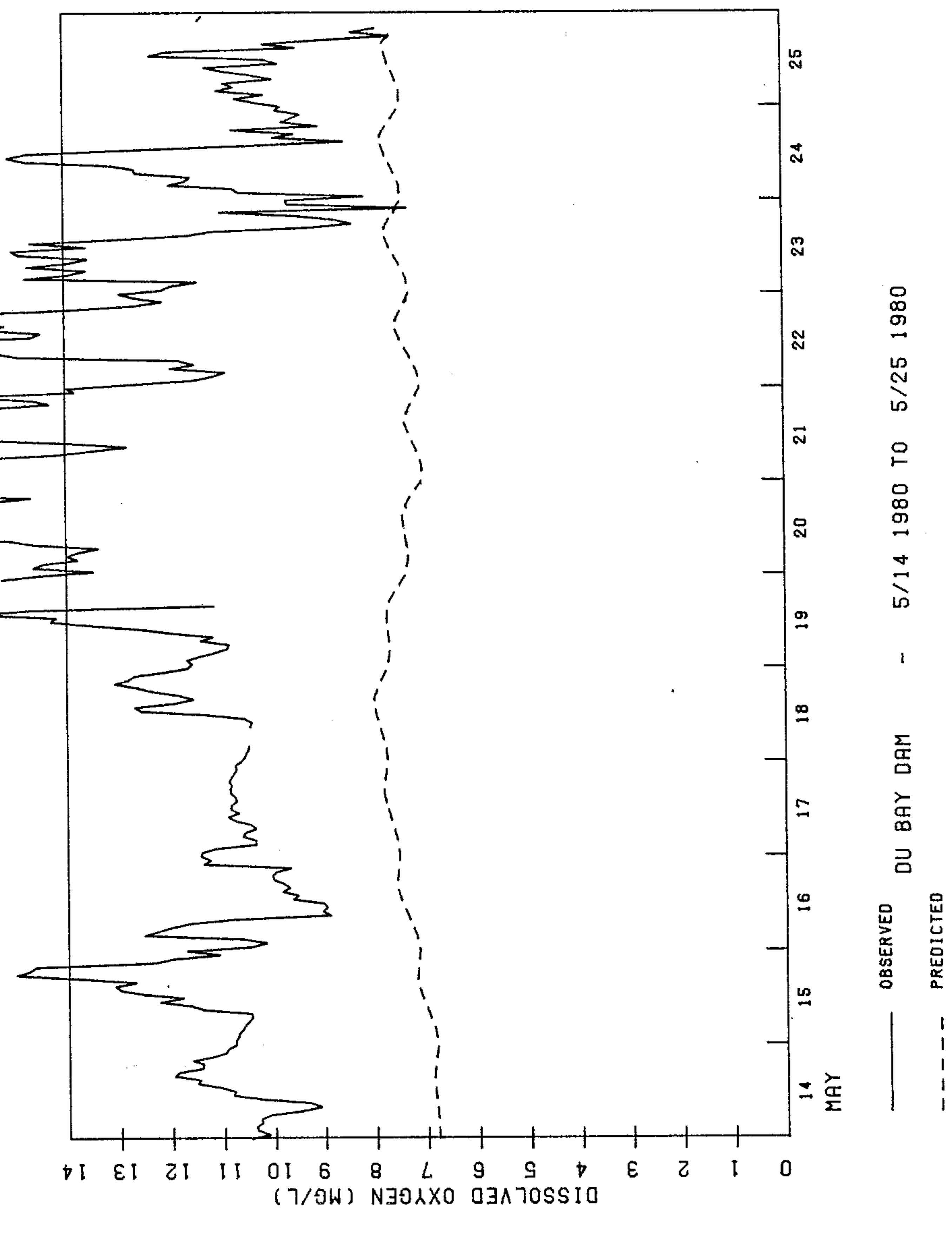

DU BAY DAM - 5/14 1980 TO 5/25 1980
OBSERVED
PREDICTED
DISSOLVED OXYGEN (MG/L)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
MAY
14
15
16
17
18
19
20
21
22
23
24
25

Figure G-4

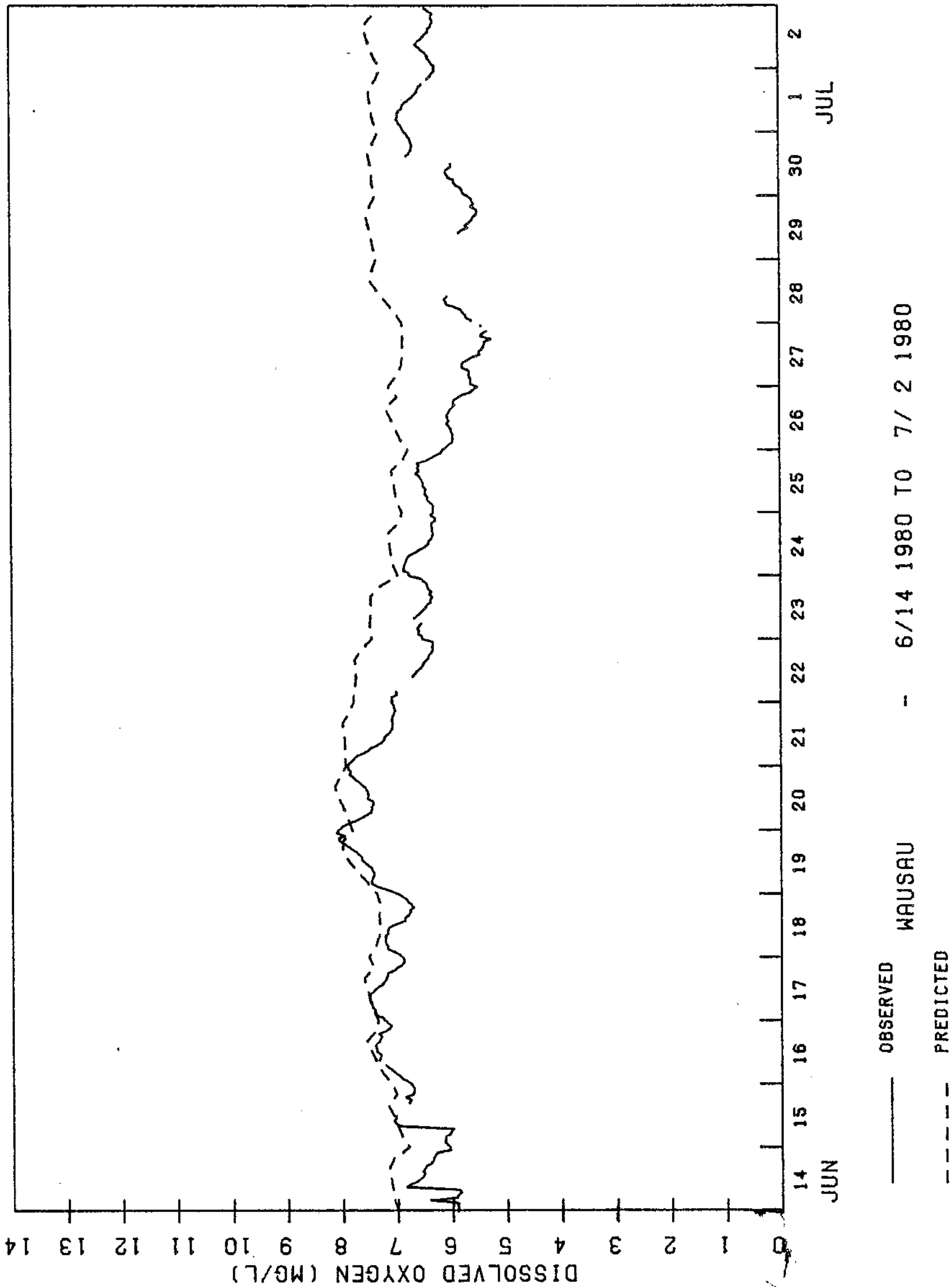

DISSOLVED OXYGEN (MG/L)
JUN
JUL
WAUSAU - 6/14 1980 TO 7/ 2 1980
OBSERVED
PREDICTED

Figure G-5

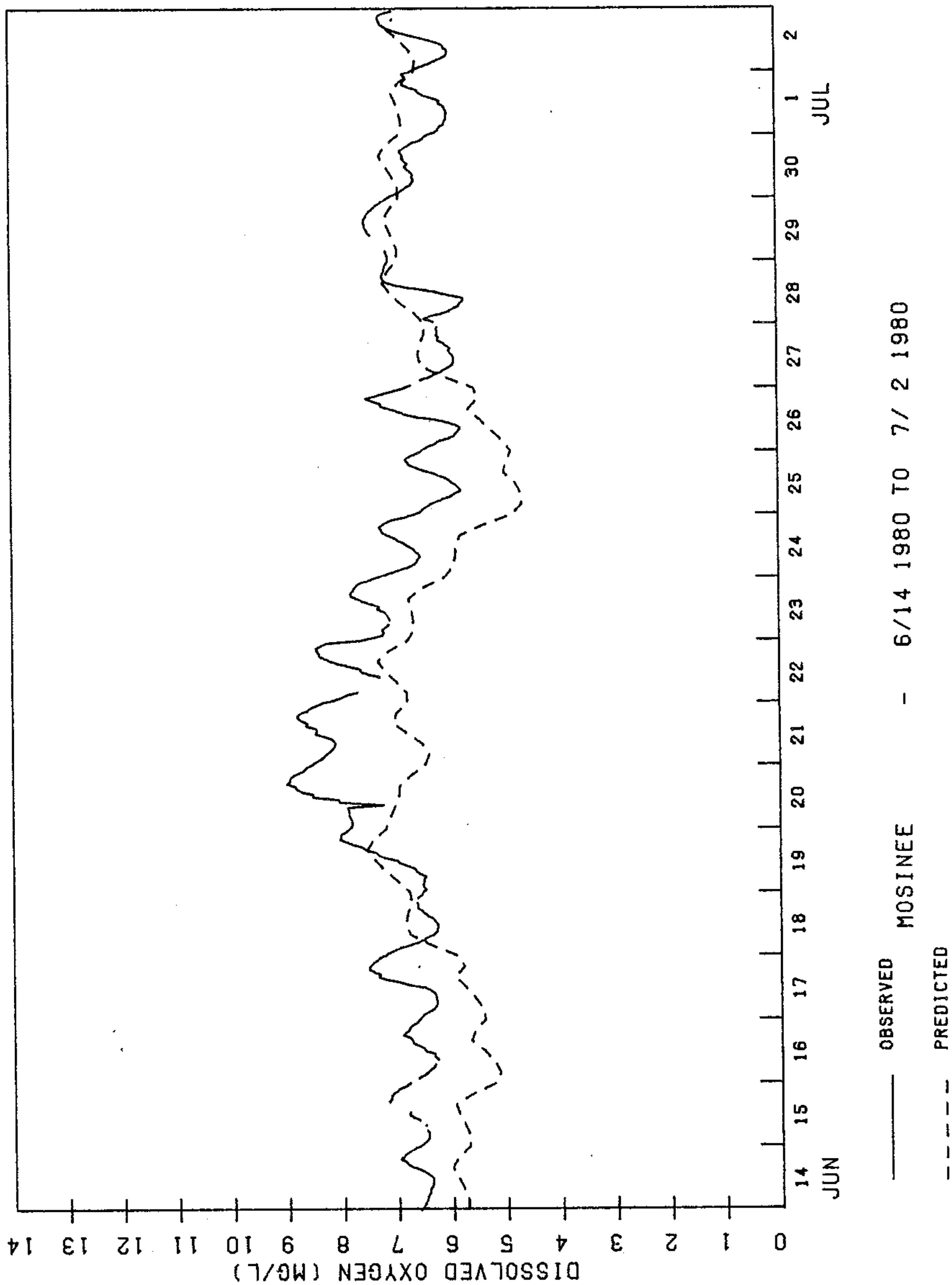

MOSINEE - 6/14 1980 TO 7/ 2 1980
OBSERVED
PREDICTED
DISSOLVED OXYGEN (MG/L)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
JUN
14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
JUL
1 2

Figure G-6

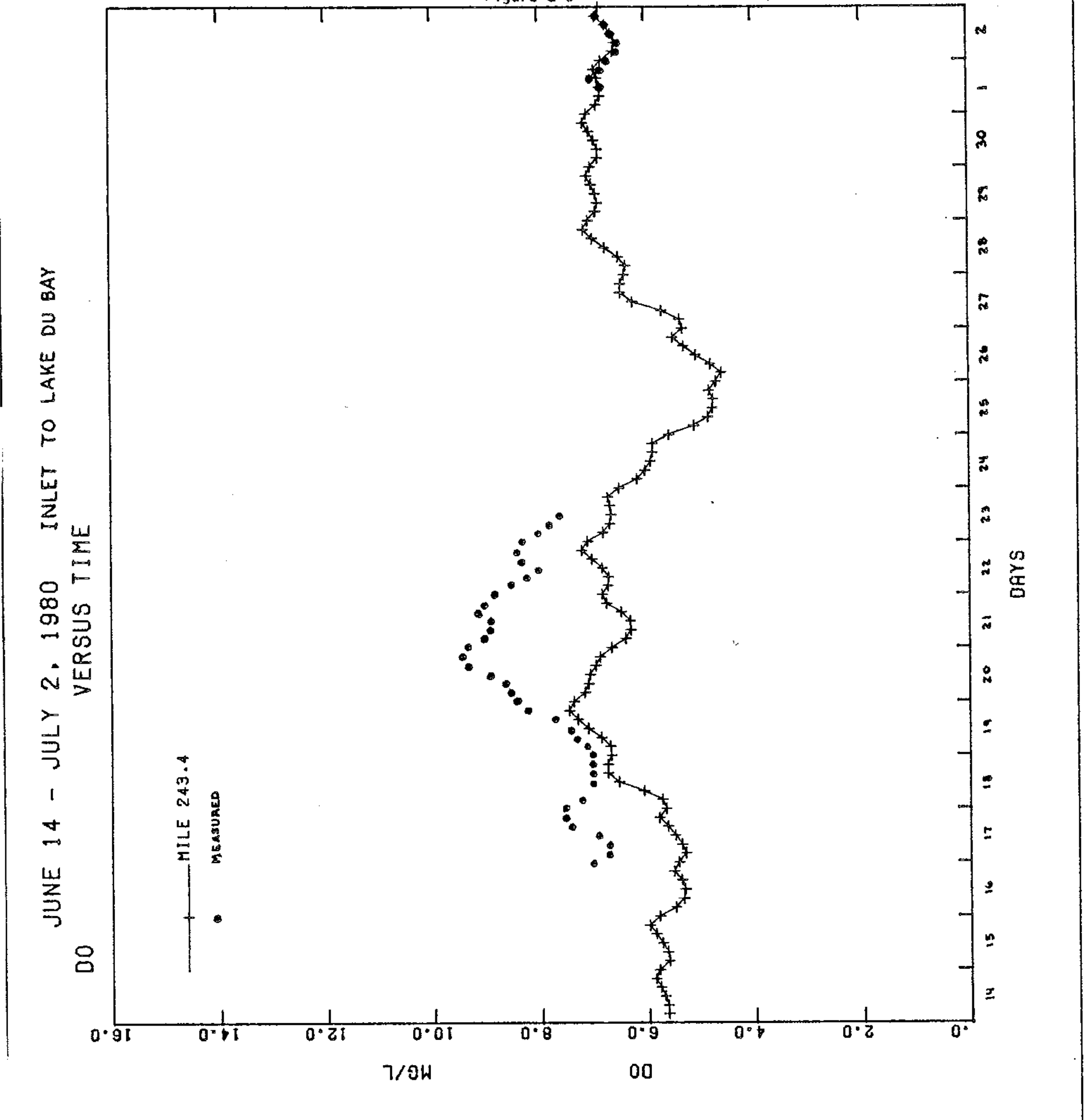

DO
JUNE 14 - JULY 2, 1980 INLET TO LAKE DU BAY
VERSUS TIME
MILE 243.4
MEASURED
DO MG/L
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
.0
DAYS
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
1
2

