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PREDICTED WATER QUALITY IMPACTS FROM REDUCING FLOW OUT OF GAVINS POINT ON THE MISSOURI RIVER

by

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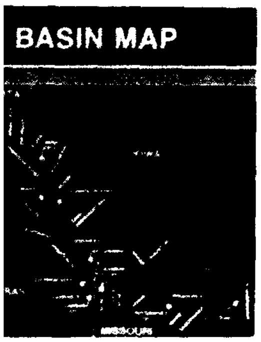

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13. ABSTRACT *(Maximum 200 words)*

This report documents efforts to evaluate the far field effects of altering flow rates from Gavins Point Dam on key water quality constituents in the Missouri River. A modified version of the US Environmental Protection Agency's one-dimensional riverine water quality model, QUAL2E, was used as a predictive tool to assess impacts from operational changes. Data for calibration and verification of the modified version of QUAL2E were collected by the Omaha and Kansas City Districts. Some of the topics addressed in this report are model description and modifications, calibration/verification, scenario and base condition boundary conditions, scenario results, and conclusions from the study results.

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PREFACE

This report presents conclusions drawn from a study of water quality in the lower Missouri River. This report was prepared in the Environmental Laboratory (EL), US Army Engineer Waterways Experiment Station (WES), Vicksburg, MS. The study was sponsored by the US Army Engineer Division, Missouri River, and was funded under Military Interdepartmental Purchase Request No. 0887-90, dated 31 August 1990 and No. 1880-91, dated 29 November 1991.

The Principal Investigator of this study was Ms. Dorothy H. Tillman of the Water Quality Modeling Group (WQMG), Environmental Research Simulation Division (ERSD), EL. This report was prepared by Ms. Tillman under the direct supervision of Dr. Mark Dortch, Chief, WQMG, and under the general supervision of Mr. Donald L. Robey, Chief, ERSD, and Dr. John Harrison, Director, EL. Technical reviews by Dr. Dortch and Mr. Ross Hall, WQMG, are gratefully acknowledged.

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CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acre-feet	1,233.489	cubic meters
cubic feet	0.02831685	cubic meters
degrees (angle)	0.01745329	radians
feet	0.3048	meters
feet per mile	0.1893935	meters per kilometers
miles (US statute)	1.609347	kilometers
square miles	2.589998	square kilometers

PREDICTED WATER QUALITY IMPACTS FROM REDUCING FLOW OUT OF GAVINS POINT DAM ON THE MISSOURI RIVER

PART I: INTRODUCTION

Background

1. The US Army Engineer Division, Missouri River (MRD), regulates the main stem Missouri River projects for various authorized in-pool and downstream purposes. The original Master Water Control Plan by which the system was operated, was published in December 1960 and reviewed by a committee of representatives from the 10 basin states and Federal agencies. There have been two major revisions of the original manual (1975 and 1979) since the first publication.

2. The authorized purposes of the reservoirs in the Missouri River system are:

- a. Projects operate for flood control.
- b. Lower Missouri River operated for navigation.
- c. Irrigation and other upstream water uses for beneficial consumption purposes.
- d. Water supply and water quality requirements for downstream municipalities and industries.
- e. Releases from the reservoirs above Gavins Point Dam provide hydropower to meet the area's needs.
- f. Projects operate for maximum benefit to recreation, fish, and wildlife.

3. In recent years, the Missouri River basin has experienced a moderate to severe drought which has affected users of the system on the upper and lower basin. Since the economies of the upper and lower basin employ different uses of the Missouri River, the operation of the main stem system has become a major concern. Not only have the general public, private industries, public and private-owned utilities become concerned about the operations of the Missouri River system, but Federal and state agencies are also concerned with river operations.

4. All these concerns led to a reevaluation of the operation of the Missouri River main stem system and the Master Water Control Manual. The main reasons for the Master Water Control Manual Review and Update effort are:

a. The last update occurred in 1979.

b. The drought has emphasized potential weaknesses in the current Master Water Control Plan that may not meet the needs of the basin as the system is currently operated.

c. Recreation has become an important industry in the upper and lower reaches, which was not the case when the current Master Water Control Plan was written.

d. The current drought has emphasized the importance of the flow from the Missouri River for commercial navigation on the Mississippi River. This is an especially important concern during the summer and fall periods.

e. The current Master Water Control Manual does not have provisions for endangered or threatened species, does not include new methods for data collection, and does not include the most recent flood history that has occurred since the 1979 update.

