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Water Constraints in Power-Plant Siting and Operation

Wisconsin Power Plant Impact Study

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WATER CONSTRAINTS IN POWER-PLANT SITING AND OPERATION

Wisconsin Power Plant Impact Study

by

Nathaniel Tetrick
Erhard Joeres
Institute for Environmental Studies
University of Wisconsin-Madison
Madison, Wisconsin 53706

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Project Officer
Gary E. Glass
Environmental Research Laboratory-Duluth
Duluth, Minnesota 55804

This study was conducted in cooperation with

Wisconsin Power and Light Company,
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Wisconsin Public Service Commission
and Wisconsin Department of Natural Resources

ENVIRONMENTAL RESEARCH LABORATORY-DULUTH
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U.S. ENVIRONMENTAL PROTECTION AGENCY
DULUTH, MINNESOTA 55804

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FOREWORD

The U. S. Environmental Protection Agency (EPA) was designed to coordinate our country's efforts toward protecting and improving the environment. This extremely complex task requires continuous research in a multitude of scientific and technical areas. Such research is necessary to monitor changes in the environment, to discover relationships within that environment, to determine health standards, and to eliminate potentially hazardous effects.

One project, which the EPA is supporting through its Environmental Research Laboratory in Duluth, Minnesota, is the study "The Impacts of Coal-Fired Power Plants on the Environment." This interdisciplinary study, centered mainly around the Columbia Generating Station near Portage, Wis., involves investigators and experiments from many academic departments at the University of Wisconsin and is being carried out by the Environmental Monitoring and Data Acquisition Group of the Institute for Environmental Studies at the University of Wisconsin-Madison. Several utilities and State agencies are cooperating in this study: Wisconsin Power and Light Company, Madison Gas and Electric Company, Wisconsin Public Service Corporation, Wisconsin Public Service Commission, and Wisconsin Department of Natural Resources.

Reports from this study will appear as a series within the EPA Ecological Research Series. These reports will include topics related to chemical constituents, chemical transport mechanisms, biological effects, social and economic effects, and integration and systhesis.

Elevated nutrient levels in the Wisconsin River, resulting from heat discharges into the river, could decrease the dissolved oxygen levels in Lake Wisconsin. This report assesses the water quality in the Wisconsin River between Wisconsin Dells and Lake Wisconsin. A conceptual study was performed to determine the range of choice that will be available for determining the trade-off between organic waste discharges and heat assimilation from possible power plant sites.

Norbert A. Jaworski
Director
Environmental Research Laboratory
Duluth, Minnesota

ABSTRACT

A conceptual study of water quality in the Wisconsin River between Wisconsin Dells and Lake Wisconsin was performed to determine the range of choices that might be available for determining the trade-off between organic waste discharges and heat assimilation from possible power plant sites. The QUAL-3 river quality model, as modified by the Wisconsin Department of Natural Resources for use on the upper Wisconsin and lower Fox Rivers, was used for preliminary simulations of the effect of potential heat discharges from three possible power plant sites on the levels of dissolved oxygen, biochemical oxygen demand, and algae growth during times of extremely low flow. Hydraulic parameters for the QUAL-3 model were estimated from simulations employing the Army Corps' HEC-2 water surface profile model. Estimates of river temperature downstream of heat discharges were obtained using a simple one-dimensional river temperature model developed by Paily and Macagno (1976). Results of simulations at various levels and locations of heat discharges are presented in the presence and absence of discharge at the Portage Wastewater Treatment plant effluent into the Wisconsin River, and of concerted control of point and non-point sources of nutrients in and upstream of the regional study. These simulations indicate that heat discharges would affect levels of dissolved oxygen most critically in Lake Wisconsin, although reduced levels of nutrients entering the river might noticeably improve dissolved oxygen levels in the lake. Biochemical oxygen demand levels were found not to be constraining with regard to heat or nutrient discharges. Simulations of heat discharges from the Columbia Generating Station and from a site 18.4 km (11.5) miles upstream of the Columbia Generating Station indicated no significant differences in the lake levels of dissolved oxygen. The results suggest that the levels of dissolved oxygen in Lake Wisconsin would be most sensitive to the nutrient levels in the Wisconsin River and that elevated nutrient levels resulting from heat discharges could cause greater drops in the dissolved oxygen levels in the lake. However, deterministic predictions of these effects will require a comprehensive program to gather the physical and chemical data necessary for calibrating the QUAL-3 model.

This report was prepared with the cooperation of faculty and graduate students in the Department of Civil and Environmental Engineering at the University of Wisconsin-Madison.

Most of the funding for the research reported here was provided by the U.S. Environmental Protection Agency, but funds were also granted by the University of Wisconsin-Madison, Wisconsin Power and Light Company, Madison Gas and Electric Comparny, Wisconsin Public Service Corporation, and Wisconsin Public Service Commission. This report was submitted in fulfillment of Grant No. R803971 by the Environmental Monitoring and Data Acquisition Group, Institute for Environmental Studies, University of

Wisconsin-Madison, under the partial sponsorship of the U.S. Environmental Protection Agency. The report covers the period of August 1977 to August 1978 and work was completed as of December 1978.

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SECTION 1

INTRODUCTION

The location, design, and capacity of any power generating sation depend upon the accurate assessment of all interactions between the facility and the environment. The availability of natural resources must be considered a constraint in the determination of plant location and capacity. The required natural resources include fuel to generate power, land corridors to transmit the power, and water to cool the system. Problems arise in siting when competing uses exist for these resources. The demand for cooling water, always an important constraint in power plant siting, may become the limiting factor if the deterioration in the quality of the available water resource caused by the increase in ambient water temperature reduces the oportunity for beneficial use of the water by others. The use of a water resource by a generating station must, therefore, be allocated fairly and efficiently among users.

This research is intended as a preliminary survey of the possible trade-offs between the discharge of waste heat from power plant sites, and competing wastewater discharges utilizing the assimilative capacity of the Wisconsin River near Portage, Wis. These trade-offs can be identified by mathematical model simulations of dissolved oxygen levels, biochemical oxygen demand (BOD), temperature, nitrates, nitrites, ammonia, organic nitrogen, sediment oxygen demand, and chlorophyll-a along the river from the Wisconsin Dells to Lake Wisconsin. By evaluating the effects of changes in these constituents on dissolved oxygen, the study demonstrates a method by which competing uses of a water resource can be compared and which can provide information that affects the design, capacity, siting, and operation of power stations.

In addition to possible heat discharges from the Columbia Generating Station or from future power plants, competing uses of the Wisconsin River near Portage iclude disposal of municipal wastewaters, run-off from agricultural lands, and fishing and boating. In order to determine the best combination of uses for the water resource, the effect of each particular use upon water quality must be evaluated.

For this study the level of dissolved oxygen has been used as the tool in evaluating the effect of the competing water use on the water quality in the Wisconsin River, since increasing levels of each competing use will decrease dissolved oxygen levels. The effect of additional heat to the water is direct: in warmer water, oxygen is less soluble and algal growth is greater; levels of dissolved oxygen will fall. The effect of the addition of organic materials present in wastewaters to the river also lowers the levels of dissolved oxygen. As the organic materials decompose they use up the available dissolved oxygen faster than new oxygen can enter the river from the air by reaeration. In addition, as the organic materials decompose, nutrients are released into the water. These nutrients foster the growth of algae, which, as they grow, and subsequently die and decay, impose further demands on the level of dissolved oxygen. Since socially responsible use of the Wisconsin River dictates the maintenance of a certain minimum level of dissolved oxygen at each point along its length, there is a constraint on the competitive uses of the Wisconsin River for the discharge of heat and wastewaters.

The region of interest for this study extends from the Kilbourn Dam at Wisconsin Dells to the upper part of Lake Wisconsin. The primary area of interest is from Portage to Lake Wisconsin (Figure 1). Chief wastewater discharges into the Wisconsin River in this region come from tributary streams, from the Wisconsin Dells Sewage Treatment Plant, from the Lake Delton Sewage Treatment Plant, and from the Columbia Generating Station. In addition, the city of Portage is considering changing the outfall of its wastewater treatment plant from the Fox River to the Wisconsin River.

The primary analysis tool used in this study is the QUAL-3 water quality model, developed by the Wisconsin Department of Natural Resources and based upon the well-known QUAL-2 model of the U.S. Environmental Protection Agency (EPA). The model is used to simulate the quality of river water in successive hydrologically uniform reaches. The QUAL-3 simulations of various water quality scenarios provide a framework through which trade-offs between future uses of the river, including power plant operation, are evaluated.

Present-day water quality conditions based on current waste and heat discharges are compared with numerous combinations of possible future conditions: operation of a new joint Lake Delton-Wisconsin Dells wastewater treatment plant; diversion of the effluent of the Portage Wastewater Treatment Plant from the Fox River to the Wisconsin River; reduction of nutrient loadings into the Wisconsin River from point and non-point sources; and discharge of heated water from the Columbia Generating Station (presently prohibited) and from two possible locations of additional generating stations. The most constraining warm-season environmental conditions of low flow and high river water temperatures are used to highlight the trade-offs between competing wastewater dischargers, in this study even though comprehensive data collection studies may show that actual environmental constraints are less severe.

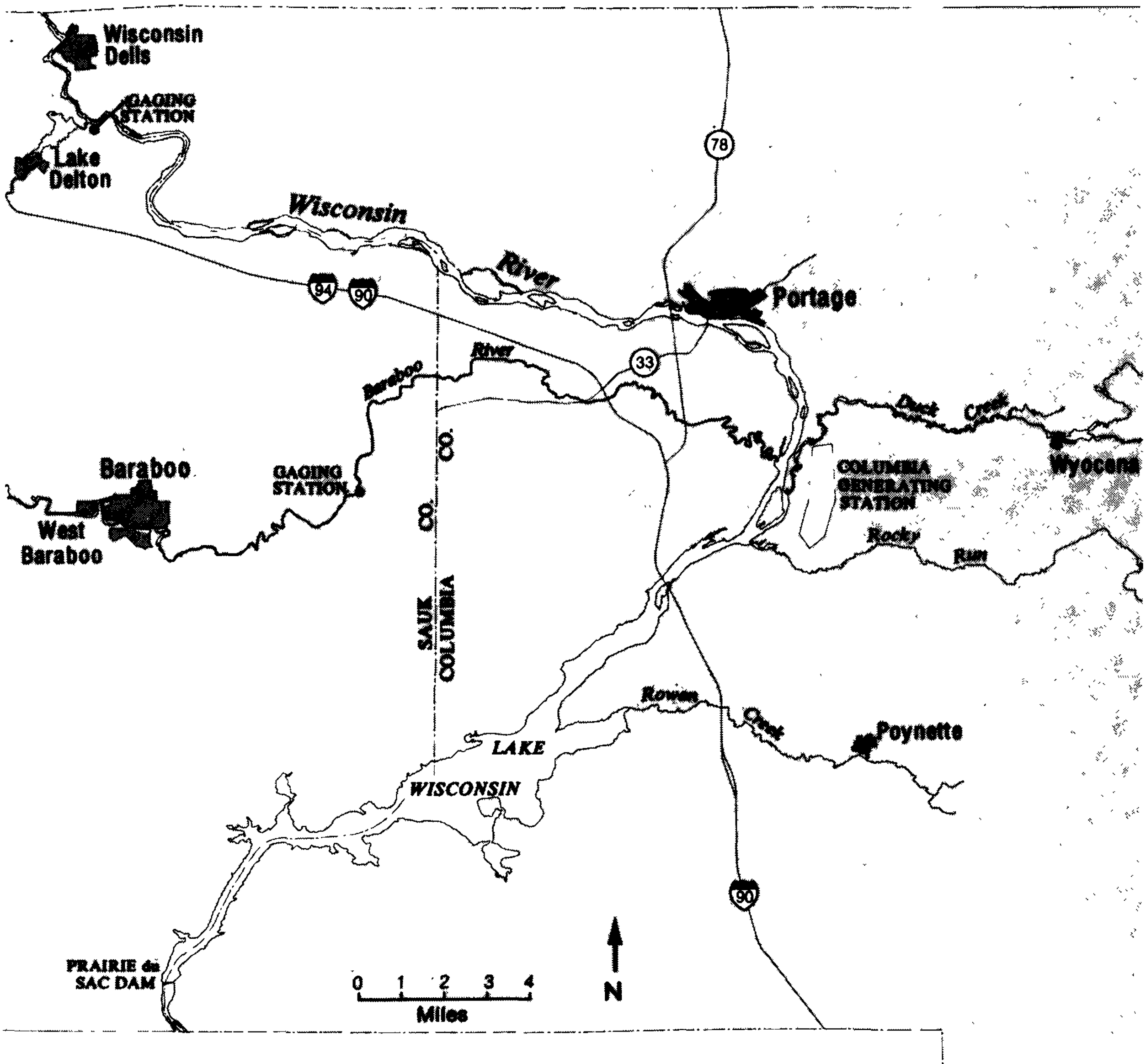

Figure 1. The Wisconsin River from Wisconsin Dells to the Prairie du Sac dam.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

The results of simulations of various scenarios of wastewater and heat discharges into the Wisconsin River near the Columbia Generating Station indicate that the minimum flow rate in the river during hot, dry periods and the discharge of nutrients into the river seriously constrain future discharges of heat. The simulations demonstrate that dissolved oxygen levels in the river, and most critically in the Lake Wisconsin portion of the river, are the constraining factor. Conversely, levels of biochemical oxygen demand (BOD) are not critical.

Although model results and field surveys indicate that current levels of dissolved oxygen are adequate, these levels were the most sensitive to increased levels of nutrients. Simulated discharge of untreated nutrients from the Portage Wastewater Treatment Plant caused the dissolved oxygen values in Lake Wisconsin to drop from 4.2 to 3.7 mg/liter. However, halving the levels of nutrients in the river system (including those from Portage) increased the level of dissolved oxygen 0.3 mg/liter above simulated levels of present conditons and nitrogen-limited scenarios (runs 17 and 18) indicated even higher levels of dissolved oxygen in Lake Wisconsin (4.7 to 5.9 mg/liter).

In all simulations the reaches most sensitive to nutrient discharges were in Lake Wisconsin. As a result, water quality and ecological factors for Lake Wisconsin would restrict any consumptive use of the Wisconsin River in the region of this study the most. Since the QUAL-3 model is a river model, a lake model should be used to examine more closely the effects on the ecology of Lake Wisconsin.

In contrast to the sensitivity of dissolved oxygen levels, in no case was the BOD level found to be a constraining condition for any future use of the river. Existing levels of BOD ranged from 4.0 to 1.3 mg/liter, much of which was degrading very slowly and which therefore may be caused by industrial discharges into the Wisconsin River upstream of the study region. Model simulations indicated that upgrading the Wisconsin Dells Sewage Treatment Plant or closing the Lake Delton Sewage Treatment Plant would have only small effects on the levels of BOD and dissolved oxygen in the Portage vicinity. Discharge from the Portage Wastewater Treatment Plant would also have little effect on the BOD level in the river.

Discharges of heated water into the river are potentially constraining, both directly and indirectly, through their effects on levels of dissolved oxygen. If a 5°F increase in river temperature is allowed, then a power station utilizing river water for condenser cooling is limited to a waste heat discharge equvalent to 550 MW of generating capacity; if a 10°F increase could be tolerated, heat equivalent to 1,086 MW of generated power can be discharged. In general, higher river temperatures harm fish and wildlife before serious chemical imbalances occur.

Some trade-offs are evident between heat discharge levels and influx of nutrient levels into the river, either through the sewage treatment plants or through non-point agricultural run-off. For example, the heat discharge from a potential 550-MW power plant at river mile 108.5 might cause a 0.5-mg/liter drop in the dissolved oxygen in Lake Wisconsin. In contrast, if all nutrient inflows were reduced by half, approximately the present levels of dissolved oxygen could be maintained in Lake Wisconsin with such a heat discharge anywhere in the study region. Because of uncertainties in hydraulic tuning of the QUAL-3 model and in the nutrient levels entering the river, algal blooms in Lake Wisconsin could considerably lower levels of dissolved oxygen in all these scenarios.

Given the inaccuracy of some of the flow data, as well as incomplete definition of the nutrient, BOD, and dissolved oxygen data, extreme flow and temperature conditions were used to determine the utility of examining the trade-offs between heat discharges and BOD and nutrient discharges from other sources further. For this study the HEC-2 model was used as a surrogate for unavailable hydraulic data. Any serious consideration of river discharge to absorb cooling tower water will require an extensive improvement in the hydraulic data base. A comprehensive physical and chemical data collection program would also be needed to fully examine remaining questions about wintertime conditions when there is an ice cover, long-term versus short-term BOD decay conditions, and resolution of the relation between high water temperatures and low flow conditions.

SECTION 3

THE QUAL-3 MODEL

The QUAL-3 model used in this study was developed by Patterson and Rogers (1978) as an improved version of QUAL-2 and QUAL-1, which were originally developed by Norton et al. (1974) and by the Texas Water Development Board (1971, 1976). This model was chosen because of its extensive use in water quality monitoring and modeling of rivers in Wisconsin, including much of the upper half of the Wisconsin River above Wisconsin Dells. These previous experiences seemed crucial in attempting preliminary calibration and simulations on the Wisconsin River near Portage. This model was used to simulate, or route, levels or chlorophyll-a, nitrates, nitrites, ammonia, organic nitrogen, sediment oxygen demand, dissolved oxygen, and (BOD).

The model is based on the assumption that concentrations of these constituents in a river can be expressed by a mathematical relationship. This equation, called the convective-dispersive transport relation is:

$$A \frac{\partial C}{\partial t} = \frac{\partial}{\partial x} \quad AE\frac{\partial C}{\partial Ex} - \frac{\partial}{\partial x} (A\bar{U}C) + AR_s \qquad (1)$$

where

- A = cross-sectional area of flow in the river
- C = concentration of the constituent being routed
- E = longitudinal dispersion coefficient
- t = time
- x = distance along the longitudinal direction
- U = mean velocity in stream (with respect to cross section)
- R_s = sources and sinks of the constituent being routed.

Application of the convective-dispersion transport relation to the QUAL-3 model for simulations of river conditions requires that Eq. (1) be modified. To do so, the portion of the Wisconsin River under study was divided into 370 elements each 0.1 mile (160.93 m) long. These elements are control volumes whose conditions can be simulated by the model. For any such element, the ith element, the convective-dispersion relation becomes:

$$\frac{\partial C_i}{\partial t} = \frac{\left[AE \frac{\partial C}{\partial x}\right]_{i+1/2} - \left[AE \frac{\partial C}{\partial x}\right]_{i-1/2}}{V_i} + \frac{Q_{-1/2}\ _{i-1} - Q_{i+1/2}C_i \pm Q_{xi}\ C_{xi}}{V_i} + S \qquad (2)$$

where

$V_i = A_i \Delta x$ = volume of ith control elements

$A_i = 1/2 (A_{i+1/2} + A_{i-1/2})$ = mean cross-sectional of the elements

Δx = length of the element (0.1 mile)

$[AE \frac{\partial C}{\partial x}]_{i-1/2}$ = total longitudinal dispersion of constituent into inflow end of element

$[AE \frac{\partial C}{\partial x}]_{i+1/2}$ = total longitudinal dispersion of constituent out of outflow end of element

$Q_{i-1/2}$ = rate of flow into the computational element

C_{i-1} = concentrtion of constituent in inflowing water into element (= concentration inside upstream element)

$Q_{i+1/2}$ = rate of flow out of computational element

C_i = concentration of constituent inside computational element

Q_{xi} = local inflows or withdrawal rates

C_{xi} = concentration of constituents in local inflows or outflows

S_i = sources or sinks of a nonconservative constituent inside computational element.

The most significant differences in the QUAL-3 model compared to the earlier versions are Patterson and Roger's (1978) development of equations governing the S term of Eq. (2). Development of these equations and other relations describing the local changes in concentrations of the various constituents are included in Appendix B.

Values of reaction coefficients used in this study, summarized in Table 1, are based on values used by the Wisconsin Department of Natural Resources (1976) in simulations of a portion of the upper Wisconsin River (river miles 210 to 235, miles are numbered from the confluence of the Wisconsin and Mississippi Rivers). Although the model includes provisions for many of these values to vary, they were not changed for the entire length of the Wisconsin River modeled in this study.

Two methods of computing the reaeration coefficient, K_2, were employed. Where the river was wide enough for the wind to be a factor (reaches 8 through 11, 9 through 21, and 23 through 25), K_2 was computed as a function of the wind speed (Wisconsin Department of Natural Resources: Source listing on the QUAL-3 water quality model). This relation is expressed as:

TABLE 1. REACTION COEFFICIENTS USED IN QUAL-3 SIMULATIONS OF WATER QUALITY OF WISCONSIN RIVER IN VICINITY OF PORTAGE.

Reaction coefficients: Name in Appendix B	Reaction coefficients: Name in QUAL-3 model	Description	Units	Suggested range of values	Reliability of suggested values (Patterson and Rogers 1978)	Temperature dependent	Values used in this study
α_0	ALPLAϕ	Ratio of chlorophyll-a to algae biomass	$\frac{\mu g\ Chl\text{-}a}{mg\ A}$	50-100 (2-50)	Fair	No	5
α_{11}	CKORGN	Rate of hydrolysis of organic N per unit of algae	$\frac{Day^{-1}}{mg\ A}$	0.0005-0.005	Fair	Yes	0.000
α_{12}	ALPHA1	Fraction of algae biomass which is N	$\frac{mg\ N}{mg\ A}$	0.04-0.10	Good	No	0.06
α_2	ALPHA2	Fraction of algae	$\frac{mg\ P}{mg\ A}$	0.01-0.015	Good	No	0.01
α_3	ALPHA3	O_2 production per unit of algae respired	$\frac{mg\ O}{mg\ A}$	1.4-2.5	Fair	No	2.00
α_4	ALPHA4	O_2 uptake per unit of algae respired	$\frac{mg\ O}{mg\ N}$	1.5-2.3	Fair	No	1.50
α_5	ALPHA5	O_2 uptake per unit of NH_3 oxidation	$\frac{mg\ O}{mg\ N}$	3.23-3.43	Excellent	No	3.4
α_6	ALPHA6	O_2 uptake per unit of NO_2 oxidation	$\frac{mg\ O}{mg\ N}$	1.11-1.14	Excellent	No	1.4
μ_{max}	GROMXX	Maximum specific growth rate of algae	$\frac{1}{day}$	1.0-3.0	Good	Yes	1.60
ρ	RESPTT	Algae respiration rate	$\frac{1}{day}$	0.05-0.5	Fair	Yes	0.15
β_1	CKNH3	Rate constant for biological oxidation of NH_3-NO_2	$\frac{1}{day}$	0.05-1.5	Good	Yes	0.80
k_E	EXCOEF	Light extinction coefficient	$\frac{1}{ft}$	0-20	Fair	No	0.38
β_2	CKNϕ2	Rate constant for biological oxidation of NO_2-NO_3	$\frac{1}{day}$	0.5-2.5	Good	Yes	2.50
β_4	DNKK	Denitrification rate	$\frac{1}{day}$	0.1-0.8	Fair	No	0.4
σ_1	ALGSET	Local settling rate for algae	$\frac{ft}{day}$	0.0-6.0	Fair	No	0.4
σ_2	SNH3	Benthos source rate for NH_3	$\frac{mg\ N}{day\text{-}ft^2}$	*	Poor	No	0
σ_3	SPHϕS	Benthos source rate for phosphorous	$\frac{mg\ P}{day\text{-}ft^2}$	*	Poor	No	0
σ_4	CK4	Organic N settling rate	$\frac{ft}{day}$	*	Poor	No	0.05
K_{11}, K_{12}	CK1	Carbonaceous BOD decay rate	$\frac{1}{day}$	0.01-2.0	Good	Yes	0.30
K_2	CK2	Reaeration rate	$\frac{1}{day}$	0.0-100	Good	Yes	†
K_3	CK3	Term 2 carbonaceous BOD decay rate	$\frac{1}{day}$	0.01-2.0	Fair	No	0.08
K_5	CK5	Particulate BOD sink rate	$\frac{ft}{day}$	0-100	Fair	No	2.0
K_N	CKN	Nitrogen half-saturation constant for algae growth	$\frac{mg}{liter}$	0.015-0.2	Fair	No	0.02
K_P	CKP	Phosphorus half-saturation constant for algae growth	$\frac{mg}{liter}$	0.001-0.5	Fair	No	0.01
K_L	CKL	Light saturation constant for algae growth	$\frac{langleys}{min}$	0.21	Good	No	0.21
*	EXPOQV	Velocity correction factor		1.00-1.2	Fair	No	1.11
	SONET	Daily solar radiation	langleys	--	Good	No	530

* Determined during model calibration.
See text for computational procedure.

$$K_2 = \frac{1 + 86,400.(\cosh(B))}{2\ D\ \mathrm{Sinh}\ (B)} \quad (1.806 \times 10^{-9}\ S)^{0.5} \tag{3}$$

where

$$D = 0.3048\ (\mathrm{DEPTH})$$

$$S = 0.04\ W/D$$

$$B = \frac{10^{-6}(-0.57835501W + 15.7735859)^2\ S^{1/2}}{4.24971 \times 10^{-5}}$$

DEPTH = depth of the river in feet

W = wind velocity in m/sec

In the remaining narrower reaches the formula proposed by O'Connor and Dobbins (1958) was utilized:

$$K_2 = \frac{2.25 \times 10^{-8}\ U}{(\mathrm{DEPTH})^{129,600}} \tag{4}$$

SCHEMATIZATION OF THE MODEL

A diagram of a typical computational element is shown in Figure 2. Since QUAL-3 is a one-dimensional routing model, the cross-sectional areas of all the elements are idealized rectangles rather than the more realistic channel shapes depicted. Complete mixing of each constituent within a computational element is assumed.

Reaches are constructed from groups of two to 20 computational elements. Within each reach all elements have the same depth and cross-sectional area of flow, dispersion characteristics, and reaction coefficient affecting the growth or decay of constituents being routed in the model. In this study the 370 computational elements were grouped into 25 reaches, which are depicted for the part of the river below mile 122.0 in Figure 3. Figure 4 is a schematic drawing showing the particular computational elements and their relation to tributaries, wastewater discharges, and potential power station sites. Above river mile 122.0 (not shown in the figures), nine reaches cover the distance to just below Kilbourn Dam. Hulbert Creek, the Wisconsin Dells Sewage Treatment Plant, the new Wisconsin Dells Wastewater Treatment Plant, the Lake Delton Sewage Treatment Plant, and Dell Creek discharge into the Wisconsin River at river miles 136.9, 136.7, 135.7, 135.6, and 134.9. Input data including control cards defining the QUAL-3 reaches, computational elements, and locations of discharges appear in Appendix A under Data Types 2,4,5, and 11.

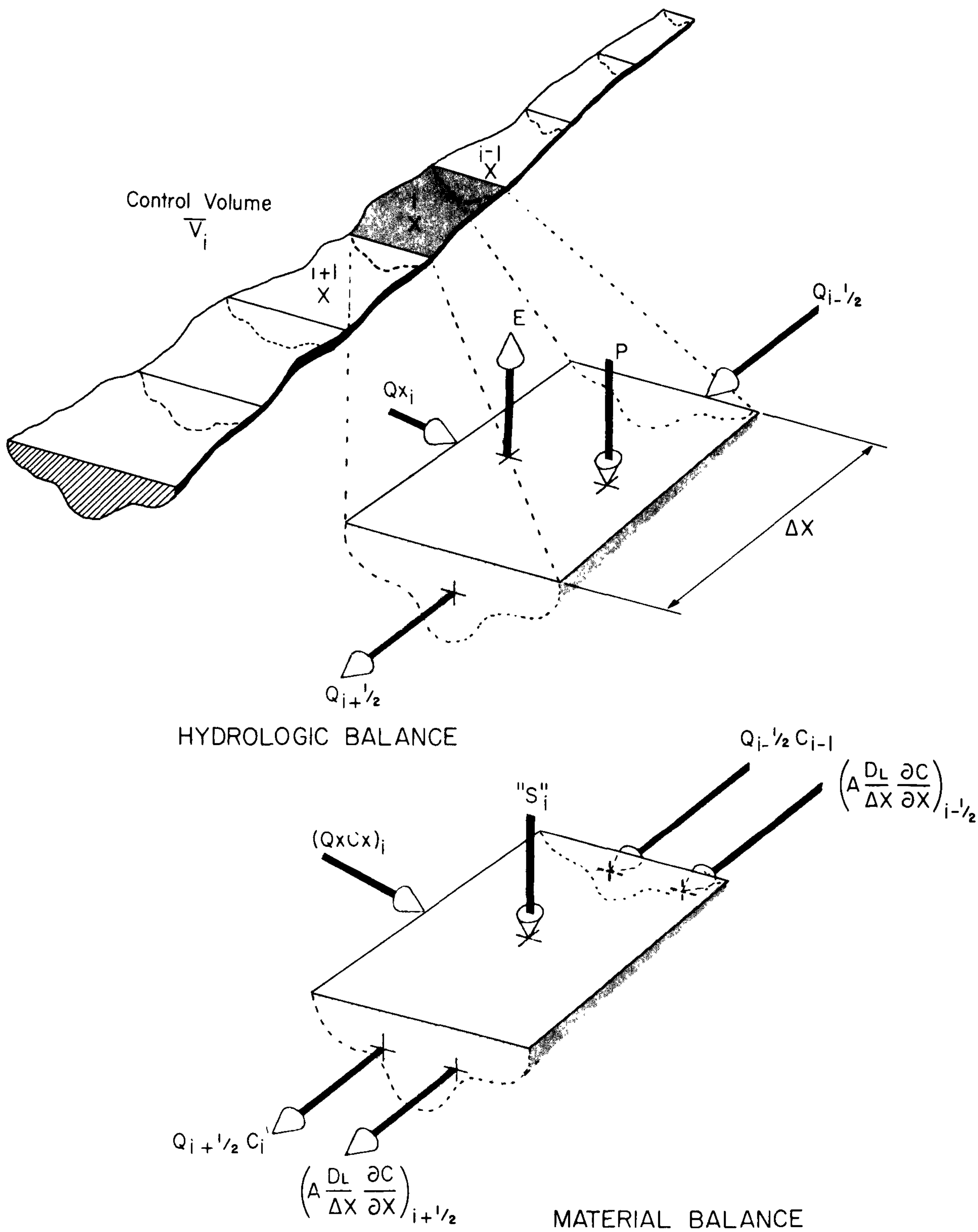

Figure 2. Discretized stream system showing computational elements with transport relations. Source: Texas Water Development Board (1971).

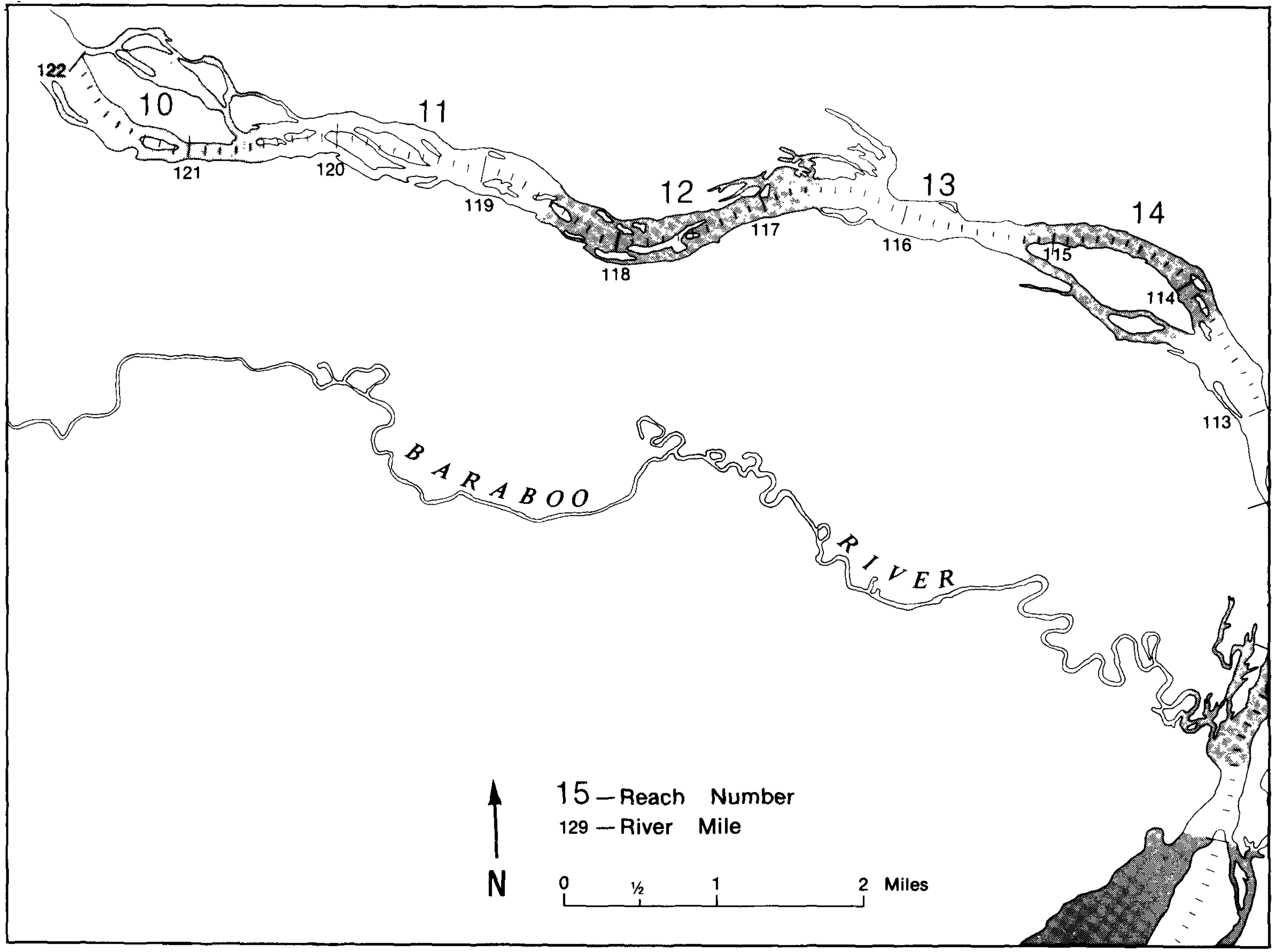

Figure 3a. Upper part of study area on Wisconsin River, showing river miles, tenths of miles, QUAL-3 reaches 10 through 14 (alternate reaches are shaded), and reach numbers.

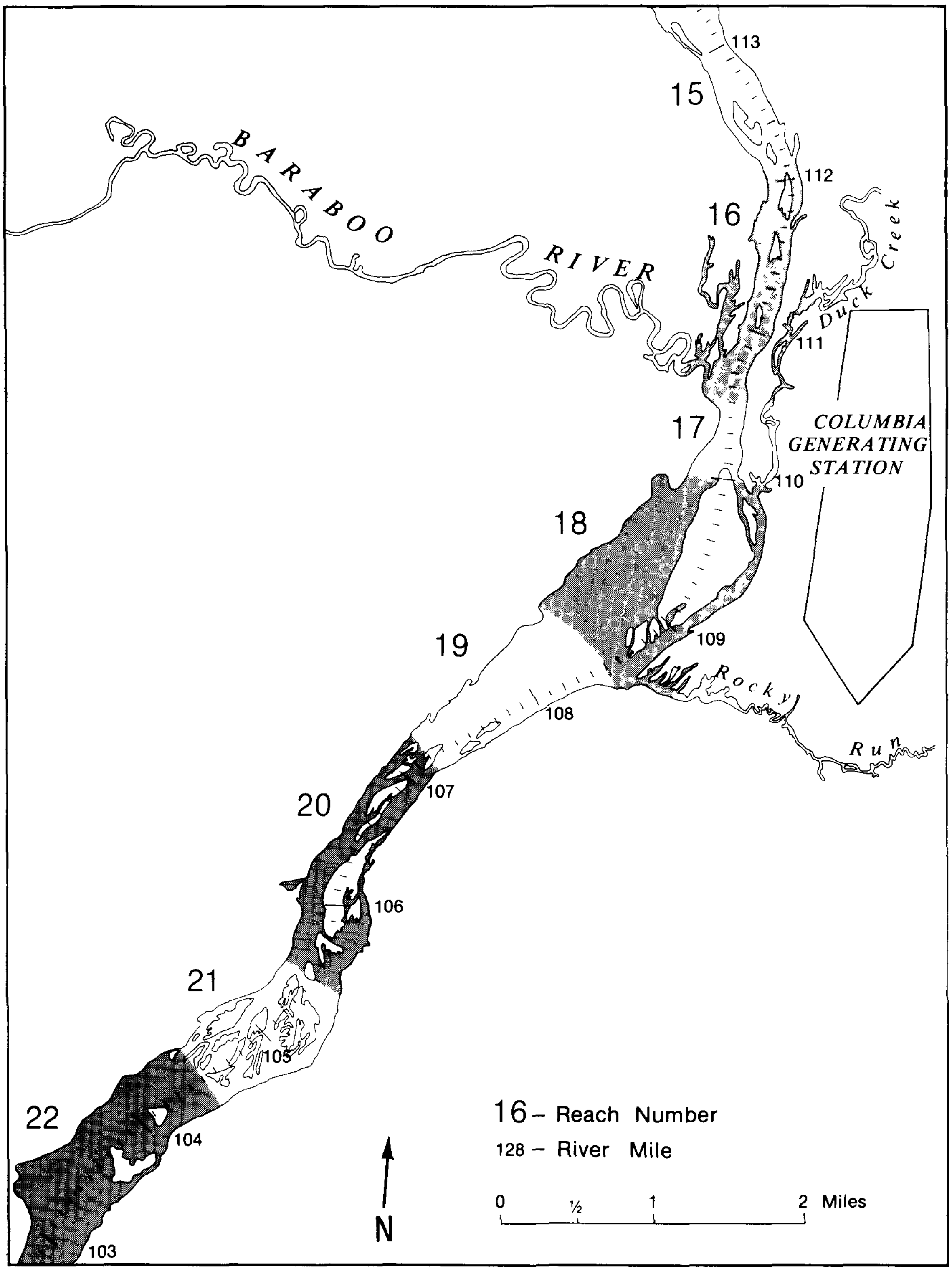

Figure 3b. Middle part of study area on Wisconsin River, showing river miles, tenths of miles, QUAL-3 reaches 15 through 22, (alternate reaches are shaded), and reach numbers.