Figure G-7

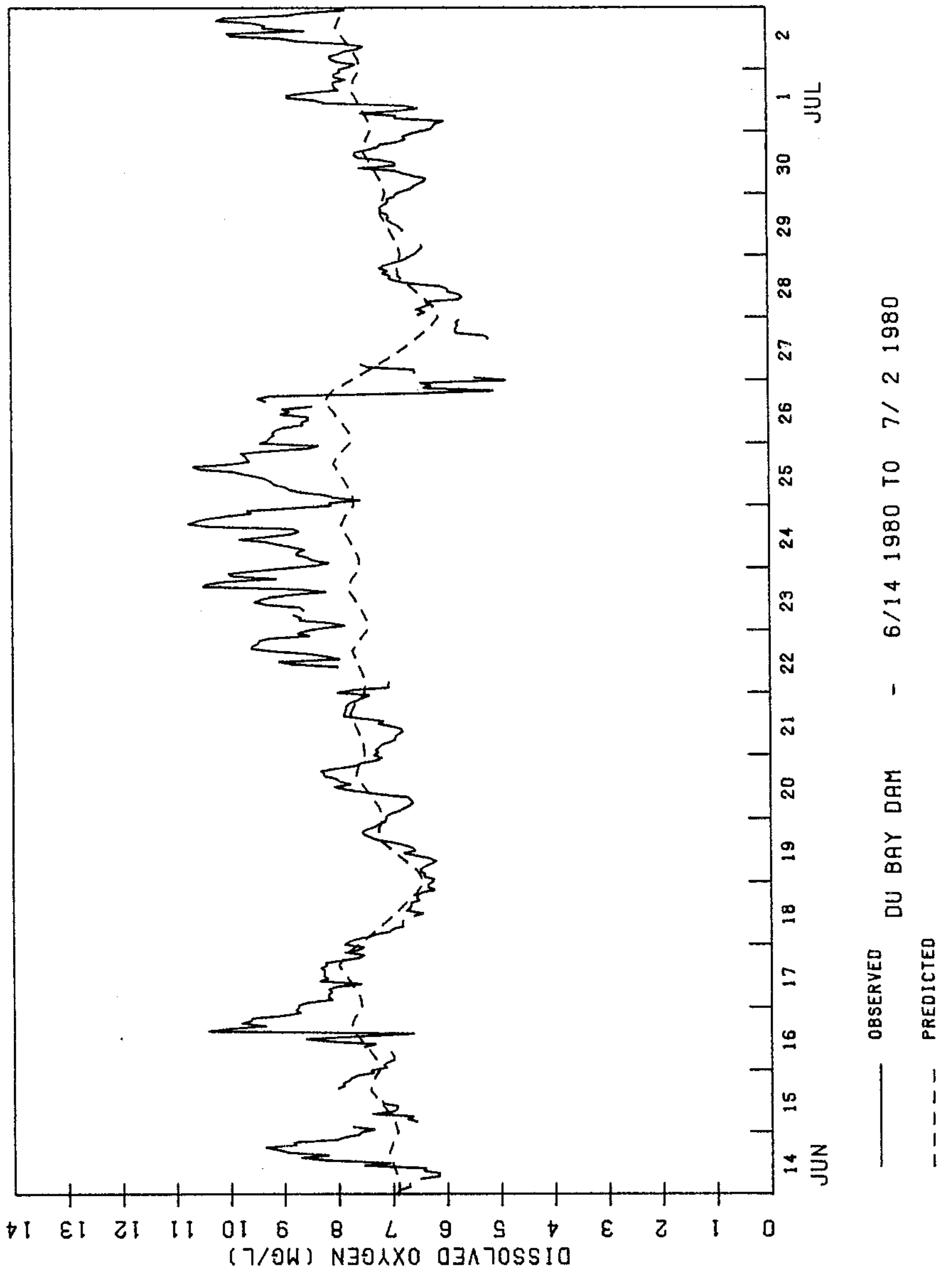

DU BAY DAM - 6/14 1980 TO 7/ 2 1980
OBSERVED
PREDICTED
DISSOLVED OXYGEN (MG/L)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
JUN
14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
JUL
1 2

Figure G-8

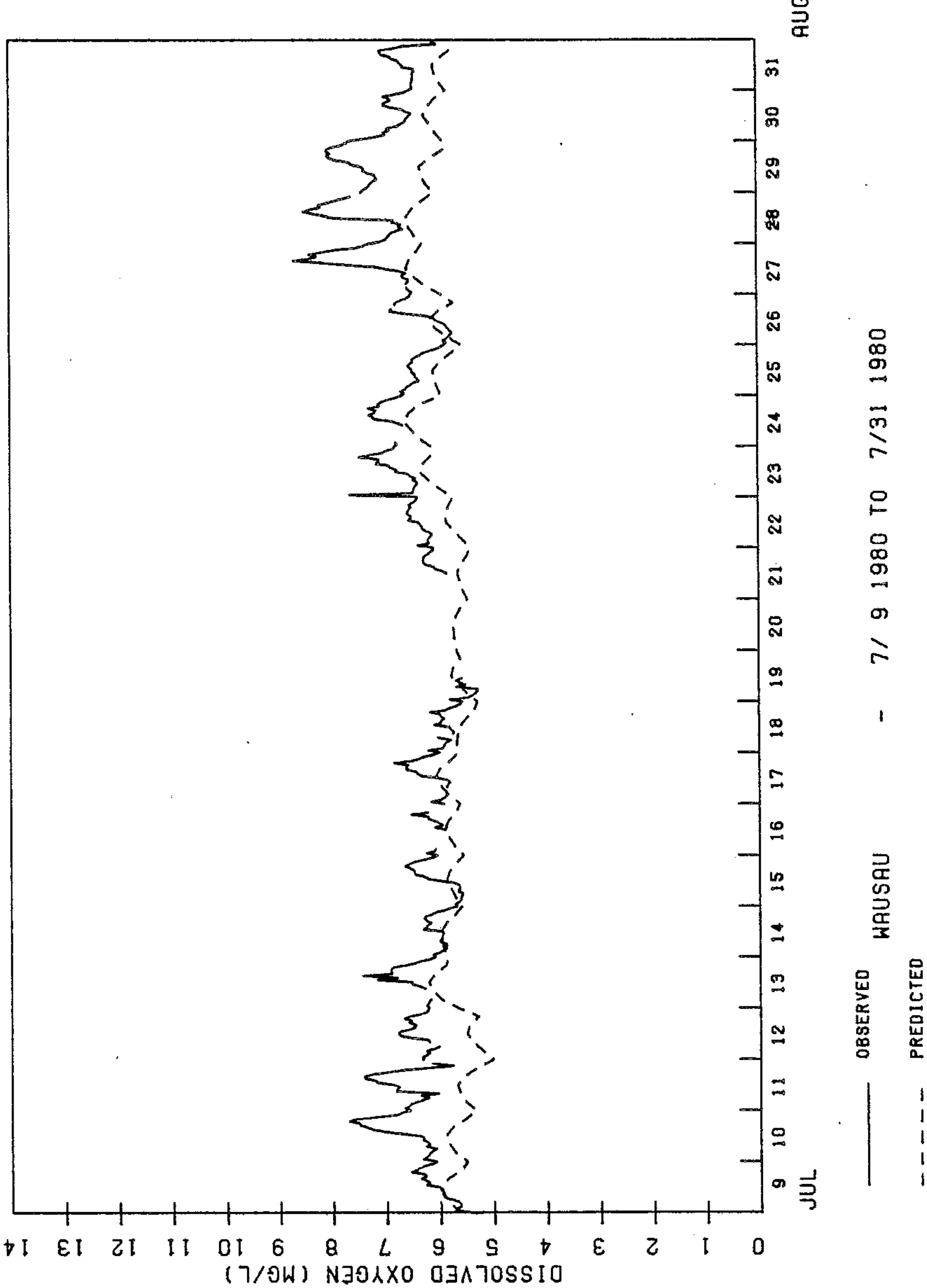

WAUSAU - 7/ 9 1980 TO 7/31 1980
OBSERVED
PREDICTED
DISSOLVED OXYGEN (MG/L)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
JUL
9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
AUG

Figure G-9

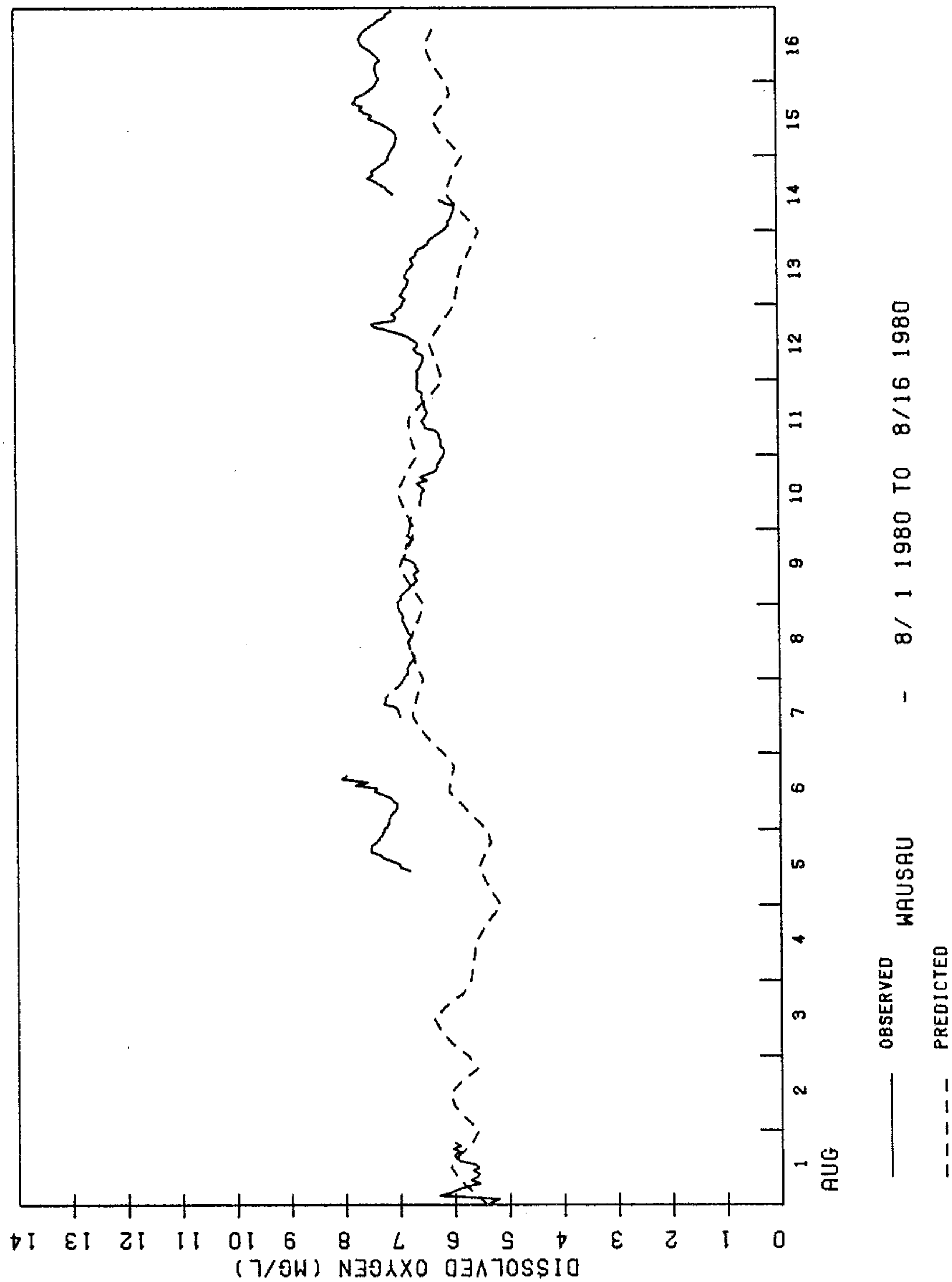

WAUSAU - 8/ 1 1980 TO 8/16 1980
OBSERVED
PREDICTED
DISSOLVED OXYGEN (MG/L)
AUG
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

Figure G-10

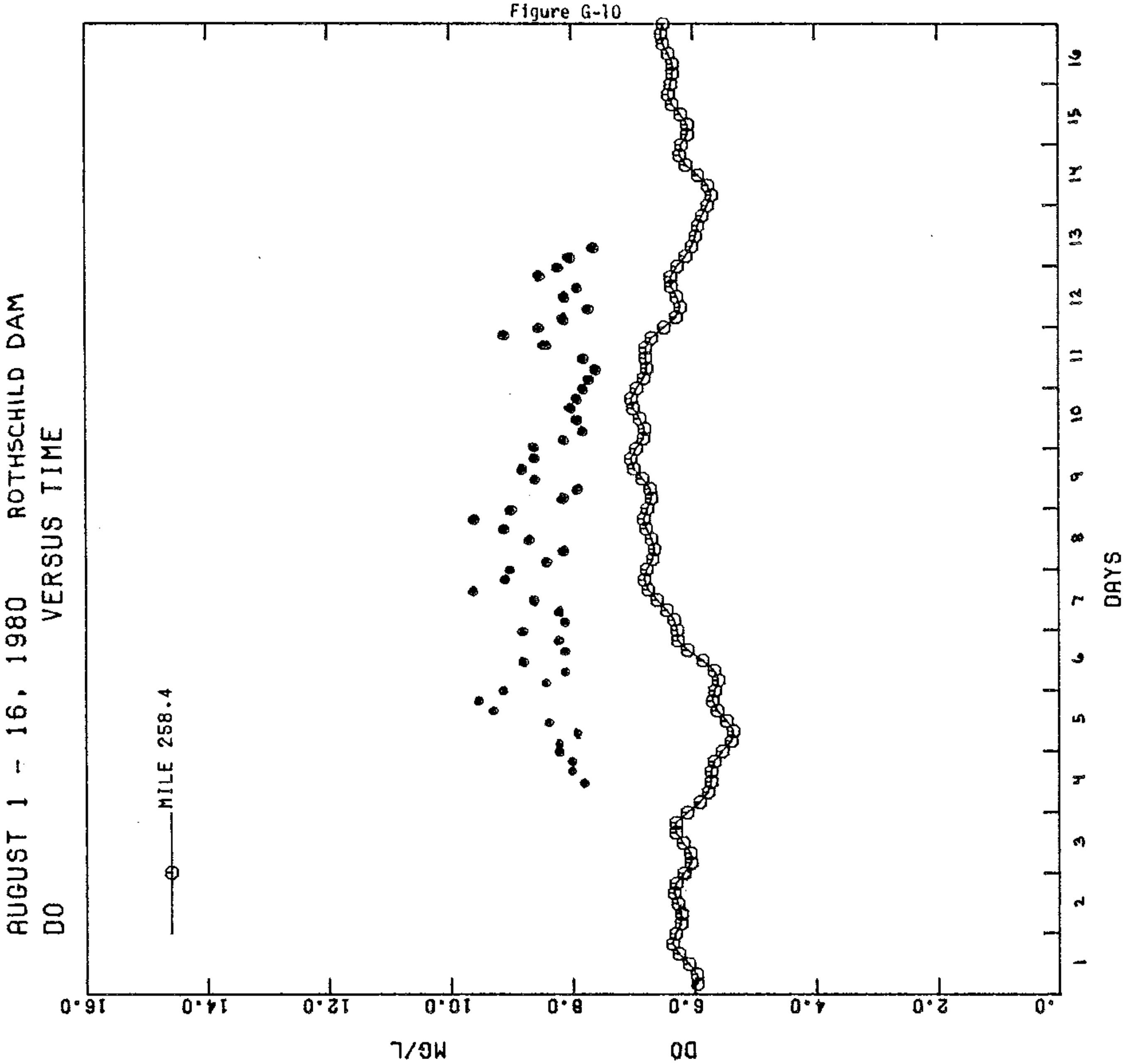

AUGUST 1 - 16, 1980 ROTHSCHILD DAM
DO VERSUS TIME
MILE 258.4
DO MG/L
DAYS
0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