The update to the Master Manual was to be completed in two phases. Phase 1, which has been completed, reviewed present operations criteria from the current Master Water Control Plan over the period of record (1898 to the present) and compared it with alternative water control plans. The draft Phase 1 report was submitted to Headquarters, US Army Corps of Engineers for review and approval. It was distributed as a draft report for public review once revisions had been made.

5. From comments received on the draft Phase 1 report as well as comments from the public meetings, the study plan for Phase 2 was formulated. Phase 2 concentrated on environmental studies required by the National Environmental Policy Act and all other environmental laws.

Study Objective

6. The Environmental Laboratory of the US Army Engineer Waterways Experiment Station (WES) was requested to assist the MRD in the numerical modeling of a number of water quality constituents in the lower Missouri River for Phase 2 of the Master Water Control Manual Review and Update. Model results were used to determine the far field (changes in water quality downstream assuming fully mixed laterally and vertically in the river) effects of altering the historical seasonal releases for a range of release temperatures at Gavins Point Dam on key water quality constituents (i.e., temperature and dissolved oxygen) in the Missouri River.

General Modeling Approach

7. Changes in water quality were assessed by numerically modeling the Missouri River Basin from Gavins Point Dam to the junction of the Mississippi River (approximately 810 miles).* A modified version of the US Environmental Protection Agency (USEPA) one-dimensional (longitudinal) riverine model, QUAL2E, was the model used for the study.

8. A steady flow, steady-state water quality modeling approach was selected for this study. Steady flow means that the flow does not change with time, but flow can change along the reach of river modeled. Steady-state water quality means that water quality concentrations do not change with time, but can change with location along the modeled reach.

9. A steady-state approach was selected for several reasons. Since most of the concerns for poor water quality resulting from reduction in release flow would occur during dry, hot periods (i.e., drought), a reasonable assumption was that tributary inflows would be essentially constant from lack of rainfall. Likewise, release flow from Gavins Point Dam are relatively constant for extended periods of time. Thus, the assumption of steady flow is a reasonable assumption. Steady-state loadings are usually associated with steady flow. Issues addressed in this study are similar to those in waste load allocation studies. As in a waste load allocation study, pollutant loadings within a stream are modeled to determine the impact on instream water quality. In this study, release flows from Gavins Point Dam would be varied between extreme limits, with waste loads unmodified, to determine impacts on water quality. For riverine water quality model studies of this type, the assumption of steady-state conditions is usually made and is an acceptable approach. Finally, steady-state models require far less data and effort to calibrate and verify than required for dynamic (i.e., time-varying) models. For example, application of a dynamic model to the lower Missouri River would require time-varying water quality boundary conditions and instream observations (for calibration/verification) for at least a month-long period. Thus, approximately daily (or every few days) monitored data would be required for all major tributaries and instream Missouri River stations (for about every 20 miles). The cost to accomplish a data collection effort of this magnitude

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 4.

would have been excessive and unjustified. When conditions are near steady-state, snapshot sampling (i.e., collection of data at all stations in a relatively short period of time, such as a day or two) can be used to support a steady-state model with much less cost. The model QUAL2E was selected for this steady-state model study for the reasons explained in Part II.

10. Calibration and verification of the modified version of QUAL2E were completed using data collected by the Omaha and Kansas City Districts in August and September of 1990. Once calibration and verification of the model were satisfactory, the scenario runs requested by the MRD were simulated. These scenario runs evaluated varying release flow and temperatures from Gavins Point Dam. Sensitivity analyses were also performed to evaluate the effects of varying flows and water quality concentrations from the tributaries, meteorological conditions, and power plant loads.

Site Description

11. The Missouri River is the longest river in the United States and lies east of the Continental Divide and west of the upper Mississippi River basin. Its origin is south of the Canadian border in Montana and flows into the Mississippi River slightly north of St. Louis, Missouri (Figure 1). The basin drainage area is approximately 522,574 square miles. Six main stem dams consisting of Fort Peck, Garrison, Oahe, Big Bend, Fort Randall, and Gavins Point (in downstream order) regulate the flow in the Missouri River with an annual discharge of 5.67×10^7 acre-ft at Hermann, Missouri.