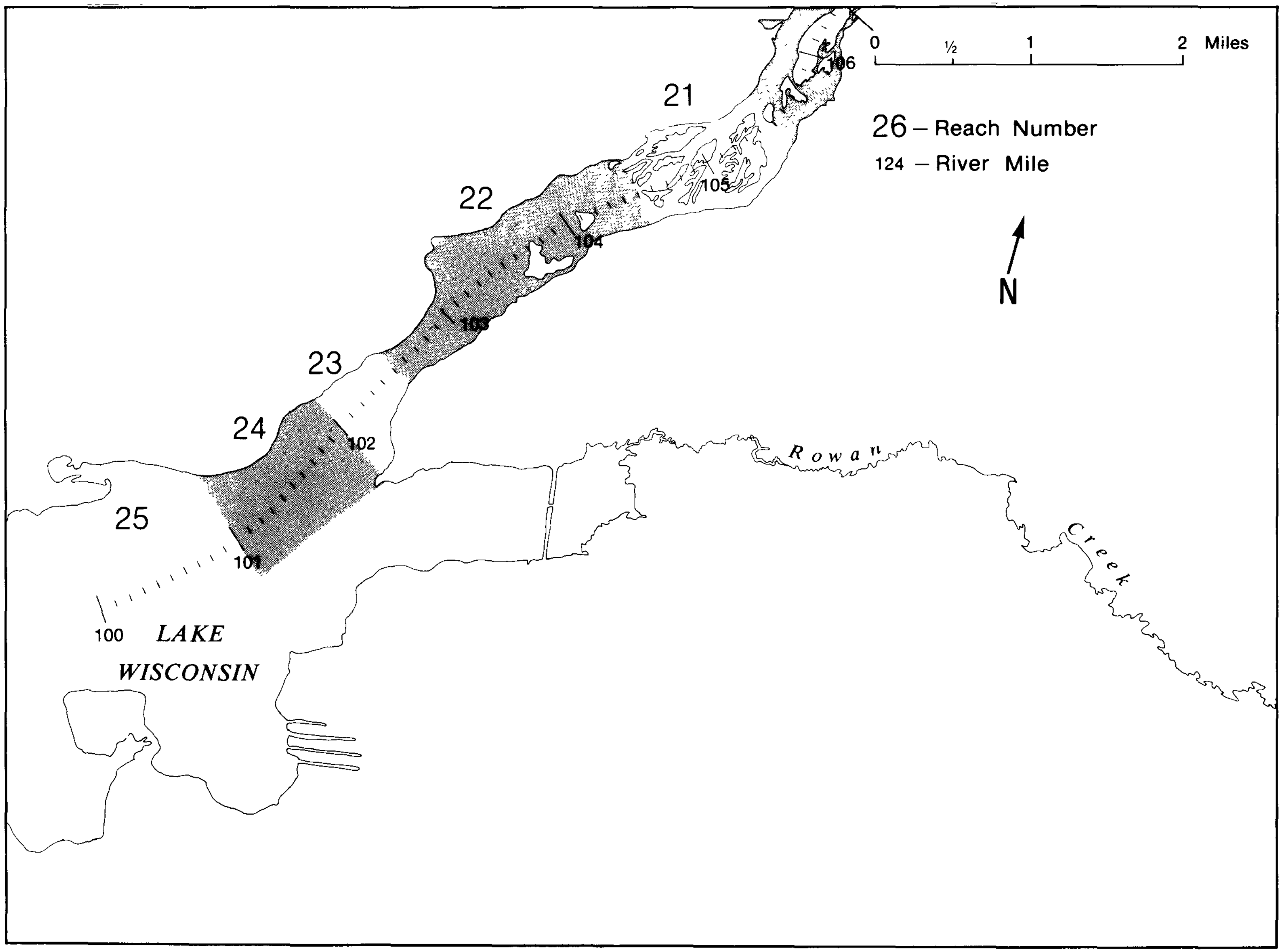

Figure 3c. Lower part of study area on Wisconsin River, showing river miles, tenths of miles, QUAL-3 reaches 21 through 25 (alternate reaches are shaded), and reach numbers.

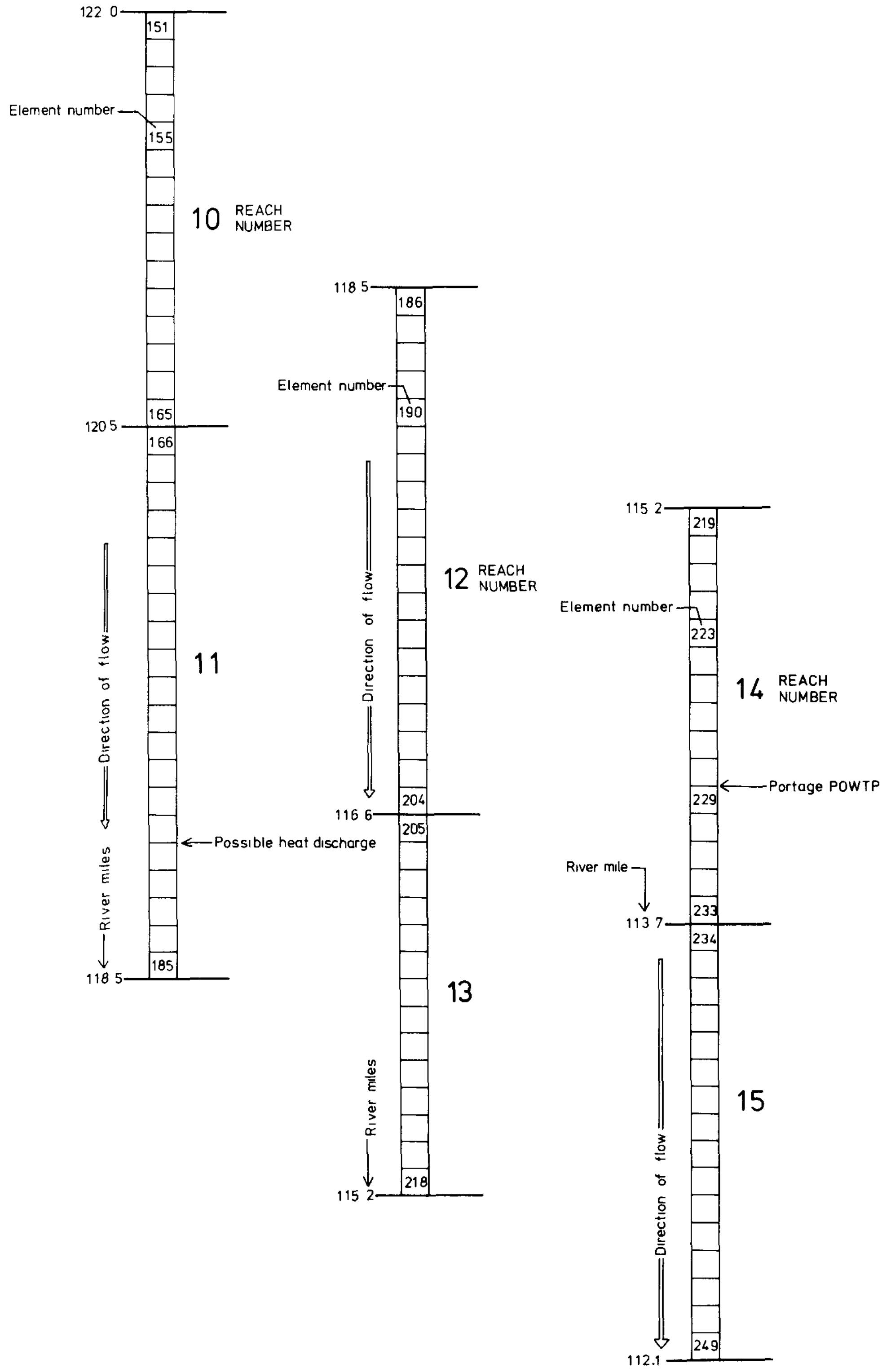

Figure 4a. Schematic of QUAL-3 elements for reaches 10 through 15 on the Wisconsin River.

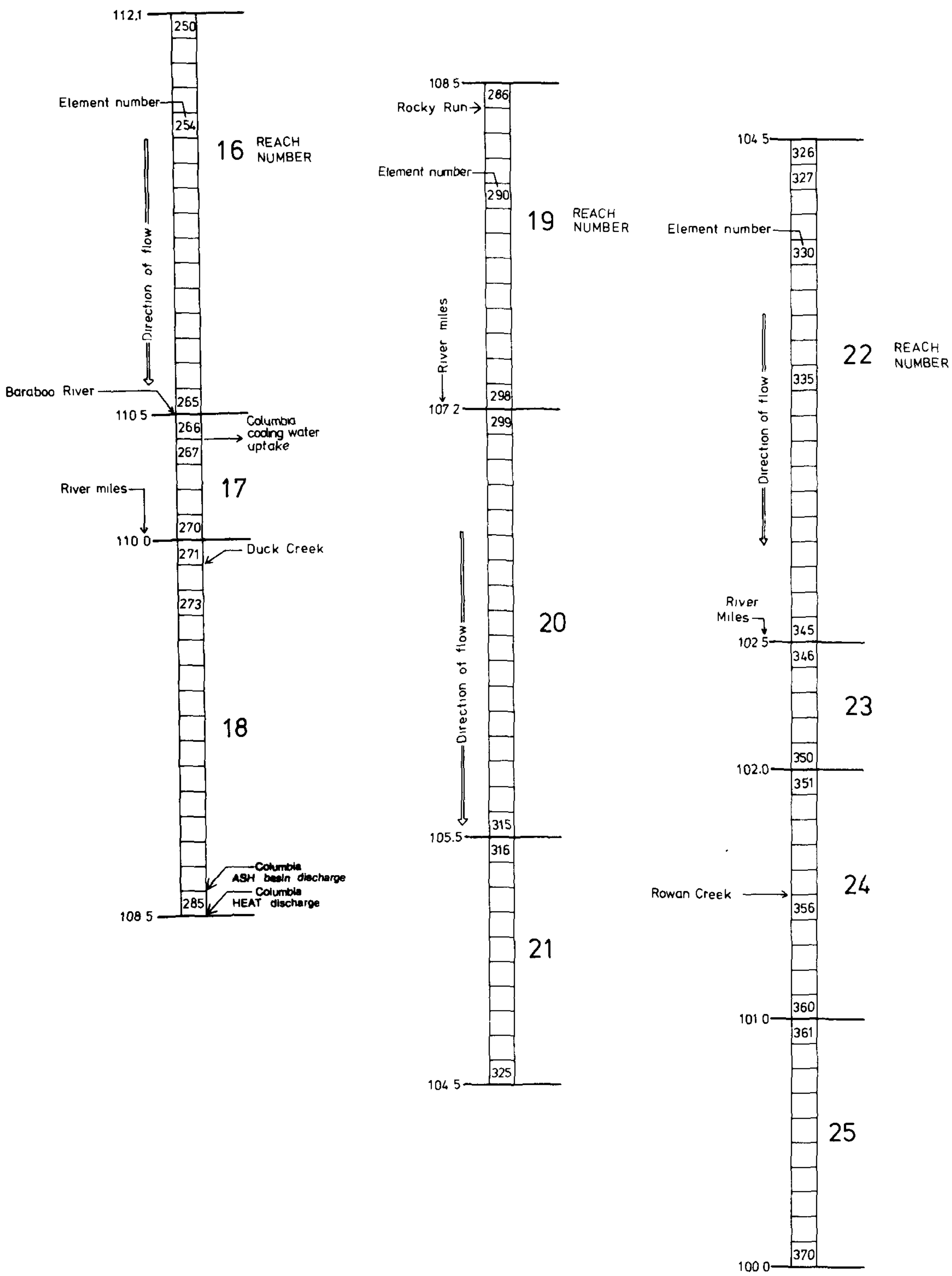

Figure 4b. Schematic of QUAL-3 elements for reaches 16 through 25 on the Wisconsin River.

SECTION 4

ACQUISITION OF THE DATA BASE

Before the effects of wastewater and heat discharges on water quality in the Wisconsin River could be simulated, information had to be collected on the amount and strengths of wastewaters and nutrients flowing into the Wisconsin River and on the amount, quality, and temperatures of water in the river itself. These data provided the necessary means to calibrate the QUAL-3 model so that it would simulate, to the closest degree possible, the water quality conditions typical of those observed during periods of extremely low flows in mid-summer. In addition, the data were used to develop the levels of nutrient and wastewater discharges for the scenario simulations.

Types of data required were the low-flow hydraulic conditions for the Wisconsin River; the location, strength, and amount of wastewater discharges into the Wisconsin River; the discharge and water quality of tributaries emptying into the Wisconsin River; and the amount and nutrient composition of incremental run-off into the Wisconsin River. Sources of these data are Table 2. The raw hydraulic data needed considerable processing before it could be used by the QUAL-3 model.

HYDROLOGIC CONDITIONS OF THE WISCONSIN RIVER

The QUAL-3 model requires three sets of hydrologic data for each reach or stretch of the river to simulate the effects of changes in the heat and nutrients in the river: the average cross-sectional area, the average depth, and a measure of the roughness of the river channel called the Manning's n. Since direct measurements of these parameters and of the river velocity were unavailable for this preliminary study, it was necessary to estimate their values from data obtained from the Army Corps of Engineers' HEC-2 Flood Routing Model (U.S. Army Corps of Engineers 1976). Average values of these parameters for each QUAL-3 reach were computed and then the cross-sectional area and velocity for each QUAL-3 reach were computed from these averages.

Computations were made for the lowest expected 7-day average flow during a 10-yr period; this hypothetical flow is called $Q_{7,10}$. This is a frequently used lower bound for simulation of the flow conditions on rivers that will most likely be affected by waste or heat discharges, and has been used by the Wisconsin Department of Natural Resources as a limit for defining water quality regulation. For this study air and water temperatures typical of late July or early August were used (see numbers 1, 2, and 6 in Table 2), although future studies should also examine

TABLE 2. SOURCES AND TYPES OF RAW DATA COLLECTED FOR ANALYSIS OF CONDITIONS IN THE WISCONSIN RIVER

Number	Title	Parameter	Location	Source
1	Pollution investigation survey	Quantity and strength of wastewater discharges: chemical sampling and temperature data spot checks	Wisconsin River and tributaries below confluence of Duck Creek	Wisconsin Dept. of Natural Resources (WDNR)
2	Pollution investigation survey	Quantity and strength of wastewater discharges: chemical sampling and temperature data	Wisconsin River and tributaries between Lemonweir and Baraboo Rivers	WDNR
3	Flood plain information (FPI)	Location of cross sections of Wisconsin River channels	Wisconsin River in Sauk and Columbia Counties	U.S. Army Corps of Engineers
4	Flood plain information (FPI)	Location of cross sections of Wisconsin River channels	Wisconsin River in Columbia County	U.S. Army Corps of Engineers
5	Cross section data (HEC-2-0877)	Computer card coded data containing cross sections (described in numbers 3 and 4) for the HEC-2 water surface profile program)	Wisconsin River from Wisconsin Dells to the I-90/94 bridge	WDNR
6	Water quality sampling data	Complete chemical analysis of water; temperature	1) Wisconsin River at at Prairie du Sac 2) Baraboo River: County Trunk Highway X near Baraboo 3) Hydroelectric plant at Wisconsin Dells	WDNR
7	Permit files of National Pollutant Discharge Elimination System (NPDES)	Detailed data regarding chemical nature and quantity of wastewater from regulated dischargers; anticipated future discharges	1) Wisconsin Dells publicly owned treatment plant (POWTP) 2) Lake Delton POWTP 3) Portage POWTP 4) Columbia Generating Station	WDNR (on file)
8	River sediment deposition studies	Depth of water upstream, alongside and downstream of Wisconsin state highway bridges; elevation of water surface	1) I-90/94 bridge 2) State Highway 33 bridge (Portage) 3) State Highway 78 bridge	Wisconsin Dept. of Transportation
9	Surface waters of the United States	Daily discharge records	1) Wisconsin River near Lake Delton 2) Dell Creek near Dake Delton 3) Baraboo River, County Trunk Highway X near Baraboo	U.S. Geological Survey (USGS)
10	Water resources investigation 45-74	Low-flow frequency of Wisconsin streams at sewage treatment plants ($Q_{7,10}$ flows)	1) Wisconsin River at Lake Delton 2) Baraboo River 3) Duck Creek 4) Rocky Run 5) Rowan Creek	USGS
11	Hydrologic investigation HA-390	Low-flow frequency of Wisconsin Streams	(same as number 10)	USGS
12		Water depth contours in Lake Wisconsin (map)		WDNR
13	Field study	Level of dissolved oxygen, level of 5-day and ultimate BOD, depth of water, levels of nitrate, nitrite, ammonia, phosphorus, total nitrogen and temperature	At selected locations between Columbia Generating Plant and and Lake Wisconsin	Project measurements (Appendix F, Table F-1)

limitations in heat discharge for wintertime conditions when a river's ice cover prevents effective aeration.

Although flow on the Wisconsin River during the period of the study was unusually high, extremely low flow did occur during the late summer months of 1976 and 1977. Observations of discharge rates and river elevations at a few locations during these periods provided the means to reconstruct the hydraulic conditions at each cross section by use of the HEC-2 river routing model.

Data for the elevation of the riverbed at cross sections across the width of the river between Wisconsin Dells and the Interstate 90/94 bridge was obtained by the U.S. Army Corps of Engineers for its 1972 and 1975 flood plain information reports (see numbers 3 and 4 in Table 2). The locations of these cross sections are shown in Figure 5 and plots of some typical cross sections are presented in Figure 6. The data are included in numeric form in Appendix C.

The HEC-2 model had to be modified to obtain elevations in the HEC-2 simulations of $Q_{7,10}$ flow that agreed with known estimates at the highway bridges and at the Lake Delton U.S. Geological Survey (USGS) gaging station (see number 9 in Table 2). Two methods were considered for highways I-90/94 state highway 33 (mile 115.0), and state highway 78 (mile 116.6) (see number 8 in Table 2). For the first method the Manning's n was adjusted at various cross sections to obtain the desired elevations and realistic conveyances at each cross section. This method was not successful since it resulted in regions of excessively steep slope in the water surface which prevented realistic simulation by the HEC-2 model. The more successful alternative involved hypothetically shutting off the flow in parts of a few cross sections where higher velocities and greater elevation changes were needed. These alterations were performed on the six cross sections shown in Figure 6. The shaded regions depict areas where the water was assumed to be standing but not flowing.

Results of the HEC-2 simulation used for determining the hydraulic parameters for the QUAL-3 model are shown in Appendix D. The shaded cross sections were altered as described.

The most serious difficulty in simulating low-flow conditions with the HEC-2 model is the tendency for the Wisconsin River to become a series of almost stagnant pools connected by relatively short stretches of flowing water. Since the HEC-2 package utilizes the standard step method (Chow 1959) to evaluate the elevation at each cross section, gradually varied flow is assumed. The cross sections used in this study were surveyed at locations and intervals along the river that the Corps of Engineers felt would provide sufficient accuracy for determining flood crest elevations. At very low discharge rates, however, the spacing of these cross sections may be insufficient to maintain realistic simulations everywhere along the river.

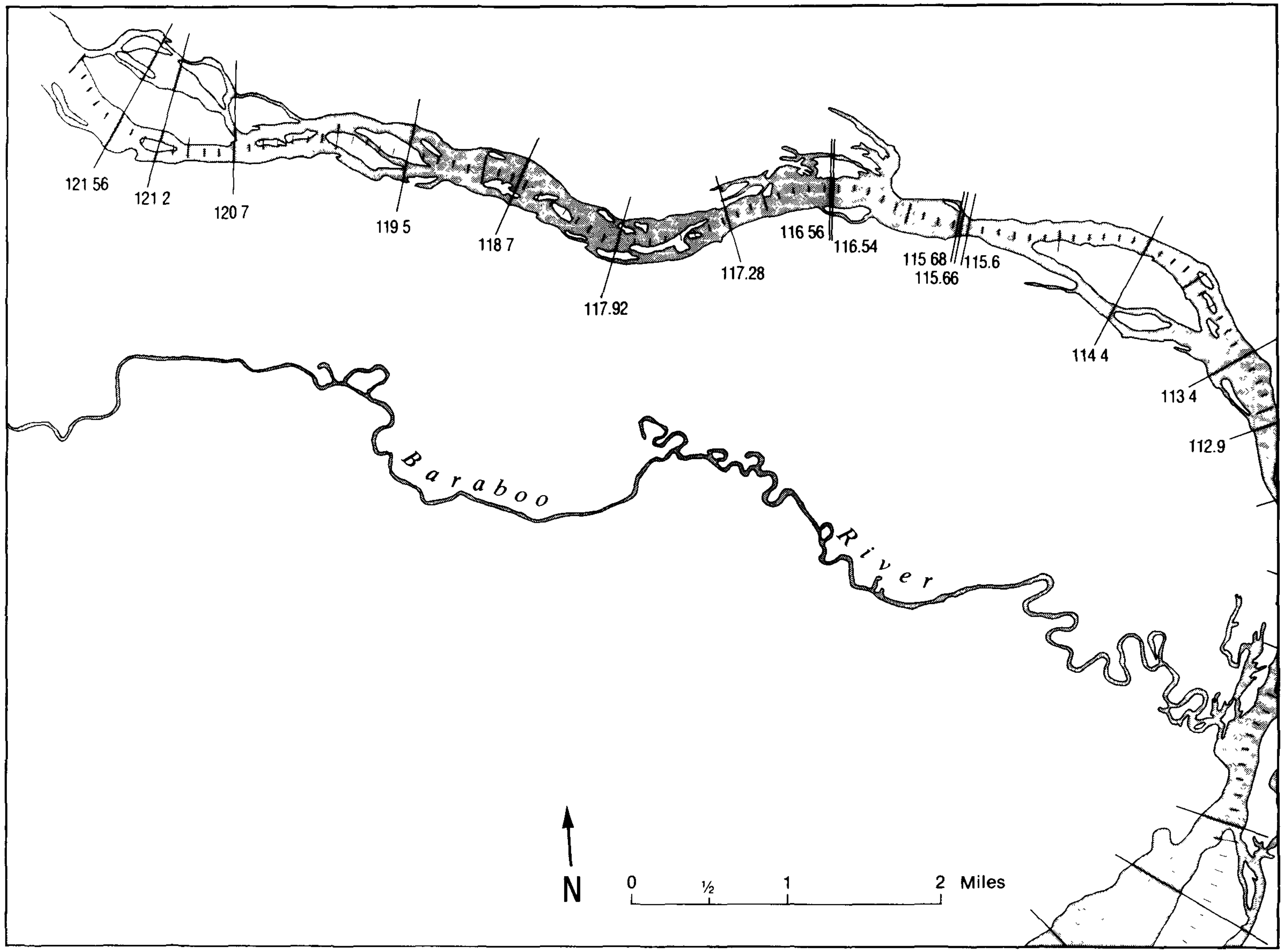

Figure 5a. Upper part of Wisconsin RIver under study showing HEC-2 cross sections (labeled according to the river miles of their locations).

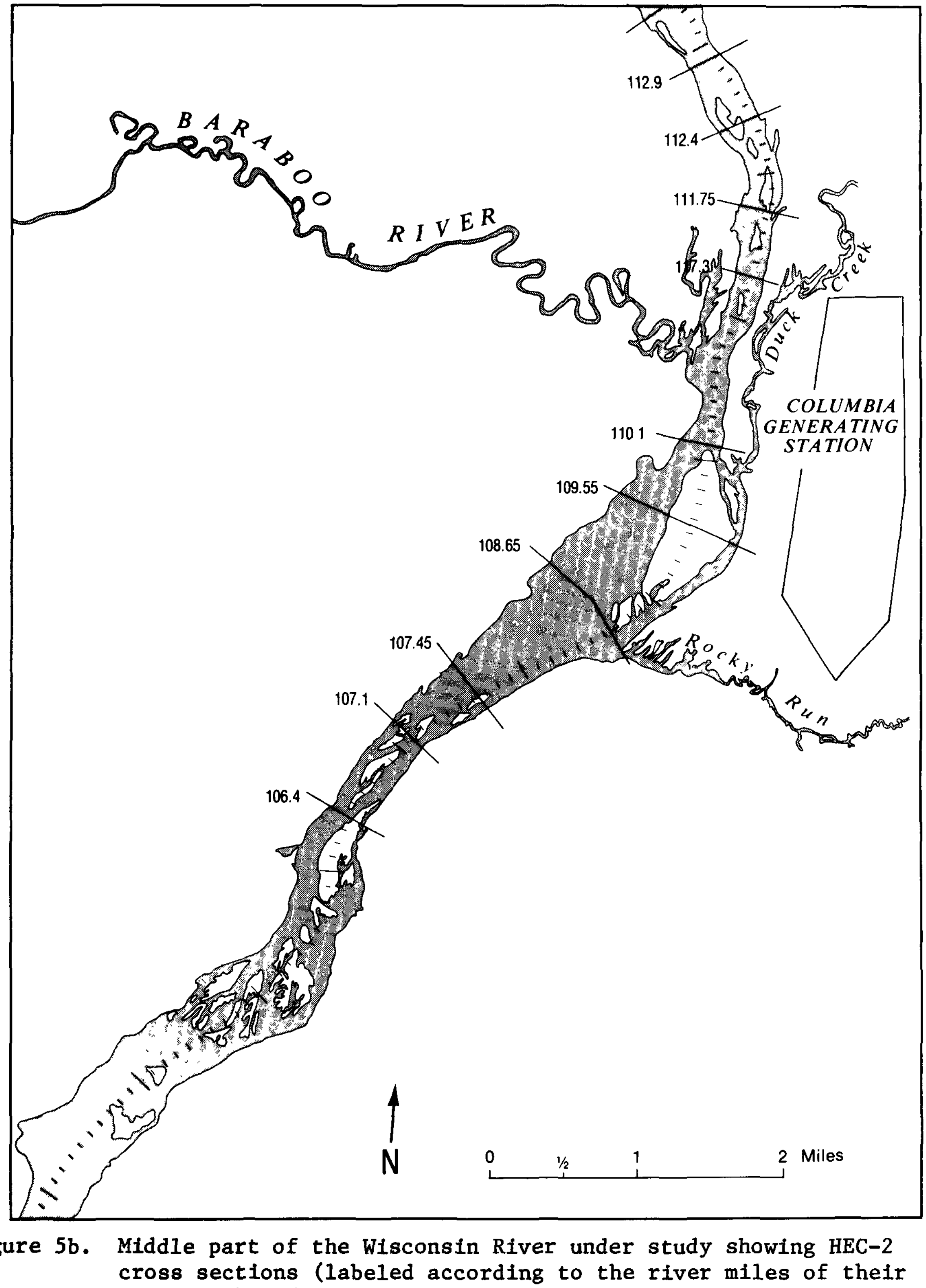

Figure 5b. Middle part of the Wisconsin River under study showing HEC-2 cross sections (labeled according to the river miles of their locations). (Cross sections stop at river mile 10614).

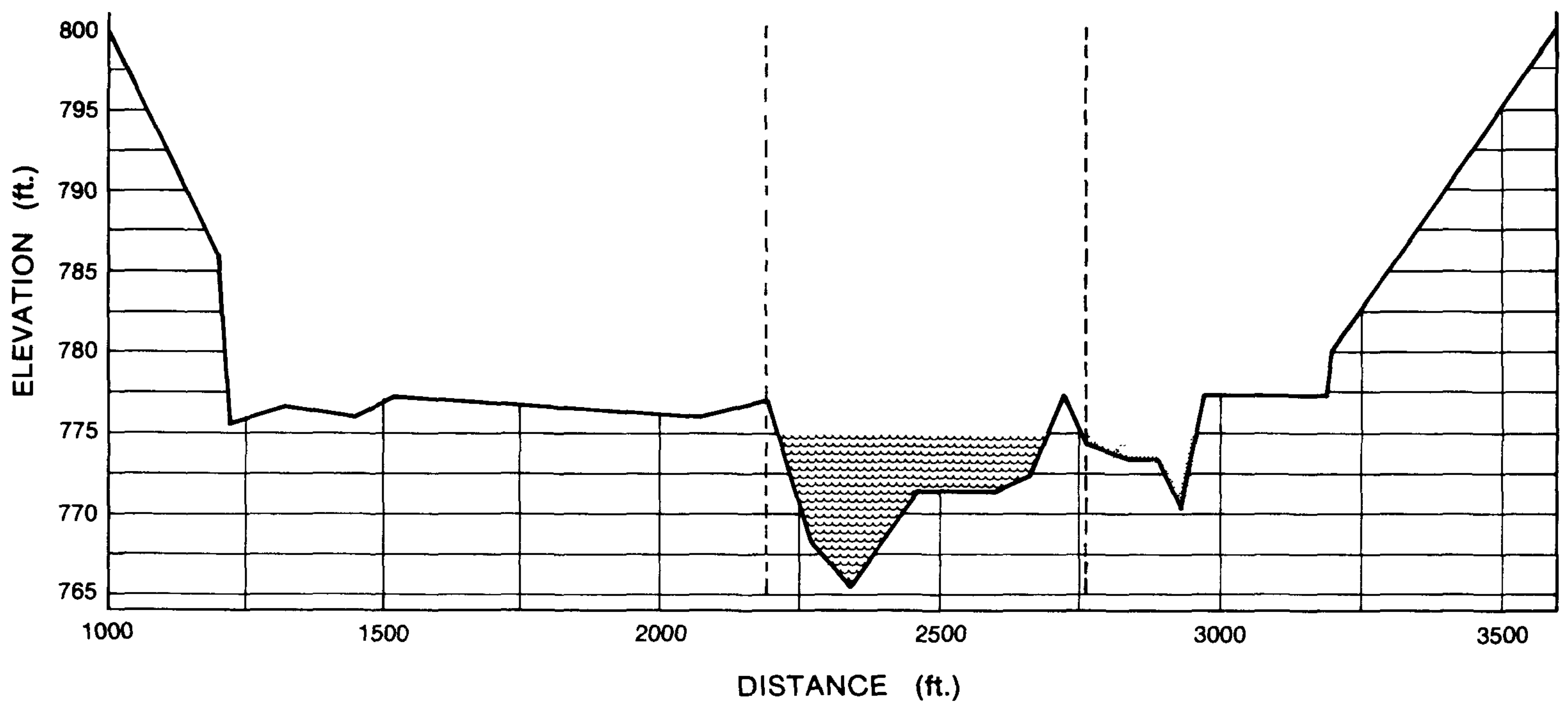

Figure 6a. Plot of HEC-2 cross-section at river mile 107.45, showing elevation or river bottom. Shaded region is area where water is assumed to be standing but not flowing. Vertical dashed lines indicate boundary of water flow assumed in HEC-2 model. The diagram assumes the viewer is looking upstream.

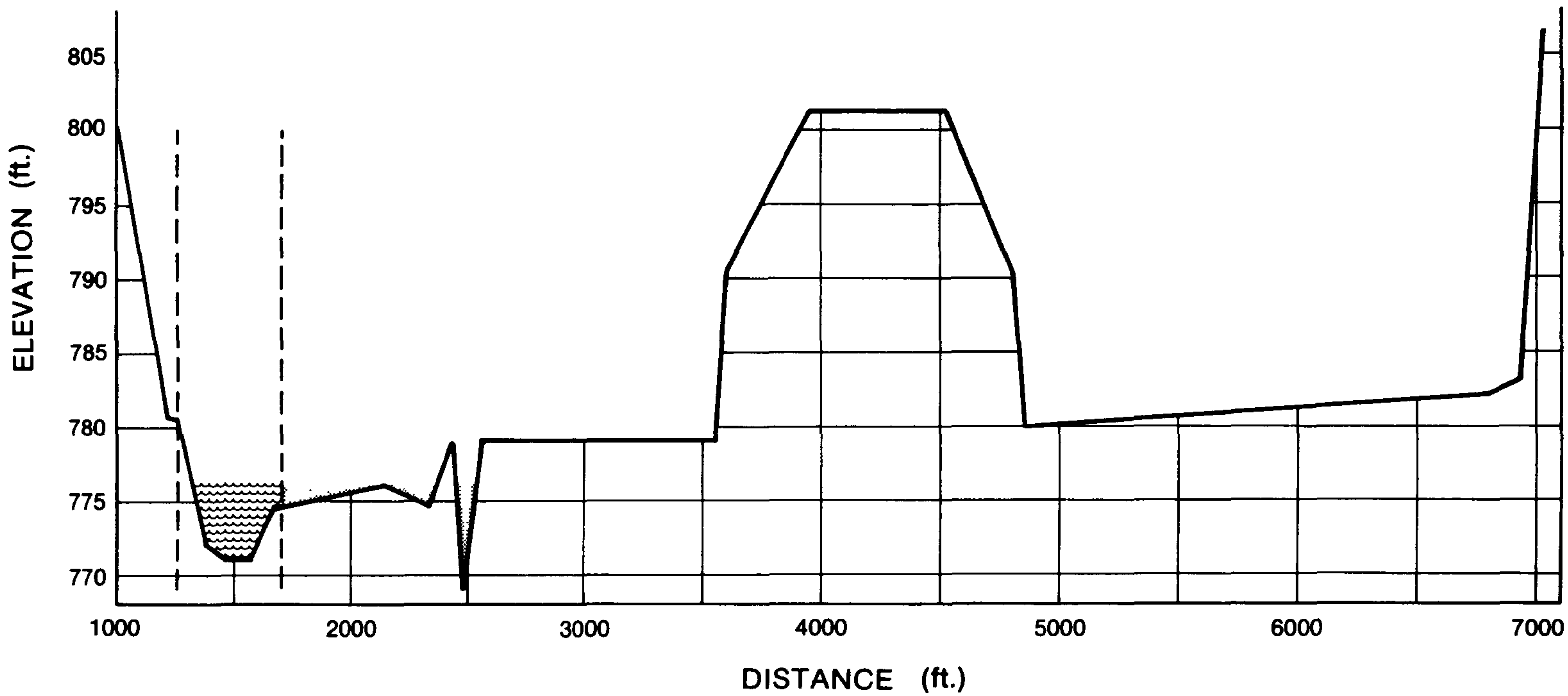

Figure 6b. Plot of HEC-2 cross-section at river mile 110.0. (See Figure 6a.)

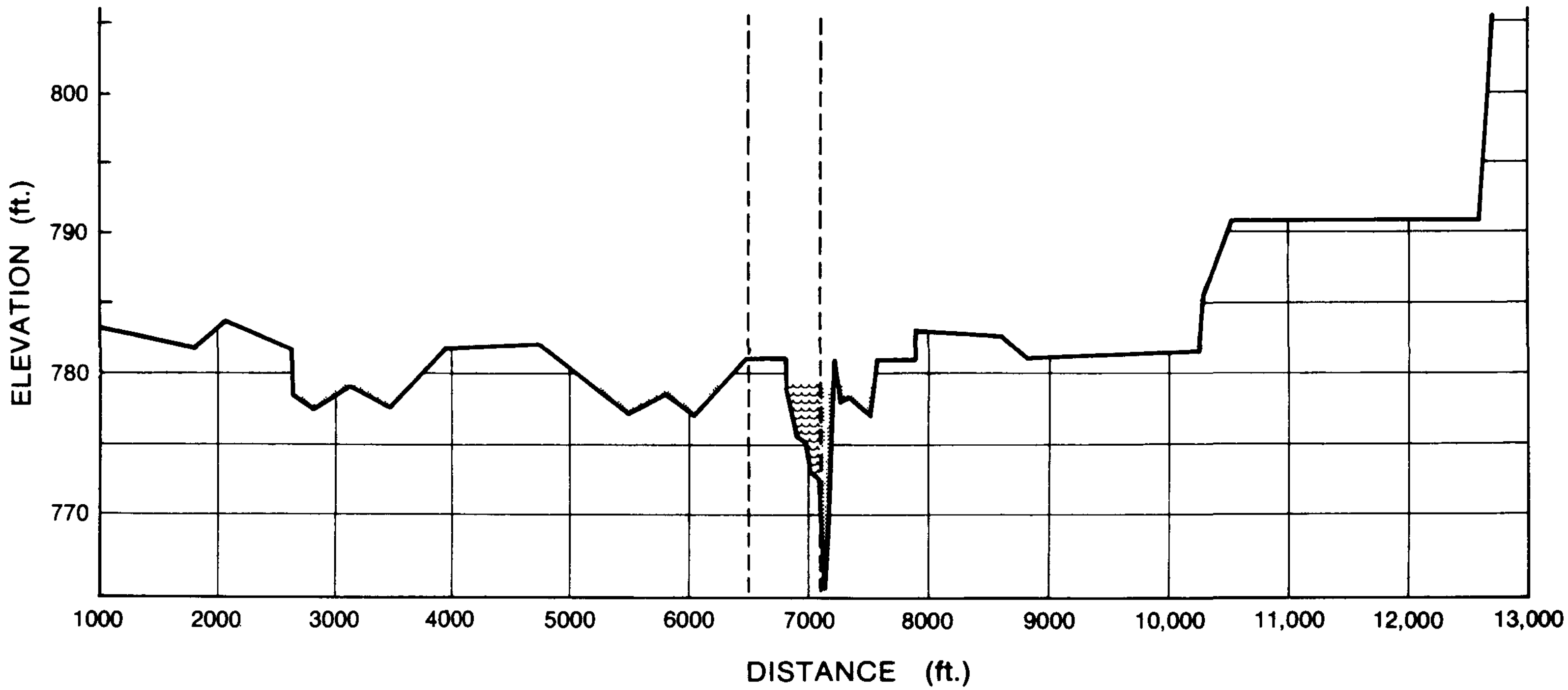

Figure 6c. Plot of HEC-2 cross-section at river mile 111.75. (See Figure 6a.)