Figure G-11

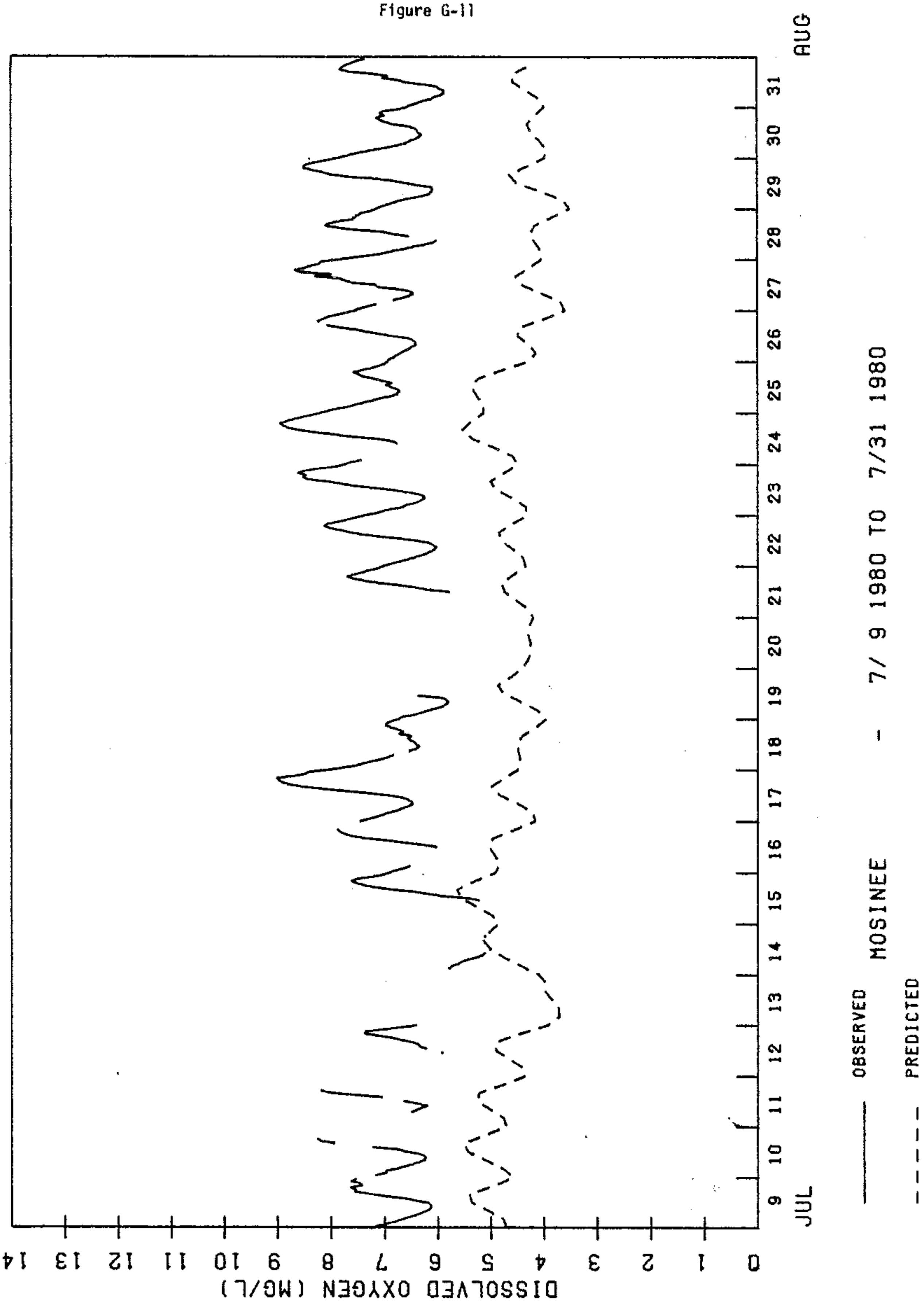

DISSOLVED OXYGEN (MG/L)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
JUL
9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
AUG
MOSINEE - 7/ 9 1980 TO 7/31 1980
OBSERVED
PREDICTED

Figure G-12

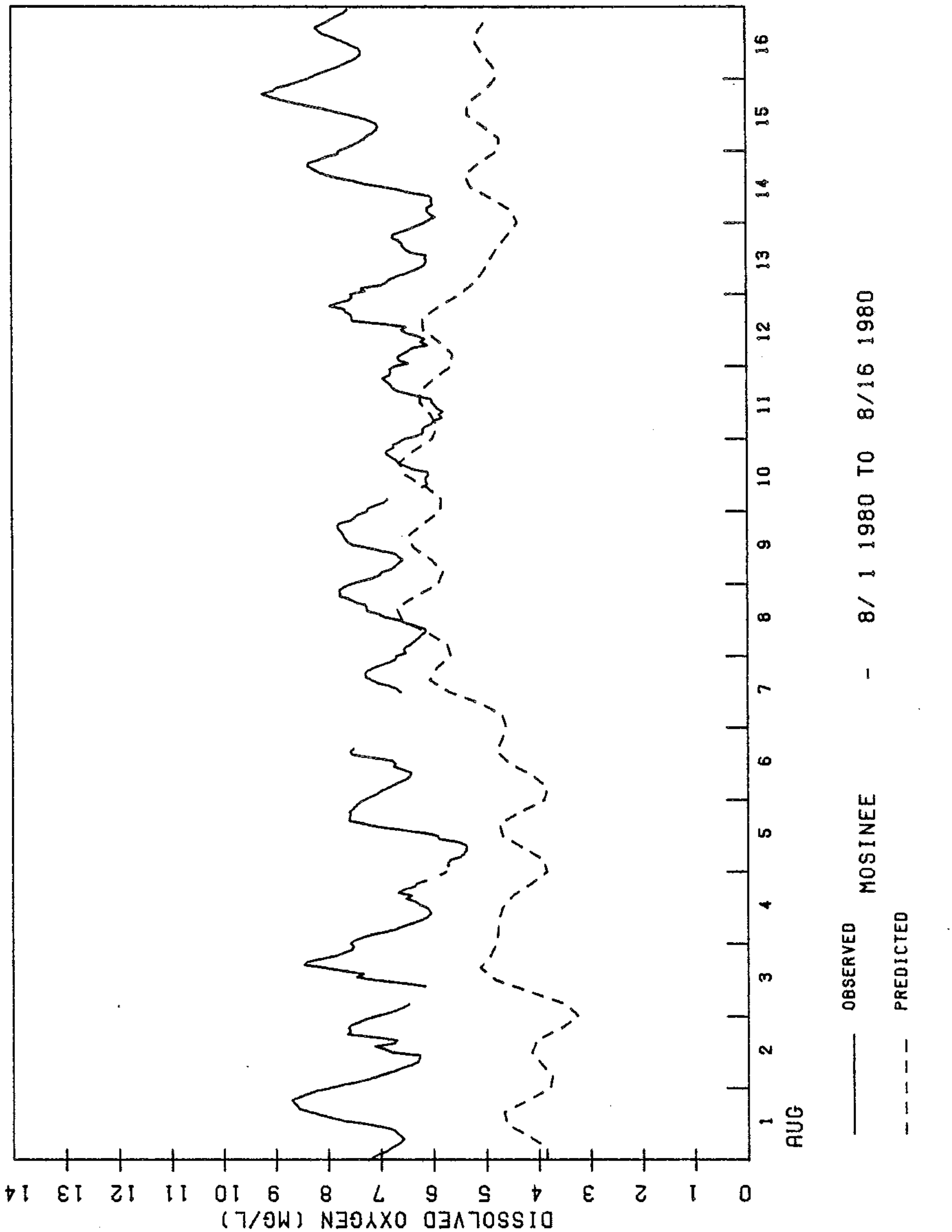

MOSINEE - 8/ 1 1980 TO 8/16 1980
OBSERVED
PREDICTED
DISSOLVED OXYGEN (MG/L)
AUG
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14

Figure G-13

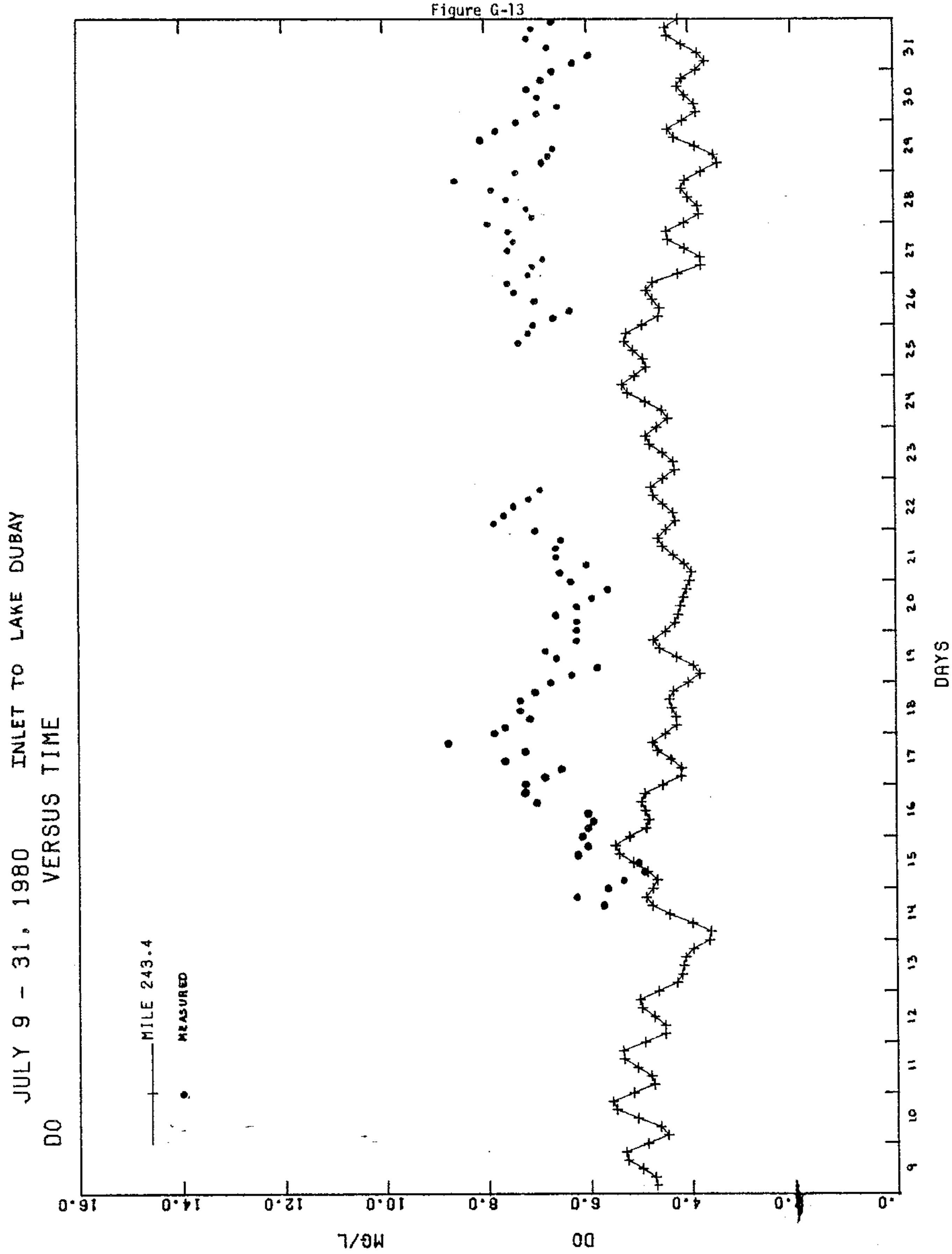

DO JULY 9 - 31, 1980 INLET TO LAKE DUBAY
VERSUS TIME
MILE 243.4
MEASURED
DO MG/L
DAYS
16.0
14.0
12.0
10.0
8.0
6.0
4.0
.0
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31

Figure G-14

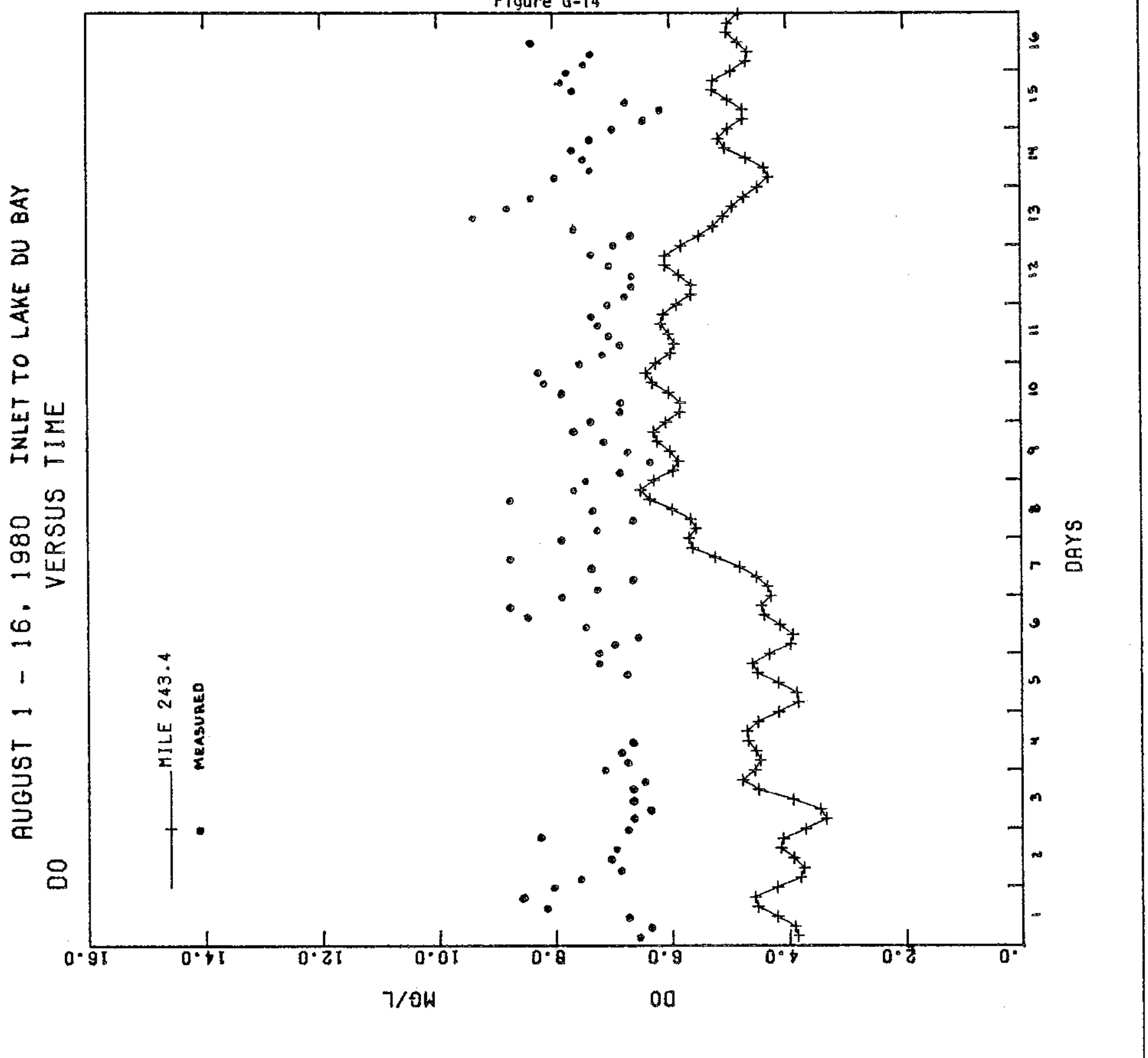

DO AUGUST 1 - 16, 1980 INLET TO LAKE DU BAY
VERSUS TIME
MILE 243.4
MEASURED
DO
MG/L
DAYS
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
.0