12. The study reach of interest for this study extends approximately 810 miles from Gavins Point Dam to the Mississippi River. From the mouth of the Missouri River to Sioux City, Iowa (730.4 miles), commercial navigation is achieved by structural measures (i.e., dikes, revetments, and sills) and regulation of streamflow to provide a navigable channel.

13. Maximum releases during non-navigation season range from 6,000 to 23,000 cfs, and during navigation season (April through November), the releases are maintained in the range of 25,000 to 35,000 cfs. Discharges from the tributaries during navigation season can add an additional 15,000 to 20,000 cfs between Sioux City, Iowa, and the mouth of the Missouri River.

14. Average velocities in the Missouri River range from 3 to 6 fps, and during navigation season, mid-channel velocities are in the range of 4 to almost 7 fps (MRD 1978). The slope of the bed is approximately 1 ft/mile. In

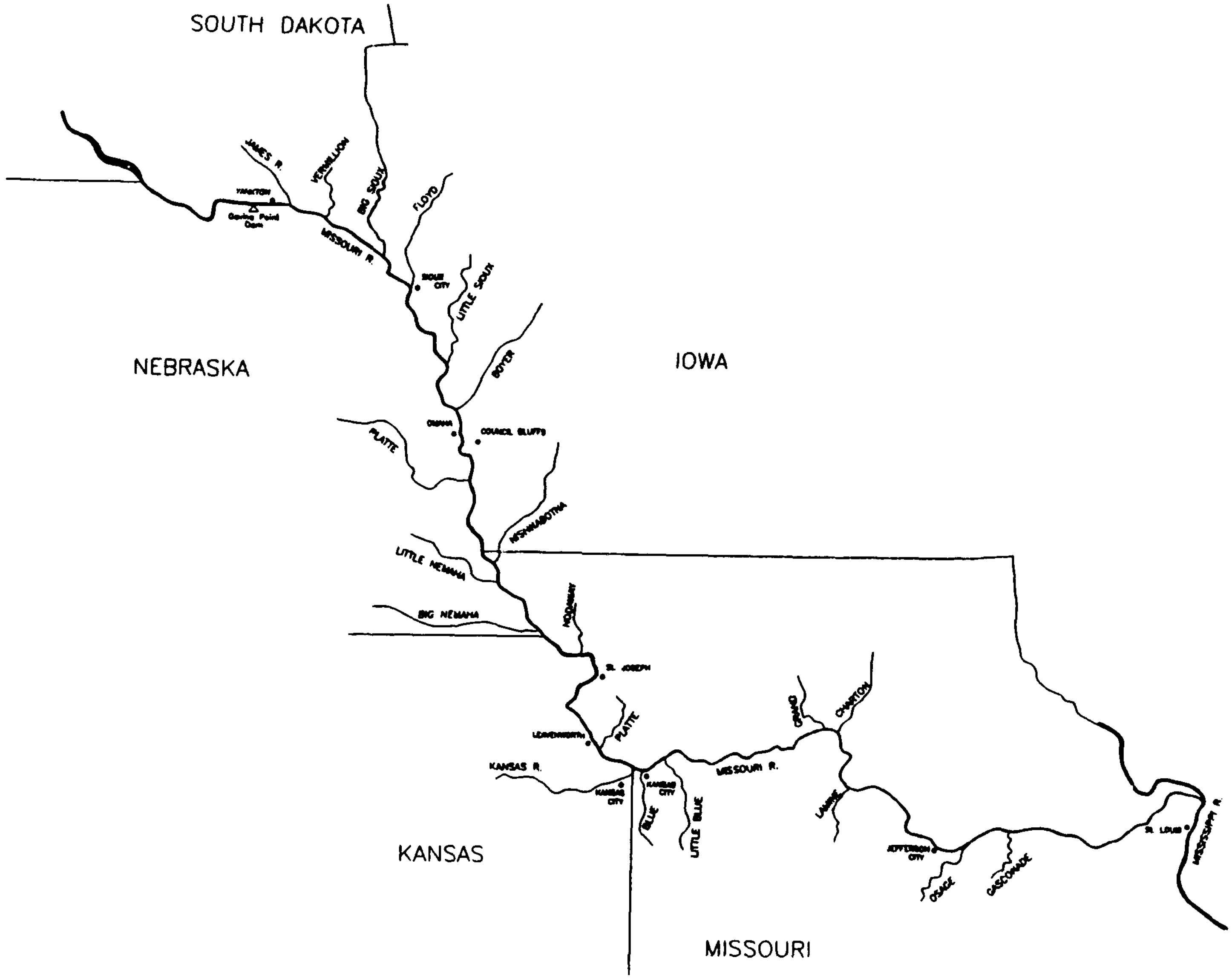


Figure 1. Basin map

the 1960s and 1970s, a lowering of the river bed had occurred but has stabilized except for the reach between Sioux City, Iowa, and Blair, Nebraska, which is still experiencing bed lowering (MRD 1978).