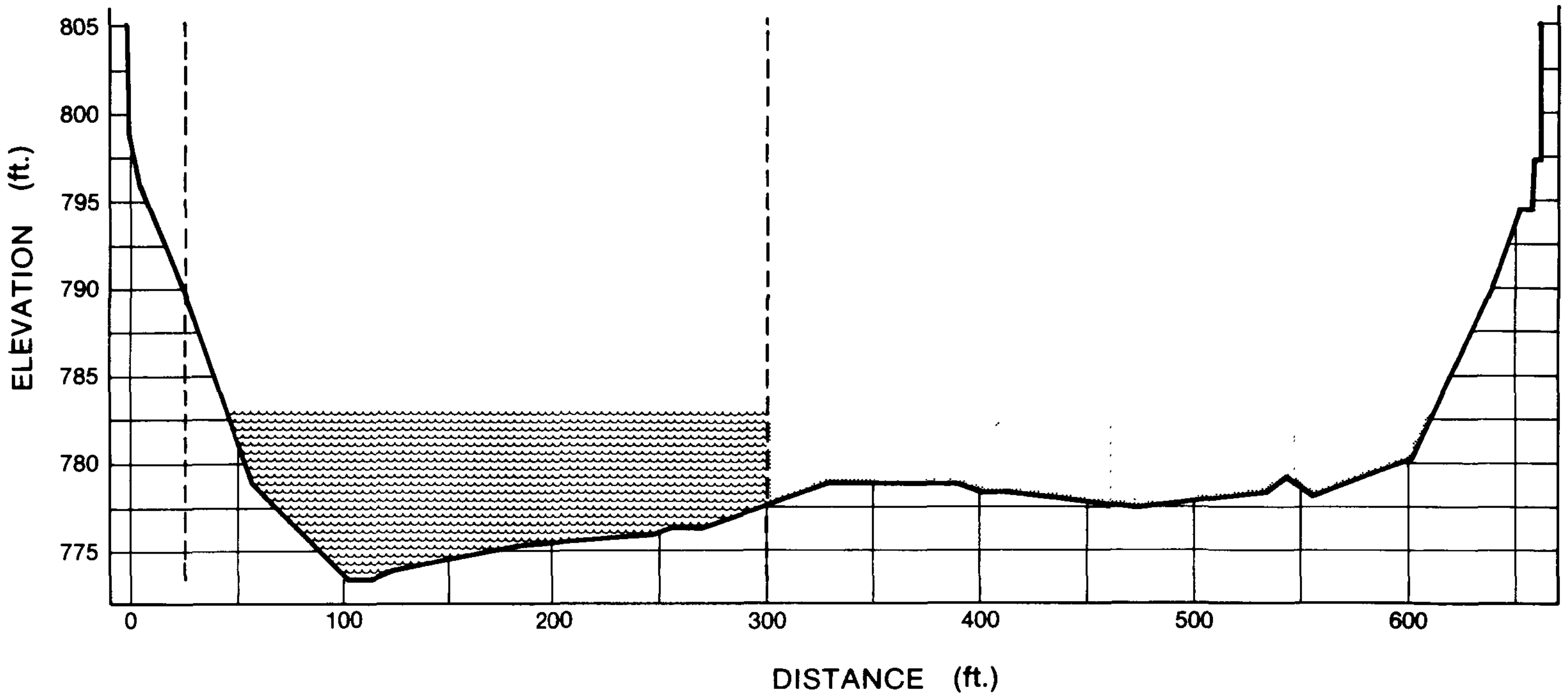

Figure 6d. Plot of HEC-2 cross-section at river mile 115.66. (See Figure 6a.)

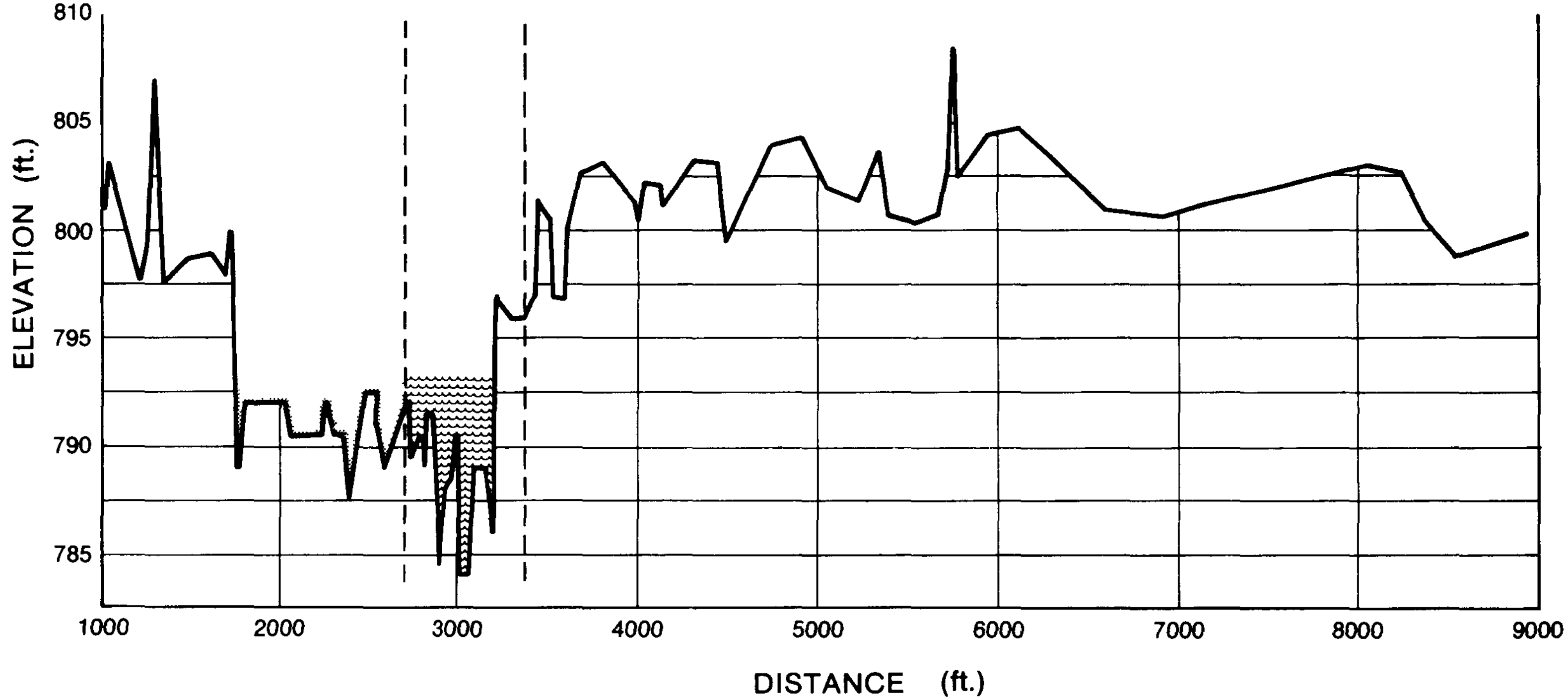

Figure 6e. Plot of HEC-2 cross-section at river mile 122.26. (See Figure 6a.)

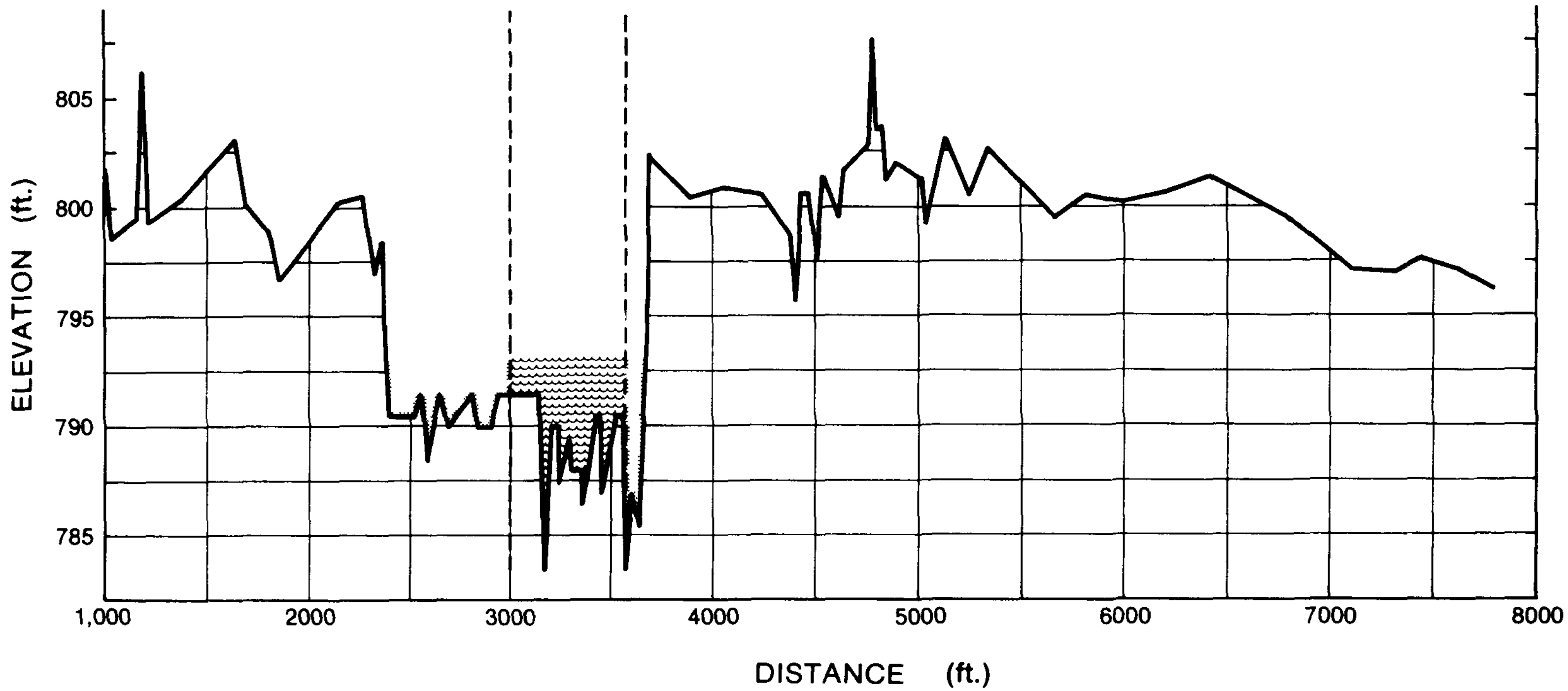

Figure 6f. Plot of HEC-2 cross-section at river mile 122.68. (See Figure 6a.)

Attempts to match the Corps of Engineer's guidelines of conveyance ratios (see Appendix D), which were between 0.7 and 1.4, led to unrealistically high velocities and elevations. As a result, larger variations in the conveyance ratios had to be allowed in order to match the elevations at the highway bridges. Nevertheless, serious uncertainties remain as to the extent and effect of ponding in the river at the low discharges modeled in this study; these uncertainties could not be fully resolved with extensive field work.

Since the HEC-2 cross sections (Figure 5) were located at uneven intervals with respect to the QUAL-3 elements and reaches, it was necessary to compute weighted averages of areas of flow, velocities, and Manning's n for all cross sections in the vicinity of each QUAL-3 reach. Each cross section was weighted according to a hypothetical region of influence extending halfway to the adjacent cross sections on each side or to a QUAL-3 reach boundary, if a reach boundary lay between the cross section and the halfway point. For example, in Figure 7 three HEC-2 cross sections (at river miles 113.4, 112.9, and 112.4) describe the flow conditions in reach 15. Regions of the reach described by these cross sections comprise 0.34, 0.32, and 0.34 of the total length of the reach (adding up to 1.00). Using the values of velocity and topwidth predicted by the HEC-2 model for these cross sections (Appendix B), the average velocity for QUAL-3 reach 15 was computed to be (0.34)(1.54) + (0.32)(0.94) + (0.34)(1.19) = 1.23 ft/sec.

Conversion of the HEC-2 Hydraulic Data to QUAL-3 Hydraulic Data

A complicated procedure was required to convert the HEC-2 data to data for the QUAL-3 model. The HEC-2 data for average flow, velocities, and Manning's n were derived from and applicable to cross sections of the river. These cross-sectional averages had to be converted to averages for the entire river in the study area. The first step in this conversion was to divide the Wisconsin River in the study area into 16 reaches (reaches 10 through 25, as shown in Figures 3 and 4). The reaches vary in length from 1 to 2 miles. Each reach was then divided into elements, each 0.1 mile long (Figure 4). The topwidth and Manning's n were similarly computed to be 797.18 ft and 0.035. From these averages the area of flow A was computed from A = Q/V, where Q = flow rate and V = velocity. The hydraulic depth of flow D was computed from D = A/W, where W = topwidth of the river.

Computations similar to these were performed on reaches 1 through 20 using the computer program presented in Appendix E. The resulting hydraulic parameters appear in Data Type 5 of Appendix A. Computations involving the six altered cross sections shown in Figure 6 were based upon the effective (i.e., reduced) areas of flow; however, the actual widths of the river (shown in parenthesis in Appendix D) were substituted for reduced widths.

A problem arose with reaches 21 through 25 because the Army Corps of Engineers' flood study for the Portage area extended only as far downstream as river mile 106.4, or about where Interstate 90/94 crosses the Wisconsin River south of Portage. Since this location is only 2 miles downstream of a potential future heat discharge from the Columbia Generating Station (mile 108.5), the QUAL-3 model had to be extended farther downstream to assess

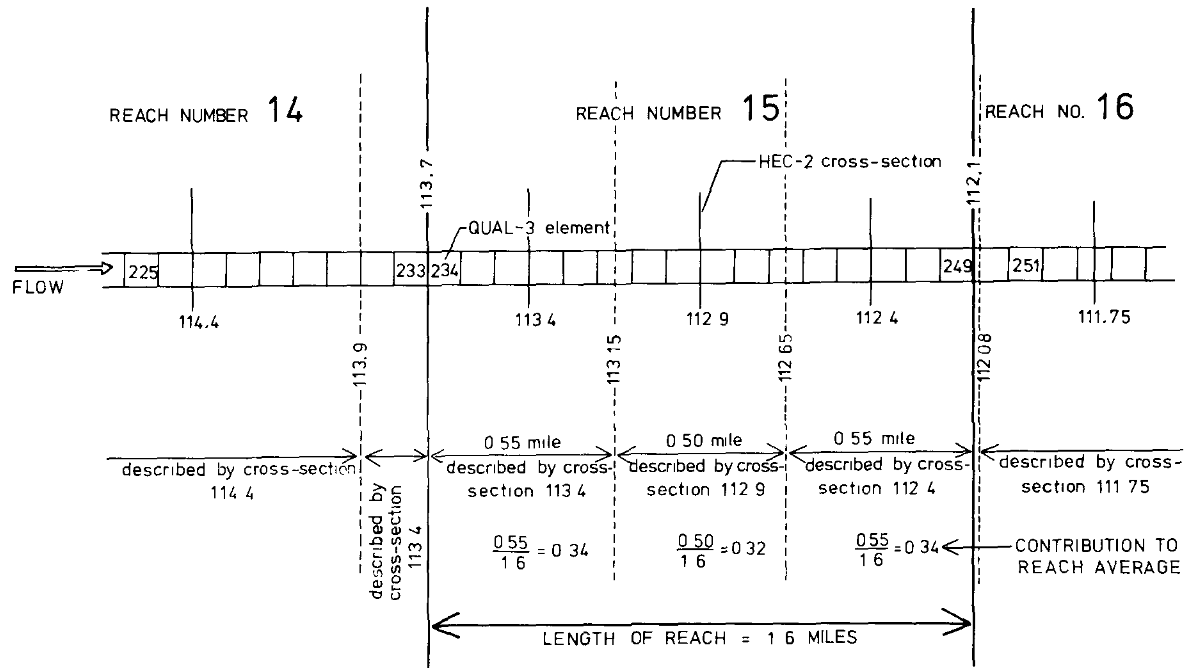

Figure 7. Relationship between the output of the HEC-2 model and the reach averages of velocity, cross-sectional area, and depth required for input to the QUAL-3 model.

properly the full effects of any heat or wastewater discharges. Although a bathymetric chart of water depths in Lake Wisconsin (Wisconsin Department of Natural Resources, undated) was available, no information was available for the Wisconsin River from mile 106.4 to the northeast end of Lake Wisconsin.

Two strategies were employed to derive inputs for reaches 21 through 25. In reaches 24 and 25 the total volume of water in each reach was estimated using lake depth information based on a lake elevation of 774.00 ft above mean sea level (see number 12 in Table 2). From these volumes, detention times were computed using $\theta = \frac{V}{Q_{7,10}}$, where V = volume of water in the reach. Using the length and representative width of each reach, the velocity, cross-sectional area of flow, and depth were computed for input to the QUAL-3 model. In reaches 21 through 23, the topwidth was estimated from USGS maps with a scale of 1:24,000. The average depth was assumed to vary linearly from 6.66 ft in Lake Wisconsin to 3.60 ft at cross-section 106.4 (the first HEC-2 cross section). The results of these estimates are shown in Table 3. Subsequent field work, in which the depth of the river was measured at cross sections at river miles 102.4, 104.0, 105.0, and 105.6, has shown these to be reasonable approximations.

TABLE 3. VALUES OF HYDRAULIC PARAMETERS COMPUTED FOR QUAL-3 REACHES 21 THROUGH 25 ON THE WISCONSIN RIVER

Reach	Assumed width (ft)	Total volume (ft^3)	Depth (ft) (interpolated)	Area flow (ft^2)	Width (ft)	Velocity (ft/sec)
21	1,200	--	4.25	5,100	1,200	0.35
22	2,700	--	5.00	13,500	2,700	0.13
23	2,300	--	5.75	13,225	2,300	0.14
24	6,349	208,989,189	6.23	39,581	6,349	0.048
25	12,030	422,883,000	6.66	80,092	12,630	0.024

WATER TEMPERATURES IN THE WISCONSIN RIVER

The water temperature affects the river's absorption of oxygen from the atmosphere, the river's biochemical utilization of dissolved oxygen, algal growth, respiration, oxygen production, and the numerous nitrogen and phosphorus-related chemical reactions described in Appendix B. Because water temperature is so critical, we examined the data very carefully to determine the natural temperature range for summer, low-flow conditions. We found little evidence indicating that the natural summer water temperature in the Wisconsin River changed drastically from one reach to the next (see number 13 in Table 2). Examination of USGS data at Wisconsin Dells and at the Prairie du Sac dam (see number 6 in Table 2) indicates that maximum river temperatures ran as high as 75°F during low-flow periods in late July and early August. Chemical sampling data from the Wisconsin DNR (see numbers 1 and 2 in Table 2) indicated temperatures as high as 81° at the Prairie du Sac dam and as high as 75°F below the Wisconsin Dells dam. On the basis of this data we used a zero heat discharge river temperature of 77.8°F upstream of river mile 122.0 and 78.8°F below river mile 122.0.

WASTEWATER DISCHARGES

Information on wastewater discharges in the area of interest was obtained from numbers 1, 2, and 7 in Table 2. The WDNR Pollution Investigation surveys outline 35 dischargers into the surface waters emptying into the Wisconsin River. However, measurements of the levels of dissolved oxygen and BOD in the Wisconsin River, Baraboo River, Duck Creek, Rocky Run, Rowan Creek, and Dell Creek indicated that only three dischargers directly affected the water quality in the Wisconsin River: the Lake Delton Sewage Treatment Plant, the Wisconsin Dells Sewage Treatment Plant, and the Columbia Generating Station. Therefore, only these three sources of wastewater were simulated in the model runs.

Mid-summer BOD values were determined for several tributaries of the Wisconsin River. Mid-summer values of BOD in the Baraboo River were about 6 mg/liter 17 miles upstream of its confluence with the Wisconsin River. We assumed that these values would be similar to those in the Wisconsin River at the confluence with the two rivers. Similar assumptions were made of Rowan Creek (BOD = 2.0 mg/liter 2.6 miles above its confluence with the Wisconsin River) and Duck Creek (BOD = 3.0 mg/liter 8.1 miles above its confluence with the Wisconsin River). No significant discharges into Rocky Run or into Dell Creek were found.

Wastewater Treatment Plants

Since this study is concerned with future scenarios affecting power plant siting and operation, future wastewater discharge conditions had to be considered. The first significant change involves the construction of a new publicly owned wastewater treatment plant for the cities of Wisconsin Dells and Lake Delton. These communities, each of which has a primary treatment facility that becomes overloaded during peak tourist periods, have been ordered to construct a new secondary treatment plant to serve both communities jointly. Simulations were based upon discharge from such a new facility discharging about 0.5 million gal/day (mgd) of wastewater with a strength of 30 mg/liter BOD.

The second partial change in wastewater discharges is the possible discharge of the upgraded Portage Sewage Treatment Plant into the Wisconsin River instead of the Fox River. Although this plant will meet the discharge standards for secondary treatment, the requirement that it also remove nutrients is still being considered. This plant would discharge about 2 mgd of wastewater with a strength of 30 mg/liter BOD. However, if the same standards are applied to Wisconsin River discharge as to Fox River discharge, ammonia discharge would have to be $\leq$ 3 mg/liter, dissolved oxygen

$\leq$ 5 mg/liter, and phosphorus $\leq$ 1 mg/liter. Because of the uncertainty of this potential source, we have considered several different scenarios (see Section 5).

For all other major sources of wastewater discharge into the Baraboo River, Duck Creek, and Rowan Creek, no evidence was found that any significant increases would occur during the next 20 yr.

The Columbia Generating Station

The Columbia Generating Station consists of two nearly identical coal-fired units each capable of generating 527 MW of electrical energy. A 480-acre cooling lake and two cooling towers operating in parallel provides the cooling water that carries away the heat wasted in the generating process. At present, all cooling needs can be met without direct discharge of cooling water into the Wisconsin River.

The National Pollutant Discharge Elimination System (NPDES) discharge permit for the station currently lists five point source discharges from the plant: (1) from the ash settling basin, (2) from the coal pile settling basin, (3) from the two cooling towers, (4) from a small sewage treatment plant, and (5) from an oil/grease separator fed by the condenser sump pit and the storm drain system for the plant. Only the first of these discharges feeds directly into the Wisconsin River through the ash pit drain located at the southern extremity of the site. The remaining discharges drain into the cooling lake which provides the primary mechanism to cool heated water by means of evaporative transfer of heat into the atmosphere.

Although direct overflow of warm water from the cooling lake is prohibited (except momentarily), significant amounts of water seep underground from the lake. In the summer, water enters the lake at the hot effluent end at 100.2°F and cools to 84.7°F as it travels the 17,000 ft of lineal traveling distance to the cool water intake. An overflow spillway is located 12,000 ft from the hot effluent end of the lake, but the NPDES permit prohibits operating the intake pump that brings Wisconsin River water into the lake in such a way as to cause overflow through this spillway, except momentarily. Despite these restrictions, underground seepage of warm water from the lake amounts to 7,370 gal/min. This rate is slightly more than half the rate that water is withdrawn from the Wisconsin River and it is almost twice the rate of evaporative loss from the lake. Other studies indicate that this seepage has increased groundwater temperatures in the sedge meadow and marsh located between the lake and the river (Andrews and Anderson, in press).

Although a large portion of this groundwater flow probably reaches the Wisconsin River, its effect was not modeled for several reasons. First, information regarding the actual temperatures reaching the river is not yet available. Second, the amount of this seepage is less than 1% of the $Q_{7,10}$ flow (1,800 cfs). Third, assuming an unusually high groundwater temperature of 90°F and a river temperature of 78°F, this flow would increase the temperature in the river only 0.11°F. Fourth, the effect of elevated temperatures would be greatest in winter because of observed time lags in the response of the groundwater temperature to the changing seasons of the year (Andrews and Anderson, in press).

Discharge from the ash settling basin is allowed only from May through September. Flow is 3.5 mgd with a strength of 1 mg/liter BOD; temperature is about 90°F. The effect of this thermal discharge on river water temperature during the summer months was considered very small (an increase of about 0.05°F) and was neglected in this study.

Headwater and Incremental Run-Off Conditions

Headwater for the QUAL-3 simulations of the Wisconsin River was located at the Kilbourn Dam in Wisconsin Dells. No reaeration of the water was assumed to take place from either spillway discharge or passage through the turbine-powered electric generators at the dam. The expected average 7-day flow in 10 yr for the QUAL-3 simulations must be specified at the headwater point. It was computed to be 1,788 cfs. This value was based upon the $Q_{7,10}$ flow of 1,800 cfs at the USGS gaging stations on the Wisconsin River at Lake Delton minus the $Q_{7,10}$ flow of 12 cfs from Dell Creek. Values of nutrients, dissolved oxygen, and BOD were based on measurements performed by the WDNR (see numbers 2 and 6 in Table 2). These values are presented in Section 5.

No information was obtained regarding the amount of nutrient content of incremental run-off (i.e., water reaching the Wisconsin River from sources including groundwater and overland run-off but excluding wastewater and tributary discharges). Values used in simulations were based upon those used in simulations of parts of the Upper Wisconsin River (Wisconsin Department of Natural Resources, 1976). Elevated values of incremental run-off were employed in the Columbia Generating Station vicinity in order to simulate the effect of infiltration from the cooling pond. Incremental run-off conditions used in simulations in this study are presented in Section 5.

SECTION 5

DESCRIPTION OF SCENARIOS FOR MODEL SIMULATIONS

Model simulations of various scenarios were performed to provide some measure of the limiting nature of the water resource of the Wisconsin River as a means of heat discharge for a power plant. Although the Columbia Generating Station is presently prohibited from discharging warm water directly into the river, such discharge may be permitted in the future from the Columbia site or from additional power plant sites. These scenarios were grouped into five general classes.

The first class considered the Wisconsin River as it was observed by the Wisconsin Department of Natural Resources (1972, 1973, and unpublished). The objectives in this class of scenarios were to obtain a simulation of the Wisconsin River that was as close as possible to these observations.

The second scenario class involved possible future heat discharges from the present Columbia site and from potential power plant sites at river miles 119.0 and 130.0. Simulation of heat discharge from the Columbia Generating Station measures the effects of such a discharge if it were permitted or if a third generating unit using once-through cooling water were constructed at the same site. The sites at miles 119.0 and 130.0 were chosen to evaluate the effects of a heat discharge upstream of a possible wastewater discharge from the Portage Wastewater Treatment Plant. The specific locations were considered only on the basis of reasonable topography for a generating station and relatively close proximity to a rail line.

The third scenario class included possible discharge from the Portage Wastewater Treatment Plant into the Fox River (with no effect on the Wisconsin River), into the Wisconsin River with no nutrient (phosphorus) limitations, and into the Wisconsin River with the same nutrient controls as required for discharge into the Fox River.

The fourth class considered nighttime conditions in order to determine whether algal respiration is a limiting factor on the level of dissolved oxygen at night.

The fifth class modeled the effect of various nutrient levels that were already present in the Wisconsin River and that might be discharged into it from several potential point sources. This experiment provided a measure of whether control of point and non-point sources of nitrogen and phosphorus would appreciably affect the quality of river water, especially the level of dissolved oxygen.

The various scenario options for the different parameters included are listed in Table 4. Table 5 then lists the combinations of scenario options used in each of the 18 simulations or runs that were made with the QUAL-3 model.

TABLE 4. SCENARIO OPTIONS CONSIDERED FOR MODEL SIMULATIONS

Scenario class	Code	Description
Temperature	T1	Natural river temperature; no heat discharge
	T2	Heat discharge equivalent to 550 MW of heat
	T3	Heat discharge equivalent to 1,086 MW of heat
Discharge from Portage Waste-water Treatment Plant	P1	Discharge into Fox River
	P2	Discharge into Wisconsin River, no phosphorus/nitrogen
	P3	Discharge into Wisconsin River, with same phosphorus/nitrogen treatment as required for discharge into Fox River
Time of day	D	Daytime simulation
	N	Nighttime simulation
Location of additional power plant	C1	At present Columbia site (river mile 108.5)
	C2	At river mile 119.0
	C3	At river mile 130.0
Background nutrients in river	A1	Present-day levels of nitrogen and phosphorus
	A2	One-half present-day levels of nitrogen and phosphorus
	A3	Simulated levels of nutrients containing nitrogen concentrations limiting to growth of algae
	A4	One-half simulated levels of nutrients in scenario A3

SIMULATION OF HEAT DISCHARGE

The version of the QUAL-3 model used in this study did not have the capability of routing river temperatures. Such routing required a separate simulation of heat discharges from potential power plant sites. The simple one-dimensional model developed by Paily and Macagno (1976) for studying wintertime response of the Mississippi River to power plant discharge was adapted for summertime use in this study. This model solves the convective-dispensive equation for fully mixed river temperature T:

$$\frac{\partial T}{\partial t} + \frac{1}{A} + \frac{\partial}{\partial x}(QT) = \frac{1}{A}\frac{\partial}{\partial x} AE \frac{\partial T}{\partial x} + Rs \qquad (5)$$

where

- t is the independent time variable
- A is the cross-sectional area of flow
- Q is the flow rate
- E is the dispersion
- Rs are the temperature changes caused by the river-atmosphere heat flux

A prismatic river cross section was assumed (that is, one with constant width and depth) and no attempt was made to incorporate the effects of near-field thermal mixing processes. A predictor-corrector method, based upon a modified Crank-Nicholson procedure using the Thomas Algorithm (Ames 1977), was used to solve for the tridiagonal system of equations. (See Appendix G for a listing of this program).

Since the Wisconsin River usually reaches its lowest flow rates during the warmest parts of the year, we anticipated that its ability to carry waste heat from a power plant would be constrained heavily by limitations imposed by four factors: (1) the total amount of flow in the river (at minimum flow conditions), (2) the maximum tolerable increase in river water temperature, (3) the maximum temperature increase desirable from an efficiency standpoint for the cooling water as it passes through the condensers, and (4) the maximum amount of flow that could be directed from the river for cooling.

TABLE 5. SIMULATIONS PERFORMED ON THE QUAL-3 MODEL USING DIFFERENT COMBINATIONS OF OPTIONS LISTED IN TABLE 4

Simulation or run	Scenario option	Simulation or run	Scenario option
1	T1, P1, D, C1, A1	10	T1, P3, D, C1, A1
2	T1, P2, D, C1, A1	11	T3, P1, D, C1, A1
3	T1, P2, N, C1, A1	12	T3, P2, D, C1, A2
4	T2, P2, D, C1, A1	13	T2, P2, D, C2, A1
5	T2, P2, N, C1, A1	14	T2, P3, D, C2, A2
6	T2, P3, D, C1, A2	15	T2, P2, D, C3, A1
7	T2, P3, N, C1, A2	16	T2, P3, D, C3, A2
8	T1, P3, D, C1, A2	17	T2, P2, D, C1, A3
9	T1, P3, N, C1, A2	18	T2, P3, D, C1, A4

At 1,800 cfs low flow, waste heat from each 100 MW of generated power will raise the river temperature 0.84°F. If we assume that a 5°F temperature increase is the maximum that is tolerable during summer low flow conditions, the waste heat from 593 MW of waste energy, or slightly more than that produced by one of the Columbia units, could be passed into the river. If only one-half the flow (900 cfs) is diverted for cooling, the temperature of the cooling water would be expected to increase 10°F (or about 6°F less than the temperature difference at the influent and effluent ends of the cooling pond at the Columbia Station). Such an increase is well within normal operating designs for power plant condensers.

Hence, the essential constraints are the 5°F rule and the low flow rate. Heat discharge simulations in this study were thus based upon the waste heat discharge from a single Columbia unit, which would produce a 4.64°F increase in the Wisconsin River at 1,800 cfs.

Tables 6 and 7 summarize the various parameters that were used in the model for the three potential heat discharge locations to determine the temperature profiles downstream of these dischargers. All simulations were based on the assumption that all cooling waters diverted from the river for cooling would be returned to the river flow. Variables marked with "a" in Table 6 varied according to the location of the discharge and the reaches being modeled. Values for the clean sky solar radiation were based on a daily value of 900 cal/cm^2/day. These were prorated over a period of 13 h instead of 24 h so that the incoming solar radiation could be set at zero during nighttime hours. Values of air temperature and relative humiditywere chosen to represent typical hot weather periods during late July and early August. Steady-state temperatures in the simulations were obtained after integration for 10 days.

Compatibility between QUAL-3 simulations containing a power plant heat discharge and those based on natural river temperatuares was maintained by basing the natural river temperatures used in the QUAL-3 simulations on the no-heat discharge simulations of the Paily and Macagno (1976) model. Thus, daytime temperatures were set at 77.84°F upstream of river mile 122 and 78.78°F downstream of mile 122 and nighttime temperatures were set at 75.45°F upstream of mile 122 and 76.25°F downstream of mile 122.

Discharge From the Portage Wastewater Treatment Plant

The city of Portage is in the unusual position of being able to choose whether to discharge its treated wastewater into either the Great Lakes/St. Lawrence River watershed or into the Wisconsin/Mississippi River basin. Although discharge is presently into the Fox River and thence into Lake Michigan, discharging into the Wisconsin River is being considered. Table 8 summarizes the three discharge conditions used for simulations in this study. The unrealistically high levels of nitrogen discharges were used in Scenario P2 (Table 4) to ensure that maximum algal growth would take place in response to the phosphorus discharge from the Portage treatment plant.

TABLE 6. INPUT DATA USED IN PAILY AND MACAGNO (1976) HEAT MODEL SIMULATIONS

Variable	Description	Day	Both day and Night	Night
QE	Effluent flow rate	*		
TE	Increase in water temperature passing through plant	*		
QN	Natural river flow rate	1,800-QE cfs		
TR	Natural river temperature initially		*	
M	No. of elements		*	
DELX	Length of each element		1,056 ft	
DELT	Duration of each time step		900 sec	
WIDTH	Width of river		*	
DEPTH	Depth of river		*	
S	Scale factor		1.0	
E	Dispersion coefficient		*	
K_{MAX}	Total no. of time steps in simulation		960	
C	Amount of cloudiness	7.3 tenths		1.5 tenths
H	Cloud height	1,000 m		1,000 m
RH	Relative humidity	0.30		0.92
TA	Air temperature	26.7		21.6
PCL	Clear sky solar radiation	1,661.5 $\frac{cal}{cm^2}$/day		0.0 $\frac{cal}{cm^2}$/day
VA	Velocity of wind	3.50 m/sec		1.0 m/sec
PA	Air pressure	989.27 mb		989.27 mb
DAYSEC	Time of sunset/sunrise	72,000 sec		25,200 sec

*See Table 5 for values.

TABLE 7. TEMPERATURE MODEL INPUT DATA FOR DAY AND NIGHT SIMULATIONS (SEE APPENDIX G AND TABLE 4 FOR EXPLANATION OF VARIABLES)

Variables	Site at river mile 108.5		Site at river mile 119.0	Site at river mile 130.0
	108.5-104.5 (river)	104.5-100.0 (lake)		
QE (cfs)	900	0	900	900
TE (°F)	9.28	-	9.28	9.28
TR (°F)	77	77	77	77
M	50	50	100	100
Width (ft)	2,000	3,040.54	738	791
Depth (ft)	1.5	6.66	2.33	1.94
E ($miles^2$/day)	4	8	4.94	6.34

TABLE 8. INPUT DATA FOR DISCHARGE CONDITIONS FROM PORTAGE WASTEWATER TREATMENT PLANT

Variable	No discharge (discharge into Fox River)	Discharge with no phosphorous nitrogen treatment	Discharge with removal of phosphorus/nitrogen
Discharge (cfs)	0	3.09	3.1
BOD (mg/liter)	-	30	30
DO (mg/liter)	-	2.0	5.0
Ammonia (mg/liter)	-	6.0	1.0
NO_2/NO_3 (mg/liter)	-	144	12
PO_4 (mg/liter)	-	12	3.0

NUTRIENT LEVELS IN THE RIVER

Five nutrient scenarios were created to simulate the various conditions of nitrogen and phosphorus concentrations and discharges into the Wisconsin River (Table 9). Scenario A0 was created as a special case of present-day conditions with no limits to algal growth. Scenario A1 represents the best approximation to present-day conditions as represented by the WDNR measurements. Almost all the phosphorus in the river was assumed to be tied up in the algae; hence this scenario represents a phosphorus-limiting condition for the growth of algae.

Scenario A2 considers the effect of a program to reduce both point and non-point sources of phorphorus and nitrogen discharges into the Wisconsin River. The nitrogen and dissolved phosphorus levels at the headwater of the model, Kilbourn Dam, and in water entering the model as incremented run-off were assumed to be half of those in Scenario A1.

Scenarios A3 and A4 examined the effects of limited levels of nitrogen on algal growth. In Scenario A3 the level of nitrogen from run-off conditions was reduced to one-fourth the level of Scenario A1 and in Scenario A4 it was reduced to one-eighth the level of A1. In Scenarios A3 and A4 values of dissolved phosphorus entering the model at Kilbourn Dam were assumed to be 10 times greater than in Scenario A1 and Scenario A2. Levels of nitrate entering the flow at the headwater were assumed to be less than one-third of the level in Scenarios A1 and A2. Levels of nutrients in Scenario A4 were set at one-half the levels assumed in Scenario A3.

OTHER SIMULATION CONDITIONS

All daytime simulations were run as steady-state runs, in which 15 h of model time were allowed for steady-state to be reached. Nighttime conditions were considered to be nonsteady-state; hence, they were simulated as dynamic runs using the steady-state daytime conditions as initial conditions. Maximum dynamic simulation time was 10 h, using a time step of 15 min. Nighttime algal oxygen production was set at zero and nighttime temperatures predicted by the heat model were employed.

Model tuning was performed with discharge conditions as they were in the summer of 1978 (i,e., no Portage discharge and primary treatment discharges from Wisconsin Dells and Lake Delton Sewage Treatment Plants), but scenario simulations were carried out with the possible wastewater loads anticipated for the year 2000.