Figure G-15

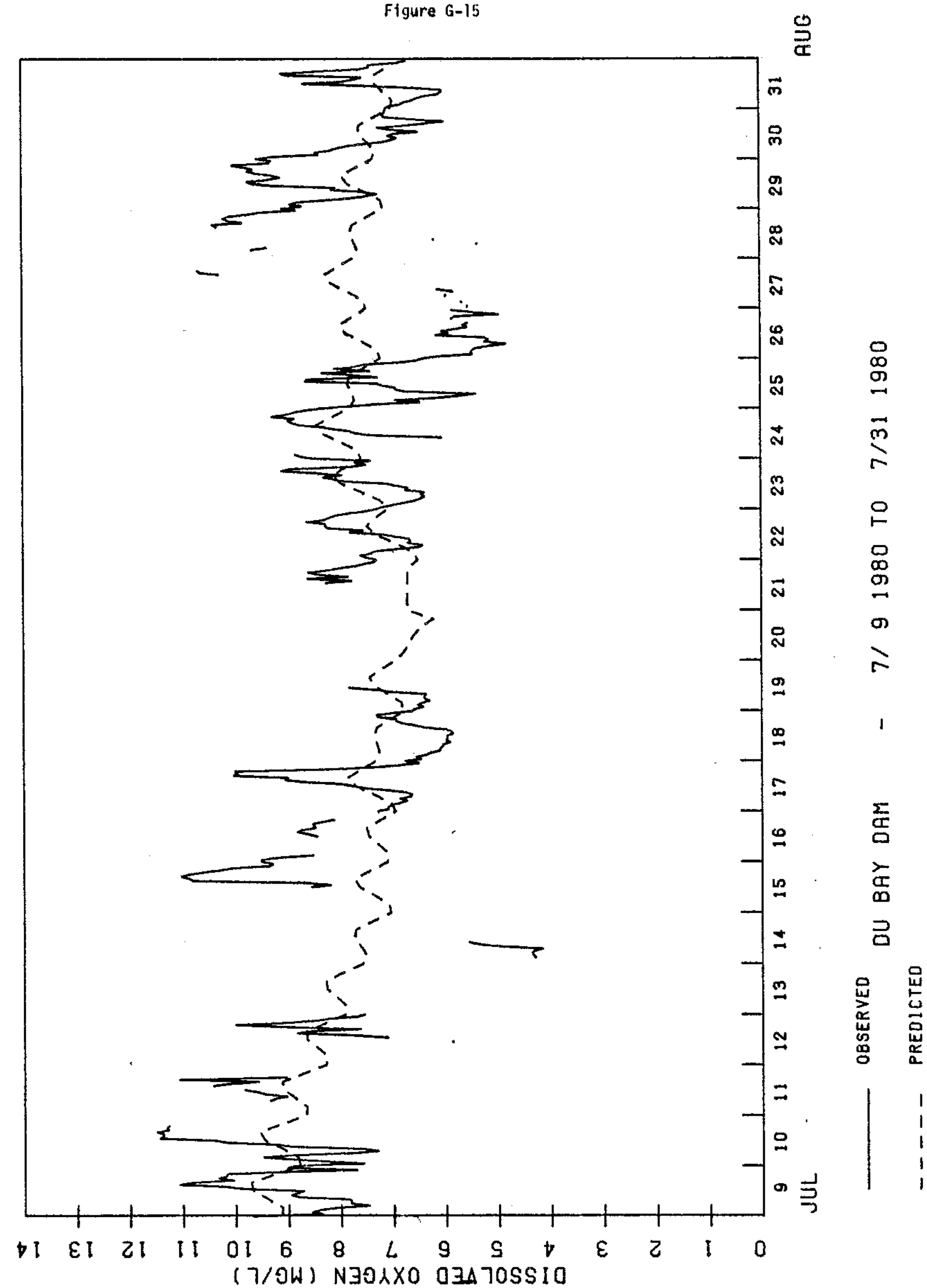

DISSOLVED OXYGEN (MG/L)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
JUL
9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
AUG
DU BAY DAM - 7/ 9 1980 TO 7/31 1980
OBSERVED
PREDICTED

Figure G-16

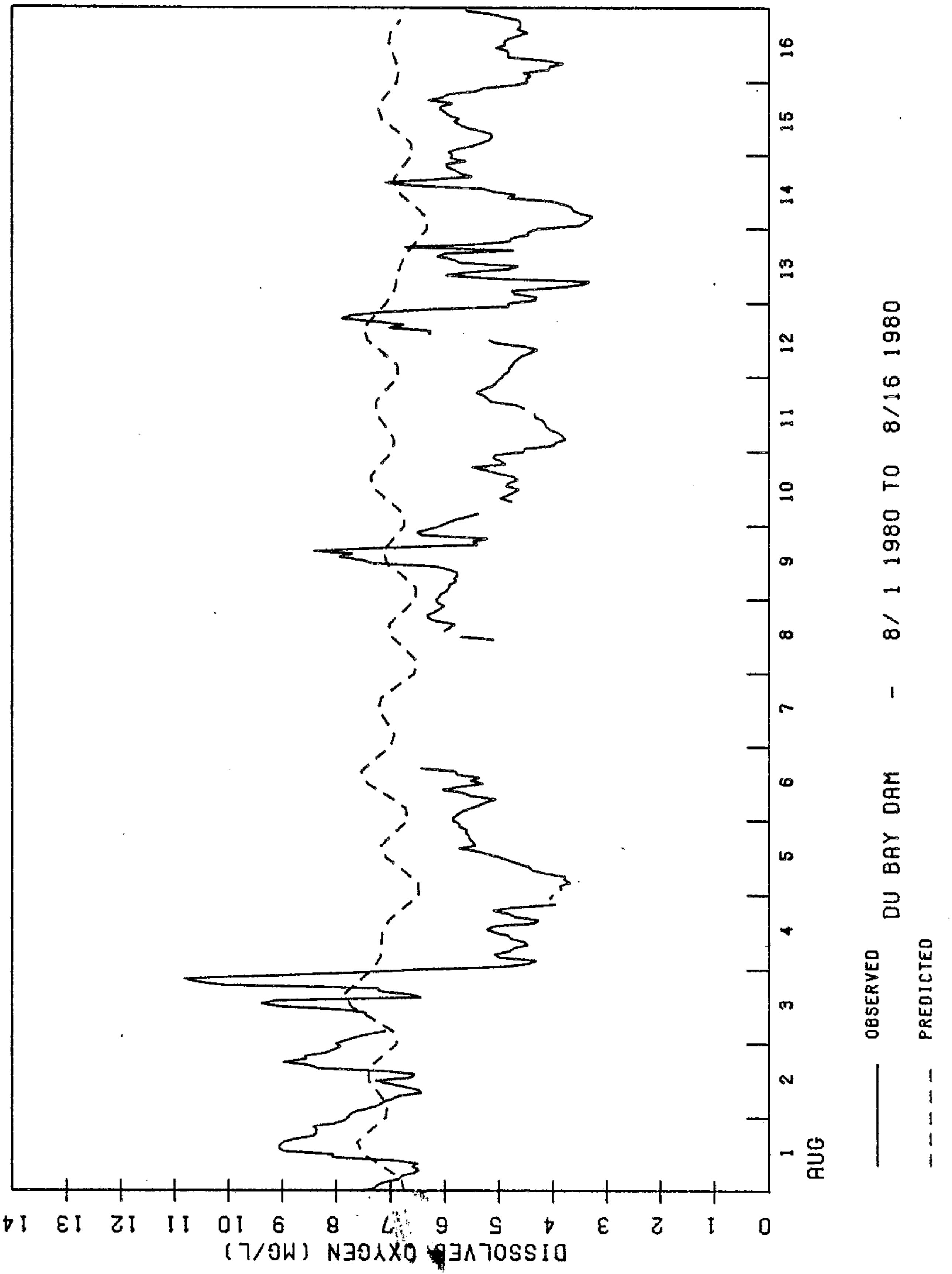

DISSOLVED OXYGEN (MG/L)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
AUG
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
OBSERVED
PREDICTED
DU BAY DAM - 8/ 1 1980 TO 8/16 1980

Figure G-17

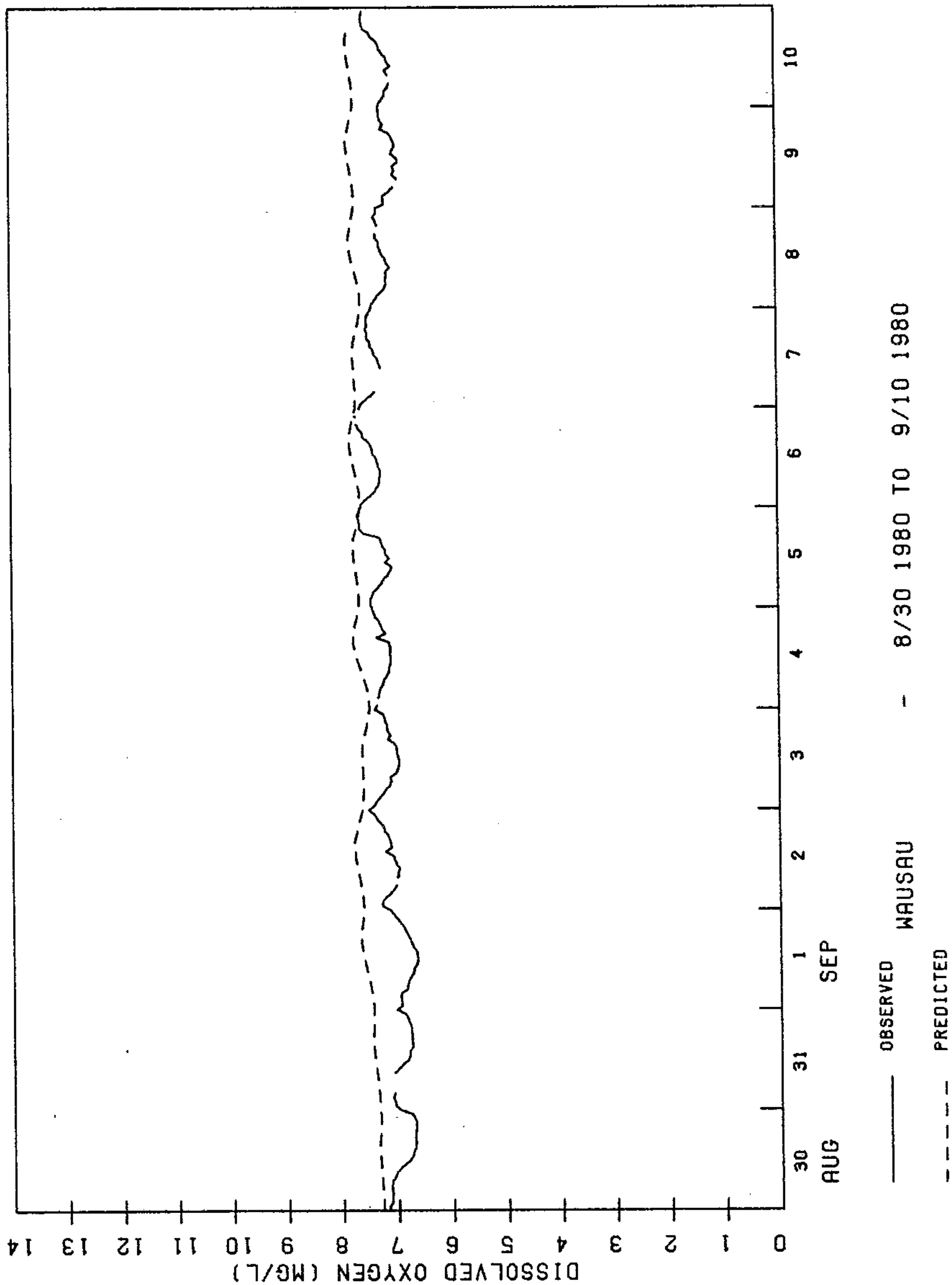

DISSOLVED OXYGEN (MG/L)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
30 AUG
31
1 SEP
2
3
4
5
6
7
8
9
10
OBSERVED
PREDICTED
WAUSAU - 8/30 1980 TO 9/10 1980

Figure G-18

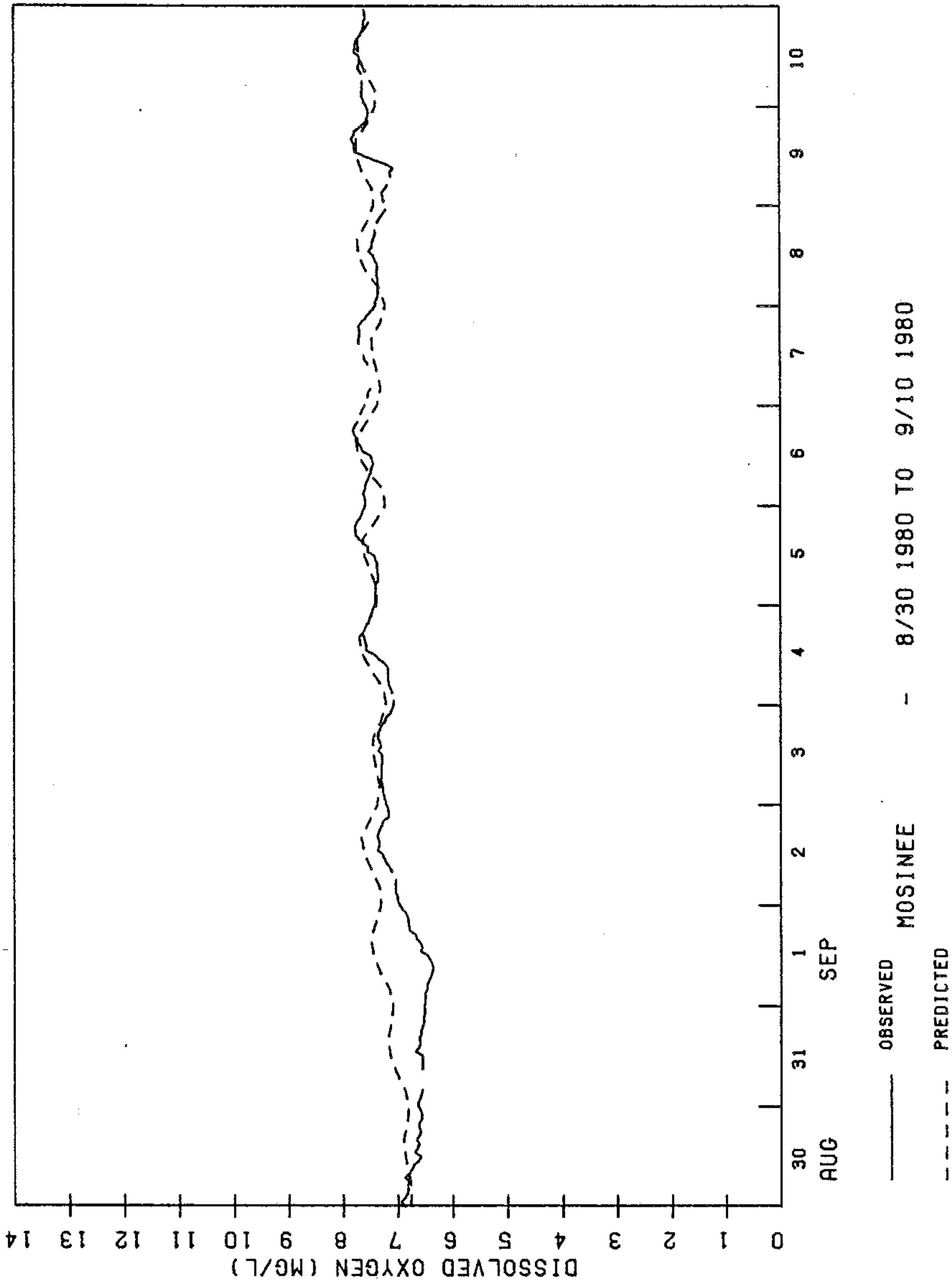

MOSINEE - 8/30 1980 TO 9/10 1980
OBSERVED
PREDICTED
DISSOLVED OXYGEN (MG/L)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
30 AUG
31
1 SEP
2
3
4
5
6
7
8
9
10