TABLE 9. HEADWATER AND RUN-OFF CONDITIONS OF NITROGEN AND PHOSPHORUS FOR NUTRIENT LEVEL SCENARIO CLASSIFICATION

Parameter	A0	A1	A2	A3	A4
Headwater conditions					
Flow (cfs)	1,788	1,788	1,788	1,788	1,788
Temperature (°F)	77.84	77.84	77.84	77.84	77.84
Dissolved oxygen (mg/liter)	8.3	8.3	8.3	8.3	8.3
Short-term BOD (mg/liter)	0	0	0	4.0	4.0
Long-term BOD (mg/liter)	4.0	4.0	4.0	0	0
Chlorophyll-a (/liter)	21	21	21	21	21
Ammonia (mg/liter)	0.10	0.10	0.05	0.10	0.05
Phosphorus (mg/liter)	0.10	0.01	0.005	0.10	0.05
Nitrite (mg/liter)	0.20	0.002	0.001	0.002	0.001
Nitrate (mg/liter)	0.01	0.20	0.10	0.06	0.03
Organic Nitrogen (mg/liter)	0.80	0.80	0.40	0.80	0.40
Run-off conditions					
Flow (cfs/mile)	0.01/0.03	0.01/0.03	0.01/0.03	0.01/0.03	0.01/0.03
Temperature (°F)	70	70	70	70	70
Dissolved oxygen (mg/liter)	7.0	7.0	7.0	7.0	7.0
Short-term BOD (mg/liter)	0.	0.	0.	0.7	0.7
Long-term BOD (mg/liter)	0.7	0.7	0.7	0	0
Nitrite (mg/liter)	0.10	0.10	0.05	0.05	0.025
Nitrate (mg/liter)	4.0	4.0	2.0	0.2	0.1
Phosphorus, dissolved (mg/liter)	0.03	0.03	0	0.03	0.015
Organic nitrogen (mg/liter)	0.80	0.80	0.40	0.20	0.10

SECTION 6

RESULTS OF SIMULATIONS

INITIAL MODEL RUNS AND MODEL FITTING

Initial runs were performed with the QUAL-3 model using present-day conditions (Run 1, Figure 8) and with nutrient values equivalent to those in Scenario A3. The following discrepancies appeared between the model results and data collected by the WDNR, the USGS, and by this study: (1) simulated levels of dissolbed oxygen were lower than observed levels for miles 106.4 to 102.0, (2) simulated levels of phosphorus and nitrates were much lower than observed levels, (3) the model predicted levels of biochemical oxygen demand (BOD) in Lake Wisconsin that were about one-fourth the observed levels, and (4) simulated organic nitrogen levels were only one-half of observed levels. The nutrient discrepancy may have been caused by lower incremental run-off of nutrients in the model than actually is the case, by inadequate production of algal biomass as a result of nitrification, or by to rapid settling out of the algal biomass to the bottom of the river in the model. The precipitous drop in the levels of dissolved oxygen and BOD in the part of the model where Lake Wisconsin begins is due to four important factors: (1) reduced aeration due to the lower flow velocities and less mechanical mixing, (2) greater settling rates of particulates (3) die-off of some of the algal biomass due to reduced sunlight in deeper water, and (4) greater detention time in each computational element of organically decaying matter.

Tuning activities in this study were limited to producing a modeling tool reliable for the evaluation of the various trade-offs between heat, BOD, and nitrogen/phosphorus discharges. More elaborate tuning would have been required to develop a water quality enforcement and monitoring tool. The following changes from the initial runs (Scenarios A3 and A4 in Table 9) were made. (1) All BOD entering the model through the headwater or from incremental run-offs was assumed to have a decay rate 0.08/day lower than BOD from sewage treatment plant discharges. (2) The levels of nitrogen in the model were increased, primarily in the incremental run-off, so as to increase the model's sensitivity to phosphorus discharges into the river. (3) Because of the extremely low levels of orthophosphorus found in the field survey, almost all the background phosphorus in the model was assumed to be part of the algal biomass. (4) The levels of dissolved phosphorus entering the region was reduced by a factor of 10 in the QUAL-3 simulations. This adjustment was made because the total amount of observed phosphorus (including that in the algal biomass) in the Wisconsin River near Lake Wisconsin was 0.02 to 0.05 mg/liter, whereas the initial runs simulated total phosphorus levels to be 0.12 to 0.14 mg/liter. These changes produced somewhat higher BOD and dissolved oxygen values in the Lake Wisconsin parts

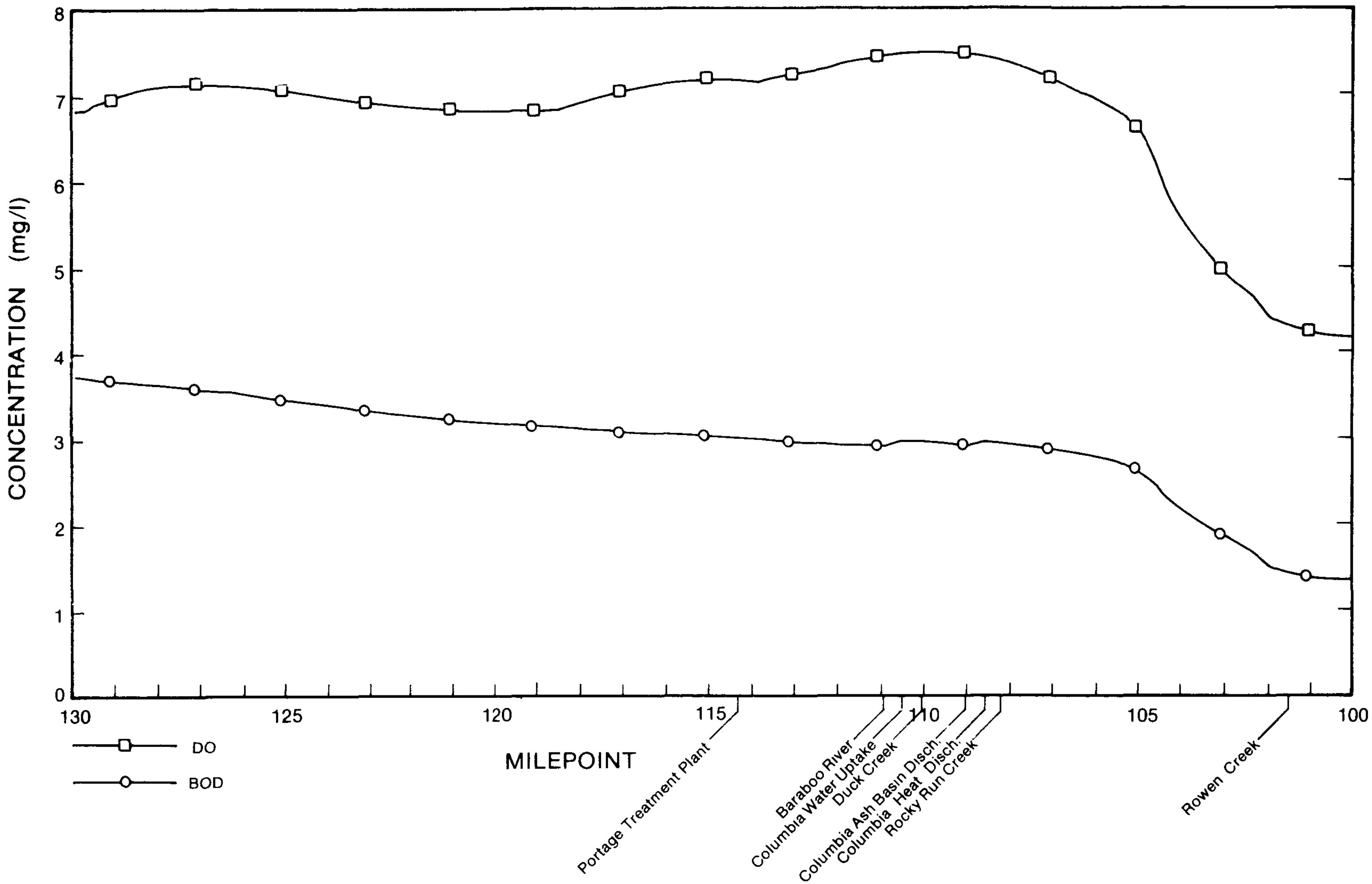

Figure 8. Levels of dissolved oxygen (DO) and biochemical oxygen demand (BOD) in the Wisconsin River in the simulation of present-day conditions (run 1). (See Table 4 and Table 5.)

of the model. In addition, total phosphorus levels in the model more closely matched the values obtained in the field survey.

An additional refinement in the model simulations was required because of the imminent upgrading of the Wisconsin Dells Sewage Treatment Plant and the closing of the Lake Delton Sewage Treatment Plant. Because of the lack of information on the nitrogen/phosphorus content of the effluents of these two treatment plants,, their effects were not included. Nevertheless, the simulations indicated a modest decrease in the level of total BOD in the river and no apparent increase in the dissolved oxygen level. The reasons for this are (1) levels of dissolved oxygen are already close to saturation and (2) most of the BOD entering the model (just below Kilbourn Dam at Wisconsin Dells) is the slow biodegrading type resulting from industrial discharges into the upper Wisconsin River. Hence, the small decrease in overall BOD had a negligible effect on the levels of dissolved oxygen. The remaining scenarios assumed discharge from a new Wisconsin Dells Sewage Treatment Plant.

Nighttime simulations indicated little change from the daytime steady-state simulations and, therefore, only the daytime results are discussed.

SIMULATED EFFECTS OF HEAT DISCHARGES

Conversion of Heat Model Output to QUAL-3 Reach Temperatures

Simulations were performed for heat discharges at three locations along the Wisconsin River that were considered as possible sites for future electric generating stations: (1) at mile 108.5 (site of present Columbia Generating Station), (2) at mile 119.0, and (3) at mile 130.0 (approximately 16 miles northwest of Portage). Simulations at the first discharge location extended into Lake Wisconsin, which resulted in wide discrepancies between the convective transports in the heat model (which are the same everywhere in the model) and convective transports in the QUAL-3 model, where river velocities are allowed to vary by reach.

In the heat model the deeper, slower-moving water in Lake Wisconsin impeded cooling because of the smaller ratio of surface area to water volume. The reduced rate of the convective transport of high temperatures downstream, which gave the water "more time" to cool down, counteracted this trend. Preliminary tests indicated that the convective transport effect might dominate until the depth became great enough for the lake effect to predominate. To capture this effect, the simulations of heat discharges from the present Columbia site were split into two parts, the first covering from mile 108.5 to 104.5, where the river behaved mostly like a river, and the second from 104.5 to 100.0, where the behavior was similar to a lake. For the first simulation, the convective variations were assumed to predominate. The detention time in each QUAL-3 element was converted into a distance in the heat model using the average (constant) velocity in the heat model. These distances were then converted into the appropriate element numbers by dividing the horizontal element size by DELX in the heat model. For temperature simulations with a large air/water temperature differential, this method would not represent an accurate picture of the thermodynamic processes at work. However, since the air temperature was within 5°C of the water temperature in this study, mixing an densimetric instability effects were probably minimal.

In the lake portion of the first simulation, perfect matching with the river portion was not obtained. However, the temperature gradient observed in the lake simulation was used to extrapolate the temperature from mile 104.5 to mile 100.0. The resulting temperatures used in the QUAL-3 simulations are shown in Figure 9a. The square-toothed pattern results from specifying averages by QUAL-3 reach (except for nighttime simulations in which temperatures were specified by computational element).

Simulations of heat discharges at miles 119.0 and 130.0 covered regions of the river where the flow velocities are thought to be much more uniform. Therefore, a direct one-to-one distance mapping from the heat model to the QUAL-3 model was used. Temperatures used in simulations of discharges from these sites are presented in Figure 9b. The slightly elevated Lake Wisconsin temperature (at mile 100.0) for the simulation of heat discharge at mile 130.0 is the result of higher dispersive and convective transports assumed in that heat simulation.

Effects of Heat Discharges from Three Power Plant Sites

Discharges of waste heat at miles 108.5, 119.0, and 130.0 are compared in Figure 10. In these simulations dissolved oxygen dropped 0.30 mg/liter in stretches of the river 12 to 18 miles downstream of the discharge points. Although some of this effect resulted from the reduced concentration of oxygen at saturation due to higher temperatures, the dotted curve in Figure 11 indicates that this reduction in dissolved oxygen was reversed by reductions of the nitrogen and phosphorus levels in the river (from Scenarios A1 to A2). In general, runs 14 and 18 (Table 5) indicate that the overall balance of nutrients in the river would affect the level of dissolved oxygen to a greater extent than the position of any heat discharge.

These results illustrate the complex interaction among the various constituents of nitrogen, phosphorus, algae, dissolved oxygen, and the rates of reaction affecting algal growth, nitrification, and denitrification. In general, the higher levels of nitrogen and phosphorus is the presence of a heat discharge caused greater drops in the levels of dissolved oxygen, especially where mechanical reaeration was limited in the backwaters of Lake Wisconsin. At the same time, nitrate levels dropped more rapidly, and ammonia and nitrite levels increased somewhat (Figure 12, 13 and 14). The complex relationships among levels of these nutrients were not analyzed in depth in this study, but the preliminary simulations indicated that higher ammonia levels resulted from heat addition to both low- and high-level nitrogen/phosphorus backgrounds (Scenarios A1 and A2).

Simulations were run with extremely high heat discharges at river mile 108.5. The addition of heat equivalent to that produced by generation of 1,086 MW of electricity is enough to raise the river temperature 10°F at 1,800 cfs. In the absence of any effluents from the Portage Wastewater

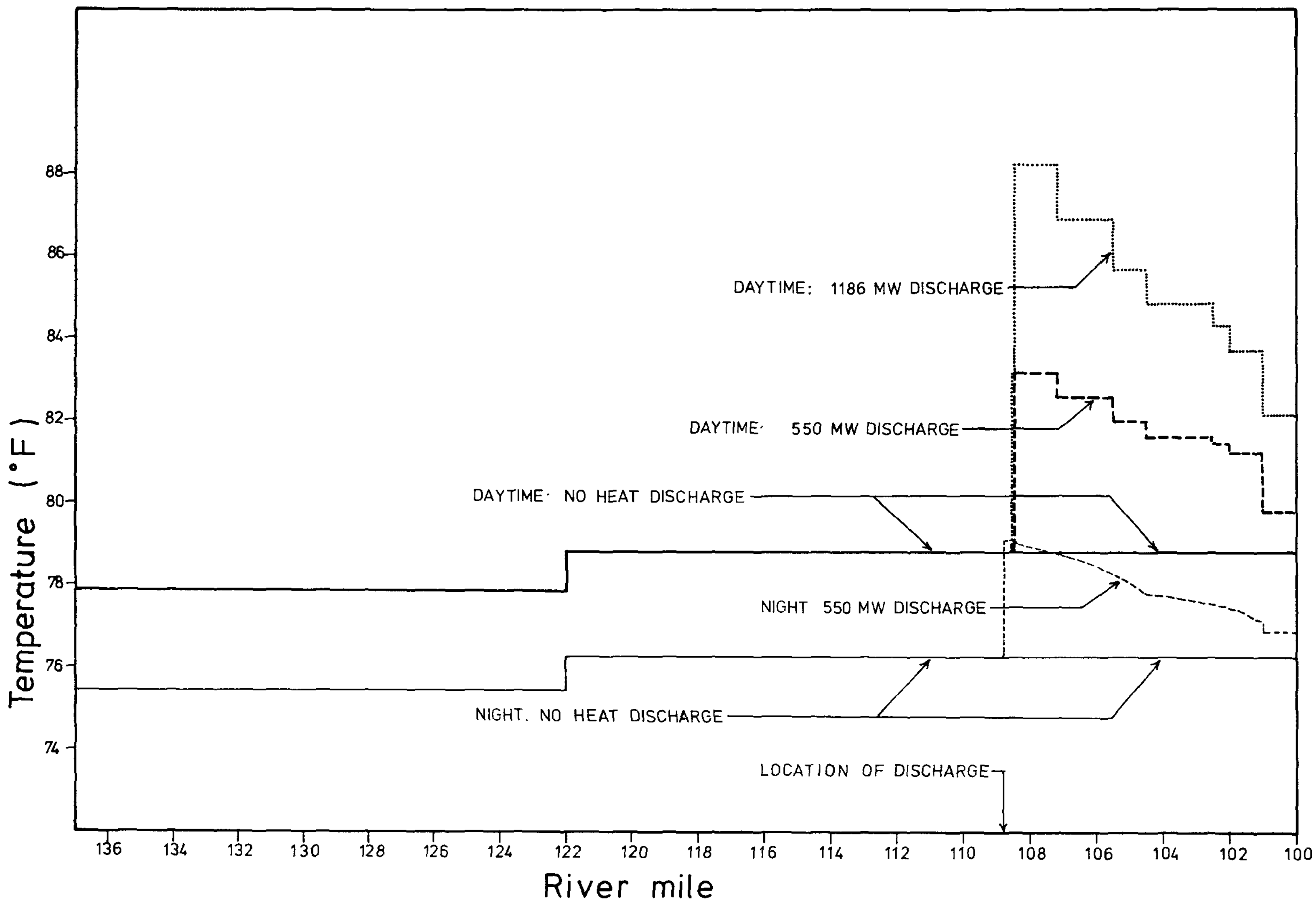

Figure 9a. Temperatures used in QUAL-3 simulations of heat discharges from the site of the Columbia Generating Station (river mile 108.5). All temperatures, except those for the nighttime simulations of 550 MW heat discharges, were specified in the QUAL-3 model according to averages within each reach.

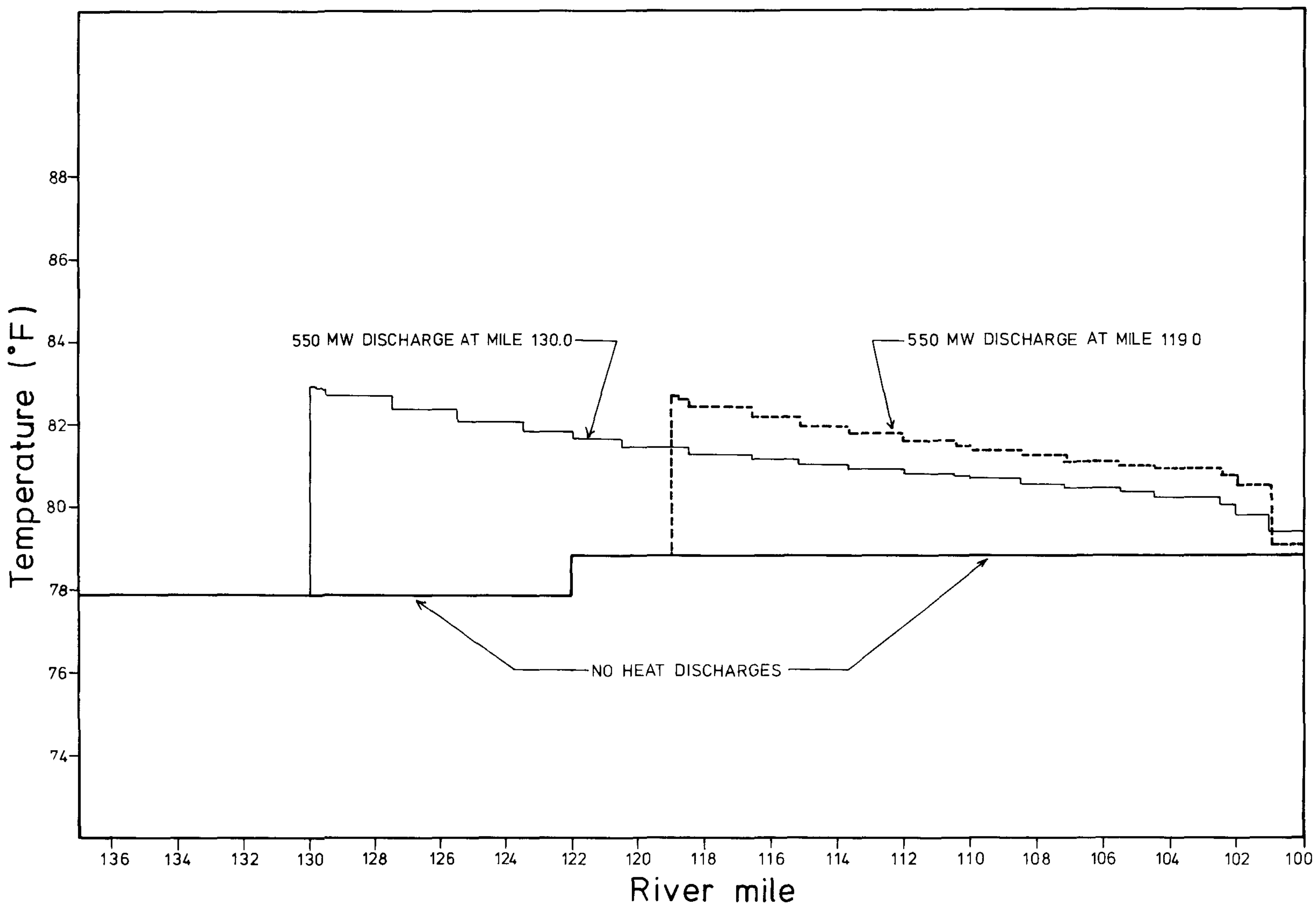

Figure 9b. Temperatures used in QUAL-3 simulations of heat discharges from possible power plant sites at river miles 119.0 and 130.0.

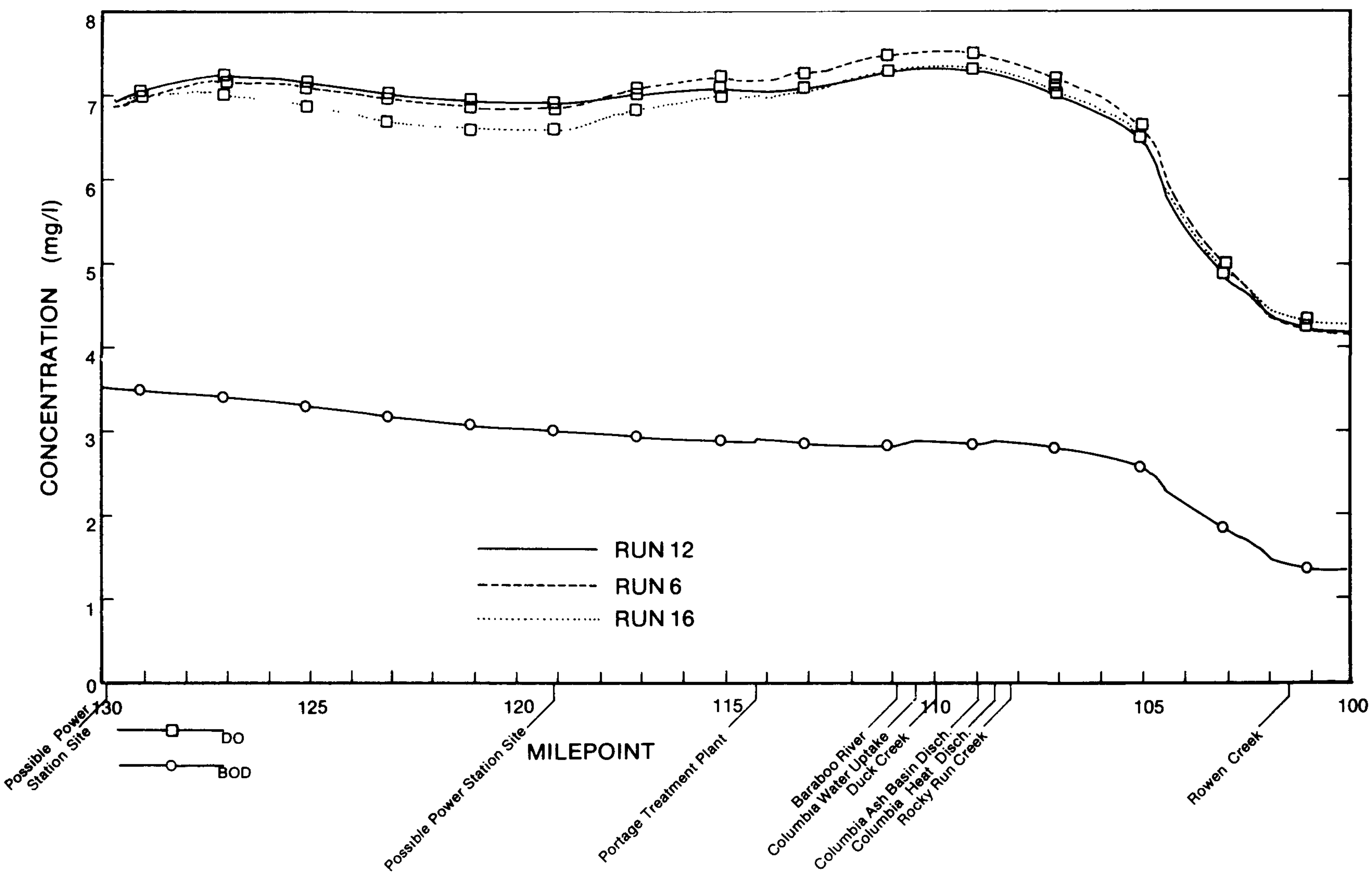

Figure 10. Levels of dissolved oxygen (DO) and biochemical oxygen demand (BOD) in the Wisconsin River assuming heat discharges from power plants at miles 108.5 (run 6), 119.0 (run 12), and 130.0 (run 16). (See Table 4 and Table 5.)

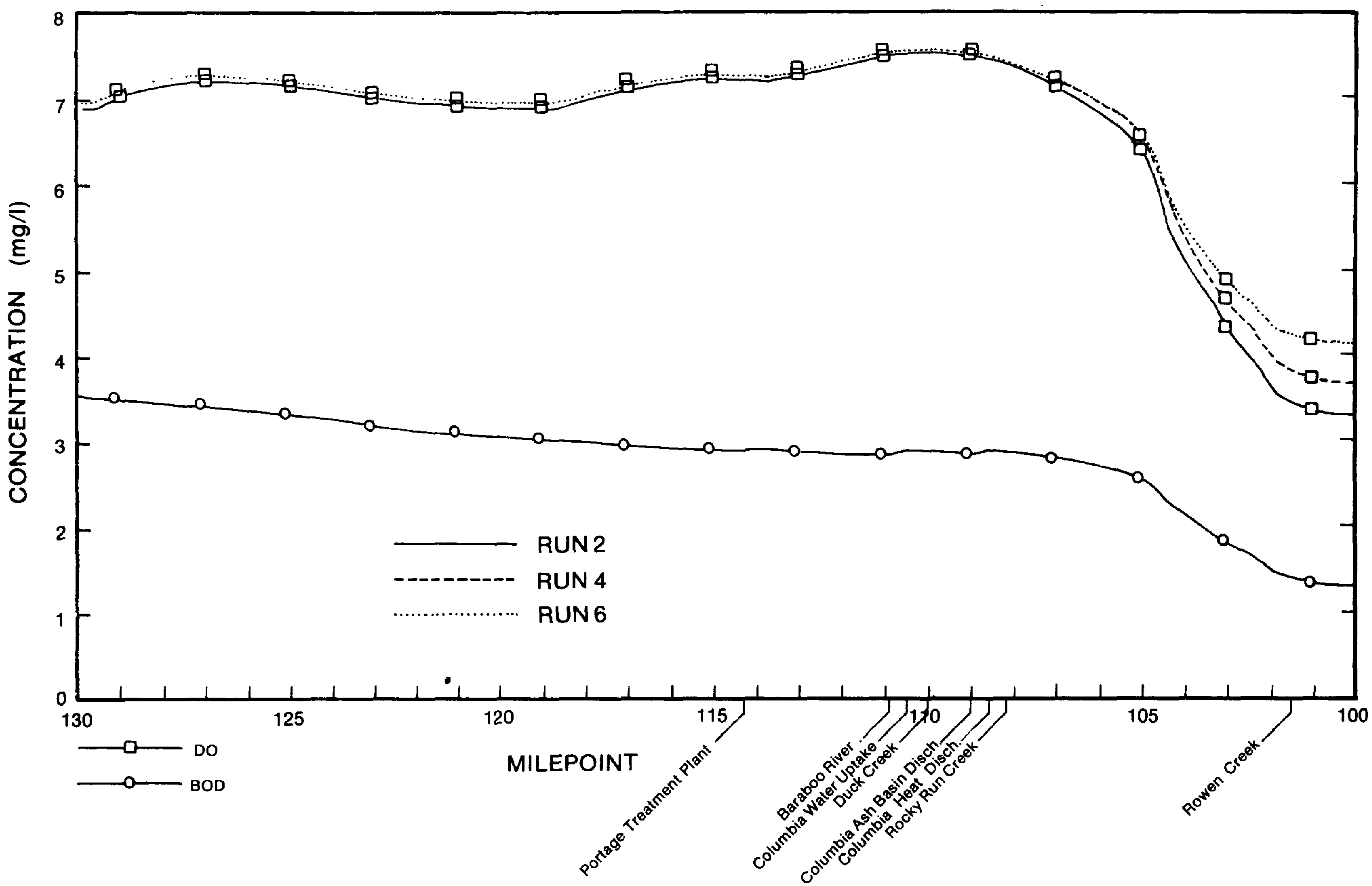

Figure 11. Levels of dissolved oxygen (DO) and biochemical oxygen demand (BOD) in the Wisconsin River assuming no heat discharge (run 2), 550-MW heat discharge at river mile 108.5 (run 4), and the same heat discharge but with reduced nitrogen/phosphorus levels (run 6). (See Table 4 and Table 5.)

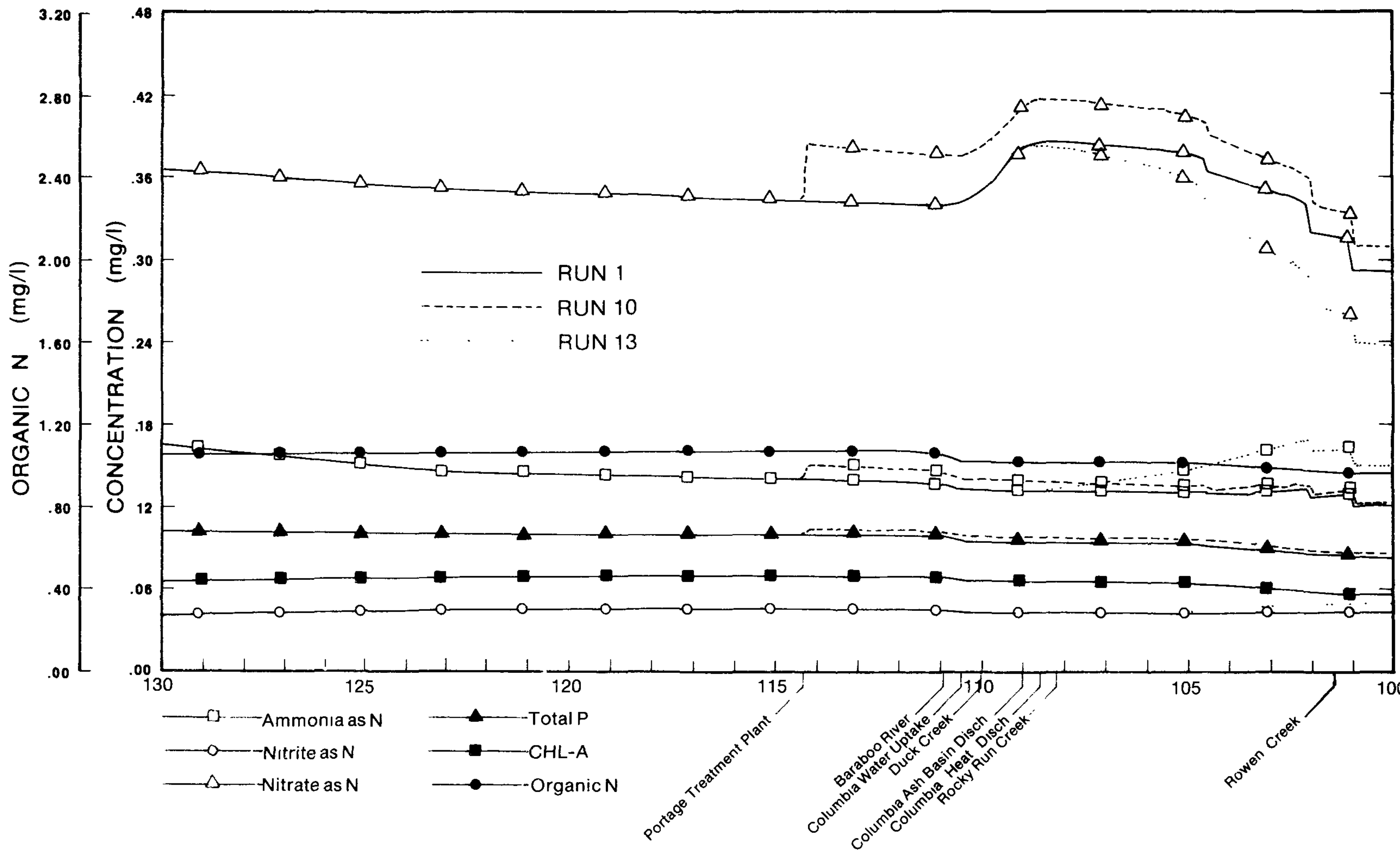

Figure 12. Levels of nutrients in the Wisconsin River assuming the conditions specified for runs 1, 10, and 13. (See Table 4 and Table 5.)

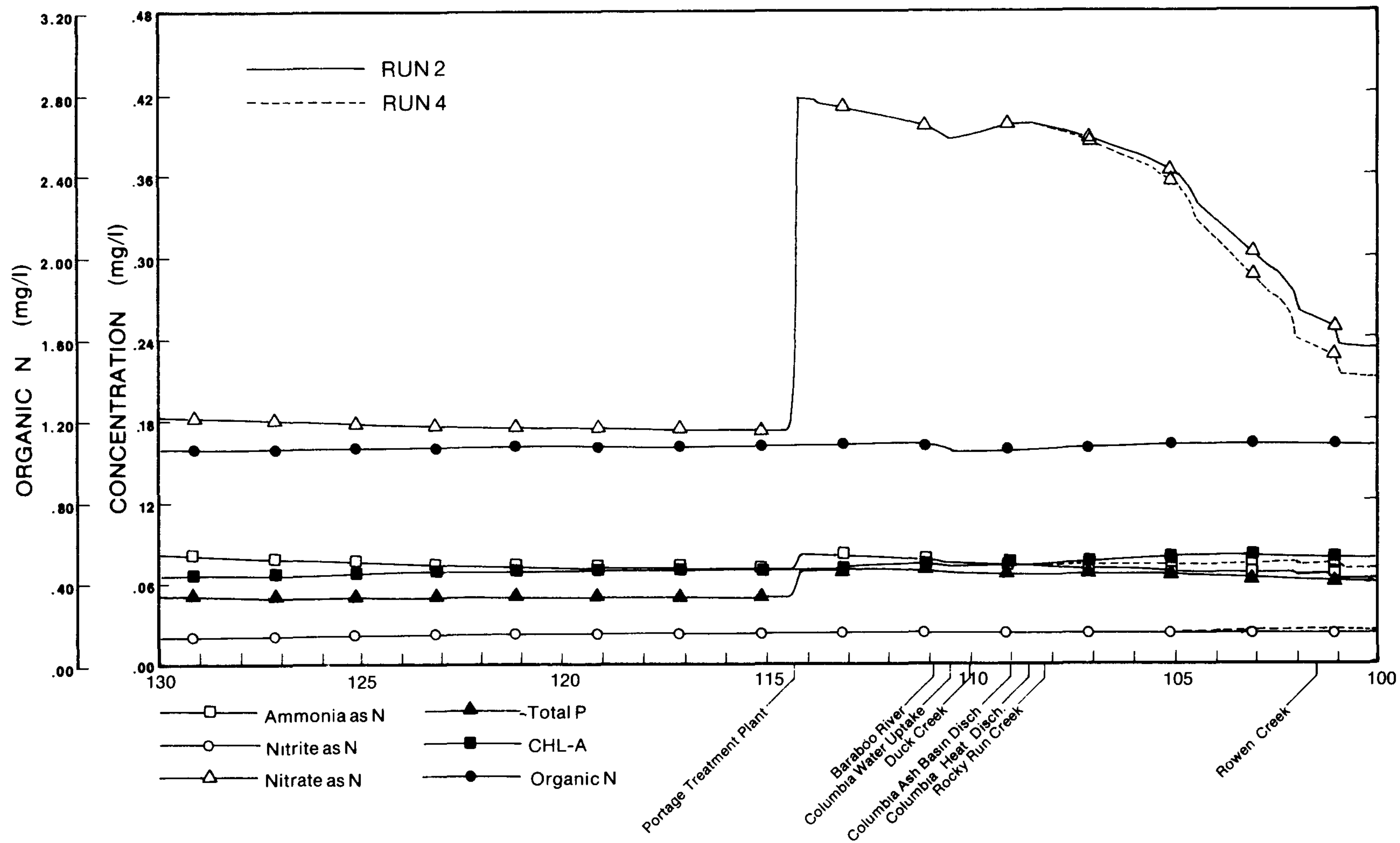

Figure 13. Levels of nutrients in the Wisconsin River assuming the conditions specified for runs 2 and 4. (See Table 4 and Table 5.)

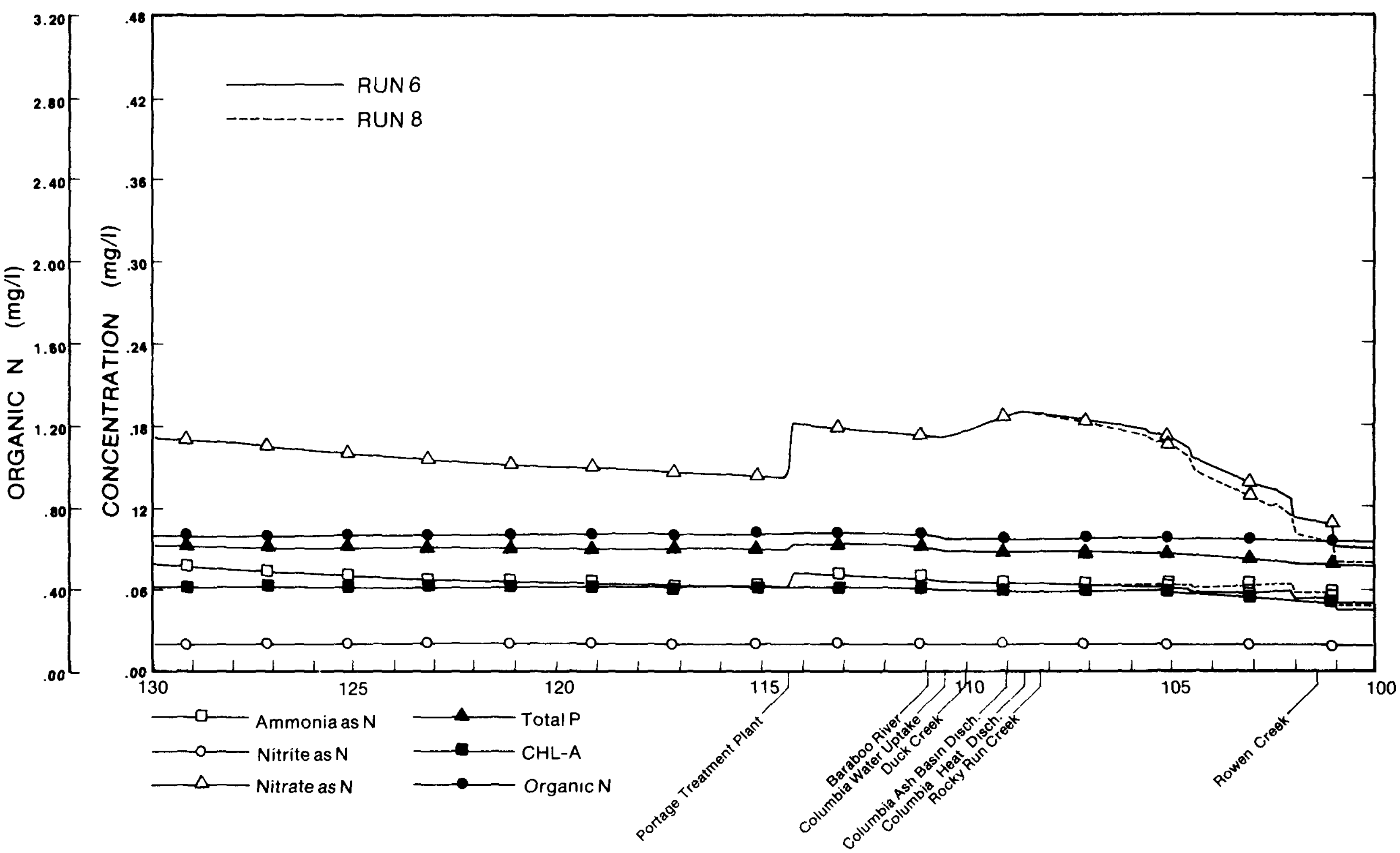

Figure 14. Levels of nutrients in the Wisconsin River assuming the conditions specified for runs 6 and 8. (See Table 4 and Table 5.)

Treatment Plant, this amount of heat produced conditions very similar to the discharge of heat from 550 MW of electric generation with discharges from Portage having high levels of nutrients (Figures 15 and 16). Such a high level of heat discharges was not intended to be a realistic scenario, but by including it we hoped to explore the practical limits of the river's capacity for waste heat. The results are not conclusive since the simulated temperatures probably exceeded the range for which the QUAL-3 model is valid. Nevertheless, the high heat simulations were useful in clarifying two effects: (1) Addition to heat does lower the dissolved oxygen simply because of the lowered level of saturation of dissolved oxygen in warmer water and (2) the presence of nutrients increases the river's sensitivity to the adverse effects of heat discharges, especially in the region of Lake Wisconsin. The exact mechanisms causing this second effect are unclear, but they seem to be linked to the increased rates of algal growth in the flowing parts of the river and to elevated levels of oxygen consumption as the algae die and consume oxygen in decomposition.

SIMULATED EFFECTS OF DISCHARGES FROM PORTAGE WASTEWATER TREATMENT PLANT

Simulations showing the effects of various types of discharges from an outfall of the Portage Wastewater Treatment Plant into the Wisconsin River are depicted in Figure 15. In all cases a tiny increase in the BOD level is predicted. The most likely scenario for the level of dissolved oxygen is the middle curve below mile 108, labeled "without Portage POWTP discharge." These conditions are almost identical to those simulated with present-day levels of background nitrogen and phosphorus in the river, 80% phosphorus removal (and similar reductions in nitrogen levels) from any Portage effluent, and heat discharge equivalent to 550 MW of electrical generation into the river at mile 108.5 (see Figure 9). In the absence of heat discharges, discharge from the Portage outfall is expected to raise dissolved oxygen levels by 0.5 mg/liter at mile 100.0.

Although the Portage discharges were simulated to take place at mile 114.2 (Figure 4a), the effects of the discharges might extend considerably downstream. Because of the continually decreasing velocity of flow, the deeper water, and the decreasing reaeration as the river becomes influenced by the backwaters of Lake Wisconsin below mile 106.4, the classical oxygen sag curve is not evident. Figure 15 indicates that the most sensitive area for maintenance of adequate water quality in terms of sufficient levels of dissolved oxygen is the deeper, more stagnant Lake Wisconsin, as opposed to the reaches of the river immediately downstream of Portage.

An additional scenario (P2) was run assuming a high phosphorus discharge from the Portage Wastewater Treatment Plant whose effects are not limited by nitrogen (solid line in Figure 11). This configuration is the extreme case, representing the maximum possible drop in the level of dissolved oxygen in Lake Wisconsin caused by potential discharge from the Portage treatment plant, with the possible exception of unpredictable effects of algal blooms in Lake Wisconsin.

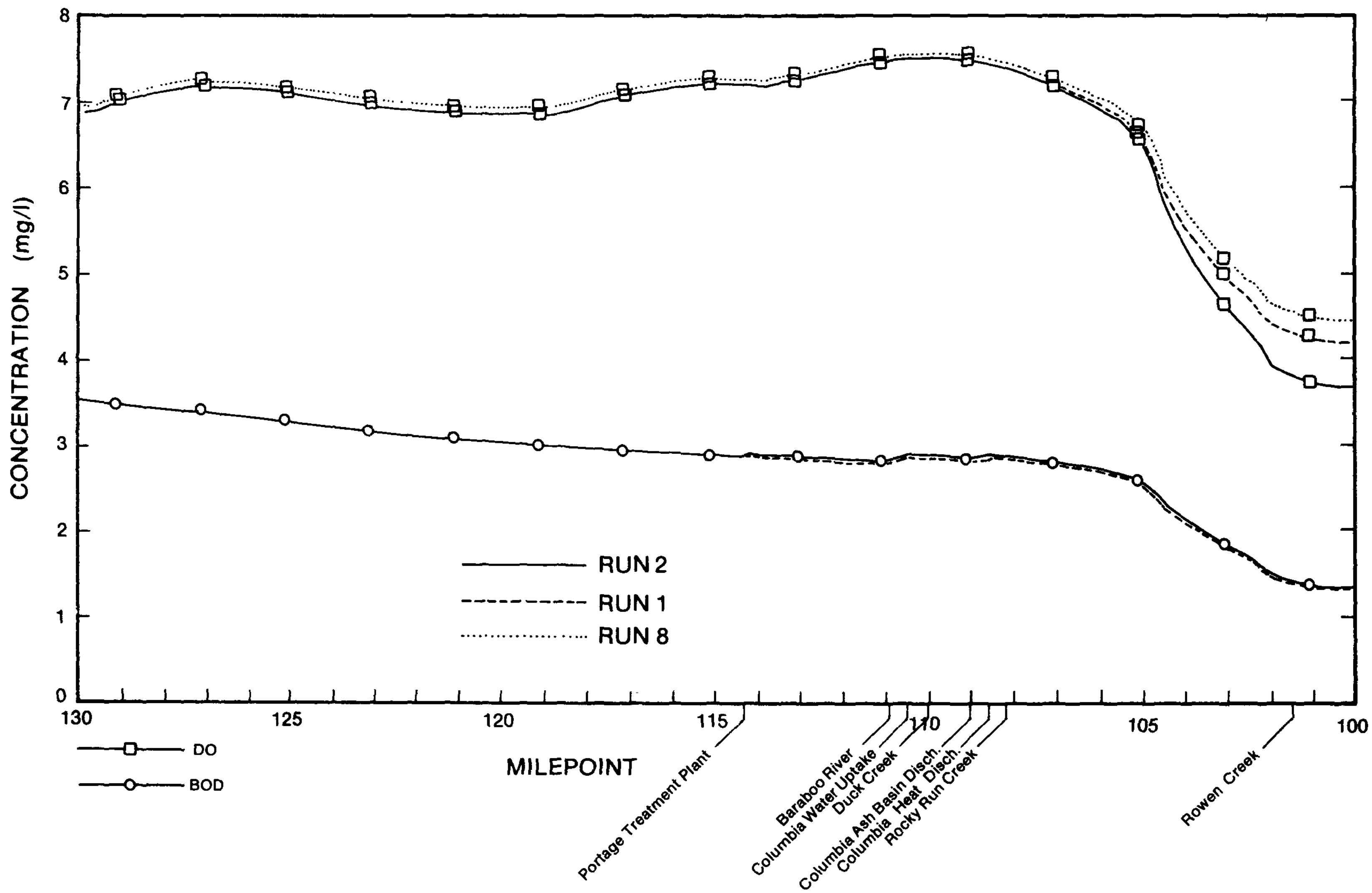

Figure 15. Levels of dissolved oxygen (DO) and biochemical oxygen demand (BOD) in the Wisconsin River assuming the conditions specified for runs 1, 2, and 8. (See Table 4 and Table 5.)

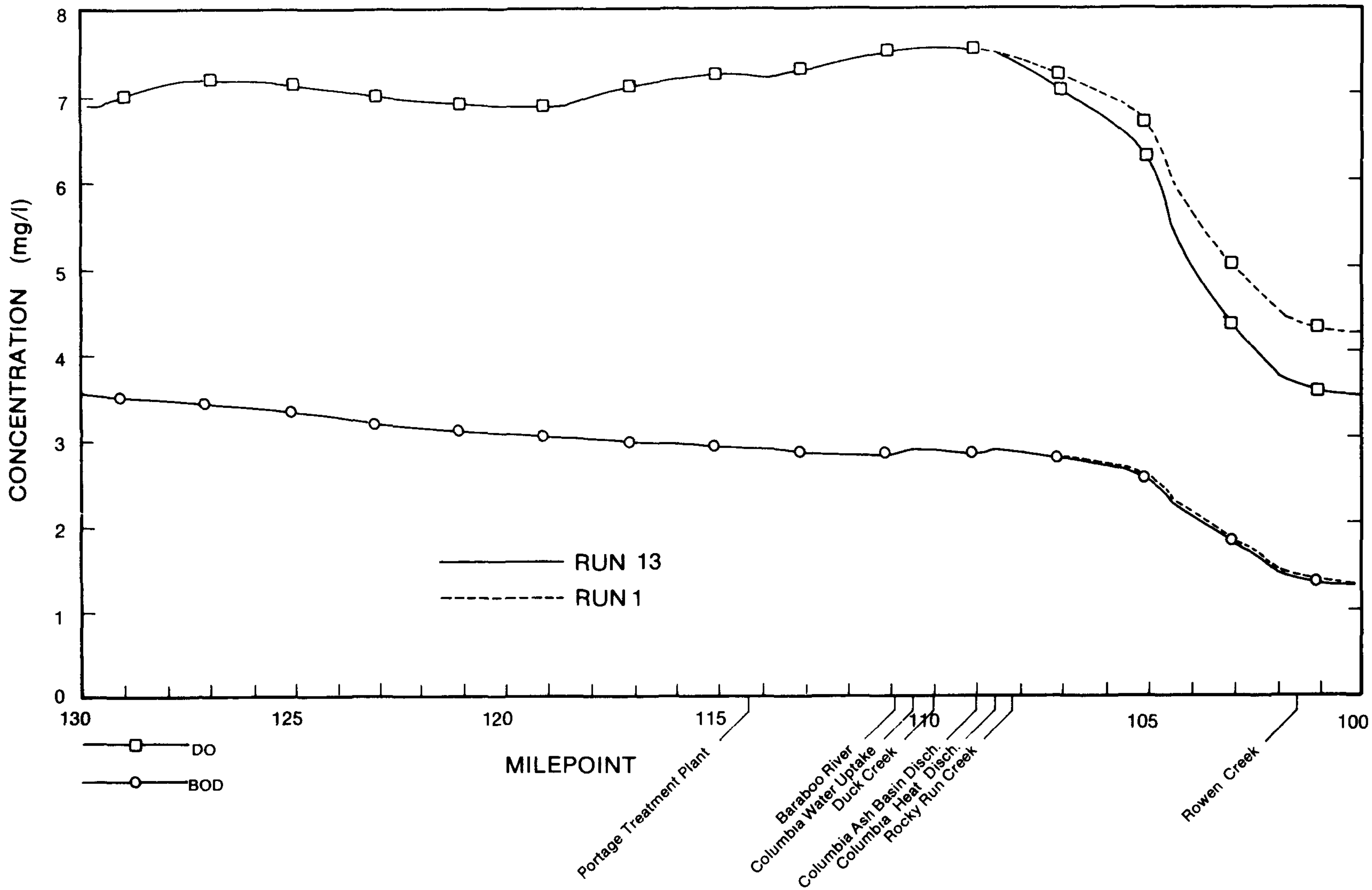

Figure 16. Levels of dissolved oxygen (DO) and biochemical oxygen demand (BOD) in the Wisconsin River assuming the conditions specified for runs 1 and 13. (See Table 4 and Table 5.)

EFFECTS OF NUTRIENT LEVELS IN THE WISCONSIN RIVER

The levels of nitrates and dissolved phosphates had the greatest effects on dissolved oxygen levels in the study region. Figure 17 compares results of four simulations using four levels of background nitrogen and phosphorus and with treated versus untreated nutrient discharge from the Portage Wastewater Treatment Plant. The most significant results are that as the nutrient load increases, the level of dissolved oxygen decreases and that the largest decreases in dissolved oxygen tend to occur in Lake Wisconsin (below river mile 106.4).

Increased nutrient levels have the potential of causing sudden and extensive algal growth, which in turn may lead to algal blooms. Such developments are difficult to predict and simulate, but they are extremely significant, for as the algae die it rapidly decreases the level of dissolved oxygen. Nowhere in the simulations performed were large growths of algae experienced. An unsuccessful attempt was made to simulate the effects of an increase in the dissolved phosphorus level at the headwater of the model from 0.01 to 0.03 mg/liter. It was anticipated that this simulation would create higher levels of algal growth and correspondingly lower levels of dissolved oxygen, especially in Lake Wisconsin. If this were the case, the Wisconsin River in the region studied would be limited by the amount of dissolved phosphorus that could enter the river either at the headwater or from any sewage treatment plant in the region.

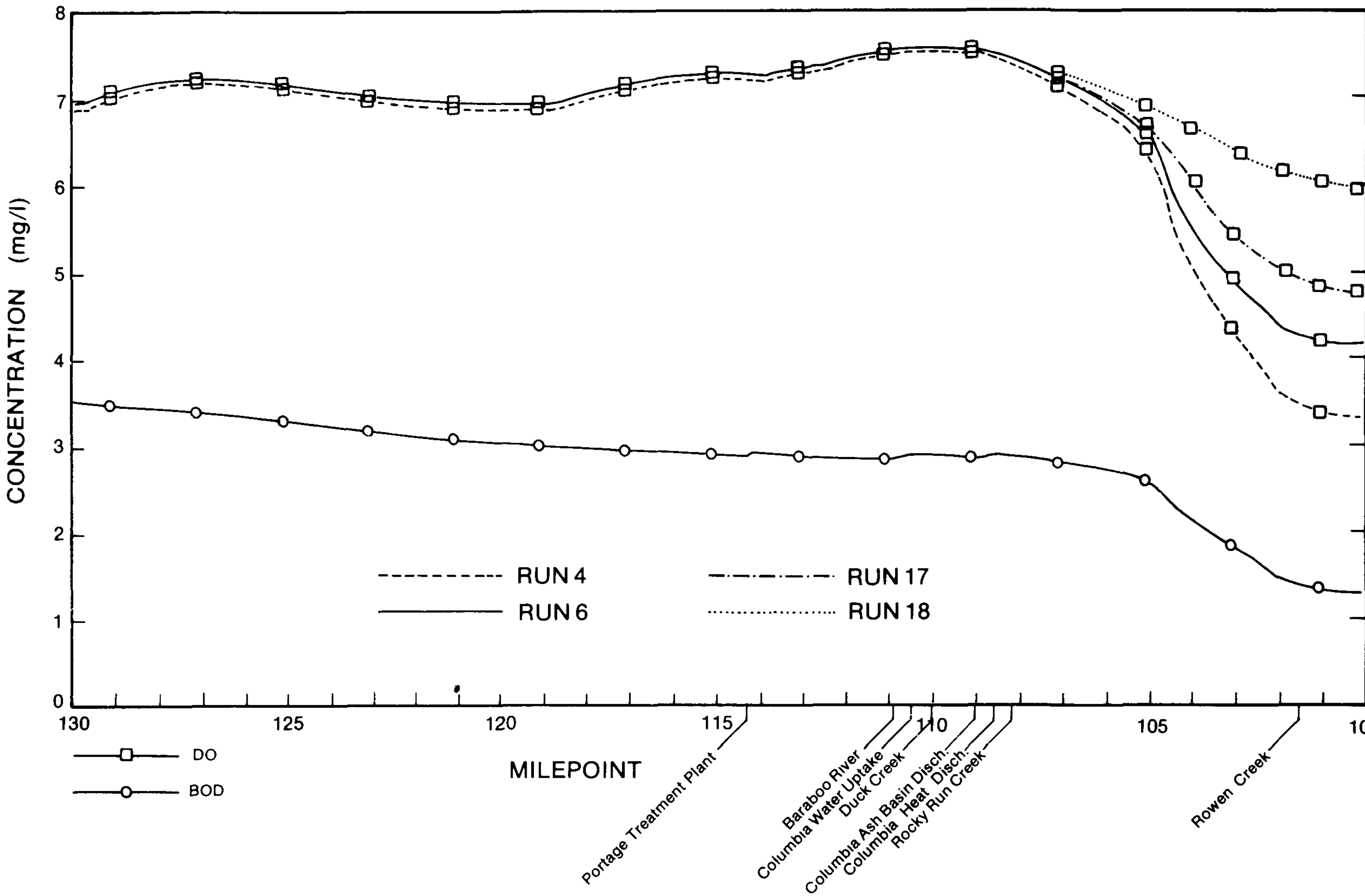

Figure 17. Levels of dissolved oxygen (DO) and biochemical oxygen demand (BOD) in the Wisconsin River assuming the conditions specified for runs 4, 6, 17 and 18. (See Table 4 and Table 5.)

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APPENDIX A

CARD INPUT USED IN QUAL-3 SIMULATIONS

Data and constants are provided as card input to the QUAL-3 model using the formats as described in the documentation to the QUAL-3 model (Patterson and Rogers 1978). Input data for Run 2 is presented in this section along with abbreviated card listings for the baseline, P1, and P3 scenarios. Variables and rate constants are the same as those in Tables 2 and 9. Concentrations are in mg/liter, except for chlorophyll-a, which is in µg/liter. Temperatures are in degrees Fahrenheit.

WISCONSIN DEPT. OF NATURAL RESOURCES

* * * DATA LIST FOR MODIFIED QUAL3 STREAM QUALITY ROUTING MODEL * * *

$$$ (PROBLEM TITLES) $$$

```
CARD TYPE                        QUAL-I PROGRAM TITLES
TITLE01             TWDB/WRE/DP-DNR VERSION QUAL-3
TITLE02             NAME OF BASIN = WIS. RIVER IN VICINITY OF PORTAGE, WISC.
TITLE03  YES        ALGAE VS BENTHIC DEMAND
TITLE04   NO        WRITE A RESTART FILE
TITLE05   NO        READ AND WRITE A RESTART FILE
TITLE06   NO        TEMPERATURE SIMULATION
TITLE07  YES       BODXY BIOCHEMICAL OXYGEN DEMAND IN MG/L
TITLE08  YES        ALGAE AS ALGAE IN MG/L
TITLE09  YES        PHOSPHOROUS SIMULATION
TITLE10  YES        AMMONIA AS N IN MG/L
TITLE11  YES        NITRITE AS N IN MG/L
TITLE12  YES        NITRATE AS N IN MG/L
TITLE13  YES        DISSOLVED OXYGEN IN MG/L
TITLE14   NO        COLIFORMS
TITLE15  YES        TELETYPE OUTPUT
TITLE16  NO         CALCOMPLOT
TITLE17  YES        CALCULATE BENTHIC UPTAKE VS  S.S.
TITLE18  YES        ORGANIC N SIMULATION
ENDTITLE
```

$$$ DATA TYPE 1 (CONTROL DATA) $$$

```
CARD TYPE                                     CARD TYPE
LIST OF DATA                                  BEGIN PRINT RCH            1.
NO FINAL SUMMARY                              END OF PRINT              25.
NO FLOW AUGMENTATION                          TELETYPE PRINT INTERVAL     5.
STEADY STATE SIMULATION                       FRACTION BENTHIC DEMNND   1.0
NUMBER OF REACHES          25.                NUMBER OF JUNCTIONS        0.
NUM    OF HEADWATERS      1.                  NUMBER OF WASTLOADS       13.
TIME STEP HOURS DELT      .25                 LENTH. OF COMP. ELEM. MI  .1
MAXIMUM ROUTE TIME         11.                TIMR INC FOR RPT2         10.
ENDATA1
O UPTAKE BY NH3 (MGO/MGN)        3.4     O UPTAKE BY NO2 (MGO/MGN)           1.14
O PROD BY ALGAE (MGO/MGN) A3   2.00      O UPTAKE BY ALGAE (MGO/GMA) A4  1.50
N CONTENT OF ALGAE(MGN/MGA) A1  .06      P CONTENT OF ALGAE(MGP/MGA) A2  .01
ALG  TIME TO FIRST PRINT     =   00.     DENITRIFICATION RATE(1/DAY)         .4
N HALF ST CONSTANT MG/L CKN     .02      P 1/2 SAT CONST MG/L CKP           .01
LIGHT    SAT CONST LNGLY/MIN CK.21       DAILY SONET LANGLEYS               530.
ENDATA1A
```

$$$ DATA TYPE 1A (ALGAE PRODUCTION AND NITROGEN OXIDATION CONSTANTS) $$$

```
CARD TYPE                                CARD TYPE
O UPTAKE BY NH3 (MGO/MGN)        3.4     O UPTAKE BY NO2 (MGO/MGN)           1.14
O PROD BY ALGAE (MGO/MGN) A3   2.00      O UPTAKE BY ALGAE (MGO/GMA) A4  1.50
N CONTENT OF ALGAE(MGN/MGA) A1  .06      P CONTENT OF ALGAE(MGP/MGA) A2  .01
ALG  TIME TO FIRST PRINT     =   00.     DENITRIFICATION RATE(1/DAY)         .4
N HALF ST CONSTANT MG/L CKN     .02      P 1/2 SAT CONST MG/L CKP           .01
LIGHT    SAT CONST LNGLY/MIN CK.21       DAILY SONET LANGLEYS               530.
ENDATA1A
:
```

$$$ DATA TYPE 2 (REACH IDENTIFICATION) $$$

CARD TYPE	REACH ORDER AND IDENT		R. MILE		R. MILE
STREAM REACH	1. RCH=	FROM	137.0	TO	135.8
STREAM REACH	2. RCH=	FROM	135.8	TO	134.5
STREAM REACH	3. RCH=	FROM	134.5	TO	132.5
STREAM REACH	4. RCH=	FROM	132.5	TO	130.5
STREAM REACH	5. RCH=	FROM	130.5	TO	129.5
STREAM REACH	6. RCH=	FROM	129.5	TO	127.5
STREAM REACH	7. RCH=	FROM	127.5	TO	125.5
STREAM REACH	8. RCH=	FROM	125.5	TO	123.5
STREAM REACH	9. RCH=	FROM	123.5	TO	122.0
STREAM REACH	10. RCH=	FROM	122.0	TO	120.5
STREAM REACH	11. RCH=	FROM	120.5	TO	118.5
STREAM REACH	12. RCH=	FROM	118.5	TO	116.6
STREAM REACH	13. RCH=	FROM	116.6	TO	115.2
STREAM REACH	14. RCH=	FROM	115.2	TO	113.7
STREAM REACH	15. RCH=	FROM	113.7	TO	112.1
STREAM REACH	16. RCH=	FROM	112.1	TO	110.5
STREAM REACH	17. RCH=	FROM	110.5	TO	110.0
STREAM REACH	18. RCH=	FROM	110.0	TO	108.5
STREAM REACH	19. RCH=	FROM	108.5	TO	107.2
STREAM REACH	20. RCH=	FROM	107.2	TO	105.5
STREAM REACH	21. RCH=	FROM	105.5	TO	104.5
STREAM REACH	22. RCH=	FROM	104.5	TO	102.5
STREAM REACH	23. RCH=	FROM	102.5	TO	102.0
STREAM REACH	24. RCH=	FROM	102.0	TO	101.0
STREAM REACH	25. RCH=	FROM	101.0	TO	100.0
ENDATA2					

$$$ DATA TYPE 3 (TARGET LEVEL DO AND FLOW AUGMENTATION SOURCES) $$$

CARD TYPE	REACH	AVAIL HDWS	TARGET	ORDER OF AVAIL SOURCES
ENDATA3	.0	.0	.0	0. 0. 0. 0. 0.

$$$ DATA TYPE 4 (COMPUTATIONAL REACH FLAG FIELD) $$$

CARD TYPE	REACH	ELEMENTS/REACH	COMPUTATIONAL FLAGS
FLAG FIELD RCH=	1.	12.	1.6.2.6.2.2.2.2.2.2.6.6.
FLAG FIELD RCH=	2.	13.	2.2.2.2.2.2.2.2.2.6.2.2.2.
FLAG FIELD RCH=	3.	20.	2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.
FLAG FIELD RCH=	4.	20.	2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.
FLAG FIELD RCH=	5.	10.	2.2.2.2.2.2.2.2.2.2.
FLAG FIELD RCH=	6.	20.	2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.
FLAG FIELD RCH=	7.	20.	2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.
FLAG FIELD RCH=	8.	20.	2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.
FLAG FIELD RCH=	9.	15.	2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.
FLAG FIELD RCH=	10.	15.	2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.
FLAG FIELD RCH=	11.	20.	2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.
FLAG FIELD RCH=	12.	19.	2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.
FLAG FIELD RCH=	13.	14.	2.2.2.2.2.2.2.2.2.2.2.2.2.2.
FLAG FIELD RCH=	14.	15.	2.2.2.2.2.2.2.2.2.2.6.2.2.2.2.
FLAG FIELD RCH=	15.	16.	2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.
FLAG FIELD RCH=	16.	16.	2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.
FLAG FIELD RCH=	17.	5.	6.7.2.2.2.
FLAG FIELD RCH=	18.	15.	2.6.2.2.2.2.2.2.2.2.2.2.2.2.6.
FLAG FIELD RCH=	19.	13.	6.6.2.2.2.2.2.2.2.2.2.2.2.
FLAG FIELD RCH=	20.	17.	2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.
FLAG FIELD RCH=	21.	10.	2.2.2.2.2.2.2.2.2.2.
FLAG FIELD RCH=	22.	20.	2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.
FLAG FIELD RCH=	23.	5.	2.2.2.2.2.
FLAG FIELD RCH=	24.	10.	2.2.2.2.2.6.2.2.2.2.
FLAG FIELD RCH=	25.	10.	2.2.2.2.2.2.2.2.2.5.

ENDATA4

COMPUTATIONAL FLAGS

1 = headwater

2 = normal element

3 = tailwater

6 = wastewater source or tributary

7 = uptake from river

$$$ DATA TYPE 5 (HYDRAULIC COEFFICIENTS FOR VELOCITY AND DEPTH AND SLUDE) $$$

CARD TYPE	REACH	AREA OF FLOW COEFQV	EXPOQV	DEPTH COEFQH	EXPOQH	MANNING'S N CMANN
HYDRAULICS	RCH= 1.	3260.87	1.11	9.69	1.00	.042
HYDRAULICS	RCH= 2.	3610.27	1.11	7.93	1.00	.041
HYDRAULICS	RCH= 3.	2575.29	1.11	4.82	1.00	.040
HYDRAULICS	RCH= 4.	2562.00	1.11	3.61	1.00	.040
HYDRAULICS	RCH= 5.	2097.41	1.11	3.12	1.00	.036
HYDRAULICS	RCH= 6.	1307.64	1.11	1.85	1.00	.035
HYDRAULICS	RCH= 7.	1970.55	1.11	2.48	1.00	.035
HYDRAULICS	RCH= 8.	1631.73	1.11	1.86	1.00	.038
HYDRAULICS	RCH= 9.	1879.83	1.11	1.50	1.00	.040
HYDRAULICS	RCH= 10.	1674.63	1.11	1.66	1.00	.036
HYDRAULICS	RCH= 11.	1356.44	1.11	1.49	1.00	.036
HYDRAULICS	RCH= 12.	1486.44	1.11	1.86	1.00	.038
HYDRAULICS	RCH= 13.	1209.01	1.11	2.13	1.00	.038
HYDRAULICS	RCH= 14.	1455.53	1.11	3.16	1.00	.035
HYDRAULICS	RCH= 15.	1460.82	1.11	1.84	1.00	.035
HYDRAULICS	RCH= 16.	1259.02	1.11	1.39	1.00	.035
HYDRAULICS	RCH= 17.	1487.60	1.11	1.37	1.00	.035
HYDRAULICS	RCH= 18.	1572.74	1.11	2.10	1.00	.035
HYDRAULICS	RCH= 19.	2349.99	1.11	3.30	1.00	.035
HYDRAULICS	RCH= 20.	3105.02	1.11	3.59	1.00	.035
HYDRAULICS	RCH= 21.	5100.00	1.11	4.25	1.00	.040
HYDRAULICS	RCH= 22.	13500.00	1.11	5.00	1.00	.035
HYDRAULICS	RCH= 23.	13225.00	1.11	5.75	1.00	.035
HYDRAULICS	RCH= 24.	39581.00	1.11	6.23	1.00	.035
HYDRAULICS	RCH= 25.	80092.00	1.11	6.66	1.00	.035

ENDATA5

$$$ DATA TYPE 6 (REACTION COEFFICIENTS FOR DEOXYGENATION AND REAERATION) $$$

CARD TYPE	REACH	CK1	CK3	Re-aeration option K2OPT	Wind speed (m/s) COEQK2
REACT COEF RCH>	1.	0.30000	0.080	3.	2.0
REACT COEF RCH>	2.	0.30000	0.080	3.	3.2
REACT COEF RCH>	3.	0.30000	0.080	3.	3.2
REACT COEF RCH>	4.	0.30000	0.080	3.	3.2
REACT COEF RCH>	5.	0.30000	0.080	3.	3.2
REACT COEF RCH>	6.	0.30000	0.080	3.	3.2
REACT COEF RCH>	7.	0.30000	0.080	3.	3.2
REACT COEF RCH>	8.	0.30000	0.080	8.	3.2
REACT COEF RCH>	9.	0.30000	0.080	8.	3.2
REACT COEF RCH>	10.	0.30000	0.080	8.	3.2
REACT COEF RCH>	11.	0.30000	0.080	8.	3.0
REACT COEF RCH>	12.	0.30000	0.080	3.	3.0
REACT COEF RCH>	13.	0.30000	0.080	3.	3.0
REACT COEF RCH>	14.	0.30000	0.080	3.	3.0
REACT COEF RCH>	15.	0.30000	0.080	3.	3.0
REACT COEF RCH>	16.	0.30000	0.080	3.	3.0
REACT COEF RCH>	17.	0.30000	0.080	3.	3.0
REACT COEF RCH>	18.	0.30000	0.080	3.	3.0
REACT COEF RCH>	19.	0.30000	0.080	8.	3.0
REACT COEF RCH>	20.	0.30000	0.080	8.	3.0
REACT COEF RCH>	21.	0.30000	0.080	8.	3.0
REACT COEF RCH>	22.	0.30000	0.080	3.	3.0
REACT COEF RCH>	23.	0.30000	0.080	8.	3.0
REACT COEF RCH>	24.	0.30000	0.080	8.	3.0
REACT COEF RCH>	25.	0.30000	0.080	8.	3.0

ENDATA6

$$$ DATA TYPE 6A (ALGAE, NITROGEN, AND PHOSPHOROUS CONSTANTS) $$$

CARD TYPE	REACH	ALPHAO	ALGSET	CKNH3	CKNO2
ALGAE, N AND P COEF	RCH> 1.	5.	0.400	.80	02.50
ALGAE, N AND P COEF	RCH> 2.	5.	0.400	.80	02.50
ALGAE, N AND P COEF	RCH> 3.	5.	0.400	.80	02.50
ALGAE, N AND P COEF	RCH> 4.	5.	0.400	.80	02.50
ALGAE, N AND P COEF	RCH> 5.	5.	0.400	.80	02.50
ALGAE, N AND P COEF	RCH> 6.	5.	0.400	.80	02.50
ALGAE, N AND P COEF	RCH> 7.	5.	0.400	.80	02.50
ALGAE, N AND P COEF	RCH> 8.	5.	0.400	.80	02.50
ALGAE, N AND P COEF	RCH> 9.	5.	0.400	.80	02.50
ALGAE, N AND P COEF	RCH> 10.	5.	0.400	.80	02.50
ALGAE, N AND P COEF	RCH> 11.	5.	0.400	.80	02.50
ALGAE, N AND P COEF	RCH> 12.	5.	0.400	.80	02.50
ALGAE, N AND P COEF	RCH> 13.	5.	0.400	.80	02.50
ALGAE, N AND P COEF	RCH> 14.	5.	0.400	.80	02.50
ALGAE, N AND P COEF	RCH> 15.	5.	0.400	.80	02.50
ALGAE, N AND P COEF	RCH> 16.	5.	0.400	.80	02.50
ALGAE, N AND P COEF	RCH> 17.	5.	0.400	.80	02.50
ALGAE, N AND P COEF	RCH> 18.	5.	0.400	.80	02.50
ALGAE, N AND P COEF	RCH> 19.	5.	0.400	.80	02.50
ALGAE, N AND P COEF	RCH> 20.	5.	0.400	.80	02.50
ALGAE, N AND P COEF	RCH> 21.	5.	0.400	.80	02.50
ALGAE, N AND P COEF	RCH> 22.	5.	0.400	.80	02.50
ALGAE, N AND P COEF	RCH> 23.	5.	0.400	.80	02.50
ALGAE, N AND P COEF	RCH> 24.	5.	0.400	.80	02.50
ALGAE, N AND P COEF	RCH> 25.	5.	0.400	.80	02.50

ENDATA6A

$$$ DATA TYPE 6B (OTHER COEFFICIENTS) $$$

CARD TYPE	REACH	CK4	CK5	EXCOEF	GROMXX CK6	KORGN	RESPTT
OTHER COEFFICIENTS	RCH> 1.	0.050	2.0	00.38	1.60	0.000	00.15
OTHER COEFFICIENTS	RCH> 2.	0.050	2.0	00.38	1.60	0.000	00.15
OTHER COEFFICIENTS	RCH> 3.	0.050	2.0	00.38	1.60	0.000	00.15
OTHER COEFFICIENTS	RCH> 4.	0.050	2.0	00.38	1.60	0.000	00.15
OTHER COEFFICIENTS	RCH> 5.	0.050	2.0	00.38	1.60	0.000	00.15
OTHER COEFFICIENTS	RCH> 6.	0.050	2.0	00.38	1.60	0.000	00.15
OTHER COEFFICIENTS	RCH> 7.	0.050	2.0	00.38	1.60	0.000	00.15
OTHER COEFFICIENTS	RCH> 8.	0.050	2.0	00.38	1.60	0.000	00.150
OTHER COEFFICIENTS	RCH> 9.	0.050	2.0	00.38	1.60	0.000	00.15
OTHER COEFFICIENTS	RCH> 10.	0.050	2.0	00.38	1.60	0.000	00.15
OTHER COEFFICIENTS	RCH> 11.	0.050	2.0	00.38	1.60	0.000	00.15
OTHER COEFFICIENTS	RCH> 12.	0.050	2.0	00.38	1.60	0.000	00.15
OTHER COEFFICIENTS	RCH> 13.	0.050	2.0	00.38	1.60	0.000	00.15
OTHER COEFFICIENTS	RCH> 14.	0.050	2.0	00.38	1.60	0.000	00.15
OTHER COEFFICIENTS	RCH> 15.	0.050	2.0	00.38	1.60	0.000	00.15
OTHER COEFFICIENTS	RCH> 16.	0.050	2.0	00.38	1.60	0.000	00.15
OTHER COEFFICIENTS	RCH> 17.	0.050	2.0	00.38	1.60	0.000	00.15
OTHER COEFFICIENTS	RCH> 18.	0.050	2.0	00.38	1.60	0.000	00.150
OTHER COEFFICIENTS	RCH> 19.	0.050	2.0	00.38	1.60	0.000	00.15
OTHER COEFFICIENTS	RCH> 20.	0.050	2.0	00.38	1.60	0.000	00.15
OTHER COEFFICIENTS	RCH> 21.	0.050	2.0	00.38	1.60	0.000	00.15
OTHER COEFFICIENTS	RCH> 22.	0.050	2.0	00.38	1.60	0.000	00.15
OTHER COEFFICIENTS	RCH> 23.	0.050	2.0	00.38	1.60	0.000	00.15
OTHER COEFFICIENTS	RCH> 24.	0.050	2.0	00.38	1.60	0.000	00.15
OTHER COEFFICIENTS	RCH> 25.	0.050	2.0	00.38	1.60	0.000	00.15