Figure G-19

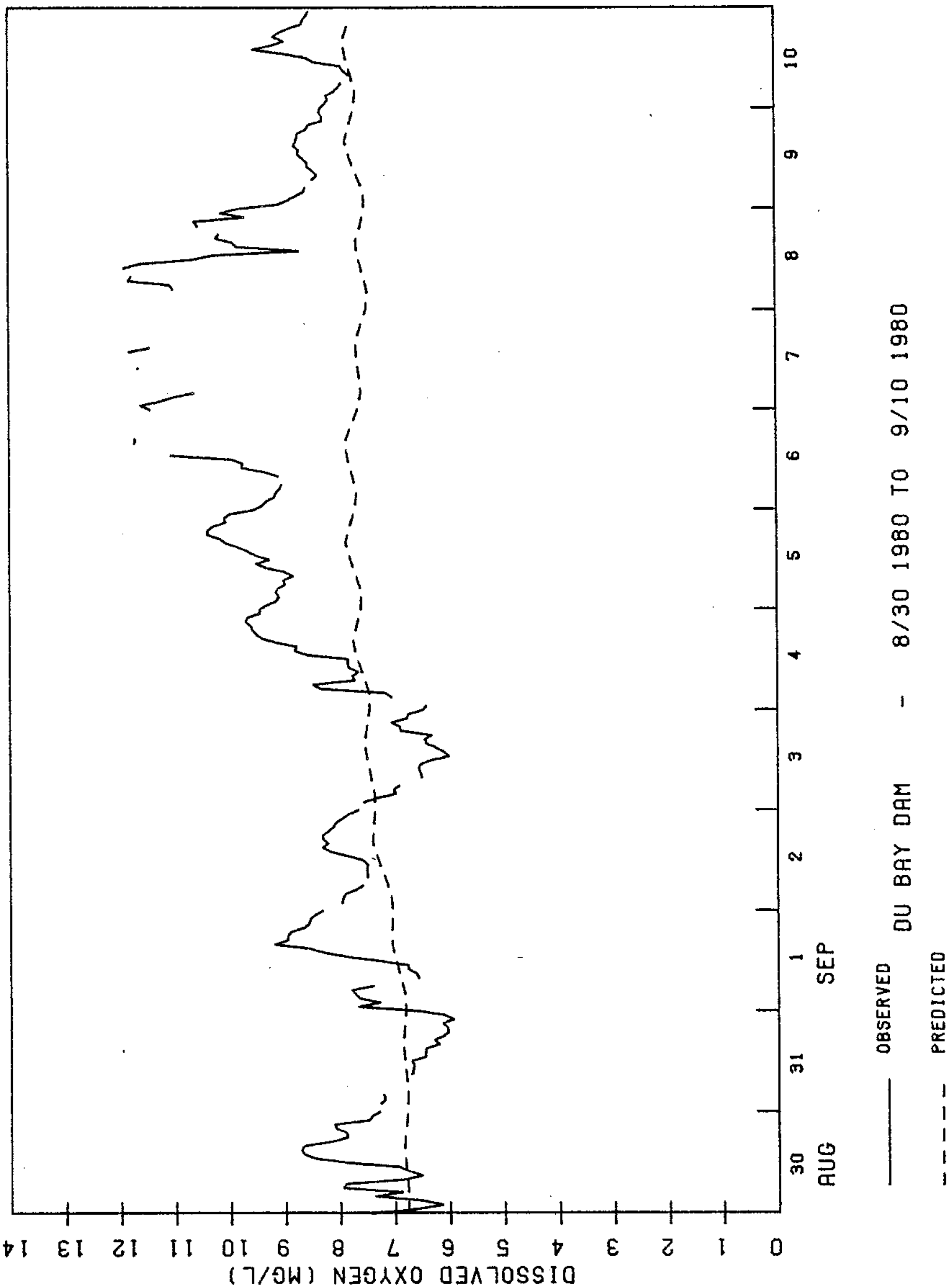

DU BAY DAM - 8/30 1980 TO 9/10 1980
OBSERVED
PREDICTED
DISSOLVED OXYGEN (MG/L)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
30 31 1 2 3 4 5 6 7 8 9 10
AUG
SEP

Figure G-20

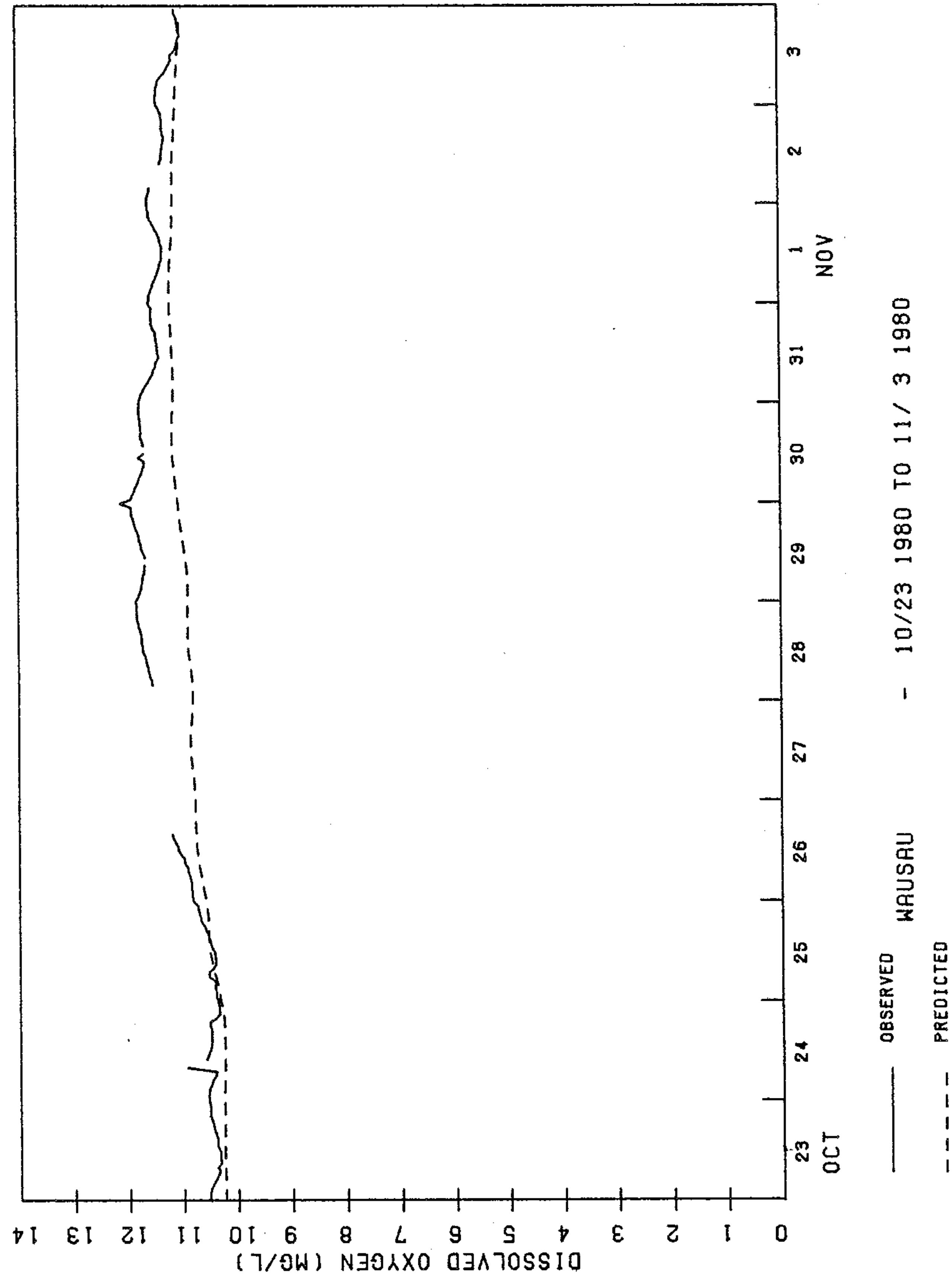

DISSOLVED OXYGEN (MG/L)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
OCT
23 24 25 26 27 28 29 30 31 1 2 3
NOV
WAUSAU - 10/23 1980 TO 11/ 3 1980
OBSERVED
PREDICTED

Figure G-21

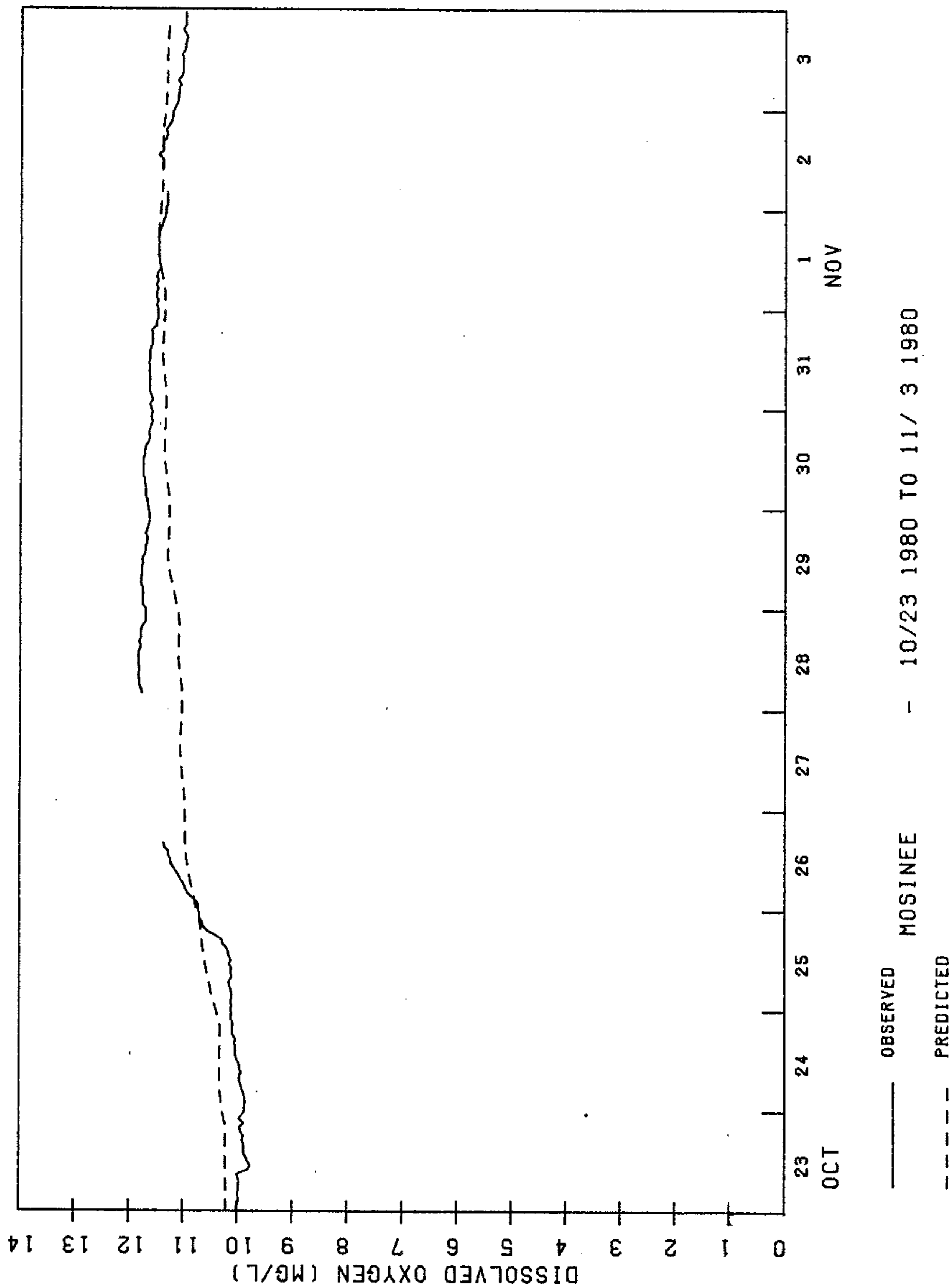

MOSINEE - 10/23 1980 TO 11/ 3 1980
DISSOLVED OXYGEN (MG/L)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
23
OCT
24
25
26
27
28
29
30
31
1
NOV
2
3
OBSERVED
PREDICTED

Figure G-22

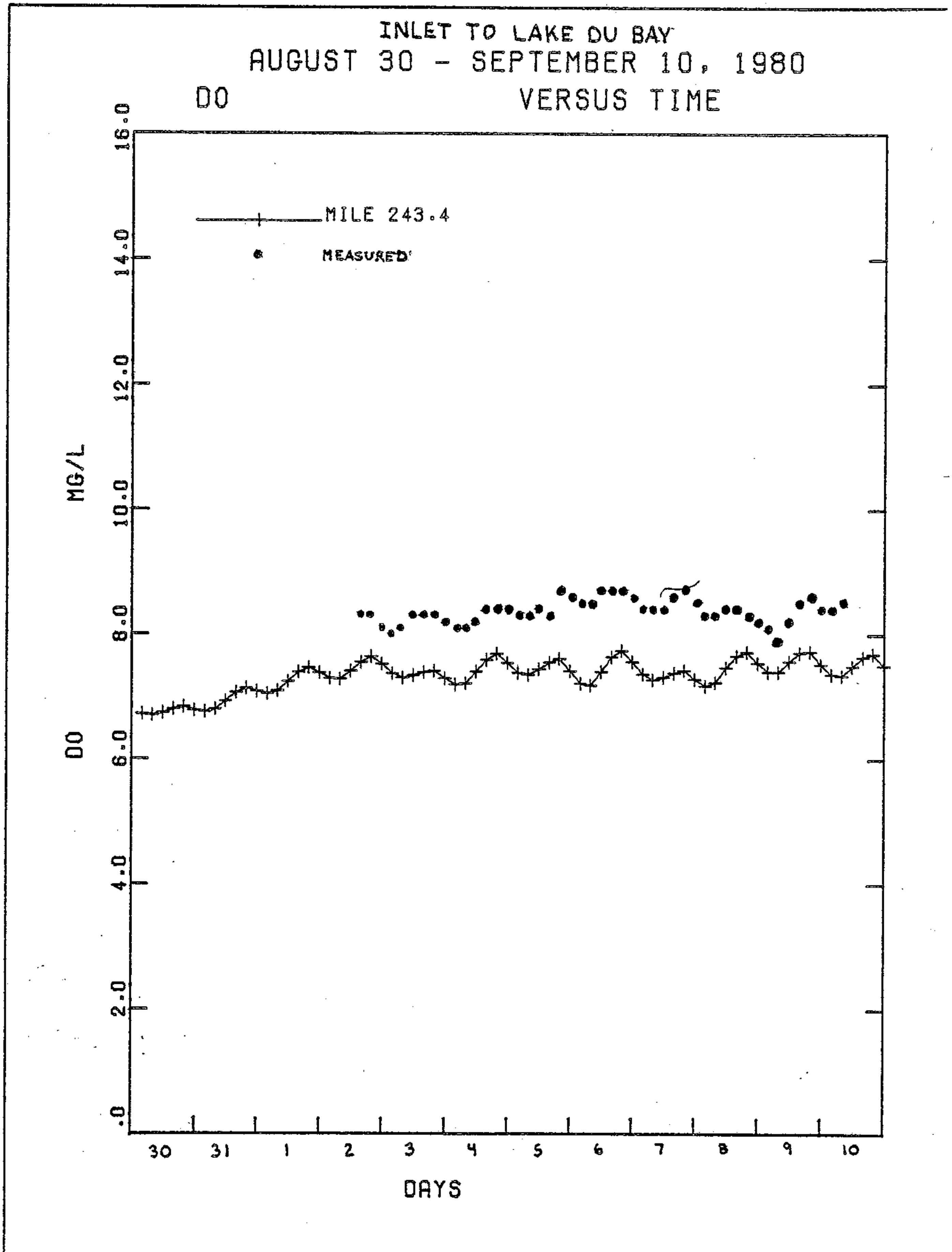

INLET TO LAKE DU BAY
AUGUST 30 - SEPTEMBER 10, 1980
DO
VERSUS TIME
MILE 243.4
MEASURED
MG/L
DO
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
.0
30
31
1
2
3
4
5
6
7
8
9
10
DAYS