ENDATA6B

$$$ DATA TYPE 7 (INITIAL CONDITIONS) $$$

CARD TYPE		REACH	TEMP
INITIAL CONDITIONS	RCH>	1.	77.84
INITIAL CONDITIONS	RCH>	2.	77.84
INITIAL CONDITIONS	RCH>	3.	77.84
INITIAL CONDITIONS	RCH>	4.	77.84
INITIAL CONDITIONS	RCH>	5.	77.84
INITIAL CONDITIONS	RCH>	6.	77.84
INITIAL CONDITIONS	RCH>	7.	77.84
INITIAL CONDITIONS	RCH>	8.	77.84
INITIAL CONDITIONS	RCH>	9.	77.84
INITIAL CONDITIONS	RCH>	10.	78.78
INITIAL CONDITIONS	RCH>	11.	78.78
INITIAL CONDITIONS	RCH>	12.	78.78
INITIAL CONDITIONS	RCH>	13.	78.78
INITIAL CONDITIONS	RCH>	14.	78.78
INITIAL CONDITIONS	RCH>	15.	78.78
INITIAL CONDITIONS	RCH>	16.	78.78
INITIAL CONDITIONS	RCH>	17.	78.78
INITIAL CONDITIONS	RCH>	18.	78.78
INITIAL CONDITIONS	RCH>	19.	78.78
INITIAL CONDITIONS	RCH>	20.	78.78
INITIAL CONDITIONS	RCH>	21.	78.78
INITIAL CONDITIONS	RCH>	22.	78.78
INITIAL CONDITIONS	RCH>	23.	78.78
INITIAL CONDITIONS	RCH>	24.	78.78
INITIAL CONDITIONS	RCH>	25.	78.78

ENDATA7

$$$ DATA TYPE 7A (INITIAL CONDITIONS FOR CHLOROPHYLL A, NITROGEN, PHOSPHOROUS, COLIFORM AND ORGN) $$$

CARD TYPE		REACH	CHLORA
INITIAL COND-2	RCH>	1.	.1
INITIAL COND-2	RCH>	2.	.1
INITIAL COND-2	RCH>	3.	.1
INITIAL COND-2	RCH>	4.	.1
INITIAL COND-2	RCH>	5.	.1
INITIAL COND-2	RCH>	6.	.1
INITIAL COND-2	RCH>	7.	.1
INITIAL COND-2	RCH>	8.	.1
INITIAL COND-2	RCH>	9.	.1
INITIAL COND-2	RCH>	10.	.1
INITIAL COND-2	RCH>	11.	.1
INITIAL COND-2	RCH>	12.	.1
INITIAL COND-2	RCH>	13.	.1
INITIAL COND-2	RCH>	14.	.1
INITIAL COND-2	RCH>	15.	.1
INITIAL COND-2	RCH>	16.	.1
INITIAL COND-2	RCH>	17.	.1
INITIAL COND-2	RCH>	18.	.1
INITIAL COND-2	RCH>	19.	.1
INITIAL COND-2	RCH>	20.	.1
INITIAL COND-2	RCH>	21.	.1
INITIAL COND-2	RCH>	22.	.1
INITIAL COND-2	RCH>	23.	.1
INITIAL COND-2	RCH>	24.	.1
INITIAL COND-2	RCH>	25.	.1

ENDATA7A

$$$ DATA TYPE 8 (RUNOFF CONDITIONS) $$$

CARD TYPE		REACH	Q	TEMP	D.O.	
RUNOFF CONDITIONS	RCH>	1.	0.3	70.0	7.0	0.7
RUNOFF CONDITIONS	RCH>	2.	0.3	70.0	7.0	0.7
RUNOFF CONDITIONS	RCH>	3.	0.3	70.0	7.0	0.7
RUNOFF CONDITIONS	RCH>	4.	0.3	70.0	7.0	0.7
RUNOFF CONDITIONS	RCH>	5.	0.3	70.0	7.0	0.7
RUNOFF CONDITIONS	RCH>	6.	0.3	70.0	7.0	0.7
RUNOFF CONDITIONS	RCH>	7.	0.3	70.0	7.0	0.7
RUNOFF CONDITIONS	RCH>	8.	0.3	70.0	7.0	0.7
RUNOFF CONDITIONS	RCH>	9.	0.3	70.0	7.0	0.7
RUNOFF CONDITIONS	RCH>	10.	0.3	70.0	7.0	0.7
RUNOFF CONDITIONS	RCH>	11.	0.3	70.0	7.0	0.7
RUNOFF CONDITIONS	RCH>	12.	0.1	70.0	7.0	0.7
RUNOFF CONDITIONS	RCH>	13.	0.1	70.0	7.0	0.7
RUNOFF CONDITIONS	RCH>	14.	0.1	70.0	7.0	0.7
RUNOFF CONDITIONS	RCH>	15.	0.1	70.0	7.0	0.7
RUNOFF CONDITIONS	RCH>	16.	0.1	70.0	7.0	0.7
RUNOFF CONDITIONS	RCH>	17.	8.2	70.0	7.0	0.7
RUNOFF CONDITIONS	RCH>	18.	8.2	70.0	7.0	0.7
RUNOFF CONDITIONS	RCH>	19.	0.1	70.0	7.0	0.7
RUNOFF CONDITIONS	RCH>	20.	0.1	70.0	7.0	0.7
RUNOFF CONDITIONS	RCH>	21.	0.1	70.0	7.0	0.3
RUNOFF CONDITIONS	RCH>	22.	0.1	70.0	7.0	0.3
RUNOFF CONDITIONS	RCH>	23.	0.1	70.0	7.0	0.3
RUNOFF CONDITIONS	RCH>	24.	0.1	70.0	7.0	0.3
RUNOFF CONDITIONS	RCH>	25.	0.1	70.0	7.0	0.3

ENDATA8

$$$ DATA TYPE 8A (INCREMENTAL FLOW CONDITIONS FOR NITROGEN, PHOSPHOROUS, COLIFORM AND ORG-N) $$$

CARD TYPE		REACH	NH3	NO3	PO4	ORGN
RUNOFF COND-	RCH	1.	0.100	4.0	.00	0.80
RUNOFF COND-	RCH	2.	0.100	4.0	.00	0.80
RUNOFF COND-	RCH	3.	0.100	4.0	.00	0.80
RUNOFF COND-	RCH	4.	0.100	4.0	.00	0.80
RUNOFF COND-	RCH	5.	0.100	4.0	.00	0.80
RUNOFF COND-	RCH	6.	0.100	4.0	.00	0.80
RUNOFF COND-	RCH	7.	0.100	4.0	.00	0.80
RUNOFF COND-	RCH	8.	0.100	4.0	.00	0.80
RUNOFF COND-	RCH	9.	0.100	4.0	.00	0.80
RUNOFF COND-	RCH	10.	0.100	4.0	.00	0.80
RUNOFF COND-	RCH	11.	0.100	4.0	.00	0.80
RUNOFF COND-	RCH	12.	0.100	4.0	.00	0.80
RUNOFF COND-	RCH	13.	0.100	4.0	.00	0.80
RUNOFF COND-	RCH	14.	0.100	4.0	.00	0.80
RUNOFF COND-	RCH	15.	0.100	4.0	.00	0.80
RUNOFF COND-	RCH	16.	0.100	4.0	.00	0.80
RUNOFF COND-	RCH	17.	0.100	4.0	.00	0.80
RUNOFF COND-	RCH	18.	0.100	4.0	.00	0.80
RUNOFF COND-	RCH	19.	0.100	4.0	.00	0.80
RUNOFF COND-	RCH	20.	0.100	4.0	.00	0.80
RUNOFF COND-	RCH	21.	0.100	4.0	.00	0.80
RUNOFF COND-	RCH	22.	0.100	4.0	.00	0.80
RUNOFF COND-	RCH	23.	0.100	4.0	.00	0.80
RUNOFF COND-	RCH	24.	0.100	4.0	.00	0.80
RUNOFF COND-	RCH	25.	0.100	4.0	.00	0.80

ENDATA8A

$$$ DATA TYPE 9 (STREAM JUNCTIONS) $$$

CARD TYPE	JUNCTION ORDER AND IDENT	UPSTRM	JUNCTION	TRIB
ENDATA9	0.	0.	0.	0.

$$$ DATA TYPE 10 (HEADWATER SOURCES) $$$

CARD TYPE	HDWATER ORDER AND IDENT	FLOW	TEMP	D.O.	BOD2
HEADWATER	1. HWD>KILBRN DAM,WI DL	1788.	77.84	8.3	4.0
ENDATA10					

$$$ DATA TYPE 10A (HEADWATER CONDITIONS FOR CHLOROPHYLL, NITROGEN, PHOSPHOROUS, COLIFORM AND ORGN) $$$

CARD TYPE	HDWATER	CHLORA	NH3	NO2	NO3	PO4	COLI	ORGN
HEADWATER-2	HWD> 1.	21.0	0.10	0.002	.20	0.01	.1	0.80
ENDATA10A								

$$$ DATA TYPE 11 (WASTE LOADINGS) $$$

CARD TYPE	WASTE LOAD ORDER AND IDENT		FLOW	TEMP	D.O.	BOD	CM-III
WASTELOAD	1. WSL=HULBERT CR	T	0.0				2.00
WASTELOAD	2. WSL=WISC DELL STP	E	0.0	68.	2.0	600.	1.43
WASTELOAD	3. WSL=NEW WI DEL STP	E	1.55	68.	2.0	30.	1.43
WASTELOAD	4. WSL=L DELTON STP	E	0.0	68.	2.0	330.	1.43
WASTELOAD	5. WSL=DELL CREEK	T	12.00	75.	8.0	5.0	2.00
WASTELOAD	6. WSL=PORTAGE STP	E	3.09	68.	2.0	30.	1.43
WASTELOAD	7. WSL=BARABOO RIVER	T	84.	74.	7.5	5.	2.00
WASTELOAD	8. WSL=COLMB PWR UPTK	W	-30.3				2.00
WASTELOAD	9. WSL=DUCK CREEK	T	3.2	77.	8.2	3.	2.00
WASTELOAD	10. WSL=COLUMBIA ASH	E	5.56	90.	2.	30.	1.43
WASTELOAD	11. WSL=COLUMBIA EFFL	E	0.0				2.00
WASTELOAD	12. WSL=ROCKY RUN	T	0.0				2.00
WASTELOAD	13. WSL=ROWEN CREEK	T	2.8				2.00
ENDATA11							

$$$ DATA TYPE 11A (WASTE LOAD CHARACTERISTICS - ALGAE, NITROGEN, PHOSPHOROUS, COLIFORM AND ORGN) $$$

CARD TYPE	WASTE LOAD ORDER AND IDENT	NH3	NO3	PO4
WASTELOAD-2	WSL> 1.			
WASTELOAD-2	WSL> 2.			
WASTELOAD-2	WSL> 3.			
WASTELOAD-2	WSL> 4.			
WASTELOAD-2	WSL> 5.			
WASTELOAD-2	WSL= 6.	6.	144.	12.
WASTELOAD-2	WSL> 7.			
WASTELOAD-2	WSL> 8.			
WASTELOAD-2	WSL> 9.			
WASTELOAD-2	WSL> 10.			
WASTELOAD-2	WSL> 11.			
WASTELOAD-2	WSL> 12.			
WASTELOAD-2	WSL> 13.			
ENDATA11A				

```
WASTELOAD    1. WSL=HULBERT CR      T          0.0                                      2.00
WASTELOAD    2. WSL=WISC DELL STP   E          0.77  68.    2.0 600.                   1.43
WASTELOAD    3. WSL=NEW WI DEL STP  E          0.0                                      2.00
WASTELOAD    4. WSL=L DELTON STP    E          0.46  68.    2.0 330.                   1.43
WASTELOAD    5. WSL=DELL CREEK      T         12.00  75.    8.0   5.0                  2.00
WASTELOAD    6. WSL=PORTAGE STP     E          0.0   68.    2.0  30.                   1.43
WASTELOAD    7. WSL=BARABOO RIVER   T         84.    74.    7.5   5.                   2.00
WASTELOAD    8. WSL=COLMB PWR UPTK  W        -30.3                                      2.00
WASTELOAD    9. WSL=DUCK CREEK      T          3.2   77.    8.2   3.                   2.00
WASTELOAD   10. WSL=COLUMBIA ASH    E          5.56  90.    2.   30.                   1.43
WASTELOAD   11. WSL=COLUMBIA EFFL   E          0.0                                      2.00
WASTELOAD   12. WSL=ROCKY RUN       T          0.0                                      2.00
WASTELOAD   13. WSL=ROWEN CREEK     T          2.8                                      2.00
ENDATA11
WASTELOAD-2     WSL>  1.
WASTELOAD-2     WSL>  2.
WASTELOAD-2     WSL>  3.
WASTELOAD-2     WSL>  4.
WASTELOAD-2     WSL>  5.
WASTELOAD-2     WSL=  6.          6.            144.      12.
WASTELOAD-2     WSL>  7.
WASTELOAD-2     WSL>  8.
WASTELOAD-2     WSL>  9.
WASTELOAD-2     WSL> 10.
WASTELOAD-2     WSL> 11.
WASTELOAD-2     WSL> 12.
WASTELOAD-2     WSL> 13.
ENDATA11A
MISC FACTORS 01.013.80 20.0 20.0 0.56 0.00 0.00 1.75 00.0 00.0
ENDATA12
```

```
WASTELOAD   1. WSL=HULBERT CR     T          0.0                                    2.00
WASTELOAD   2. WSL=WISC DELL STP  E          0.0   68.   2.0 600.                   1.43
WASTELOAD   3. WSL=NEW WI DEL STP E          1.55  68.   2.0  30.                   1.43
WASTELOAD   4. WSL=L DELTON STP   E          0.0   68.   2.0 330.                   1.43
WASTELOAD   5. WSL=DELL CREEK     T         12.00  75.   8.0   5.0                  2.00
WASTELOAD   6. WSL=PORTAGE STP    E          0.0   68.   2.0  30.                   1.43
WASTELOAD   7. WSL=BARABOO RIVER  T         84.    74.   7.5   5.                   2.00
WASTELOAD   8. WSL=COLMB PWR UPTK W        -30.3                                    2.00
WASTELOAD   9. WSL=DUCK CREEK     T          3.2   77.   8.2   3.                   2.00
WASTELOAD  10. WSL=COLUMBIA ASH   E          5.56  90.   2.   30.                   1.43
WASTELOAD  11. WSL=COLUMBIA EFFL  E          0.0                                    2.00
WASTELOAD  12. WSL=ROCKY RUN      T          0.0                                    2.00
WASTELOAD  13. WSL=ROWEN CREEK    T          2.8                                    2.00
ENDATA11
WASTELOAD-2     WSL>  1.
WASTELOAD-2     WSL>  2.
WASTELOAD-2     WSL>  3.
WASTELOAD-2     WSL>  4.
WASTELOAD-2     WSL>  5.
WASTELOAD-2     WSL=  6.          6.            144.      12.
WASTELOAD-2     WSL>  7.
WASTELOAD-2     WSL>  8.
WASTELOAD-2     WSL>  9.
WASTELOAD-2     WSL> 10.
WASTELOAD-2     WSL> 11.
WASTELOAD-2     WSL> 12.
WASTELOAD-2     WSL> 13.
ENDATA11A
```

```
WASTELOAD    1. WSL=HULBERT CR      T           0.0                              2.00
WASTELOAD    2. WSL=WISC DELL STP   E           0.0    68.    2.0 600.           1.43
WASTELOAD    3. WSL=NEW WI DEL STP  E           1.55   68.    2.0  30.           1.43
WASTELOAD    4. WSL=L DELTON STP    E           0.0    68.    2.0 330.           1.43
WASTELOAD    5. WSL=DELL CREEK      T          12.00   75.    8.0   5.0          2.00
WASTELOAD    6. WSL=PORTAGE STP     E           3.09   68.    5.0  30.           1.43
WASTELOAD    7. WSL=BARABOO RIVER   T         84.      74.    7.5   5.           2.00
WASTELOAD    8. WSL=COLMB PWR UPTK  W        -30.3                               2.00
WASTELOAD    9. WSL=DUCK CREEK      T           3.2    77.    8.2   3.           2.00
WASTELOAD   10. WSL=COLUMBIA ASH    E           5.56   90.    2.   30.           1.43
WASTELOAD   11. WSL=COLUMBIA EFFL   E           0.0                              2.00
WASTELOAD   12. WSL=ROCKY RUN       T           0.0                              2.00
WASTELOAD   13. WSL=ROWEN CREEK     T           2.8                              2.00
ENDATA11
WASTELOAD-2     WSL>  1.
WASTELOAD-2     WSL>  2.
WASTELOAD-2     WSL>  3.
WASTELOAD-2     WSL>  4.
WASTELOAD-2     WSL>  5.
WASTELOAD-2     WSL=  6.           3.             12.       1.
WASTELOAD-2     WSL>  7.
WASTELOAD-2     WSL>  8.
WASTELOAD-2     WSL>  9.
WASTELOAD-2     WSL> 10.
WASTELOAD-2     WSL> 11.
WASTELOAD-2     WSL> 12.
WASTELOAD-2     WSL> 13.
ENDATA11A
MISC FACTORS 01.013.80 20.0 20.0 0.56 0.00 0.00 1.75 00.0 00.0
ENDATA12
```

APPENDIX B

BRIEF DESCRIPTION OF THE QUAL-3 MODEL

This appendix is reprinted from Chapter II of QUAL-III Water Quality Model Documentation, by D.J. Patterson and J.W. Rogers, 1978, Wisconsin Department of Natural Resources.

THEORETICAL CONSIDERATIONS

Advective Dispersive Equations

The QUAL model numerically solves the advection-dispersion mass transport equation for each water quality consttituent being modeled. This equation considers the effects of advection, dispersion, individual constituent changes, and all sources or sinks for each constituent. The equation is written:

$$A \frac{\partial c}{\partial t} = \frac{\partial (A D_L \frac{c}{x})}{\partial x} - \frac{\partial (A \bar{U} C)}{\partial x} \pm A"S" \qquad \text{(B-1)}$$

where

C = concentration (mg/liter)

x = distance (L)

t = time (T)

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

D_L = dispersion coefficient (L^2/T)

$\bar{U}$ = average stream velocity (L/T)

"S" = source of sink (mg/liter/T)

The term $\frac{\partial c}{\partial t}$ defines the local derivative and under steady state conditions is zero.

The term $\frac{\partial c}{\partial t}$ defines constituent changes that occur independently of advection, dispersion or waste inputs. These time changes are the physical, chemical, and biological reactions that occur in the stream. Decay of BOD, algal growth, and reaeration are examples of this type of reaction.

Dispersion Term

The term D_L is a measure of the rate of longitudinal dispersion in the river. In a physical sense, it measures the rate of increase in an area covered by any substance injected in the stream such as a dye tracer. It is measured in units of area per unit time (L^2/T). In general, the value of D_L cannot be easily estimated from bulk parameters for a real stream due to the irregularities of any natural channel. However, Fisher (1968) has shown that a reasonable approximation of D_L can be obtained by:

$$D_L = \frac{0.3\ \overline{U'}^2\ L^2}{R_H U_*} \qquad \text{(B-2)}$$

where

D_L = dispersion coefficient (ft^2/sec)

L = distance from further bank to point of highest velocity of flow (ft)

R_H = hydraulic radius (ft)

U_* = friction velocity

$\overline{U'}^2$ = space averaged mean squared velocity difference from the mean velocity

All the terms in Eq. B -2 are calculable except $\overline{U'}^2$. However, we can let $U = \overline{U} + U'$ or $U' = U - \overline{U} = U - \frac{Q}{A}$

where

U' = difference between local velocity and mean

$\overline{U}$ = mean velocity = Q/A

U = actual velocity

We can evaluate U' if we can assume a velocity distribution for U. By neglecting bottom friction and assuming a rectangular channel we can fit an equation of the form:

$$U = K\left[\frac{W^n}{2^n} - /Y^n/\right] \qquad \text{(B-3)}$$

where

Y = lateral position (0 = center of stream)

W = width of stream

n = some integral power

K = a constant

If $n = 2$, Eq. B-3 gives a parabolic velocity profile similar to laminar flow in a pipe. It is known that the flow in large streams is highly turbulent and it would be logical to look at higher values of n. The higher the n value the flatter the velocity profile is and the value of U' decreases. After substituting the velocity equation, squaring and integrating over the width to obtain a mean, we arrive at:

$$\overline{U'^2} = \frac{2}{w}\int_0^{w/2} U'^2 \, dy = \frac{2}{w}\int_0^{w/2} K[(\frac{w^n}{2^n} - /Y^n/ \approx dy = K'\overline{U} \qquad \text{(B-4)}$$

where K' is inversely proportional to n. This shows that $\overline{U'^2}$ is simply a fraction of U. The value of n must be chosen such that when $\overline{U'^2}$ is substituted, Eq. (A-2) yields a dispersion coefficient in line with measurements. We have found a value of approximately 24 for n to yield dispersion coefficients in line with measurements for the Lower Fox River. This gives K' a value of about 0.008.

<u>Numerical Dispersion</u>

Because the QUAL model solves the advective dispersion differential equation by finite differences, the solution technique causes a numerical spreading to occur similar to dispersion. This error is known as numerical dispersion and acts essentially similar to actual dispersion. This error is an artifact of the finite difference approximation and can be evaluated by looking at the Taylor series expansion of the finite difference equations. This type of analysis shows that numerical dispersion is a first-order error for a backward differences approximation such as used in the QUAL model. This implies that:

$$D_{NUM} = \frac{\overline{U}}{2} (\Delta X + \overline{U}\, \Delta t) \qquad \text{(B-5)}$$

where

ΔX = distance step (ft)

Δt = time step (sec)

$\overline{U}$ = mean velocity (ft/sec)

Notice that D_{NUM} has the same units as D_L. It is interesting to note that numerical dispersion in the implicit backward finite difference scheme used by the QUAL model is the sum of the numerical dispersion caused by Δt and ΔX. Note also that for steady state runs (i.e. $\frac{\partial}{\partial t} = 0$) the portion of the dispersion due to Δt goes to zero leaving only $D_{NUM} = U\Delta X/2$. .

One way to reduce this error is to treat the numerical dispersion as if it is real dispersion and simply reduce D_L by the calculated D_{NUM}. However, if D_{NUM} is greater than D_L, then its error cannot be totally eliminated, only reduced. As Eq.(B-5) shows, decreasing ΔX or Δt or both will decrease D_{NUM}, however, this will increase the computation time and money required to run the model.

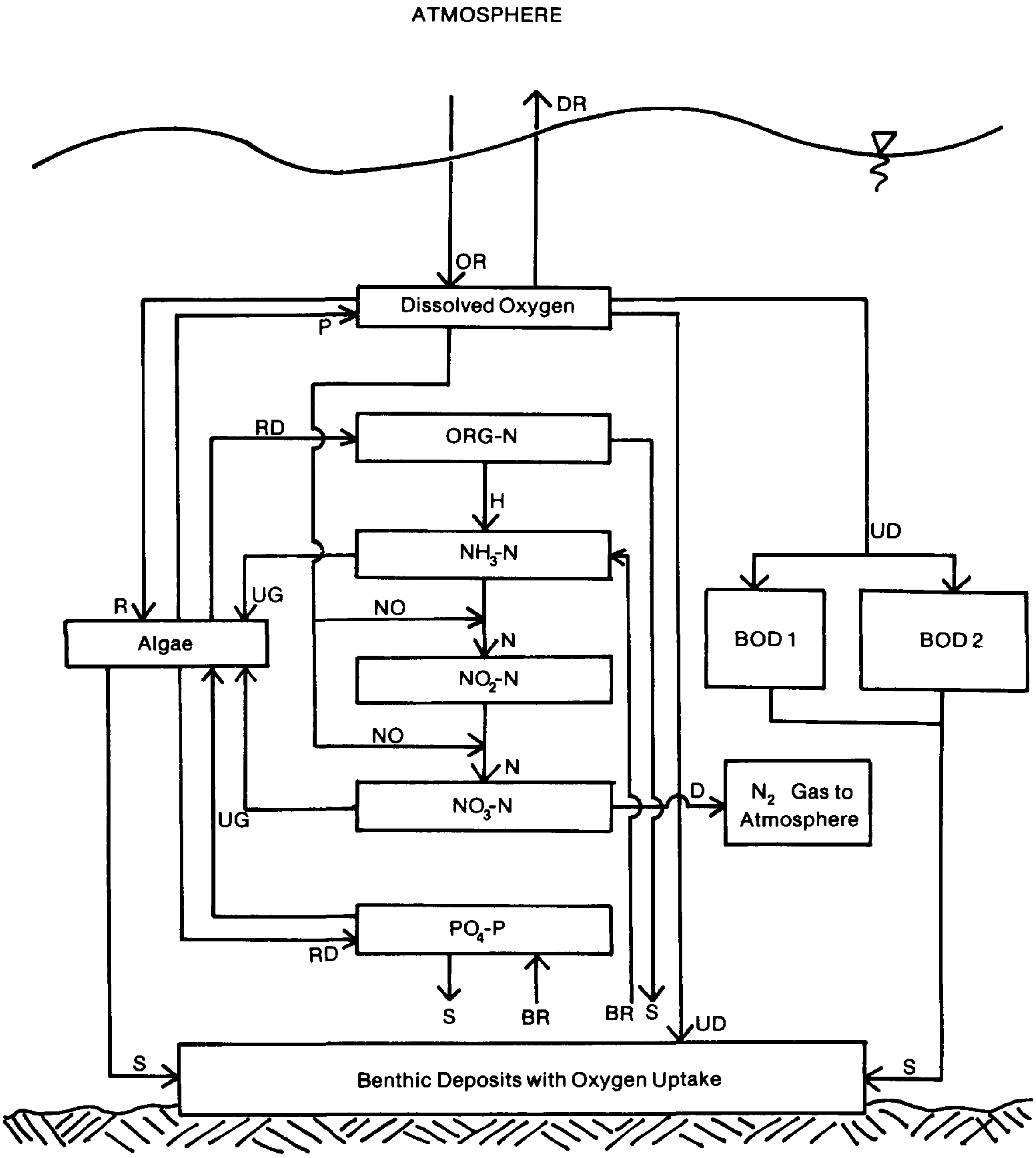
MODEL SCHEMATIZATION

Any water quality model (or any model for that matter) is of necessity a simplification of the real world situation. For a given application of a model to a particular situation to be of value to planners, designers, and administrators, the model must be constructed carefully so that all of the important aspects of the problem are considered. On the other hand, the model must be simple enough so that it can be used easily and understood not only by the user but by those who must review the results and apply them. One of the largest criticisms of modeling stems from the difficulty in getting the people who would most likely use the results of the model (i.e., administrators, planners, etc.) to understand the capabilities and limitations of the model. It is not necessary to understand all the equations that model must solve. However, it is entirely necessary to understand the rules which the modeler has defined as acceptable or possible interactions within the system. This can best be illustrated by a simple diagram that pinpoints the flow of events in cause and effect relationships. A potential user or applier of this model will do well to carefully study Figure B-1 to understand all the acceptable or possible pathways of interaction and feedback in the model.

CONSTITUENT REACTIONS AND INTERACTIONS

The following section discusses each parameter that is considered in the model and discusses the mathematical description of all possible interactions. Basically, any quantity routed through the model may do any one of the following four things:

1. Continue into the next stream reach with no change.
2. Be lost to the water system due to any removal mechanism such as settling, withdrawal, or decay.
3. Enter the system from the atmosphere or any waste input or tributary.



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

Figure B-1. Possible pathways of interaction and feedback in the QUAL-3 water quality model.

4. Be transformed into another substance by biological or chemical reactions.

Chlorophyll-a

Chlorophyll-a is assumed to be directly proportional to the concentration of algal biomass. Algal biomass is converted to chl-a by the simple formula:

$$\text{Chl-a} = \alpha_0 A \qquad \text{(B-6)}$$

where

Chl-a = chlorophyll-a concentration (μg/liter)

A = algal biomass concentration (mg/liter)

α_o = conversion factor

The differential equation that controls the growth and respiration of algae (chl-a) is:

$$\frac{dA}{dt} = A(\mu - \rho - \frac{\sigma}{D}) \qquad \text{(B-7)}$$

where

A = algal biomass (mg/liter)

t = time

μ = local specific growth rate (defined below) (day^{-1})

ρ = local respiration rate of algae (day^{-1}) (temperature dependent)

σ = local settling rate of algae (ft/day)

D = depth (ft)

The local specific growth rate μ is calculated using Michaelis Menton growth limiting terms. Also, the algal growth rate is temperature dependent. The equation for local algal growth is:

$$\mu = \mu_{MAX}(\theta^{T-20})\left(\frac{P}{K_P+P}\right)\left(\frac{N_1+N_3}{K_N+N_1+N_3}\right)(r) \qquad \text{(B-8)}$$

where

μ_{MAX} = maximum possible algal growth rate (day^{-1})

θ = temperature correction coefficient for algae

T = temperature (°C)

P = concentration of available phosphorus

N_1 = concentration of ammonia nitrogen (mg/liter) as N

N_3 = concentration of nitrate nitrogen (mg/liter) as N

K_P = half saturation constant for phosphorous (mg/liter)

K_N = half saturation constant for nitrogen (mg/liter)

r = growth reduction factor due to local light conditions

Equation B-8 is straightforward except for the final term r. The factor r represents a function of light penetration, depth of water and a normalized growth function for light intensity. To elaborate on this factor it is necessary to describe the effects of algal populations and the resultant light penetration. Light penetration is usually described by an exponential function with an extinction coefficient of the form:

$$I(Z) = I_o e^{-k_E Z} \qquad \text{(B-9)}$$

where

I_o = light intensity at the water surface (langleys/h)

I(Z) = light intensity with depth

Z = depth below surface (ft)

e = base of natural logs

k_E = light extinction coefficient (ft^{-1})

The extinction coefficient can be divided into two parts which consist of (1) the light extinction due to things other than algae and (2) the portion of the light extinction due to algae self-shading. This can be expressed as:

$$k_E = K_{oe} + 0.004(\text{Chl-a}) + 0.05(\text{Chl-a})^{2/3} \qquad \text{(B-10)}$$

where:

K_{oe} = portion of extinction coefficient due to things other than algae (this is entered in the input data)

Chl-a = concentration of chlorophyll-a (μg/liter)

Knowing the intensity of the incident light, the formula of Steele (1965) can be applied for the normalized growth of phytoplankton as a function of light. Steele's (1965) equation relates the normalized growth rate of algae to the local light intensity of a "saturated" light intensity (i.e., the light intensity at which growth is maximum):

$$F(I) = I/I_s \, e(-I/Is + 1) \qquad \text{(B-11)}$$

where

F = normalized growth rate

I = local light intensity (langleys)

I_s = light intensity for which algal growth is maximum (langleys/h)

To obtain the normalized growth rate in a volume element, Eq. (B-11) is integrated over the depth and time step. The intensity I_o at the surface of the water is, of course, a function of time of day. If we assume that I_o is a constant over the time step, then the fractional growth rate r in a given volume element during a given time step is:

$$r = \frac{1}{D} \int_o^D \frac{1}{t} \int_o^F I_a e^{-k_E Z}/I_s \cdot e^{(I_a e^{-k_E Z} \; I_s + 1)} \, dt \, dz \qquad \text{(B-12)}$$

where

D = depth (ft)

t = time step (h)

f = hours in the time step that have daylight

I_a = average light intensity at the surface during time step (langleys/h)

If the integration of Eq.(B-12) is completed:

$$r = \frac{ef}{tk_E D} \left(e^{-A_1} - e^{-A_o}\right) \qquad \text{(B-13)}$$

where

$$A_1 = I_a/I_s \cdot e^{-k_E D} \qquad \text{(B-14)}$$

$$A_o = I_a/I_s \qquad \text{(B-15)}$$

Nitrogen Cycle

The nitrogen cycle in QUAL-III can be routed in one of two ways. The original version of QUAL-II allowed for three components of nitrogen (ammonia, nitrite, and nitrate). Nitrification could transform ammonia to nitrite and finally nitrate. Feedback was allowed through algal growth utilizing nitrate and algae respiration producing ammonia. This cycle can still be routed if desired. In modifying the QUAL program, it was decided to include organic nitrogen as a routable constituent. Also, it was decided to allow algal growth to utilize ammonia as well as nitrate. Thirdly, the nitrogen cycle was modified to allow nitrogen to be lost to the system through denitrification.

"Organic Nitrogen"

The equation for organic nitrogen is:

$$\frac{dN_o}{dt} = \alpha_{12}\rho\ A - \alpha_{11}N_o - \frac{\sigma_4}{D}N_o \qquad \text{(B-16)}$$

where

N_o = concentration of organic nitrogen (mg/liter)

α_{12} = the fraction of algal biomass which is nitrogen

σ_4 = settling rate of organic nitrogen (ft/day)

α_{11} = rate of conversion of organic nitrogen to NH_3-N (liter/day) (temperature dependent) is related to the amount of chlorophyll-a in the water column by:

$$\alpha_{11} = 0.05 + \alpha_0\ A\ K_{ORG} \qquad \text{(B-17)}$$

where

K_{ORG} = rate of recycle of organic nitrogen per unit of algae

Organic nitrogen routed in this way only represents organic nitrogen not associated with live algal cells.

"Ammonia Nitrogen"

The equation for ammonia nitrogen is:

$$\frac{dN_1}{dt} = \alpha_{11}N_o - \beta_1 N_1 - \beta_3 N_1\left(\frac{N_1}{N_1 + N_3}\right) + \sigma_2 \qquad \text{(B-18)}$$

where

N_1 = ammonia nitrogen as N (mg/liter)

β_1 = rate of conversion of NH_3-N to NO_2 (liter/day) (temperature dependent)

β_3 = rate of utilization of nitrogen by algae (temperature dependent)

N_3 = nitrate nitrogen as N (mg/liter)

σ_2 = local source rate of ammonia from the sediments (mg/liter/day)

The ratio $N_1/(N_1+N_3)$ represents the portion of algal nitrogen that comes from ammonia. It is assumed that the nitrogen form utilized is in proportion to its fraction of the sum of NH_3 and NO_3. Equation (B-15) can be used to force nitrate utilization over ammonia.

"Nitrite Nitrogen"

The equation for nitrite nitrogen is:

$$\frac{dN_2}{dt} = \beta_1 N_1 - \beta_2 N_2 \qquad \text{(B-19)}$$

where

N_2 = nitrite nitrogen as N (mg/liter)

β_2 = rate of convrsion of nitrite to nitrate (liters/day) (temperature dependent)

"Nitrate Nitrogen"

The equation for nitrate nitrogen is:

$$\frac{dN_3}{dt} = \beta_2 N_2 - \beta_3 N_3 \left(\frac{N_3}{N_1 + N_3}\right) - \beta_4 N_3 \qquad \text{(B-20)}$$

where

β_4 = rate of denitrification (liter/day)

It should be noted that β_1, β_2, and β_4 are reaction rates that are dependent on the level of dissolved oxygen; β_1 and β_2 are maximum when DO is high and suppressed when DO is low. For β_4 the rate is the inverse of this. Also, a coupling exists between the conversion of nitrogen (ammonia and nitrate) and the production of algae to close the loop shown in Figure B-1. This coupling is expressed by:

$$\alpha_{12}\mu A = \beta_3 \left(\frac{N_3^{\,2} + N_1^{\,2}}{N_3 + N_1}\right) \qquad \text{(B-21)}$$

Phosphorous Cycle

The phosphorus cycle is relatively simple compared to the nitrogen cycle in the model. Phosphorus interactions are limited to uptake by growing algae, resolubilization by respired algae, and sediment exchanges. The equation is:

$$\frac{dP}{dt} = \alpha_7 \rho A - \beta_5 P + \sigma_3 \qquad \text{(B-22)}$$

where

α_7 = the fraction of algae biomass that is phosphorus

β_5 = rate constant for the uptake of phosphorus by algae

σ_3 = local source or sink rate of phosphorus (mg/liter)

P = concentration of available phosphorus

Again, it must be noted that the phosphorus routed in the model does not include the phosphorus that is associated with live algal cells. Also, a coupling exists between the production of algal biomass and the conversion of phosphorus; this coupling is expressed by:

$$\beta_5 P = \alpha_7 \mu A \qquad \text{(B-23)}$$

Carbonaceous BOD

Carbonaceous BOD may be expressed as a two-term equation. The general equation for BOD is:

$$L(t) = L_1(1-e^{-K_{11}t}) + L_2(1-e^{-K_{12}t}) \qquad \text{(B-24)}$$

where

L(t) = ultimate BOD exerted at time t (mg/liter)

L_1, L_2 = ultimate BOD associated with each term (mg/liter)

K_{11}, K_{12} = decay rates of BOD for each term (liter/day)

L_1 = term 1 BOD

L_2 = term 2 BOD

If the user wishes to input BOD as a single term, then L_2 is calculated in the program*. When routing BOD, the user may request that the BOD be routed as 5-day BOD. If the BOD_5 approach is taken, the QUAL-III model automatically converts to BOD_5 to ultimate BOD by the equation:

$$L_u = L(5) * K_F \qquad \text{(C-19)}$$

*The program calculates L_1 and L_2 from the input BOD (L = input Bod) as:

$L_1 = L*K_F*$ (1-WSFBSS) where WSFBSS = $\frac{\text{(particulate BOD)}}{\text{(total BOD)}}$ input by waste load

$L_2 = L*K_F*$ (1-WSFBSS)

where

L_u = ultimate BOD (mg/liter)

$L(5)$ = BOD_5 (mg/liter)

K_F = ratio of ultimate BOD to 5-day BOD read in by waste load

The differential equations expressing BOD decay take the form:

$$\frac{dL_1}{dt} = -(K_{11} + K_5)\, L_1 \qquad \text{(B-26)}$$

and

$$\frac{dL_2}{dt} = -(K_{12} + K_5)\, L_2 \qquad \text{(B-27)}$$

where

K_5 = rate of decay of L_2 due to settling (liter/day) (K_5 is input as a settling rate in ft/day, dividing by the local depth yields a decay rate)

Note that settling is allowed only for L_2.

Particulate BOD and Benthic Oxygen Demand

A new feature that has recently been added to the model is the ability to estimate sediment oxygen demand. By knowing the approximate average settling rate of the particulate BOD (ft/day) and the amount of potential BOD carried with it, the resultant benthic oxygen demand can be estimated. The differential equation for particulate BOD is shown above as Eq. (B-27). The rate K_5 is input in terms of a settling rate (ft/day) by reach. It is converted to a decay rate (liter/day) by dividing by the local depth. Furthermore, K_5 is reduced by a factor that is inversely proportional to five times the local water velocity. The reduction factor is given by:

$$R = \frac{1}{5V} \qquad \text{(B-28)}$$

where

R = fraction of maximum settling velocity (R is constrained to be $<$ 1.0)

V = local velocity (ft/sec)

The factor R is derived from the fact that data for large streams have indicated that approximately 1/10 of the horizontal water velocity goes into the generation of vertical turbulent energy half of which serves to decrease settling. The local benthic oxygen demand is calculated by:

$$B = RK_5(L_1 + L_2) + B_o + \frac{R\sigma_1}{D}(\alpha_4 faA) \tag{B-29}$$

where:

B = local benthic oxygen demand (mg/liter/day)

B_o = background benthic demand (mg/liter/day)

fa = nonrefractory portion of algal biomass

It should be noted that this routine is only usable for steady-state simulations.

Algae settling also has been related to the benthic oxygen demand. Stoichiometrically, 1.0 mg of algal biomass can consume about 1.80 mg of O_2 by decomposition. If it is assumed that 100% of the settled algal biomass contributes to the benthic oxygen demand, then the final term in Eq. (B-29) represents the algal contribution with fa = 1.0. By assuming 100% of the settled algae contribute to the benthic demand we are of of course calculating the maximum algae contribution to the benthic oxygen uptake. Jewell and McCarty (1971), however, has indicated that a significant fraction of algal biomass is refractory.

Coliforms and Conservative Elements

Originally, the QUAL-II model had the capability of routing coliforms and up to three conservative elements in one run. To save computer space it was decided to eliminate the routines for conservative elements but to keep the routine for coliforms. Actually, the coliform routine can route any substance that decays with first order kinetics. The general equation is:

$$\frac{dC_o}{dt} = -K_5 C_o \tag{B-30}$$

where

C_o = concentration of the substance (MPN or mg/liter)

K_5 = decay rate (liters/day) (temperature dependent)

To use this routine to route a conservative substance, simply set the decay rate (K_5) to zero. In this way time changes are ignored and C_o would be routed as if it did not decay. Since K_5 also is used in the BOD equations, it is not possible to route BOD and a conservative substance through this routine at the same time. Separate runs have to be made for each.

Dissolved Oxygen

The dissolved oxygen equation can now be written in terms of all of the above reactions that add or subtract DO plus the reaeration term:

$$\frac{dO}{dt} = K_2(O^*-O) + A(\alpha_3\mu\alpha_4\rho) - K_{11}L_1 - L_{12}L_2 - \alpha_5\beta_1N_1 - \alpha_6\beta_2N_2 - B \qquad \text{(B-31)}$$

where

O = dissolved oxygen (mg/liter)

O^* = dissolved oxygen saturation (mg/liter)(temperature dependent)

α_3 = photosynthetic oxygen production per unit of algal growth

α_4 = respiration oxygen use per unit of algal respiration

α_5 = oxygen equivalent of ammonia to nitrite

α_6 = oxygen equivalent of nitrite to nitrate

K_2 = reaeration rate (liter/day) temperature dependent

Temperature-Dependent Terms

Many of the reaction rates described above are labeled as "temperature dependent." This means that the rate of the reaction is in part a function of the local temperature. All of the temperature-dependent terms are adjusted by the equation:

$$K_{(T)} = K_{20}\,\theta^{T-20} \qquad \text{(B-32)}$$

where

$K_{(T)}$ = decay or reaction rate at T°C

K_{20} = decay or reaction rate at 20°C

T = temperature (°C)

θ = an adjustment coefficient

For most reactions θ is chosen to be a constant. The value of the constant depends on the type of reaction. However, for BOD and benthic demand, θ is a function of temperature. For these two reactions θ is given by:

$$\theta BOD = 0.00649\ T + 1.1776 \qquad T < 20$$

$$\theta BOD = 1.047 \qquad T \geq 20 \qquad (B-33)$$

$$\theta SOD = -0.00175\ T + 1.1 \qquad \text{All } T$$

The θ equation for BOD was derived from data presented by Zanoni (1969). The BOD temperature-related equation was forced to hit θ = 1.047 at T = 20°C. The SOD equation nearly parallels the BOD equation except it is forced to hit θ = 1.065 at T = 20°C. The θ correction factor also is a function of temperature for nitrification reactions. These equations are also based on Zanoni (1969). For those terms the equations take the form:

$$K_{(T)} = (K_{20})\ (1.2034)\ (0.877^{T-22}) \qquad T \geq 22^0C \qquad (B-34)$$

$$K_{(T)} = (K_{20})\ (1.097^{T-20}) \qquad T < 22^0C$$

For other reactions:

θ = 1.047 for algal growth, coliforms, organic nitrogen

Special Reaction Coefficients

Several of the reaction rate coefficients have been coupled to various dependent parameters in the model. This necessitates the iterative technique to arrive at the final answer when solving for the steady-state solution. Examples of such reaction rate coefficients are nitrification rates and algal growth rates.

Nitrification rates are related to the dissolved oxygen concentration. This is a result of the fact that nitrifying bacteria are very sensitive to DO levels. At low DO values nitrification slows rapidly. To couple this rate, the maximum decay rate of ammonia and nitrite are reduced by the factor

$$PN = 1.0\ e^{-0.52*0} \qquad (B-35)$$

where

PN = nitrification reduction factor

O = DO (mg/liter)

Denitrification is coupled in a similar manner except the effect is reversed. For high dissolved oxygen levels, the denitrification rate is reduced. The coupling equation is:

$$PD = e^{-0.35*0} \quad \text{(B-36)}$$

where

PD = denitrification reduction factor

The algal growth rate is related to the concentration of nitrate, ammonia, and phosphorus as already described. The three feedback mechanisms require the model to iterate several times for the steady-state solution. The iterations are stopped when a convergence check is satisfied.

REFERENCES

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Steele, J. H. 1965. Notes on some theoretical problems in production ecology. pp. 383-398. In: C. R. Goldman (ed.) Primary production in aquatic systems. 18th Supplement. Memorial Institute for Hydrobiology, University of California-Berkeley.

Zanoni, A. E. 1969. Secondary effluent deoxygenation at different temperatures. J. Water Pollut. Control Fed. 41:640-659.

APPENDIX C

CROSS SECTION DATA USED AS INPUT TO HEC-2 PROGRAM

Data is organized on computer punch cards according to standard HEC-2 format (Patterson and Rogers 1978). Data begins with title cards (beginning with T1, T2, and T3) followed by program control cards (beginning with J1, J2, J3, and J5). Data for each cross section then follows according to the following format:

Card beginning with	Data
NC	Manning's n data: the third member refers to the Manning's n for the channel
NH	Manning's n data; used to describe variation in roughness along a cross section
X1	Identifies cross section and location; first number is cross section identifier (river mile); second number refers to total number of stations on GR cards; the next numbers refer to horizontal stations on (= distance from left-most end of cross section looking upstream) of left bank and right bank, and lengths of reaches to next downstream cross section at left overbank, right overbank, and at the channel.
X3	Used to identify ineffective flow areas: usually two pairs of numbers to identify stations and elevations (for left and right banks) outside of which there is no flow.
GR	Ground profile: pairs of numbers specifying the ground or channel bottom elevation and the horizontal station associated with that elevation.

Other types of cards are used. Details may be found in Patterson and Rogers (1978).

```
T1      WISCONSIN RIVER AT PORTAGE, WISCONSIN- QUAL3 CALIBR
T2      EXISTING CONDITIONS- CROSS-SECTIONS TAKEN LOOKING UPSTREAM
T3      DISCHARGE =    1800 CFS                                      ]
J1  -10.                0       0       0       0       1    1800  774.50        0
J2    -1                -1
J338.   4.      26.     17.     25.     53.     54.     58.      1.       0.
J3 0.   0.      0.      0.
J5-10.  -10.
NC .1000   .1000   .0350   .2000   .4000
X1 106.4      15  1100.0  2135.0  4665.0  4665.0  4665.0  0.        0.
X3                        1100.    800.    1930.   800.
GR 800.0  1000.0   774.8  1100.0   769.8  1260.0   768.8  1430.0   768.8  1510.0
GR 766.8  1600.0   770.7  1680.0   772.2  1840.0   775.0  1930.0   777.6  1930.0
GR 771.2  1960.0   772.7  2030.0   769.7  2100.0   777.6  2135.0   777.6  2605.0
X1107.10      24  1000.0  2240.0  3575.0  3575.0  3575.0  0.        0.
X3                        1000.    800.    2240.   800.
GR 795.0  1000.0   777.4  1010.0   776.8  1060.0   769.3  1130.0   768.3  1200.0
GR 771.8  1320.0   775.5  1380.0   778.9  1380.0   772.3  1420.0   773.3  1460.0
GR 770.4  1520.0   777.8  1540.0   773.4  1600.0   772.4  1710.0   773.9  1770.0
GR 772.4  1870.0   772.4  2070.0   771.4  2130.0   772.9  2180.0   777.8  2240.0
GR 777.8  2630.0   778.9  2630.0   778.9  2770.0   795.0  2780.0
X1107.45      22  2190.0  3200.0  4080.0  4080.0  4080.0  0.        0.
X3                        2190.    800.    2760.   800.
GR 800.0  1000.0   785.9  1200.0   775.6  1220.0   776.6  1320.0   776.0  1450.0
GR 777.2  1520.0   776.0  2070.0   777.0  2190.0   768.3  2270.0   765.4  2340.0
GR 771.4  2460.0   771.4  2600.0   772.3  2660.0   777.3  2720.0   774.3  2760.0
GR 773.3  2840.0   773.3  2890.0   770.3  2930.0   777.3  2970.0   777.3  3190.0
GR 780.0  3200.0   800.0  3600.0
NC .1200   .1000   .0350   .2000   .4000
X1108.65      27  3020.0  4310.0  3640.0  4080.0  4080.0  0.        0.
X3                        3020.    800.    3820.   800.
GR 800.0  1000.0   790.2  1125.0   782.1  1135.0   777.3  1270.0   776.4  1520.0
GR 778.1  1800.0   778.3  2250.0   776.4  2510.0   776.6  2780.0   779.2  3020.0
GR 774.5  3030.0   771.5  3120.0   770.4  3200.0   770.3  3380.0   773.5  3470.0
GR 770.8  3600.0   775.4  3820.0   773.0  3870.0   774.4  3920.0   771.5  4060.0
GR 777.4  4110.0   771.8  4150.0   773.8  4220.0   770.3  4290.0   777.4  4310.0
GR 777.4  4700.0   800.0  4730.0
NC .1200 -1.0000   .0350   .2000   .4000
NH     4   .1200  3000.0   .0350  3730.0   .1200  7400.0   .0700 12530.0
X1109.55      51  3000.0  3730.0  3430.0  8400.0  4650.0  0.        0.
X3                        3000.    800.    3730.   800.
GR 797.0  1000.0   780.2  1520.0   780.2  1680.0   777.7  2000.0   778.9  2200.0
GR 778.9  2480.0   778.0  2610.0   776.5  2610.0   776.5  2670.0   778.5  2780.0
GR 780.0  3000.0   772.8  3050.0   774.8  3140.0   773.3  3220.0   773.8  3260.0
GR 773.8  3310.0   772.8  3350.0   772.8  3400.0   773.4  3440.0   777.8  3480.0
GR 776.4  3485.0   772.4  3540.0   773.4  3570.0   773.9  3630.0   773.4  3660.0
GR 773.9  3700.0   777.8  3730.0   777.8  3930.0   778.4  3930.0   778.4  6270.0
GR 781.1  6280.0   781.0  6800.0   779.9  7000.0   779.8  7280.0   778.4  7400.0
GR 778.4  7600.0   777.5  7800.0   779.3  8200.0   778.6  8400.0   779.7  8600.0
GR 780.4  9000.0   780.7  9600.0   781.4  9800.0   782.2 10320.0   781.7 10600.0
GR 782.8 11200.0   783.3 11600.0   784.3 11770.0   786.0 11790.0   790.0 12300.0
GR 795.0 12530.0
NC .1000 -1.0000   .0350   .2000   .4000
NH     4   .1000  1260.0   .0350  2555.0   .1200  4850.0   .0700  7020.0
X1 110.1      22  1260.0  2555.0  4750.0  5220.0  4600.0  0.        0.
X3                        1260.    800.    1700.   800.
GR 801.0  1000.0   780.6  1220.0   780.5  1260.0   772.0  1380.0   771.0  1470.0
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GR 771.0  1570.0    774.5  1670.0    776.0  2130.0    774.5  2330.0    779.0  2430.0
GR 774.9  2440.0    769.0  2480.0    779.0  2555.0    779.0  3555.0    790.4  3600.0
GR 801.2  3940.0    801.2  4520.0    790.0  4800.0    780.0  4850.0    782.1  6800.0
GR 783.1  6930.0    806.5  7020.0
NC .1300   .1200    .0350   .2000    .4000
X1111.30      30   5200.0  6330.0   3750.0  6020.0  4970.0  0.         0.
X3                        5200.   805.    6330.   805.
GR 800.0  1000.0    796.4  1070.0    782.5  1090.0    781.0  1840.0    783.0  2110.0
GR 781.0  2650.0    777.6  2690.0    776.6  2860.0    778.4  3170.0    776.8  3520.0
GR 779.0  3630.0    781.0  4000.0    781.3  4800.0    778.5  5200.0    777.3  5360.0
GR 775.2  5420.0    775.6  5560.0    777.1  5630.0    775.3  5770.0    777.2  5980.0
GR 776.7  6120.0    775.2  6190.0    776.3  6260.0    782.1  6330.0    782.3  6470.0
GR 780.5  6800.0    780.6  7400.0    782.2  7600.0    780.5  8020.0    803.0  8070.0
NC .1250 -1.0000    .0350   .2000    .4000
NH     4   .1250   6810.0   .0350   7580.0   .1200 10520.0    .0800 12690.0
X1111.75      36   6810.0  7580.0   2510.0  4560.0  4030.0  0.         0.
X3                        6500.   805.    7100.   805.
GR 796.4  1000.0    783.1  1045.0    781.7  1800.0    783.6  2070.0    781.7  2620.0
GR 778.4  2640.0    777.4  2810.0    779.0  3120.0    777.5  3470.0    781.7  3950.0
GR 782.0  4740.0    777.1  5490.0    778.5  5800.0    777.0  6040.0    781.0  6480.0
GR 781.0  6810.0    779.0  6810.0    775.5  6900.0    775.0  6980.0    773.0  7020.0
GR 772.5  7100.0    765.0  7140.0    781.0  7220.0    777.9  7270.0    778.5  7330.0
GR 777.0  7520.0    781.0  7580.0    781.0  7890.0    783.0  7900.0    782.6  8620.0
GR 781.1  8820.0    781.5 10260.0    785.4 10290.0    790.8 10520.0    790.8 12590.0
GR 805.0 12690.0
NC .1200 -1.0000    .0350   .2000    .4000
NH     4   .1200   8420.0   .0350   9275.0   .1000  9895.0    .1200 12600.0
X1112.40      31   8420.0  9275.0   2350.0  4750.0  3000.0  0.         0.
X3                        8420.   805.    9895.   805.
GR 782.0  1000.0    780.8  1840.0    785.4  2520.0    785.5  3310.0    779.5  6700.0
GR 782.5  7140.0    782.8  8000.0    785.5  8420.0    772.8  8450.0    774.7  8490.0
GR 775.7  8680.0    782.9  8710.0    779.7  8715.0    778.2  8830.0    778.8  8955.0
GR 778.1  9020.0    778.5  9200.0    782.9  9275.0    782.9  9895.0    784.0  9900.0
GR 782.0 10050.0    782.0 10270.0    784.4 10290.0    785.4 10410.0    783.5 10500.0
GR 784.6 10760.0    782.8 11080.0    784.0 11470.0    786.0 11510.0    786.0 12580.0
GR 789.5 12600.0
NC .0900   .1000    .0350   .2000    .4000
X1 112.9      23   5760.0  6940.0   3040.0  1870.0  1870.0  0.         0.
X3                        5760.   805.    7160.   805.
GR 782.1  1000.0    782.7  2100.0    780.3  3330.0    780.8  4500.0    784.6  4550.0
GR 786.5  5080.0    782.6  5130.0    785.4  5590.0    781.0  5760.0    776.0  5860.0
GR 779.0  5930.0    779.4  6000.0    775.0  6210.0    775.0  6280.0    778.5  6350.0
GR 778.4  6860.0    783.7  6940.0    783.9  7160.0    787.0  7420.0    781.8  7740.0
GR 784.7  7900.0    782.4  8380.0    791.7  8400.0
NC .1000   .1200    .0350   .2000    .4000
X1113.40      20   1820.0  2950.0   4540.0  3790.0  3790.0  0.         0.
X3                        1820.   805.    3290.   805.
GR 803.5  1000.0    792.1  1290.0    783.4  1330.0    784.9  1680.0    783.6  1820.0
GR 782.1  2200.0    780.0  2240.0    780.2  2350.0    777.5  2390.0    777.5  2460.0
GR 780.5  2580.0    781.5  2690.0    780.0  2840.0    772.0  2920.0    782.3  2950.0
GR 786.5  3010.0    782.8  3090.0    782.8  3120.0    788.2  3290.0    792.8  3310.0
X1114.40      15   1000.0  2100.0   3550.0  3550.0  3550.0  0.         0.
X3                        1000.   805.    2100.   805.
GR 795.5  1000.0    786.8  1020.0    788.0  1060.0    776.0  1110.0    778.5  1250.0
GR 778.4  1350.0    787.9  1390.0    782.5  1390.0    782.5  1865.0    775.0  1990.0
GR 784.0  2025.0    784.0  2080.0    787.9  2100.0    787.9  4360.0    795.0  4370.0
X1115.60      14   1120.0  1810.0   6265.0  6265.0  6265.0  0.         0.
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X3                         1120.   805.    1810.   805.
GR 806.0  1000.0   794.8  1040.0   797.9  1120.0   779.4  1140.0   778.9  1220.0
GR 780.9  1300.0   780.4  1400.0   781.4  1440.0   778.5  1470.0   779.9  1490.0
GR 780.4  1650.0   782.5  1720.0   796.0  1770.0   800.0  1810.0
NC.1    .1      .04     .2      .4
X1115.66      29    -2.     661.    300.    300.    300.
X3                       25.     805.    300.    805.
GR805.  -2.     798.9   -2.     798.9   -1.     795.8   0.      795.8   4.
GR790.  24.     778.9   56.     773.3   102.    773.3   113.    773.9   124.
GR775.3 184.    775.9   247.    776.3   257.    776.3   270.    778.9   329.
GR778.8 389.    778.3   401.    778.3   414.    777.4   473.    778.3   534.
GR779.2 544.    778.2   557.    780.3   602.    790.    639.    794.5   652.
GR794.5 658.    797.3   659.    797.3   661.    805.    661.
SB.9    1.5     3.0             510.    12.     10440.  1.5
NC.1    .1      .04     .2      .4
X1115.68      32   998.   1662.    100.    100.    100.
X2              1.      797.5   800.
X3                      998.    805.    1660.   805.
BT7.    988.    803.5   798.9   1117.   805.6   796.2   1260.   807.3   797.5
BT1403. 807.3   797.4   1546.   806.    796.    1573.   805.6   796.3   1662.
BT804.4 797.3
GR803.5 998.    798.8   998.    798.8   1000.   795.7   1001.   795.7   1005.
GR790.  1026.   778.8   1057.   772.3   1102.   772.9   1113.   772.9   1117.
GR772.9 1125.   775.4   1185.   774.8   1247.   775.3   1258.   775.5   1260.
GR776.4 1269.   778.8   1331.   778.4   1390.   778.9   1403.   778.4   1414.
GR777.4 1474.   777.5   1535.   778.4   1546.   778.3   1558.   779.1   1573.
GR780.4 1603.   790.    1638.   794.5   1654.   794.5   1659.   797.2   1660.
GR797.2 1662.   804.4   1662.
NC.1    .1      .04     .2      .4
X1116.53      35     0.    1119.   4500.   4500.   4500.
GR806.5 0.      798.2   0.      785.    9.      782.5   57.     781.5   104.
GR782.  115.    782.    128.    783.6   189.    782.    256.    782.1   266.
GR782.5 277.    784.    337.    783.6   401.    783.1   413.    784.5   423.
GR784.5 490.    784.5   550.    784.    561.    783.    571.    785.5   637.
GR784.6 697.    783.6   707.    783.1   719.    781.6   784.    781.6   846.
GR780.  856.    779.6   867.    781.    930.    782.5   994.    782.5   1004.
GR782.5 1014.   783.6   1063.   785.    1109.   798.7   1119.   810.    1119.
SB.9    1.5     3.0             1080.   21.     18870.  1.5
X1116.54      35     0.    1119.    40.     40.     40.
X2              1.      800.    805.
BT9.    0.      808.2   801.1   116.    810.    801.2   264.    811.    802.2
BT413.  812.    803.2   561.    813.    804.3   707.    813.2   804.6   856.
BT813.  804.2   1003.   811.9   803.5   1118.   810.6   802.5
GR810.  0.      798.5   0.      785.    10.     782.5   61.     781.6   106.
GR782.  116.    782.5   128.    783.5   190.    780.6   256.    780.6   266.
GR780.6 278.    784.    335.    783.5   405.    784.5   413.    783.6   424.
GR784.5 489.    784.    550.    784.    563.    782.6   572.    785.5   636.
GR784.  696.    784.5   708.    782.    719.    781.6   784.    780.5   845.
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BT413.  812.    803.2   561.    813.    804.3   707.    813.2   804.6   856.
BT813.  804.2   1003.   811.9   803.5   1119.   810.6   802.5
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GR 789.9    5843    789.5     5903    797.5     5915    798.2   5915.9    799.3   5937.7
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X1125.49        96     6950    7950    3700     3700     3700
X3                     1400.              8150.
GR819.00 1000.00   812.70 1015.40   814.60 1028.40   815.20 1048.60   814.10 1065.20
GR819.60 1078.70   819.60 1097.30   824.00 1113.10   823.40 1132.80   810.40 1172.40
GR811.80 1231.20   807.00 1350.70   812.40 1391.80   812.60 1405.70   812.50 1421.40
GR804.00 1455.70   804.70 1650.80   804.00 1850.90   804.10 2055.10   804.10 2260.00
GR804.50 2465.20   805.30 2670.80   806.50 2872.20   806.80 3067.90   807.90 3187.30
GR804.90 3236.00   805.90 3618.40   805.50 3724.00   806.80 3774.10   806.00 3962.00
GR806.20 4153.60   802.20 4290.20   806.50 4470.30   806.50 4631.40   809.00 4715.30
GR807.30 4907.50   806.00 5107.90   806.10 5301.80   802.60 5468.80   809.50 5668.60
GR805.30 5868.90   807.20 6012.70   806.20 6091.10   799.60 6109.70   799.60 6174.30
GR 799.9    6374    798.3     6950    794.3     6965    793.8     7065    795.3     7075
GR 793.3    7240    795.3     7255    793.3     7265    793.3     7555    792.3     7565
GR 791.3    7640    792.3     7655    798.3     7665    802.2     7950    806.8     8366
GR800.00 8468.80   799.30 8504.60   799.30 8605.20   806.70 8633.80   806.80 8726.40
GR813.90 8813.30   805.70 8955.40   807.20 8972.80   807.40 8979.90   807.20 8989.20
GR803.10 9018.30   801.30 9213.30   803.90 9411.10   804.60 9611.30   802.60 9811.00
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GR834.5013122.70
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X3                        3300.           10300.
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GR804.80 1552.50  804.80 1580.10  805.60 1724.10  812.20 1799.10  812.20 1821.80
GR805.90 1846.90  805.70 2040.00  805.10 2425.50  810.30 2447.00  803.00 2476.40
GR810.40 2523.30  810.40 2551.80  804.10 2578.10  805.60 2611.00  805.60 2810.20
GR805.60 3010.20  805.70 3209.70  807.00 3407.00  806.30 3580.70  806.30 3700.30
GR806.70 3904.40  807.70 4300.00  807.10 4500.10  807.10 4700.00  808.10 4900.30
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GR805.70 6262.30  808.60 6603.00  805.60 6795.00  806.80 6955.10  807.10 7107.10
GR 799.5  7194.3   799.0    7195   795.0    7213   795.0    7273   796.0    7303
GR 795.5    7333   793.0    7353   793.5    7418   793.0    7433   794.5    7473
GR 795.0    7513   790.0    7523   795.0    7563   794.0    7578   795.     7593
GR 791.5    7613   794.5    7628   794.5    7663   792.0    7664   794.5    7703
GR 792.5    7713   793.0    7743   795.5    7768   795.5    7933   790.0    7953
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GR809.2011000.40  808.7011141.60  809.7011274.90  807.3011454.60  807.3011800.70
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GR874.6 15051.6
NC   .16     .16    .035
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GR 803.2  4888.6   799.5  4906.5   799.7    4907   793.7    4970   795.3    4991
GR 794.7    5066   795.7    5092   794.8    5201   792.3    5243   795.3    5369
GR 793.7    5437   795.3    5487   793.7    5571   795.3    5630   793.7    5664
GR 795.2    5706   793.7    5714   793.7    5782   796.7    5824   799.7    5832
GR 799.5  5832.1   809.0  5854.7   809.0  5854.8   809.0  5854.9   809.0  5855.0
GR809.00 5860.20  807.00 6058.90  810.00 6258.10  810.40 6439.60  806.90 6631.20
GR810.20 6784.90  805.80 6807.40  805.70 7005.70  805.90 7087.40  803.60 7123.20
GR800.30 7130.20  800.30 7212.60  809.30 7236.90  809.60 7332.60  806.90 7377.80
GR808.50 7575.60  808.30 7773.90  807.20 7972.20  808.30 8171.40  808.70 8370.40
GR807.90 8569.30  808.30 8695.30  806.00 8719.60  809.30 9000.20  807.80 9200.00
GR809.10 9599.10  809.40 9797.90  811.5010196.60  809.6010397.30  810.6010598.40
GR822.4010796.80  825.9010996.70  838.7011316.60  849.7011427.60  853.6011486.20
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GR896.9012557.00  868.8012649.10  868.4012655.90  871.8012667.20  872.8012688.70
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X3                        3000.            9020.
X4    13   800.0    5720   800.0    5800   800.6    6529   795.6    6535   794.6
X4  6572   791.6    6578   792.6    6658   795.6    6695   794.6    6966   796.6
X4  7102   795.1    7132   796.6    7274   800.6    7286
GR813.20 1000.00  811.80 1206.00  811.20 1400.90  812.10 1600.90  812.70 1803.60
GR812.40 2000.50  812.60 2202.00  814.10 2600.50  814.60 2801.60  813.20 3200.60
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GR809.40 4349.70   810.30 4495.70   809.30 4584.20   811.40 4730.40   811.60 4840.20
GR806.00 5000.10   808.50 5399.00   808.80 5599.50   810.40 5698.20   802.50 5706.90
GR802.50 5829.90   806.30 5850.40   809.60 6049.50   810.10 6247.80   809.10 6388.00
GR812.20 6445.10   807.20 6510.50   802.00 6528.40   802.00 7286.30   803.70 7311.60
GR811.30 7337.60   807.10 7483.00   809.50 7682.20   811.50 7704.00   808.40 7804.60
GR811.80 7866.40   806.30 7902.90   811.10 7992.30   810.30 8045.30   807.10 8061.60
GR809.10 8257.50   807.90 8415.60   810.90 8458.80   809.10 8653.70   811.20 8760.30
GR810.10 8797.90   807.50 8820.80   807.60 9020.50   806.70 9172.40   809.90 9184.80
GR809.00 9287.10   813.10 9330.20   812.80 9348.60   811.70 9360.10   837.90 9506.20
GR841.30 9544.50   835.80 9630.80   840.00 9820.80   843.30 9998.40   841.2010108.60
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NH9187.8      .16  12461.4
X1128.06       96   7591.5  9187.8     2800    2800     2810
X3                       5600.             9900.
GR 809.4     1000    810.9  2400.2    812.2  2600.4    811.8  2775.6    810.9  2783.8
GR813.60 2794.40   813.60 2815.30   812.50 2824.00   813.10 2915.50   810.80 2992.00
GR810.20 4000.50   812.40 4200.80   812.10 4400.40   812.40 4601.00   813.60 4809.20
GR813.30 5000.30   815.40 5400.00   815.40 5600.20   815.10 5636.20   809.00 5706.80
GR813.80 5914.80   812.90 6124.20   810.70 6153.00   812.30 6202.90   805.50 6282.90
GR810.20 6445.70   804.30 6511.70   808.40 6560.50   808.30 6720.20   808.90 6900.60
GR811.10 7103.40   811.00 7302.10   805.00 7346.40   805.80 7488.40   802.00 7591.50
GR 801.4     7592    796.4     7634    795.4     7698    796.9     7712    796.9     7734
GR 795.4     7748    795.9     7776    796.9     7812    795.4     7833    795.9     7904
GR 798.4     7917    797.4     7925    797.4     8032    794.4     8082    798.4     8110
GR 801.4     8117    802.0   8117.2    805.4   8138.8    810.2   8264.2    810.6   8417.1
GR 807.0   8609.8    801.8   8634.4    801.4     8641    798.4     8651    798.4     8676
GR 797.4     8681    797.9     8696    798.4     8706    797.4     8776    798.4     8801
GR 795.4     8911    796.4     8926    796.4     8948    794.9     8951    794.9     8991
GR 795.4     9001    795.4     9081    796.9     9086    792.4     9091    792.4     9136
GR 796.4     9161    796.9     9176    801.4     9181    801.8   9187.8    809.7   9209.8
GR807.20 9475.80   809.80 9561.40   809.30 9702.90   810.20 9853.30   809.3010021.60
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NH 11684
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X3                       5350.             8100.
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GR812.00 2196.10   813.60 2509.40   813.80 2707.60   815.20 3000.00   815.60 3400.00
GR814.00 3600.00   814.60 3800.00   814.70 4000.00   813.70 4200.00   812.60 4408.80
GR815.50 4584.00   816.30 4763.90   816.30 4956.20   815.30 5155.50   813.90 5358.80
GR817.20 5562.70   815.00 5717.80   811.80 5869.00   807.50 5905.30   809.40 6103.00
GR809.60 6301.10   807.40 6501.10   805.90 6545.70   809.90 6606.00   805.70 6662.60
GR810.40 6756.50   810.10 6952.40   810.90 7109.30   812.80 7187.70   802.30 7203.60
GR 802.2     7205    796.7     7215    797.7     7235    796.3     7275    797.2     7325
GR 796.2     7355    797.7     7490    795.2     7495    796.3     7530    795.7     7535
GR 796.7     7835    797.8     7865    796.3     7885    802.3     7895    802.3   7900.8
GR 803.4   7963.7    804.4   8266.8    804.3     8267    804.2     8268    804.1     8269
GR804.10 8347.20   845.10 8626.70   845.30 8692.30   841.70 8705.90   844.00 8719.50
GR843.80 8743.10   836.00 8817.90   834.50 8926.80   825.60 9108.10   825.60 9300.60
GR828.20 9388.70   853.00 9567.60   855.10 9638.90   848.10 9748.60   849.60 9900.80
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X3                               5200.
X4       2     801.0      7585    800.5     7630
GR827.10 1000.00    819.70 1039.50   813.10 1182.60   812.20 1365.80   813.10 1522.80
GR812.50 1918.70    813.80 2071.90   813.00 2269.60   810.50 2437.70   809.80 2591.10
GR812.80 2699.60    811.80 2904.60   812.20 3100.50   813.80 3217.40   812.50 3400.00
GR813.40 3701.70    812.60 3895.70   813.50 4059.70   812.80 4252.10   813.50 4448.10
GR813.50 4644.30    815.40 4838.70   814.60 5032.30   817.10 5226.90   817.10 5235.90
GR812.00 5250.80    813.90 5259.40   814.00 5268.50   814.50 5279.20   814.50 5288.30
GR811.20 5383.20    811.10 5518.80   810.90 5741.40   814.10 5824.70   813.00 5914.50
GR 809.9  5963.1     811.8  6102.7    803.6  6119.3    803.2    6120    796.2    6172
GR 797.2    6232     797.2    6252    798.3    6277    798.3    6297    798.7    6332
GR 798.3    6392     798.7    6457    798.7    6567    799.2    6592    799.2    6677
GR 803.6    6857     805.1  6859.2    810.9  7157.2    808.0  7274.6    810.0  7404.6
GR808.40 7502.90    804.00 7517.10   803.50 7573.20   803.50 7649.20   804.50 7724.70
GR886.20 7871.30    887.10 7913.60   887.10 7952.50   882.70 8015.70   882.70 8021.00
GR884.70 8025.90    885.20 8036.90   884.90 8048.50   882.30 8060.20   871.00 8381.70
GR862.20 8647.10    862.20 8692.20   867.60 8764.10   869.50 8845.30   872.50 9052.30
GR869.70 9188.30    875.40 9580.90   873.90 9733.30   873.70 9848.10   881.4010010.40
GR883.3010036.00    878.4010065.30   878.7010075.10   881.2010078.40   883.2010107.10
NH       5       .07    3100.1      .15   6529.1     .045   7113.1      .15   8648.5      .07
NH9422.6
X1129.86          76    6529.1   7113.1     4400     3500     3910
X3                               4500.
X4      17     803.6      6530    800.6     6536    800.6     6548    799.1     6552    800.6
X4    6568     800.6      6632    799.1     6648    800.1     6688    800.6     6793    799.6
X4    6905     796.1      6979    793.1     7009    793.6     7049    792.6     7073    793.6
X4    7097     798.6      7109    803.6     7113
GR820.50 1000.00    815.80 1213.40   814.80 1406.70   814.50 1606.70   814.40 1806.70
GR814.60 2006.70    814.60 2206.70   814.50 2317.30   813.90 2510.10   814.20 2709.90
GR813.80 2900.00    816.10 3100.10   816.10 3300.10   816.30 3500.10   815.80 3597.20
GR817.10 3613.00    818.20 3672.00   816.20 3781.80   817.00 3900.10   817.30 4096.50
GR817.70 4288.00     820.0 4344.80   810.60 4371.60   810.60 4531.00   811.90 4554.60
GR814.60 4747.20    814.60 4925.00   813.70 5053.70   815.60 5161.00   820.00 5315.00
GR808.80 5338.60    806.80 5525.50   807.20 5668.80   803.20 5697.90   803.20 5737.50
GR812.60 5760.20    812.10 5783.00   808.40 5807.30   807.10 5846.00   814.50 5881.70
GR816.30 5948.40    816.30 5974.10   805.70 5995.70   805.20 6005.20   807.40 6027.00
GR808.20 6061.20    803.30 6080.50   803.30 6101.70   805.20 6109.20   806.30 6299.70
GR803.90 6529.10    803.90 7113.10   810.00 7129.80   811.40 7282.50   806.00 7334.30
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GR886.50 7958.60    884.00 7992.20   885.70 7996.30   886.80 8053.50   886.30 8250.70
GR886.00 8449.40    887.10 8648.50   885.30 8787.10   886.00 8914.10   884.20 9035.00
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GR884.00 9422.60
NC     .16       .15       .04
X1130.56          47    4028.6   4940.6     4200     3300     3700
X3                               2000.             5000.
X4      13     803.9      4029    800.4     4040    798.4     4138    798.4     4212    795.9
X4    4256     799.9      4373    799.9     4613    797.4     4675    797.9     4737    795.9
X4    4879     793.4      4916    797.9     4932    803.9     4948
GR830.10 1000.00    829.60 1013.50   825.80 1030.00   818.40 1264.40   818.50 1431.50
GR819.40 1730.30    817.10 1815.20   819.20 1888.40   819.20 2057.00   819.50 2259.80
GR820.20 2411.90    822.20 2538.30   829.70 2580.00   827.90 2598.40   827.90 2598.50
GR816.20 2662.60    817.80 2693.80   816.60 2763.50   817.60 2796.70   816.80 2845.30
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GR811.20 2885.40   809.90 3000.10   809.40 3054.80   808.40 3072.20   812.40 3121.20
GR809.10 3181.50   811.90 3278.90   811.60 3428.30   811.60 3569.50   812.70 3598.90
GR813.10 3737.20   816.00 3759.70   817.70 3833.10   816.70 3947.20   814.10 3998.60
GR804.20 4028.60   804.20 4940.60   815.10 4953.70   812.70 4977.00   812.00 5101.20
GR805.70 5154.50   805.70 5183.70   811.50 5226.60   829.40 5453.10   822.30 5497.10
GR827.40 5521.10   827.50 5532.00
NC   .15     .15      .04
X1131.01      57     2149   3022.7     2400     2400     2400
X3                                          3900.
X4     2   810.7   3037.3    808.7   3073.0
GR832.60 1000.00   833.40 1016.70   830.20 1038.10   832.00 1068.40   834.40 1219.00
GR823.70 1357.70   823.10 1409.80   826.10 1473.30   823.70 1559.20   827.40 1602.00
GR823.30 1703.70   832.20 1820.10   824.60 1873.10   824.90 1926.80   807.40 2026.90
GR 806.6  2122.1    804.7     2149    804.4     2150    801.9     2155    801.9     2175
GR 799.9    2200    799.4     2265    795.9     2460    799.4     2480    798.4     2740
GR 799.9    2840    797.4     2900    801.4     3015    804.4     3020    804.7   3022.7
GR811.40 3185.70   809.30 3216.50   813.80 3258.00   814.40 3314.20   818.20 3350.00
GR816.30 3381.90   816.60 3413.90   821.30 3452.50   820.90 3487.70   817.80 3504.00
GR819.70 3517.10   819.70 3529.90   819.70 3543.70   815.60 3605.80   817.90 3711.40
GR817.50 3841.40   815.40 4002.50   816.80 4076.50   815.80 4172.00   815.00 4376.70
GR815.20 4483.30   814.90 4577.40   817.40 4638.40   817.70 4738.70   817.60 4788.90
GR821.00 4810.30   820.50 4831.10
NH     4     .15   1569.5      .04   2329.8      .15   2475.5     .075   6547.2
X1131.60      49   1569.5   2329.8     3100     3200     3120
X3                                          2850.
X4    10   804.7     1570    798.2     1584    798.7     1598    797.2     1682    797.2
X4  1795   798.7     1879    800.2     2217    800.7     2245    801.7     2323    804.7
X4  2329
GR865.90 1000.00   865.90 1012.10   864.40 1095.90   867.30 1405.60   812.60 1515.10
GR811.40 1535.90   805.00 1569.50   805.00 2329.80   807.80 2385.30   816.20 2416.30
GR810.90 2475.50   812.80 2509.90   811.20 2547.80   811.40 2598.10   818.10 2638.10
GR816.00 2717.00   823.60 2766.70   823.00 2850.90   823.50 2861.70   823.50 2883.40
GR820.40 2913.70   821.50 3110.00   819.30 3510.00   820.90 3592.80   819.50 3771.00
GR820.70 3896.30   820.70 4072.80   820.10 4238.60   820.80 4402.90   819.30 4599.00
GR829.10 4640.50   817.30 4746.80   816.40 4923.20   823.60 4972.80   816.80 5057.00
GR823.10 5357.60   822.40 5536.00   822.80 5653.60   824.80 5678.20   821.60 5706.00
GR820.10 5839.20   820.10 6000.80   814.70 6061.80   815.60 6435.50   830.50 6479.60
GR830.30 6509.00   828.70 6527.20   830.50 6536.70   830.60 6547.20
NH     5     .16   1442.6     .045   1878.8      .17   2026.9      .07   6000.7      .16
NH7130.5
X1132.02      53   1442.6   1878.8     2000     2400     2200
X3                                          2200.
X4    11   804.9     1443    798.9     1480    792.4     1526    795.9     1572    795.9
X4  1633   795.4     1663    797.4     1805    800.9     1847    799.9     1862    801.4
X4  1874   804.9     1878
GR911.10 1000.00   911.10 1006.10   909.20 1016.30   913.10 1028.60   909.80 1089.40
GR910.00 1139.50   910.80 1168.00   909.50 1192.20   902.00 1232.30   816.30 1369.20
GR810.70 1399.70   809.40 1426.10   807.60 1434.00   806.80 1442.60   806.80 1878.80
GR807.20 1897.70   807.50 1954.70   810.20 1978.70   811.50 2056.60   814.60 2125.10
GR811.60 2218.10   826.10 2300.20   821.80 2579.20   821.30 2703.80   818.60 2859.50
GR822.40 3024.40   823.50 3201.70   818.40 3507.80   822.50 3636.20   823.60 3837.70
GR823.50 4010.00   821.90 4111.90   823.30 4283.30   819.50 4476.40   821.20 4615.00
GR822.20 4755.90   821.80 4948.00   821.80 5151.90   818.90 5213.90   810.70 5249.50
GR809.90 5416.40   830.60 5601.10   831.40 5698.30   827.10 6000.70   829.40 6267.00
GR824.60 6361.80   813.70 6392.80   813.50 6550.00   814.00 6692.40   817.10 6790.60
GR835.00 6861.50   836.70 7000.80   842.80 7130.50
NH     4    .075   1363.3      .17   1997.7     .045   2766.1      .17     7139
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X1132.69        76   1997.2  2766.1    3300     4300     3540
X3                           1700.              2900.
GR862.00 1000.00   855.50 1089.50   854.00 1150.50   855.80 1215.80   848.10 1272.70
GR840.40 1363.30   836.10 1520.40   817.60 1604.80   817.60 1664.80   826.00 1715.30
GR825.90 1736.80   818.40 1767.60   815.80 1806.00   818.00 1827.40   814.50 1936.50
GR 816.3  1980.4    807.2  1997.2    805.3     1998    800.3     2008    800.9     2031
GR 800.4    2065    801.9    2089    801.9     2118    799.4     2147    800.9     2157
GR 800.9    2186    801.4    2215    798.4     2355    800.9     2370    800.4     2432
GR 798.3    2500    799.4    2536    797.9     2582    798.4     2631    799.9     2650
GR 799.4    2693    800.3    2708    800.4     2737    799.9     2742    801.4     2761
GR 805.4    2766    807.2  2766.1    828.1     3048    827.4   3236.2    827.5   3236.8
GR827.20 3441.10   827.50 3641.10   825.70 3774.30   827.80 3908.40   826.50 4045.70
GR826.40 4227.60   828.60 4414.40   828.60 4549.10   826.70 4840.80   828.50 5040.80
GR826.60 5215.80   827.10 5343.50   827.30 5477.00   829.70 5623.00   829.50 5762.00
GR830.00 5823.70   811.80 5869.00   810.00 6002.90   811.20 6098.40   827.10 6148.10
GR835.40 6226.90   843.30 6292.10   839.50 6329.10   844.80 6386.90   863.70 6429.50
GR846.30 6473.70   847.20 6619.20   848.20 6817.50   855.30 7099.90   860.70 7130.40
GR860.90 7139.20
NC   .17     .16      .04
X1133.42        38   1887.8  2788.4    3900     3800     3850
GR832.00 1000.00   825.80 1028.70   823.60 1122.10   831.40 1169.90   831.30 1189.40
GR818.00 1233.20   821.80 1267.10   819.60 1283.80   821.70 1368.50   809.60 1418.70
GR 809.1  1498.1    811.8  1589.3    809.9   1839.3    807.6   1887.8    806.0     1900
GR 806.0    1975    807.6  2006.8    809.3   2072.4    807.6   2172.3    805.8     2173
GR 803.3    2186    803.3    2233    802.3     2300    802.8     2428    799.3     2487
GR 799.8    2494    794.8    2554    795.3     2562    792.8     2607    793.8     2668
GR 799.3    2690    795.3    2720    797.8     2742    798.3     2772    801.8     2782
GR 805.8    2788    807.6  2788.4    832.0   2867.9
NC   .18     .18     .035
X1133.91        35   1759.5    2085    2800     2400     2600
X4    12   806.0     1760   797.0    1785    795.5     1834    792.0     1903    791.0
X4  1985   793.0     2000   792.5    2010    796.0     2041    798.5     2054    797.0
X4  2067   798.5     2077   806.0    2084
GR846.50 1000.00   846.50 1025.40   821.50 1072.70   819.00 1114.70   808.00 1174.20
GR808.00 1219.80   813.90 1265.20   812.30 1529.80   811.40 1638.30   811.40 1722.30
GR807.70 1759.50   807.70 2085.00   811.80 2174.50   812.70 2272.40   866.30 2560.00
GR867.90 2589.40   940.80 2953.40   952.40 3060.50   954.90 3133.60   950.00 3264.10
GR951.30 3452.00   953.70 3611.00   958.10 3920.60   962.60 4060.90   964.60 4202.60
GR962.10 4285.00   964.20 4395.70   965.00 4687.60   955.60 4771.00   969.20 4925.40
GR968.50 4988.70   972.50 5084.50   973.50 5107.70   977.00 5133.00   977.00 5147.30
NC   .18     .18     .045
X1134.20        21   1113.8  1566.5    1500     1600     1520
GR 856.4    1000    855.6  1073.1    808.1   1113.8    806.3     1115    791.3     1140
GR 785.8    1161    786.8    1172    784.8     1195    785.3     1224    782.3     1241
GR 797.3    1375    800.3    1440    797.3     1442    801.3     1505    802.3     1522
GR 799.8    1531    803.3    1550    806.3     1560    808.1   1566.5    818.9   1705.7
GR 833.0    1843
NH     4     .17   1854.6     .06    2224      .04   2815.5      .17   2965.7
X1134.72        33   2224.0  2815.5    2700     2800     2770
GR834.00 1000.00   825.30 1046.20   828.50 1066.60   826.60 1208.80   832.20 1296.30
GR830.50 1402.00   833.90 1576.30   828.40 1854.60   813.60 1956.40   812.70 2084.80
GR 814.9  2187.6    808.5    2224    806.6     2235    803.1     2243    796.6     2388
GR 797.6    2440    797.1    2465    797.6     2482    796.6     2558    797.1     2567
GR 795.6    2610    792.6    2635    793.1     2652    791.6     2677    796.1     2745
GR 799.6    2762    798.6    2779    802.6     2800    806.6     2805    808.5   2815.5
GR 813.4  2855.3    816.2  2931.3    834.0   2965.7
NC   .19     .19     .035
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X1135.04      42   1855.1   2213.3     1750     1500     1690
X4    14   806.8     1856    791.8     1860    787.8     1866    787.8     1881    776.8
X4  1892   776.8     1948    790.8     1991    788.8     2034    788.8     2089    785.8
X4  2144   788.8     2163    790.3     2195    791.8     2202    806.8     2213
GR834.00 1000.00   829.50 1082.30   827.70 1085.90   827.70 1090.00   829.50 1096.10
GR829.60 1177.30   828.60 1229.90   828.60 1237.40   832.00 1412.00   834.30 1649.20
GR835.70 1706.00   835.70 1737.50   834.30 1769.50   828.90 1802.90   811.00 1832.00
GR808.80 1855.10   808.80 2213.30   809.50 2223.50   809.60 2256.90   841.50 2298.20
GR865.60 2569.70   867.40 2628.80   858.00 2649.70   858.60 2653.80   858.30 2675.80
GR855.70 2704.50   865.90 2723.00   862.00 2800.30   853.50 2816.20   854.00 2824.40
GR854.40 2849.20   844.20 2951.20   820.40 3050.70   820.40 3146.80   818.90 3170.00
GR818.20 3223.70   819.30 3281.90   835.70 3312.10   837.50 3357.10   831.70 3501.00
GR812.90 3545.30   835.90 3635.90
NC    .2      .2     .045
X1135.52      47   3323.7   3789.2     2500     2500     2500
X4    14   807.0     3324    803.0     3334    803.0     3365    793.0     3411    795.0
X4  3449   795.0     3603    797.0     3655    801.0     3665    801.0     3680    802.0
X4  3706   801.0     3727    790.5     3748    804.0     3779    807.0     3789
GR880.90 1000.00   880.70 1018.40   863.90 1051.20   862.40 1073.80   863.90 1138.80
GR863.90 1170.70   851.30 1210.00   851.30 1248.30   857.90 1288.60   860.10 1348.80
GR849.20 1434.10   850.00 1511.20   849.20 1584.60   840.80 1635.10   828.80 1697.40
GR829.20 1759.70   829.20 1910.50   831.10 1959.20   843.40 2306.80   849.50 2491.70
GR849.50 2594.00   855.60 2791.30   875.90 3090.90   874.70 3183.50   856.00 3266.40
GR812.20 3287.30   808.90 3323.70   808.90 3789.20   806.70 3809.50   868.60 3861.90
GR879.90 3984.00   883.70 4167.40   886.70 4310.90   882.70 4351.40   882.70 4397.60
GR882.30 4471.30   882.20 4534.20   869.60 4707.80   854.10 4914.20   852.30 5007.60
GR849.10 5043.50   849.20 5054.70   849.00 5116.70   846.20 5239.10   843.80 5257.40
GR845.00 5266.30   845.40 5288.70
NC    .2      .2      .04
X1135.83      31   2076.5   2603.2     1800     1600     1630
X4    16   807.2     2080    802.7     2088    801.2     2178    796.7     2275    795.2
X4  2279   796.2     2342    795.2     2351    795.2     2397    790.2     2431    791.2
X4  2456   790.7     2469    792.2     2499    797.2     2545    802.7     2588    804.2
X4  2608   807.2     2613
GR835.30 1000.00   833.40 1074.90   859.40 1223.80   876.80 1432.80   882.70 1647.10
GR878.90 1734.50   869.40 1819.50   812.90 1914.00   811.10 1966.90   813.00 2011.90
GR810.70 2051.60   806.80 2076.50   806.80 2603.20   812.90 2653.10   810.50 2756.30
GR808.00 2793.30   814.50 2861.20   815.20 2885.00   848.10 2920.80   879.10 3082.30
GR887.30 3203.60   888.40 3338.90   886.00 3422.90   888.90 3505.20   883.20 3607.80
GR884.60 3705.50   888.40 3779.10   884.70 3880.20   880.10 3899.10   880.60 3921.00
GR880.60 3927.30
NC    .2      .2     .035
X1135.98      29   1044.2     1505      825      800      800
GR 836.0    1000    807.0   1044.2    807.3     1050    803.3     1059    798.3     1065
GR 798.3    1083    795.3     1096    795.3     1116    792.3     1125    789.3     1195
GR 791.3    1215    790.3     1236    790.8     1257    790.3     1281    790.8     1323
GR 787.8    1372    787.8     1384    790.3     1422    789.3     1430    796.8     1487
GR 801.3    1488    801.3     1499    807.3     1504    807.0     1505    821.6   1577.6
GR 822.1  1592.7    833.0   1686.9    832.6   1740.6    836.0   1747.8
NC.2     .2     .045
X1136.22      35   2011.3   2306.9     1300     1300     1300
X4     9   807.5     2020    786.9     2037    788.0     2064    788.5     2090    780.0
X4  2112   776.0     2147    779.5     2169    789.5     2244    807.5     2300
GR891.20 1000.00   892.80 1064.50   906.00 1100.40   909.50 1499.40   909.40 1637.30
GR904.10 1786.30   892.80 1869.80   807.20 2011.30   807.20 2306.90   817.70 2432.60
GR837.80 2689.50   837.70 2715.80   879.60 2782.40   890.60 2888.00   895.80 2992.00
GR898.80 3262.60   898.90 3387.70   900.80 3627.20   903.20 3964.50   902.80 4035.20
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GR900.70 4089.70   900.90 4186.30   901.90 4295.90   902.70 4396.50   901.00 4478.80
GR898.70 4547.40   896.70 4602.80   900.60 4656.60   902.90 4768.20   904.20 4871.40
GR903.70 4970.70   902.70 5005.10   904.60 5182.30   909.10 5231.90   909.00 5254.50
NC     .2      .17     .035
X1136.47        20   1295.1  1596.2    1290.     784.    1290.
X411.    796.     1302.    797.     1313.    794.     1357.    794.     1367.    794.
X4  1370    777.6     1405    773.1     1456    773.1     1464    765.6     1488    799.6
X4  1571    807.6     1596
GR896.70 1000.00   894.90 1060.00   909.70 1090.50   907.40 1146.40   895.40 1193.10
GR814.20 1227.70   807.70 1295.10   807.70 1596.20   811.70 1637.30   903.00 1708.80
GR910.40 1799.80   905.30 1964.40   905.70 2022.10   902.10 2088.20   909.90 2285.80
GR859.90 2449.10   860.10 2461.80   891.70 2536.20   896.90 2579.30   897.90 2664.80
NC     .2      .18     .05
X1136.81        25   2039.6  2337.3     1750      1750      1760
X4    18    808.4     2040    797.4     2047    798.4     2053    793.4     2060    797.9
X4  2067    796.4     2087    797.9     2100    794.4     2120    799.4     2133    798.4
X4  2173    798.9     2201    796.4     2208    800.4     2232    800.4     2252    794.9
X4  2307    789.4     2322    793.4     2335    808.4     2340
GR895.00 1000.00   893.90 1029.60   877.70 1099.00   874.80 1213.50   875.60 1237.70
GR875.40 1267.70   882.70 1297.30   883.10 1435.00   881.90 1539.30   861.90 1885.90
GR813.40 1997.80   807.80 2039.60   807.80 2337.30   813.20 2376.60   843.80 2438.00
GR850.20 2511.90   868.40 2591.00   885.60 2932.80   893.50 3141.80   903.60 3220.30
GR898.50 3266.90   900.10 3342.20   897.10 3436.20   890.00 3453.00   892.70 3504.50
X1136.97        28   1415.0  1813.2      840       840       840
X4     3    789.4     1790    793.4     1807    808.4     1813
GR863.90 1000.00   862.00 1085.40   840.90 1216.70   840.00 1414.90   807.90 1415.00
GR 808.4     1416    797.4     1425    798.4     1433    793.4     1442    797.9     1451
GR 796.4     1478    797.9     1495    794.4     1521    799.4     1539    798.4     1592
GR 798.9     1629    796.4     1638    800.4     1670    800.4     1679    794.9     1770
GR807.90 1813.20   839.70 1831.70   855.10 1867.30   862.60 1948.70   864.60 1981.70
GR865.00 2011.70   868.40 2027.60   868.50 2036.60
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APPENDIX D

OUTPUT OF HEC-2 SIMULATION USED FOR HYDRAULIC DATA TO THE QUAL-3 MODEL

Shaded cross sections indicate ones whose cross-sectional areas have been altered. The true topwidths of the river at the solution elevations for these cross sections are provided in parenthesis.

Abbreviations used in identifying columns:

SECNO	Location of cross section in river miles above the confluence of the Wisconsin River with the Mississippi River.
TOPWID	Topwidth of river; width of the river at the surface of the water in the cross section.
VCH	Average velocity of water in the cross section.
K*XNCH	Manning's n times 1,000.
AREA	Area of flow (does not include shaded ares in Figures 6a-6f of the text).
SSTA	Distance in feet from the left (south) end of the cross section to where the river begins.
ENDST	Distance in feet from the left (south) end of the cross section to where the river ends.
KRATIO	Ratio of the upstream to the downstream conveyance (=$nAR^{2/3}$ where n = Manning's n; A = area of flow; and R = hydraulic radius).
CWSEL	Elevation of water surface at the cross section.

HEC2 RELEASE DATED NOV 76 UPDATED AUG 1977
ERROR CORR - 01,02
MODIFICATION - 50,51,52,53

DISCHARGE = 1800 CFS

SUMMARY PRINTOUT

SECNO	TOPWID	VCH	K*XNCH	AREA	SSTA	ENDST	KRATIO	CWSEL
106.400	804.33	.54	35.00	3329.46	1109.60	1913.93	.00	774.50
107.100	1029.17 (645.29)	.69	35.00	2625.69	1080.25	2201.19	.57	774.64
107.450	489.00	.80	35.00	2247.17	2209.55	2760.00	1.27	774.88
108.650	776.88	.72	35.00	2489.35	3028.73	3805.61	.87	775.10
109.550	644.40 (1089.58)	1.48	35.00	1218.74	3030.95	3712.64	.58	775.54
110.100	380.25	1.21	35.00	1487.89	1319.75	1700.00	1.18	776.27
111.300	951.16 (770.00)	1.41	35.00	1278.52	5324.15	6275.31	.42	777.57
111.750	290.00	1.55	35.00	1164.17	6810.00	7100.00	1.86	779.02
112.400	734.87	1.19	35.00	1512.78	8434.49	9214.75	1.82	779.37
112.900	1089.53	.94	35.00	1909.26	5388.33	6877.86	.53	779.58
113.400	584.33	1.54	35.00	1167.93	2223.90	2945.76	.67	780.84
114.400	416.29	1.19	35.00	1513.26	1086.12	2016.18	1.93	781.73
115.600	584.92 (570.43)	1.19	35.00	1513.49	1136.29	1721.21	.80	782.83
115.660	255.43	.99	40.00	1824.42	44.57	300.00	2.05	782.86
115.680	566.23	.54	40.00	3334.14	1045.75	1611.98	1.63	782.86
116.530	545.08	2.76	40.00	651.52	45.19	1041.41	.07	783.12

116.540	590.70	2.13	40.00	846.03	48.28	1049.70	1.46	783.12
116.550	650.48	1.49	40.00	1206.64	44.28	1079.38	1.69	783.26
116.560	567.21	1.67	40.00	1076.47	43.18	1031.73	.91	783.66
117.280	1802.34	1.18	35.00	1529.05	7031.88	8034.22	1.40	785.81
117.920	758.67	1.05	40.00	1720.78	7073.08	8488.16	1.28	786.72
118.700	598.23	1.15	37.00	1571.11	8786.78	9888.14	1.09	787.88
119.500	961·86	1.62	35.00	1111.37	7265.32	8466.87	.58	789.40
120.700	1237.77	.86	35.00	2092.93	7289.30	8732.31	1.61	791.10
121.200	1153.96	1.10	36.00	1638.83	7255.56	8639.33	.68	792.09
121.420	654.18 (1288.06)	1.27	35.00	1414.20	2691.18	3769.49	1.60	792.39
122.260	568.00 (1460.77)	.88	40.00	2054.54	3000.00	3568.00	1.29	792.89
122.680	505.64	.79	40.00	2275.14	2700.00	3205.64	1.29	793.07
123.220	1033.30	1.17	40.00	1532.32	4809.12	6551.20	.67	793.32
123.860	1088.52	1.19	40.00	1517.97	4514.54	6340.34	1.00	793.80
124.450	815.54	.96	40.00	1876.23	6560.04	7375.58	.80	794.35
124.790	783.87	1.07	35.00	1678.59	5127.02	5910.89	.98	794.76
125.490	700.86	1.18	35.00	1524.91	6959.79	7660.65	.92	795.69
126.300	785.16	.88	35.00	2034.01	7205.29	7990.46	1.16	796.71
127.000	891.98	.76	35.00	2381.55	4933.33	8525.31	1.55	797.18
127.520	743.92	.97	35.00	1858.32	6532.74	7276.66	.75	797.49
128.060	878.20	1.16	35.00	1552.54	7622.39	9176.98	1.40	797.78
128.530	676.05	1.57	35.00	1146.04	7212.19	7888.24	.30	798.24
129.120	587.85	.00	35.00	1149.48	6140.41	6728.25	1.21	800.45
129.860	577.50	.98	35.00	1835.72	6533.93	7111.43	1.79	801.64

130.560	902.29	.56	40.00	3242.81	4035.20	4937.50	2.16	801.93
131.010	861.40	.65	40.00	2755.60	2154.69	3016.09	.79	802.05
131.600	748.94	.73	40.00	2463.68	1575.22	2324.16	.91	802.28
132.020	416.85	.76	40.00	2373.91	1458.31	1875.16	1.23	802.42
132.690	759.53	.86	40.00	2092.91	2003.14	2762.66	.54	802.72
133.420	538.03	.78	40.00	2304.33	2245.93	2783.96	1.66	803.11
133.910	313.51	.65	35.00	2760.11	1767.85	2081.36	2.20	803.18
134.200	429.28	.42	45.00	4278.11	1120.17	1549.45	1.30	803.20
134.720	558.08	.53	45.00	3406.34	2242.70	2800.79	.65	803.23
135.040	353.44	.30	35.00	5998.90	1856.95	2210.39	3.82	803.24
135.520	443.87	.65	45.00	2748.35	3333.39	3777.26	.19	803.24
135.830	503.22	.56	40.00	3218.38	2086.96	2590.18	1.36	803.29
135.980	441.66	.35	35.00	5073.43	1059.01	1500.66	2.64	803.30
136.220	263.48	.40	45.00	4504.21	2023.46	2286.95	.88	803.30
136.470	284.88	.33	35.00	5389.49	1297.69	1582.57	1.64	803.30
136.810	293.34	1.03	50.00	1741.87	2043.24	2336.58	.10	803.30
136.970	390.89	.75	50.00	2394.15	1420.11	1810.99	1.43	803.38

SUMMARY OF ERRORS

APPENDIX E

PROGRAM TO INTERPOLATE HEC-2 CROSS SECTIONS TO QUAL-3 HYDRAULIC DATA BY REACH

LIST OF VARIABLES USED IN THIS PROGRAM

A	Upstream boundary of cross section region of influence
AI	Reach number
AR	Area of flow in reach
B	Proportion of cross section region of influence to total QUAL-3 reach length
BI	Downstream boundary of cross section region of influence
BL	Length of QUAL-3 reach
D	Depth of flow
I	Reach number
JK	Same as K
K	Total number of HEC-2 cross sections
LWB	Downstream boundary of QUAL-3 reach
M	Number of cross sections remaining
O	Upstream cross section (miles)
Q	Flow rate (cfs)
R	Downstream boundary of QUAL-3 reach
UPB	Upstream boundary of QUAL-3 reach
V1	Upstream cross section velocity
V2	Downstream cross section velocity
VA	Distance average of HEC-2 velocities for QUAL-3 reach

VEL Cross section velocity (ft/sec)

XM Cross section number (miles)

XMAN Manning's n

XN1 Upstream cross section Manning's n

XN2 Downstream cross section Manning's n

XNA Distance average of HEC-2 Manning's n

XSCT HEC-2 cross section (miles)

W1 Upstream cross section topwidth (ft)

W2 Downstream cross section topwidth (ft)

WA Distance averaged of HEC-2 topwidths (ft)

WIDTH HEC-2 cross section top width of river (ft)

Notes--

(1) The second reach statement (line 5) reads QUAL-3 reach specification data according to QUAL-3 Form 7 starting at the most upstream reach. The Reach Specifications used in this study may be found in Appendix D.

(2) The third reach statement (line 13) reads the HEC-2 cross section data (printed double-spaced) starting at the most downstream point. The program then accesses these cross section data in the reverse order of having been read. Data read by this statement may be found on pages 2 and 3 of Appendix B (with indicated modifications).