Figure G-23

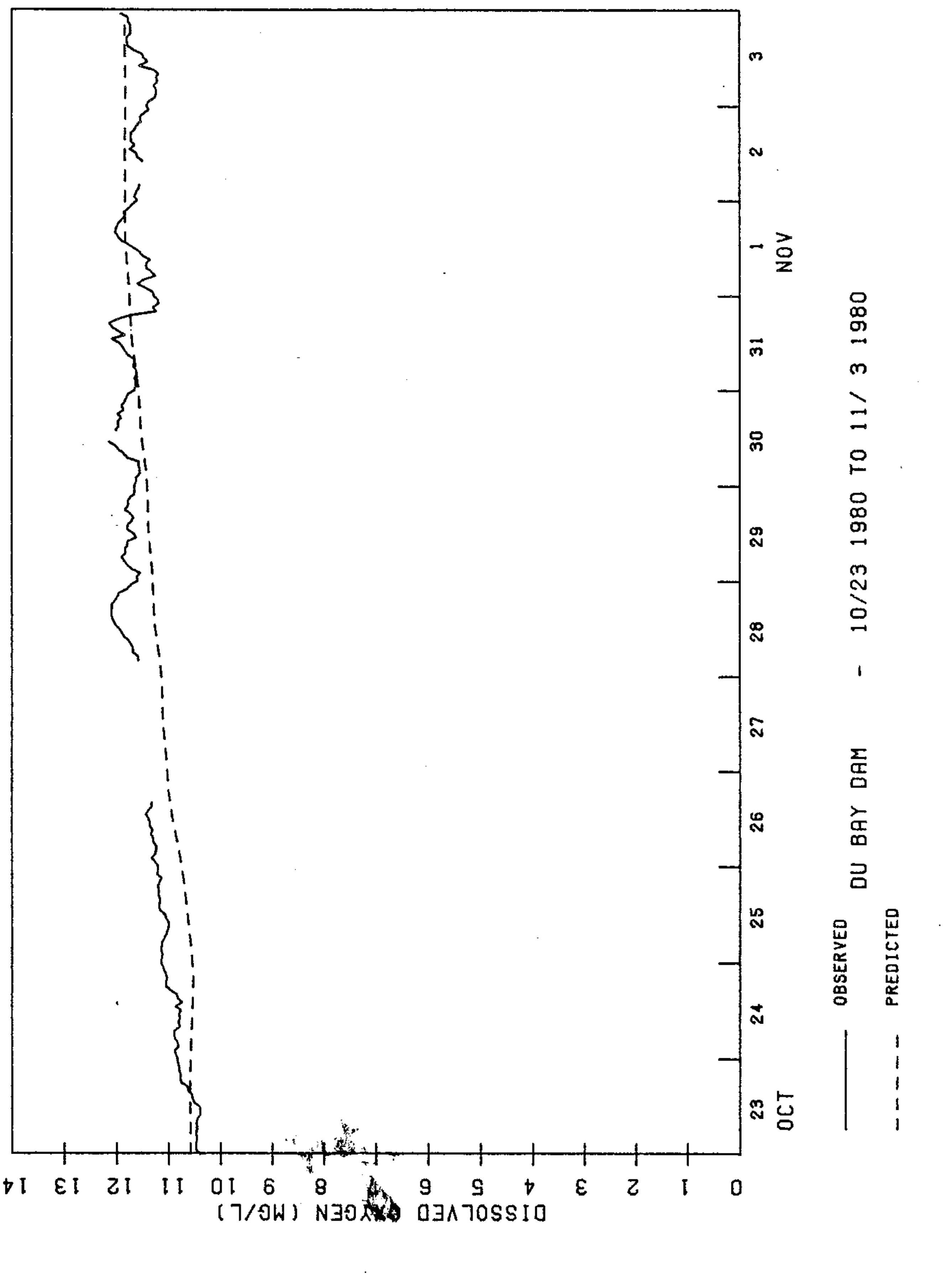

DU BAY DAM - 10/23 1980 TO 11/ 3 1980
OBSERVED
PREDICTED
DISSOLVED OXYGEN (MG/L)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
OCT
23 24 25 26 27 28 29 30 31
NOV
1 2 3

Figure G-24

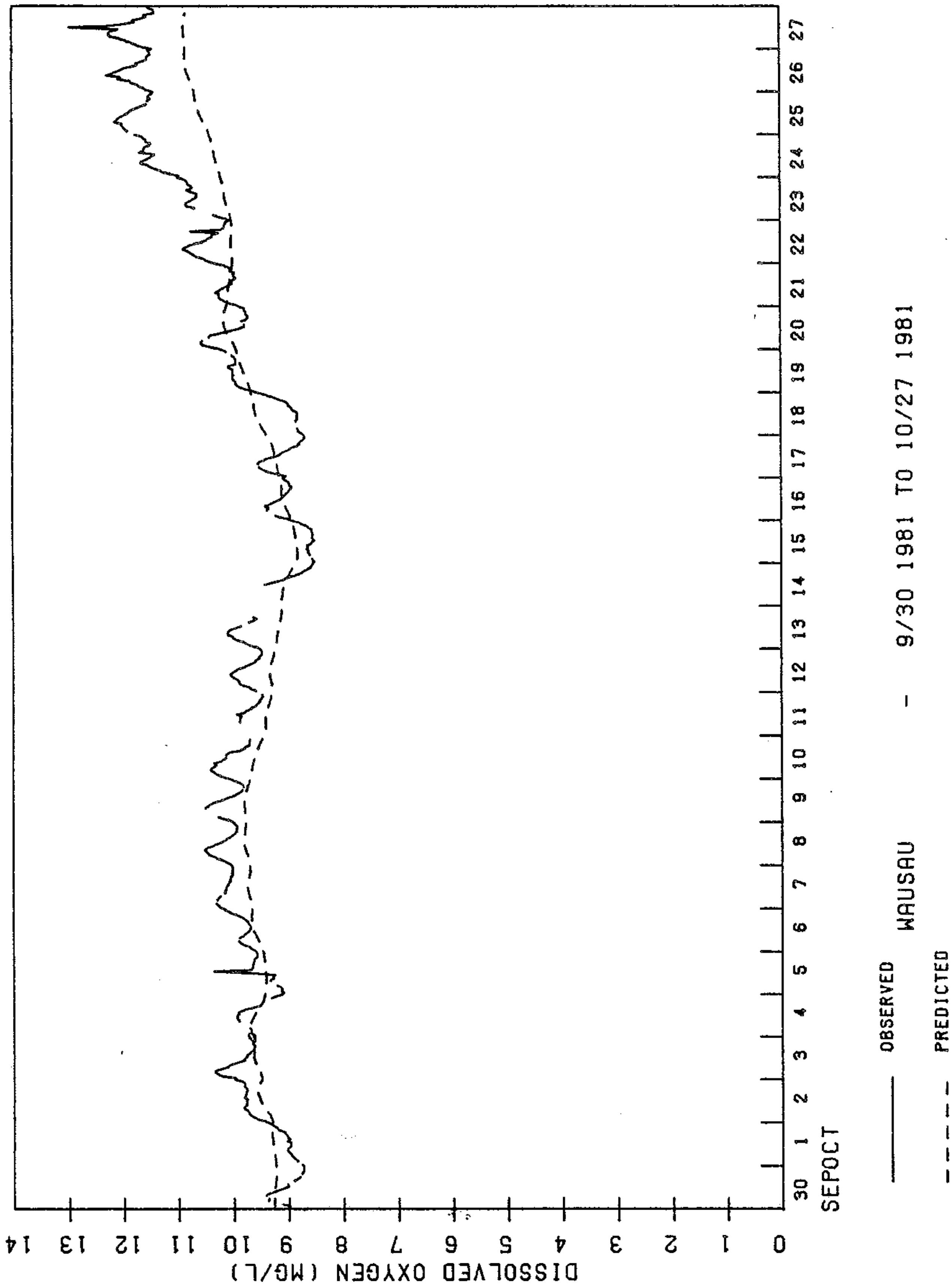

DISSOLVED OXYGEN (MG/L)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
SEPOCT
30 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27
OBSERVED
PREDICTED
WAUSAU - 9/30 1981 TO 10/27 1981

Figure G-25

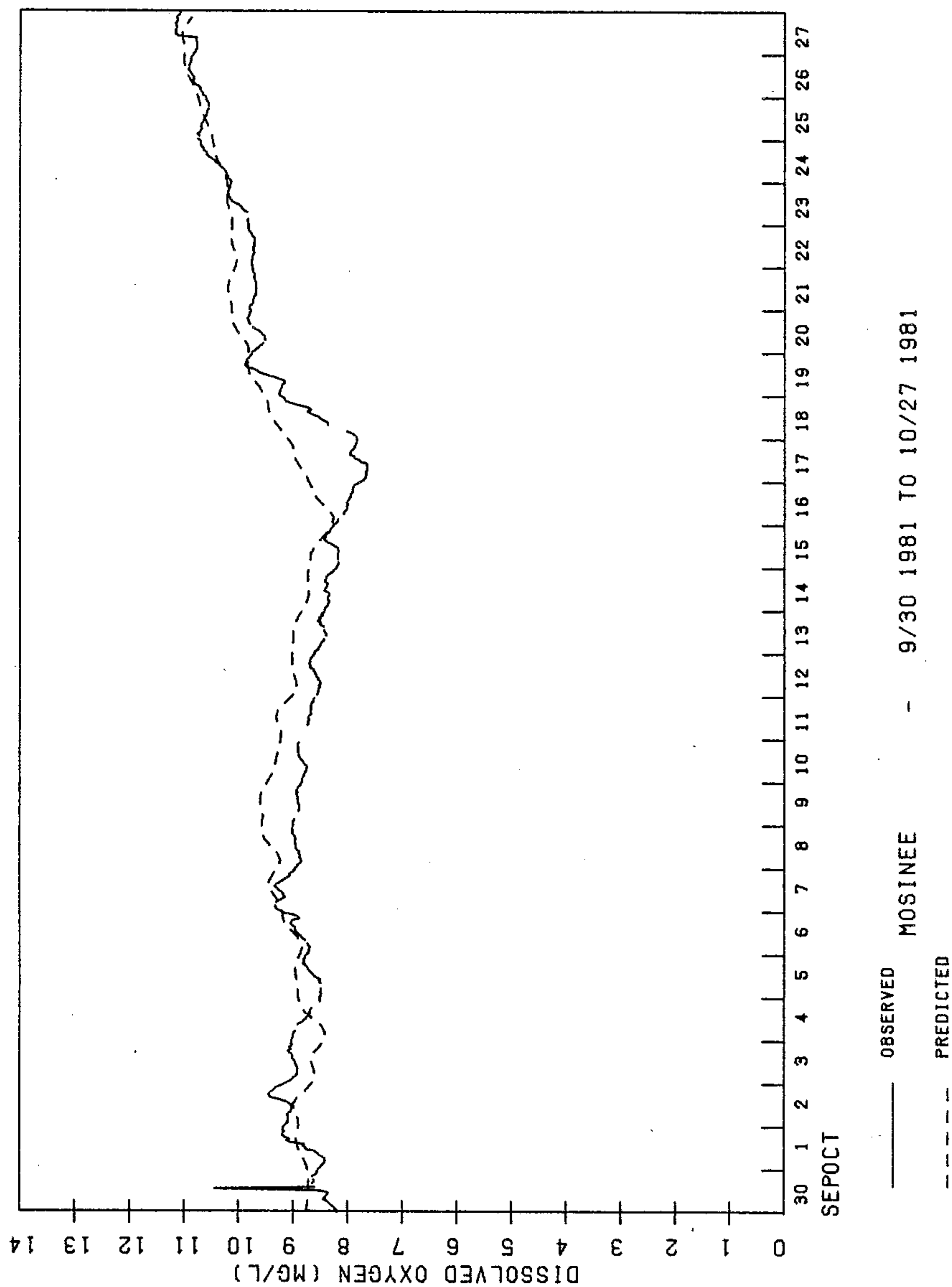
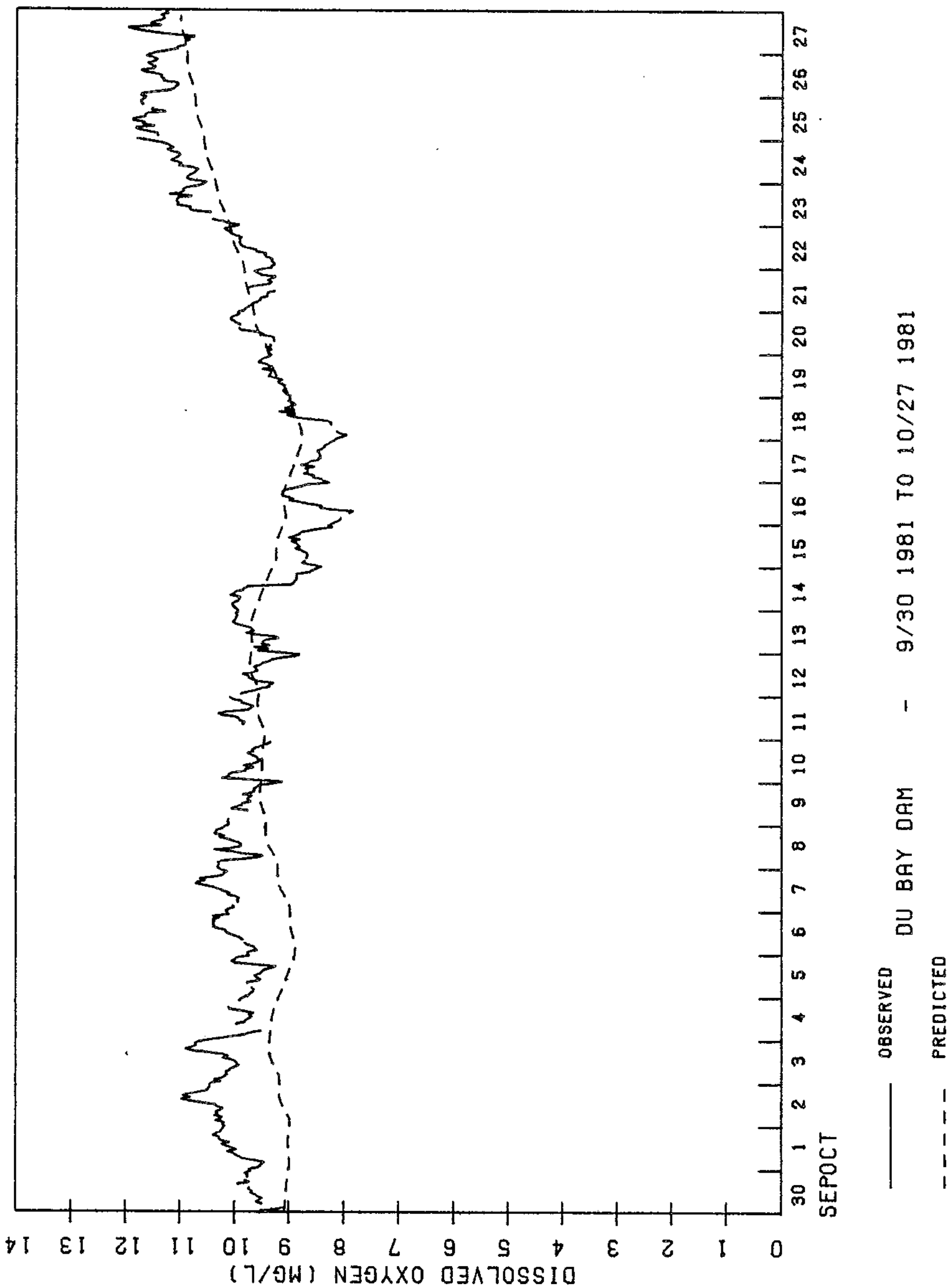

DISSOLVED OXYGEN (MG/L)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
SEPOCT
30 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27
OBSERVED
PREDICTED
MOSINEE - 9/30 1981 TO 10/27 1981

Figure G-26


DISSOLVED OXYGEN (MG/L)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
SEPOCT
30 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
OBSERVED
PREDICTED
DU BAY DAM - 9/30 1981 TO 10/27 1981

Appendix H

This appendix presents the results of the sensitivity analyses on Segment BC of the upper Wisconsin River. A typical, and frequently occurring, set of conditions was chosen for the base run. These are the conditions occurring for the September wasteload allocation with a headwater flow of 1,800 cfs and a river temperature of 63.5 degrees fahrenheit. All wastewater dischargers were discharging at their allowable maximum daily loads as listed in Wisconsin Administrative Code NR 212. The set of rate coefficients in the sensitivity analysis is that set which was determined during the calibration process and listed in Appendix D. 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. 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 change in dissolved oxygen of 0.29 mg/l at the dissolved oxygen sag point near the inlet to Lake Dubay. Use of this greatly increased algae maximum growth could only be accomplished by altering many other parameter to compensate for the difference. Such attempts would probably drive other parameters outside of their accepted limits. Another example is temperature. While varying the temperature has a large impact on the dissolved oxygen, it is constrained by survey measurements and thus not subject to manipulation to facilitate calibration. Result of the sensitivity analysis are found in Table H-2 and H-3.