```
      REAL LWB
      DIMENSION UPB(25),LWB(25),
     1          XSCT(100),WIDTH(100),VEL(100),XMAN(100)
      READ(-,-) Q
      READ(-,34) (UPB(I),LWB(I), I=1,25)
   34 FORMAT( 50X,F10.0, 10X,F10.0)
C
C     BEGIN LOOP
C
      K=0
   15 CONTINUE
      K=K+1
      READ(-,36,END=35) XSCT(K),WIDTH(K),VEL(K),XMAN(K)
   36 FORMAT (5X,F7.0, 3X,F7.0, 5X,F5.0, 4X,3PF6.0/)
      GO TO 15
   35 JK=K
      A=UPB(1)
      R=LWB(1)
      BL=A-R
      VA=0.
      WA=0.
      XNA=0.
      I=1
      M=JK-1
      O=XSCT(M)
      XN1=XMAN(M)
      V1=VEL(M)
      W1=WIDTH(M)
      GO TO 18
   10 B=(A-BI)/BL
      VA=VA+B*V1
      WA=WA+B*W1
      XNA=XNA+B*XN1
      PRINT    ,O,A,BI,B,V1,W1,XN1
      V1=V2
      W1=W2
      XN1=XN2
      A=BI
      O=XM
C
C     READ IN NEW CROSS SECTION
C
   18 M=M-1
      IF (M .LE. 0)GO TO 22
      XM=XSCT(M)
      XN2=XMAN(M)
      V2=VEL(M)
      W2=WIDTH(M)
      BI=(XM+O)/2.0
   20 IF (R .LT.  BI) GO TO 10
   22 B=(A-R)/BL
      VA=VA+B*V1
      WA=WA+B*W1
      XNA=XNA+B*XN1
      PRINT     ,O,A,BI,B,V1,W1,XN1
      AR=Q/VA
      D=AR/WA
```

```
      A=R
      AI=I
      WRITE(14,47)AI,AR,D,XNA
   47 FORMAT ('HYDRAULICS RCH=',F4.0,12F8.2,6X,'1.11'
     1         ,5X,F5.2,6X, '1.00',6X,F5.3)
      VA=0.
      WA=0.
      XNA=0.
      I=I+1
      R=LWB(I)
      IF (A .LT. BI) STOP
      BL=A-R
      GO TO 20
      END
```

APPENDIX F

FIELD OBSERVATIONS

Grab samples for laboratory analyses were taken on 8 August 1978 at 1.0 to 1.5 mile increments between the site of the Columbia Generating Station and the top of Lake Wisconsin. Weather was sunny; temperature was 86°F. Flow in the Wisconsin River at the USGS gaging station below the Wisconsin Dells was 4,120 cfs on 6 August, 4,000 cfs on 7 August, and 3,740 on 8 August.

TABLE F-1. ANALYSIS OF SAMPLES OF WISCONSIN RIVER COLLECTED 8 AUGUST 1978.

Sample	River mile	Dissolved oxygen (mg/liter)	Temperature (°C)	5-day BOD level (mg/liter)		23-day BOD level (mg/liter)	
				Filtered	Unfiltered	Filtered	Unfiltered
1	109.5	11.5	24	5.3	13.3	10.8	39.3
2	108.5	9.8	24	2.8	9.3	10.3	31.1
3	106.4	10.0	24	5.3	10.3	14.3	31.3
4	105.0	10.0	24	4.1	10.2	13.0	35.3
5	103.6	10.2	24	6.5	9.0	14.8	33.3
6	102.5	9.4	25	4.4	8.7	12.0	32.0
average		10.2	24	4.7	10.1	12.5	33.8

Sample	River mile	Orthophosphorus (mg/liter)	Total P (mg/liter)	Ammonia (mg/liter)	Nitrates and Nitrites (mg/liter)	Total N (mg/liter)
1	109.5	< 0.01	0.05	0.11	0.11	0.84
2	108.5	< 0.01	0.05	0.07	0.25	1.1
3	106.4	< 0.01	---	0.07	0.04	2.2
4	105.0	< 0.01	0.03	0.14	0.07	2.0
5	103.6	< 0.01	0.02	0.04	0.04	---
6	102.5	< 0.01	0.02	0.11	0.25	---
average		< 0.01	0.03	0.09	0.13	1.5

APPENDIX G

PROGRAM TO SOLVE FOR ONE-DIMENSIONAL TEMPERATURE DISTRIBUTION IN PRISMATIC OPEN CHANNEL FLOW (PAILY AND MACAGNO 1976)

LIST OF VARIABLES

Main Program (Heat)

AP	Lower diagonal coefficient in predictor matrix.
AC	Lower diagonal coefficient in corrector matrix.
BP	Diagonal coefficient in predictor matrix.
BC	Diagonal coefficient in corrector matrix.
CP	Upper diagonal coefficient in predictor matrix.
CC	Upper diagonal coefficient in corrector matrix.
CCP	Specific heat of water.
DAYSEC	Time of day (sec) of the next sunrise or sunset.
DELT	Simulation time step.
DELX	Simulation element size.
DEPTH	Mean depth of river.
E	Diffusion coefficient.
H	Internal constant.
HTFLX	Subroutine computing heat flux from river.
K	Internal constant.
K_{MAX}	Maximum number of time steps in simulation.
KPRT	Print interval in time steps.
M	Total number of elements in simulation.
QE	Flow rate of power plant effluent (cfs).
QN	Flow rate in river just above power plant discharge.

```
      DOUBLE PRECISION T,TL,RHS,AP,BP,CP,AC,BC,CC,R,S,H,HTFLX,U,K
      DOUBLE PRECISION V,TR
      DOUBLE PRECISION TR1,YY
      LOGICAL NK
      DIMENSION T(100),TL(100),RHS(100),AP(100),BP(100),CP(100),
     1        AC(100),BC(100),CC(100),DIST(100),YY(2),XX(2)
      COMMON NK, DAYSEC
      READ (-,-) QE,TE,QN,TR,M,DELX,DELT,WIDTH,DEPTH,S,E,KMAX,KPRT
C
C     INITIAL CONDITIONS
C
      TWODT = 2.*DELT
      NK = .TRUE.
      KK = 0
      TIMSTP = 0.0
      E = E*5280.*5280./86400.
      AREA = DEPTH*WIDTH
      DEPTH = 12.0 * 2.54*DEPTH
      CCP = 1.0
      RHO = 1.0
      DO 1 I = 1,M
      T(I) = TR
      DIST(I) = (I-1)*DELX/5280.
    1 CONTINUE
      TIN = QE*TE/(QE+QN)
      U = (QE+QN)/AREA
      H = U*DELX/(S*E)
      K = U*U*DELT/(S*E)
      R = K/(H*H)
      V = S*E/(RHO*CCP*DEPTH*U*U*86400.)
C
C     TRIDIAGONAL COEFFICIENTS
C
      MM1 = M-1
      MM2 = M-2
      DO 4 I = 1,M
      AP(I) = -R/S
      CP(I) = AP(I)
      BP(I) =  2.*(R/S + 1.0)
      AC(I)= AP(I)-R*H/2.
      CC(I) =  AP(I)+R*H/2.
      BC(I) = BP(I)
    4 CONTINUE
      AP(MM2) = AP(MM2) + R/(3.*S)
      BP(MM2) = BP(MM2) - 4.*R/(3.*S)
      AC(MM2) = AC(MM2) + ((R/S)-R*H/2.)/3.
      BC(MM2) = BC(MM2) - 4.*((R/S) - R*H/2.)/3.
C
C
C     BOUNDARY CONDITIONS
C
      T(1) = TIN + TR
   10 AF = HTFLX(TR)
      TR1 = TR + K*V*AF/2.
      TB1 = TIN + TR
C
```

```
C      PREDICTOR
C
       DO 100 I=2,MM1
       RHS(I)=R*H*T(I-1)/2. + 2.*T(I) - R*H*T(I+1)/2. + K*V*HTFLX(T(I))
   100 CONTINUE
       RHS(2) = RHS(2) + R*TB1/S
       CALL SOLV1(TL(2),AP,BP,CP,RHS(2),MM2)
C
C
C      CORRECTOR
C
       DO 101 I=2,MM1
       RHS(I) = (R/S + R*H/2.)*T(I-1) - 2.*(R/S-1.)*T(I)+(R/S-R*H/2.) *
      1         T(I+1)  +  2.*K*V*HTFLX(TL(I))
   101 CONTINUE
       AF = HTFLX(TR1)
       TR = TR + K*V*AF
       T(1) = TIN + TR
       RHS(2) = RHS(2) + ((R/S) + R*H/2.)*T(1)
       CALL SOLV1(T(2),AC,BC,CC,RHS(2),MM2)
       T(M) = (4.*T(MM1)-T(MM2))/3.
C
C      OUTPUT
C
       IF (KK .LT. 864) GO TO 125
       IF (TIMSTP .EQ. 25200.) WRITE(6,102) TIMSTP,T
       IF (TIMSTP .EQ. 72000.) WRITE(6,102) TIMSTP,T
   102 FORMAT(1H0,'TIME = ',F8.0,' SECONDS'/' RIVER TEMPERATURE IN DEGREE
      1S CELCIUS'/4(' ',16F8.3/))
C
C      INCREMENT TIME STEP
C
   125 IF (TIMSTP .LT. DAYSEC) GO TO 126
       IF (TIMSTP-DAYSEC .LT. TWODT )     NK = .TRUE.
   126 KK = KK + 1
       TIMSTP = TIMSTP + DELT
       IF (TIMSTP .GE. 86400.)TIMSTP = TIMSTP - 86400.
       IF (KK.LE. KMAX) GO TO 10
       STOP
       END
:
```

```
      SUBROUTINE SOLV1(T,A,B,C,RHS,M)
      DOUBLE PRECISION T,A,B,C,RHS,DENOM
      DIMENSION T(100),A(100),B(100),C(100),RHS(100),CX(100),DX(100)
      CX(1) = C(1)/B(1)
      DX(1) = RHS(1)/B(1)
      DO 10 I=2,M
      DENOM = B(I)-A(I)*CX(I-1)
      CX(I) = C(I)/DENOM
      DX(I) = (RHS(I)-A(I)*DX(I-1))/DENOM
   10 CONTINUE
      T(M) = DX(M)
      MK = M - 1
      DO 20 I = 1,MK
      K = M - I
      T(K) = DX(K) - CX(K)*T(K+1)
   20 CONTINUE
      RETURN
      END
```

```
      DOUBLE PRECISION FUNCTION HTFLX(T)
      DOUBLE PRECISION T
      LOGICAL K
      COMMON K,DAYSEC
      DATA SIGMA/1.171E-07/
      IF(K) GO TO 100
   99 TK = T + 2.7316D+02
      PBW = 0.970*SIGMA*(TK**4.)
      PH = (8.00+0.35*(T-TA)+3.9*VA)*(T-TA)
      PE = PH*(ES-EA)/(6.1E-04*PA*(T-TA))
      HTFLX = PR-PBW+PBA-PBR-PE-PH
      RETURN
  100 READ (-,-) C,H,RH,TA,PCL,VA,PA,DAYSEC
      TAK = TA+273.16
      ES = 6.1048*EXP(5315.08*(1./273.16 - 1./TAK))
      EA = RH * ES
      PRI = PCL*(0.35+0.061*(10-C))
      PRR = 0.108*PRI-(6.766E-05)*PRI*PRI
      PR = PRI-PRR
      A = 0.74+0.025*C*EXP(-1.92E-04*H)
      B = 4.9E-03 - 5.4E-04*C*EXP(-1.97E-04*H)
      PBA = (A+B*EA)*SIGMA*(TAK**4)
      PBR = 0.03*PBA
      K = .FALSE.
      GO TO 99
      END
```

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16. ABSTRACT A conceptual study of water quality in the Wisconsin River between Wisconsin Dells and Lake Wisconsin was performed to determine the range of choices that might be available for determining the trade-off between organic waste discharges and heat assimilation from possible power plant sites. The QUAL-3 river quality model, as modified by the Wisconsin Department of Natural Resources for use on the upper Wisconsin and lower Fox Rivers, was used for preliminary simulations of the effect of potential heat discharges from three possible power plant sites on the levels of dissolved oxygen, biochemical oxygen demand, and algae growth during times of extremely low flow. Hydraulic parameters for the QUAL-3 model were estimated from simulations employing the Army Corps' HEC-2 water surface profile model. Estimates of river temperature downstream of heat discharges were obtained using a simple one-dimensional river temperature model developed by Paily and Macagno (1976). Results of simulations at various levels and locations of heat discharges are presented in the presence and absence of discharge at the Portage Wastewater Treatment Plant effluent into the Wisconsin River, and of concerted control of point and non-point sources of nutrients in and upstream of the regional study.
The results suggest that the levels of dissolved oxygen in Lake Wisconsin would be most sensitive to nutrient levels in the Wisconsin River and that elevated nutrient levels resulting from heat discharges could cause greater drops in the dissolved oxygen levels in the lake.

17. KEY WORDS AND DOCUMENT ANALYSIS		
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