Table H-1

Boundary Condition Settings for Base Run
of Sensitivity Analysis

Headwater (Brokaw) Flow	= 1800 cfs
Wisconsin River Temperature	= 63.5 °F
Headwater Algae	= 12.8 ug/l
Headwater Phosphorus (Not in Algae)	= 0.039 mg/l
Headwater Organic Nitrogen (Not in Algae)	= 0.54 mg/l
Headwater Ammonia	= 0.052 mg/l
Headwater Nitrite	= 0.0 mg/l
Headwater Nitrate	= 0.172 mg/l
Headwater Dissolved Oxygen	= 8.55 mg/l
Incremental Runoff	= 0.18 cfs/mile
Rib River Flow	= 157 cfs
Eau Claire River Flow	= 157 cfs
Bull Junior Creek Flow	= 16 cfs
Big Eau Pleine River Flow	= 338 cfs
Johnson and Little Eau Claire Rivers Flow	= 50 cfs
Little Eau Pleine River Flow	= 45 cfs
Rib River Dissolved Oxygen	= 8.55 mg/l
Eau Claire River Dissolved Oxygen	= 8.55 mg/l
Bull Junior Creek Dissolved Oxygen	= 8.55 mg/l
Big Eau Pleine River Dissolved Oxygen	= 8.55 mg/l
Johnson and Little Eau Claire Rivers Dissolved Oxygen	= 8.55 mg/l
Little Eau Pleine River Dissolved oxygen	= 8.55 mg/l
Lake DuBay Evaporation	= -36 cfs
Solar Radiation	= 325 langleys
Hours of Daylight	= 12.34 hours
Big Eau Pleine River Algae	= 50 ug/l
Big Eau Pleine River Nitrite	= 0.02 mg/l
Big Eau Plaine River Nitrate	= 0.01 mg/l
Big Eau Pleine River Phosphorus (Not in Algae)	= 0.27 mg/l
Big Eau Pleine River Organic Nitrogen (Not in Algae)	= 3.00 mg/l

Table H-2

Sensitivity Analysis Results - Dissolved Oxygen

Change in Dissolved Oxygen (mg/l)

Parameter Altered	Change in Parameter	River Mile 265.6	River Mile 258.4	River Mile 248.9	River Mile 242.6	River Mile 235.4
Base Run	Actual Prediction	7.50	7.72	5.88	5.44	7.54
Oxygen Production by Algae	-20%	-0.08	-0.20	-0.26	-0.29	-0.56
	+20%	+0.08	+0.19	+0.26	+0.29	+0.55
Oxygen Respiration by Algae	-20%	+0.04	+0.11	+0.12	+0.13	+0.34
	+20%	-0.04	-0.12	-0.12	-0.13	-0.35
Nitrogen Content of Algae	-20%	0.00	-0.01	-0.01	-0.01	-0.03
	+20%	0.00	0.00	+0.01	+0.01	+0.02
Phosphorus Content of Algae	-20%	0.00	0.00	0.00	0.00	0.00
	+20%	0.00	0.00	0.00	0.00	0.00
Maximum Denitrification Rate	-20%	0.00	-0.01	0.00	0.00	0.00
	+20%	0.00	0.00	0.00	0.00	0.00
Nitrogen Half-Saturation Constant	-20%	0.00	0.00	+0.01	+0.01	+0.02
	+20%	0.00	-0.01	-0.01	-0.01	-0.03
Phosphorus Half-Saturation Constant	-20%	+0.01	+0.01	+0.02	+0.02	+0.03
	+20%	-0.01	-0.02	-0.02	-0.02	-0.03
Light Half-Saturation Constant	-20%	+0.01	+0.15	+0.24	+0.28	+0.54
	+20%	-0.05	-0.12	-0.16	-0.20	-0.37
Chloraphyll-A Content of Algae	-20%	+0.05	+0.09	+0.18	+0.21	+0.28
	+20%	-0.04	-0.07	-0.11	-0.14	-0.20

Table H-2 (continued)

Sensitivity Analysis Results - Dissolved Oxygen

Change in Dissolved Oxygen (mg/l)

Parameter Altered	Change in Parameter	River Mile 265.6	River Mile 258.4	River Mile 248.9	River Mile 242.6	River Mile 235.4
Base Run	Actual Prediction	7.50	7.72	5.88	5.44	7.54
Fast Term BOD Decay Rate	-20%	+0.01	0.00	+0.02	+0.03	-0.02
	+20%	-0.05	0.00	-0.01	-0.02	+0.01
Slow Term BOD Decay Rate	-20%	+0.16	+0.11	+0.43	+0.44	+0.18
	+20%	-0.15	-0.11	-0.36	-0.37	-0.15
BOD Settling Rage	0.5 ft/day	-0.04	-0.13	-0.12	-0.10	-0.36
	2.0 ft/day	-0.16	-0.44	-0.49	-0.34	-0.91
Light Extinction Coef. Indep. of Algae	-20%	+0.08	+0.21	+0.33	+0.38	+0.70
	+20%	-0.06	-0.15	-0.22	-0.24	-0.44
Maximum Algae Growth Rate	-20%	-0.08	-0.20	-0.30	-0.33	-0.60
	+20%	+0.08	+0.20	+0.41	+0.39	+0.76
Algae Death Rate	-20%	+0.04	+0.11	+0.14	+0.16	+0.38
	+20%	-0.04	-0.11	-0.13	-0.15	-0.34
Organic Nitrogen Settling Rate	-20%	0.00	0.00	0.00	0.00	-0.01
	+20%	0.00	0.00	0.00	0.00	+0.01
Organic Nitrogen Re-cycle Rater Per Algae	-20%	0.00	0.00	+0.01	+0.01	+0.03
	+20%	0.00	-0.01	-0.01	-0.01	-0.03
Ammonia Nitrification Rate	-20%	+0.01	+0.02	+0.05	+0.05	+0.08
	+20%	-0.01	-0.03	-0.05	-0.04	-0.07

Table H-2 (continued)

Sensitivity Analysis Results - Dissolved Oxygen

Change in Dissolved Oxygen (mg/l)

Parameter Altered	Change in Parameter	River Mile 265.6	River Mile 258.4	River Mile 248.9	River Mile 242.6	River Mile 235.4
Base Run	Actual Prediction	7.50	7.72	5.88	5.44	7.54
Nitrite Nitrification Rate	-20%	0.00	0.00	0.00	0.00	0.00
	+20%	0.00	0.00	0.00	0.00	0.00
Sediment Source Rate for Ammonia	120 $mg/m^2/day$	0.00	-0.03	-0.09	-0.10	-0.15
	60 $mg/m^2/day$	0.00	-0.02	-0.04	-0.05	-0.03
Sediment Source Rate for Phosphorus	120 $mg/m^2/day$	+0.01	+0.02	+0.04	+0.05	+0.09
	60 $mg/m^2/day$	+0.01	+0.02	+0.03	+0.04	+0.08
Headwater DO	-20%	-1.23	-0.63	-0.36	-0.27	-0.10
	+20%	+1.23	+0.62	+0.35	+0.28	+0.09
Headwater Fast Term BOD5	1 mg/l	-2.64	-2.52	-1.47	-1.17	-0.43
	3 mg/l	-7.50	-6.49	-3.78	-3.03	-1.17
	5 mg/l	-7.50	-7.21	-4.28	-3.48	-1.32
	8 mg/l	-7.50	-7.72	-4.71	-3.91	-1.52
Headwater Slow Term BOD5	1 mg/l	-0.38	-0.29	-0.43	-0.42	-0.18
	3 mg/l	-2.54	-1.93	-2.84	-2.82	-1.18
	5 mg/l	-4.70	-3.56	-5.20	-5.16	-2.16
Headwater Algae	-20%	-0.04	-0.06	-0.11	-0.12	-0.10
	+20%	+0.03	+0.04	+0.11	+0.10	+0.07
Headwater Algae	-20%	0.00	0.00	+0.01	+0.01	0.00
	-20%	0.00	-0.01	0.00	0.00	0.00

Table H-2 (continued)

Sensitivity Analysis Results - Dissolved Oxygen

Change in Dissolved Oxygen (mg/l)

Parameter Altered	Change in Parameter	River Mile 265.6	River Mile 258.4	River Mile 248.9	River Mile 242.6	River Mile 235.4
Base Run	Actual Prediction	7.50	7.72	5.88	5.44	7.54
Headwater Nitrate	-20%	0.00	0.00	0.00	0.00	+0.02
	+20%	0.00	0.00	0.00	0.00	-0.01
Headwater Organic Nitrogen	-20%	0.00	0.00	+0.01	+0.02	+0.03
	+20%	0.00	0.00	-0.02	-0.02	-0.04
Headwater Phosphorus	-20%	0.00	0.00	0.00	0.00	0.00
	+20%	+0.01	0.00	+0.01	+0.03	0.00
Solar Radiation	-20%	-0.06	-0.14	-0.21	-0.24	-0.44
	+20%	+0.05	+0.12	+0.20	+0.23	+0.43
Algae Settling Rate	-20%	0.00	+0.01	+0.01	+0.02	+0.04
	+20%	0.00	-0.02	-0.02	-0.02	-0.05
Big Eau Pleine R. DO	-20%	-	-	-	-	-0.08
	+20%	-	-	-	-	+0.07
Big Eau Pleine R. Phosphorus	-20%	-	-	-	-	0.00
	+20%	-	-	-	-	+0.01
Big Eau Pleine R. Organic Nitrogen	-20%	-	-	-	-	+0.02
	+20%	-	-	-	-	-0.02
Big Eau Pleine R. Nitrate	-20%	-	-	-	-	0.00
	+20%	-	-	-	-	0.00

Table H-2 (continued)

Sensitivity Analysis Results - Dissolved Oxygen

Change in Dissolved Oxygen (mg/l)

Parameter Altered	Change in Parameter	River Mile 265.6	River Mile 258.4	River Mile 248.9	River Mile 242.6	River Mile 235.4
Base Run	Actual Prediction	7.50	7.72	5.88	5.44	7.54
Big Eau Pleine R. Ammonia	-20%	-	-	-	-	0.00
	+20%	-	-	-	-	0.00
Big Eau Pleine R. Algae	-20%	-	-	-	-	-0.02
	+20%	-	-	-	-	+0.02
Big Eau Pleine R. BOD5	-20%	-	-	-	-	0.00
	+20%	-	-	-	-	0.00
Temperature	62.1°F	+0.11	+0.12	+0.24	+0.24	+0.17
	65.9°F	-0.10	-0.11	-0.21	-0.21	-0.16
Wausau Papers Phosphorus	-20%	0.00	0.00	0.00	0.00	0.00
	+20%	0.00	0.00	0.00	0.00	0.00
Wausau Papers Organic Nitrogen	-20%	0.00	0.00	+0.01	+0.01	0.00
	+20%	0.00	0.00	0.00	0.00	0.00
Wausau Papers Nitrate	-20%	0.00	0.00	0.00	0.00	0.00
	+20%	0.00	0.00	0.00	0.00	0.00
Wausau Papers Ammonia	-20%	0.00	+0.01	+0.02	+0.02	+0.02
	+20%	0.00	-0.01	-0.02	-0.02	-0.02
Wausau Papers BOD	-20%	+0.13	+0.11	+0.10	+0.09	+0.04
	+20%	-0.13	-0.11	-0.09	-0.08	-0.03

Table H-2 (continued)

Sensitivity Analysis Results - Dissolved Oxygen

Change in Dissolved Oxygen (mg/l)

Parameter Altered	Change in Parameter	River Mile 265.6	River Mile 258.4	River Mile 248.9	River Mile 242.6	River Mile 235.4
Base Run	Actual Prediction	7.50	7.72	5.88	5.44	7.54
American Can BOD	-20%	-	-	+0.03	+0.03	+0.02
	+20%	-	-	-0.02	-0.03	-0.01
Amer. Can & Wey. Phosphorus	-20%	-	-	0.00	+0.01	0.00
	+20%	-	-	0.00	0.00	0.00
Amer. Can & Wey. Organic Nitrogen	-20%	-	-	+0.01	+0.01	+0.01
	+20%	-	-	0.00	0.00	0.00
Amer. Can & Wey. Nitrate	-20%	-	-	0.00	0.00	0.00
	+20%	-	-	0.00	0.00	0.00
Amer. Can & Wey. Ammonia	-20%	-	-	0.00	0.00	0.00
	+20%	-	-	0.00	0.00	0.00
Weyerhaeuser Co. BOD	-20%	-	-	+0.36	+0.41	+0.18
	+20%	-	-	-0.35	-0.40	-0.18
Mosinee Paper Phosphorus	-20%	-	-	-	0.00	0.00
	+20%	-	-	-	0.00	0.00
Mosinee Paper Organic Nitrogen	-20%	-	-	-	0.00	0.00
	+20%	-	-	-	0.00	0.00
Mosinee Paper Nitrate	-20%	-	-	-	0.00	0.00
	+20%	-	-	-	0.00	0.00
Mosinee Paper Ammonia	-20%	-	-	-	0.00	0.00
	+20%	-	-	-	0.00	0.00

Table H-2 (continued)

Sensitivity Analysis Results - Dissolved Oxygen

Change in Dissolved Oxygen (mg/l)

Parameter Altered	Change in Parameter	River Mile 265.6	River Mile 258.4	River Mile 248.9	River Mile 242.6	River Mile 235.4
Base Run	Actual Prediction	7.50	7.72	5.88	5.44	7.54
Mosinee Paper BOD	-20%	-	-	-	+0.05	+0.04
	+20%	-	-	-	-0.05	-0.03
Reaeration Equation	Churchill	-0.15	-0.76	-1.22	-1.43	-3.14
	O'Connor-Dobbins	0.00	-0.29	-0.22	-0.17	-1.09
	Owens-Gibbs	-0.06	-0.53	-0.63	-0.70	-2.07
	Thacksten-Krenkel	-0.17	-6.79	-1.34	-1.55	-3.26
	Langbien-Durum	-0.11	-0.66	-0.96	-1.03	-2.70
	Wind Driven	+0.01	+0.07	-0.16	-0.30	+0.09

Table H-3
Sensitivity Analysis Results - Nutrients and Algae

Change in Predicted Values at River Mile 242.6 (mg/l)

Parameter Altered	Change in Parameter	BOD5	Ammonia	Nitrate	Algae (ug/l)
Base Run	Actual Prediction	1.17	0.24	0.24	2.57
Oxygen Production by Algae	-20%	0.00	0.00	0.00	0.00
	+20%	0.00	0.00	0.00	0.00
Oxygen Respiration by Algae	-20%	0.00	0.00	0.00	0.00
	+20%	0.00	0.00	0.00	0.00
Nitrogen Content of Algae	-20%	0.00	+0.01	+0.02	0.00
	+20%	0.00	-0.01	-0.02	0.00
Phosphorus Content of Algae	-20%	0.00	0.00	0.00	0.00
	+20%	0.00	0.00	0.00	0.00
Maximum Dentrification Rate	-20%	0.00	0.00	0.00	0.00
	+20%	0.00	0.00	0.00	0.00
Nitrogen Half-Saturation Constant	-20%	0.00	0.00	0.00	+0.01
	+20%	0.00	0.00	0.00	-0.01
Phosphorus Half-Saturation Constant	-20%	0.00	0.00	0.00	+0.02
	+20%	0.00	0.00	0.00	-0.02
Light Half-Saturation Constant	-20%	0.00	-0.01	-0.02	+0.28
	+20%	0.00	+0.01	+0.01	-0.20
Chlorophyll-A Content of Algae	-20%	0.00	-0.02	-0.02	+0.64
	+20%	0.00	+0.01	+0.01	-0.43
Fast Term BOD Decay Rate	-20%	+0.01	0.00	0.00	0.00
	+20%	-0.01	0.00	0.00	0.00
Slow Term BOD Decay Rate	-20%	+0.16	0.00	0.00	0.00
	+20%	-0.14	0.00	0.00	0.00

Table H-3 (continued)
Sensitivity Analysis Results - Nutrients and Algae

Change in Predicted Values at River Mile 242.6 (mg/l)

Parameter Altered	Change in Parameter	BOD5	Ammonia	Nitrate	Algae (ug/l)
Base Run	Actual Prediction	1.17	0.24	0.24	2.57
BOD Settling Rate	0.5 ft/day	-0.06	0.00	0.00	0.00
	2.0 ft/day	-0.22	0.00	0.00	0.00
Light Extinction Coef. Indep. of Algae	-20%	0.00	-0.02	-0.02	+0.39
	+20%	0.00	+0.01	+0.01	-0.25
Maximum Algae Growth Rate	-20%	0.00	+0.01	+0.02	-0.35
	+20%	0.00	-0.02	-0.02	+0.39
Algae Death Rate	-20%	0.00	0.00	0.00	+0.17
	+20%	0.00	0.00	0.00	-0.16
Organic Nitrogen Settling Rate	-20%	0.00	0.00	0.00	0.00
	+20%	0.00	0.00	0.00	0.00
Organic Nitrogen Recycle Rate per Algae	-20%	0.00	-0.01	0.00	0.00
	+20%	0.00	+0.01	0.00	0.00
Ammonia Nitrification Rate	-20%	0.00	+0.02	-0.02	0.00
	+20%	0.00	-0.02	+0.01	0.00
Nitrite Nitrification Rate	-20%	0.00	0.00	0.00	0.00
	+20%	0.00	0.00	0.00	0.00
Sediment Source Rate for Ammonia	120 mg/m^2/day	0.00	+0.12	+0.04	+0.01
	60 mg/m^2/day	0.00	+0.06	+0.02	+0.01
Sediment Source Rate for Phosphorus	120 mg/m^2/day	0.00	0.00	0.00	+0.05
	60 mg/m^2/day	0.00	0.00	0.00	+0.04
Headwater DO	-20%	0.00	0.00	-0.01	0.00
	+20%	0.00	0.00	0.00	0.00
Headwater Faster Term BOD	1 mg/l	+0.01	0.00	-0.02	0.00
	3 mg/l	+0.02	+0.03	-0.12	-0.01
	5 mg/l	+0.03	+0.04	-0.14	-0.01
	8 mg/l	+0.05	+0.05	-0.15	-0.01

Table H-3 (continued)
Sensitivity Analysis Results - Nutrients and Algae

Change in Predicted Values at River Mile 242.6 (mg/l)

Parameter Altered	Change in Parameter	BOD5	Ammonia	Nitrate	Algae (ug/l)
Base Run	Actual Prediction	1.17	0.24	0.24	2.57
Headwater Slow Term BOD	1 mg/l	+0.11	0.00	0.00	0.00
	3 mg/l	+0.71	+0.01	-0.03	0.00
	5 mg/l	+1.31	+0.03	-0.10	0.00
Headwater Algae	-20%	0.00	0.00	+0.01	-0.44
	+20%	0.00	0.00	-0.01	+0.43
Headwater Ammonia	-20%	0.00	-0.01	0.00	0.00
	+20%	0.00	0.00	0.00	+0.01
Headwater Nitrate	-20%	0.00	0.00	-0.02	0.00
	+20%	0.00	0.00	+0.02	0.00
Headewater Organic Nitrogen	-20%	0.00	-0.02	-0.01	0.00
	+20%	0.00	+0.02	+0.01	0.00
Headwater Phosphorus	-20%	0.00	0.00	0.00	0.00
	+20%	0.00	0.00	0.00	+0.01
Solar Radiation	-20%	0.00	+0.01	+0.01	-0.25
	+20%	0.00	-0.01	-0.01	+0.23
Algae Settling Rate	-20%	0.00	0.00	0.00	+0.03
	+20%	0.00	0.00	0.00	-0.03
Temperature	62.1°F	+0.05	0.00	0.00	-0.04
	64.9°F	-0.05	-0.01	0.00	+0.04
Wausau Papers Phosphorus	-20%	0.00	0.00	0.00	0.00
	+20%	0.00	0.00	0.00	0.00
Wausau Papers Organic Nitrogen	-20%	0.00	0.00	0.00	0.00
	+20%	0.00	0.00	0.00	0.00
Wausau Papers Nitrate	-20%	0.00	0.00	0.00	0.00
	+20%	0.00	0.00	0.00	0.00
Wausau Papers Ammonia	-20%	0.00	-0.02	-0.01	0.00
	+20%	0.00	+0.02	+0.01	0.00

Table H-3 (continued)
Sensitivity Analysis Results - Nutrients and Algae

Change in Predicted Values at River Mile 242.6 (mg/l)

Parameter Altered	Change in Parameter	BOD5	Ammonia	Nitrate	Algae (ug/l)
Base Run	Actual Prediction	1.17	0.24	0.24	2.57
Wausau Papers	-20%	-0.01	0.00	0.00	0.00
BOD	+20%	+0.01	0.00	0.00	0.00
American Can	-20%	-0.01	0.00	0.00	0.00
BOD	+20%	0.00	0.00	0.00	0.00
Amer. Can & Wey.	-20%	0.00	0.00	0.00	0.00
Phosphorus	+20%	0.00	0.00	0.00	0.00
Amer. Can & Wey.	-20%	0.00	0.00	0.00	0.00
Organic Nitrogen	+20%	0.00	0.00	0.00	0.00
Amer. Can & Wey.	-20%	0.00	0.00	0.00	0.00
Nitrate	+20%	0.00	0.00	0.00	0.00
Amer. Can & Wey.	-20%	0.00	0.00	0.00	0.00
Ammonia	+20%	0.00	0.00	0.00	0.00
Weyerhaeuser Co.	-20%	-0.14	0.00	0.00	0.00
BOD	+20%	+0.14	0.00	0.00	0.00
Mosinee Paper	-20%	0.00	0.00	0.00	0.00
Phosphorus	+20%	0.00	0.00	0.00	0.00
Mosinee Paper	-20%	0.00	0.00	0.00	0.00
Organic Nitrogen	+20%	0.00	0.00	0.00	0.00
Mosinee Paper	-20%	0.00	0.00	0.00	0.00
Nitrate	+20%	0.00	0.00	0.00	0.00
Mosinee Paper	-20%	0.00	0.00	0.00	0.00
Ammonia	+20%	0.00	0.00	0.00	0.00
Mosinee Paper	-20%	-0.02	0.00	0.00	0.00
BOD	+20%	+0.02	0.00	0.00	0.00

Table H-3 (continued)
Sensitivity Analysis Results - Nutrients and Algae

Change in Predicted Values at River Mile 242.6 (mg/l)

Parameter Altered	Change in Parameter	BOD5	Ammonia	Nitrate	Algae (ug/l)
Base Run	Actual Prediction	1.17	0.24	0.24	2.57
Reaeration Equation	Churchill	0.00	0.00	-0.01	0.00
	O'Connor-Dobbins	0.00	0.00	0.00	0.00
	Owens-Gibbs	0.00	0.00	-0.01	0.00
	Thacksten-Krenkel	0.00	0.00	-0.01	0.00
	Langbien-Durum	0.00	0.00	-0.01	0.00
	Wind Driven	0.00	0.00	-0.01	0.00

Appendix I

This appendix contains the flow-temperature matrices (Tables I-2 through I-5) 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 the Rothschild Dam at Rothschild. The years of data are 1958-1978. The data was supplied by the Wisconsin Valley Improvement Company. The entries in each matrix are the percentage of time that particular range of flow and temperature conditions occurred during the indicated month(s). The total number of observations are listed in Table I-1.

Table I-1

Total Observations by Month for 1958-1978

Month	Number
May-June	1281
July-August	1302
September	630
October	651

Table I-2
Segment BC Flow-Temperature
Percentage of Time Occurring at Rothschild Dam
May-June 1958-1978

Flow Range	0-980	981-1220	1221-1470	1471-1730	1731-1990	1991-2160	2161-2540	2541-2830	2831-3130	3131-3430	3431-3780	3781-4230	4231-4730	4731-5250	5251-5780	5781-6340	6341-6910	6911-More
Temp. Range																		
82.0-89.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
78.0-81.9	.0	.0	.0	.1	.1	.2	.0	.2	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0
74.0-77.9	.1	.0	.6	.7	.5	.9	1.0	.5	.4	.4	.2	.2	.1	.2	.0	.0	.1	.1
70.0-73.9	.1	.2	.9	1.9	1.7	2.3	3.1	1.6	.9	.9	.4	.5	.5	.2	.1	.2	.0	.4
66.0-69.9	.2	.3	1.6	1.7	2.0	2.2	2.4	2.4	1.7	1.5	.8	.6	1.1	1.0	.5	.5	.5	2.0
62.0-65.9	.0	.2	.3	1.5	.8	1.4	1.6	1.4	1.6	1.2	1.1	.9	.7	.2	.9	.8	.5	4.1
58.0-61.9	.0	.0	.2	.5	.3	.9	.5	1.5	1.3	1.1	1.0	.6	1.2	.6	.6	.5	.5	2.7
54.0-57.9	.0	.0	.0	.0	.4	1.0	1.2	.9	.5	.9	.5	.5	.5	.4	.7	.2	.3	2.7
50.0-53.9	.0	.0	.0	.0	.0	.0	.0	.2	.9	.8	.8	.7	.5	.3	.2	.2	.2	2.8
40.0-49.9	.0	.0	.0	.0	.0	.0	.1	.2	.1	.1	.2	.3	.3	.4	.1	.1	.1	1.2
30.0-39.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

Table I-3
Segment BC Flow-Temperature
Percentage of Time Occurring at Rothschild Dam
July-August 1958-1978

Flow Range	0-980	981-1220	1221-1470	1471-1730	1731-1990	1991-2160	2161-2540	2541-2830	2831-3130	3131-3430	3431-3780	3781-4230	4231-4730	4731-5250	5251-5780	5781-6340	6341-6910	6911-More
82.0-89.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
78.0-81.9	.2	.5	1.1	.8	.8	1.0	1.5	.2	.2	.2	.0	.0	.0	.0	.0	.0	.0	.0
74.0-77.9	.7	2.1	4.5	4.5	5.7	6.5	4.8	2.6	1.6	.8	.5	.1	.1	.3	.2	.3	.3	1.3
70.0-73.9	.1	1.8	3.3	4.3	4.6	7.1	6.8	3.5	2.5	1.1	1.1	.5	.8	.5	.4	.6	.3	1.1
66.0-69.9	.2	1.4	1.5	1.5	1.5	2.2	1.6	1.0	.5	.5	.0	.3	.1	.0	.1	.2	.2	1.4
62.0-65.9	.1	.1	.2	.3	.2	.2	.2	.0	.1	.0	.0	.2	.1	.1	.0	.1	.0	.2
58.0-61.9	.0	.0	.0	.0	.0	.0	.0	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0
54.0-57.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
50.0-53.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
40.0-49.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
30.0-39.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

Table I-4
Segment BC Flow-Temperature
Percentage of Time Occurring at Rothschild Dam
September 1958-1978

Flow Range	0- 980	981 1220	1221 1470	1471 1730	1731 1990	1991 2160	2161 2540	2541 2830	2831 3130	3131 3430	3431 3780	3781 4230	4231 4730	4731 5250	5251 5780	5781 6340	6341 6910	6911 More
Temp. Range																		
82.0-89.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
78.0-81.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
74.0-77.9	.0	.0	.0	.0	.5	.3	.2	1.3	.3	.3	.5	.3	.5	.2	.2	.0	.0	.0
70.0-73.9	.0	.2	.3	.2	1.7	.6	1.7	.5	.2	.0	.3	.5	.6	.8	.3	.0	.0	.0
66.0-69.9	.5	1.1	2.4	2.2	3.8	3.8	2.7	3.0	2.5	1.0	.3	.6	.6	.0	.3	.2	.0	.2
62.0-65.9	.0	.6	2.4	3.3	2.5	4.1	2.9	1.9	1.6	.8	.5	.8	1.3	1.3	.5	1.1	.8	1.1
58.0-61.9	.0	.5	1.6	1.4	1.9	2.1	2.5	1.6	1.6	1.9	.8	1.4	1.1	.5	.5	.8	.3	2.4
54.0-57.9	.2	.8	.0	.2	1.0	1.6	2.1	1.9	.2	.5	.0	.2	.2	.2	.2	.2	.0	.6
50.0-53.9	.0	.0	.0	.0	.0	.2	.3	.0	.3	.0	.5	.0	.0	.2	.2	.0	.0	.5
40.0-49.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.2
30-0-39.9	.0	.0	.0	.0	.0	.0	.0	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

Table I-5
Segment BC Flow-Temperature
Percentage of Time Occurring at Rothschild Dam
October 1958-1978

Flow Range	0- 980	981 1220	1221 1470	1471 1730	1731 1990	1991 2160	2161 2540	2541 2830	2831 3130	3131 3430	3431 3780	3781 4230	4231 4730	4731 5250	5251 5780	5781 6340	6341 6910	6911 More
Temp. Range																		
82.0-89.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
78.0-81.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
74.0-77.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
70.0-73.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
66.0-69.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
62.0-65.9	.0	.2	.0	.0	.0	.0	.0	.3	.3	.0	.0	.2	.0	.0	.0	.2	.0	.5
58.0-61.9	.9	1.5	1.7	.6	.3	.9	.9	1.7	.9	.3	.2	.2	.3	.3	.2	.0	.0	.0
54.0-57.9	.9	.0	.5	3.4	2.2	2.9	3.2	2.5	2.5	1.2	1.1	.9	.3	.2	.2	.3	.0	2.0
50.0-53.9	.6	.0	.8	1.7	3.7	2.9	3.4	3.4	1.7	1.4	1.2	1.1	.9	.5	.6	.2	.3	.9
40.0-49.9	2.6	.5	.0	2.2	2.5	5.4	7.1	4.3	2.5	1.7	2.3	.9	1.2	.8	1.1	.9	.3	2.2
30.0-39.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0