15. The climate in the basin is mostly a result of its latitudinal location (between 39 and 43° N) and its domination by the Polar Canadian (cold, dry air) and Tropical Continental (hot, dry air) air masses (MRD 1978). Mean annual hours of sunlight is approximately 2,800 and mean solar radiation is 375 g calories/sq cm. Mean maximum temperature throughout the basin is about 32.3 °C and occurs in July. Mean minimum temperature occurs in January and varies from 2.8 °C at the mouth of the Missouri River to -6.7 °C at Sioux City, Iowa. The annual snowfall and precipitation varies from 12 and 40 in. (respectively) at the mouth to 32 and 25 in. (respectively) at Sioux City, Iowa. The basin usually receives precipitation 105 days out of the year.

16. Agriculture is the predominant land use in the 45 counties bordering the Missouri River (MRD 1978). Iowa and Nebraska have the greatest percentages (85.2 and 81.9 percent, respectively) of counties using the land for agricultural uses such as pasture, range, and cropland. Cropland use is the greatest use in the 45-county area equaling about 56.9 percent (MRD 1978).

PART II: MODEL DESCRIPTION

Model Selection

17. Selection of a numerical model to represent a system is based on issues to be addressed, characteristics of the system, and model and data availability. For the lower Missouri River, two models were considered for the study: CE-QUAL-RIV1, the Corps of Engineers' dynamic, one-dimensional stream water quality model, and QUAL2E, the USEPA one-dimensional riverine water quality model. Each model has similar and unique capabilities (Table 1) in addition to advantages and disadvantages (Table 2) that were considered before final model selection was made.

Table 1

Capabilities of CE-QUAL-RIV1 and QUAL2E

Capabilities	CE-QUAL-RIV1	QUAL2E
Dynamic hydrology	Yes	No
Dynamic water quality	Yes	No
Variable delta X	Yes	No
Multiple met stations	No	Yes
Algae as state variable	No	Yes
Point source loads	Yes (partially)	Yes
Nonpoint source loads	Yes	Yes
Tributary inflows	Yes	Yes
Numerical accuracy (> 1st order)	Yes	No

Table 2

Advantages and Disadvantages of CE-QUAL-RIV1 and QUAL2E

Model	Advantages	Disadvantages
CE-QUAL-RIV1	Closer to state of the art Better hydrology Better numerical methods	Newer model Requires more time to set up and calibrate
QUAL2E	In use longer Widely used and accepted Standard for stream studies Versatile	Must supply hydrology Steady flow assumption

18. Consideration of each model's capabilities and advantages, study issues, and data requirements were carefully weighed before QUAL2E was chosen as the model for use in the study. Both models could have addressed the study issues. However, the two models have different capabilities. CE-QUAL-RIV1 was developed to handle unsteady flow and dynamic water quality conditions, while QUAL2E was developed with the assumption that it would be used for steady flow and usually steady-state water quality (although the model can be run in diel, or time-varying, mode for water quality). Although CE-QUAL-RIV1 can be applied in a steady flow mode and can be run to steady-state water quality conditions, the kinetic algorithms for algal-nutrient interactions are inferior to those implemented in QUAL2E. Additionally, for a steady-state approach, the advantages of the dynamic features of CE-QUAL-RIV1 would not be realized. Therefore, QUAL2E was selected since the model could satisfy study needs and is widely used and accepted for riverine water quality model studies of this type.

Model Description

19. QUAL2E is a one-dimensional riverine water quality model with the capability of simulating up to 15 water quality constituents of any branched stream. Constituents that can be modeled in any combination by the user are listed below (Brown and Barnwell 1987).

a. Dissolved oxygen (DO).

b. Carbonaceous biochemical oxygen demand (CBOD).

c. Temperature.

d. Algae as chlorophyll *a*.

e. Total organic nitrogen as N.

f. Ammonium as N.

g. Nitrite as N.

h. Nitrate as N.

i. Total organic phosphorus as P.

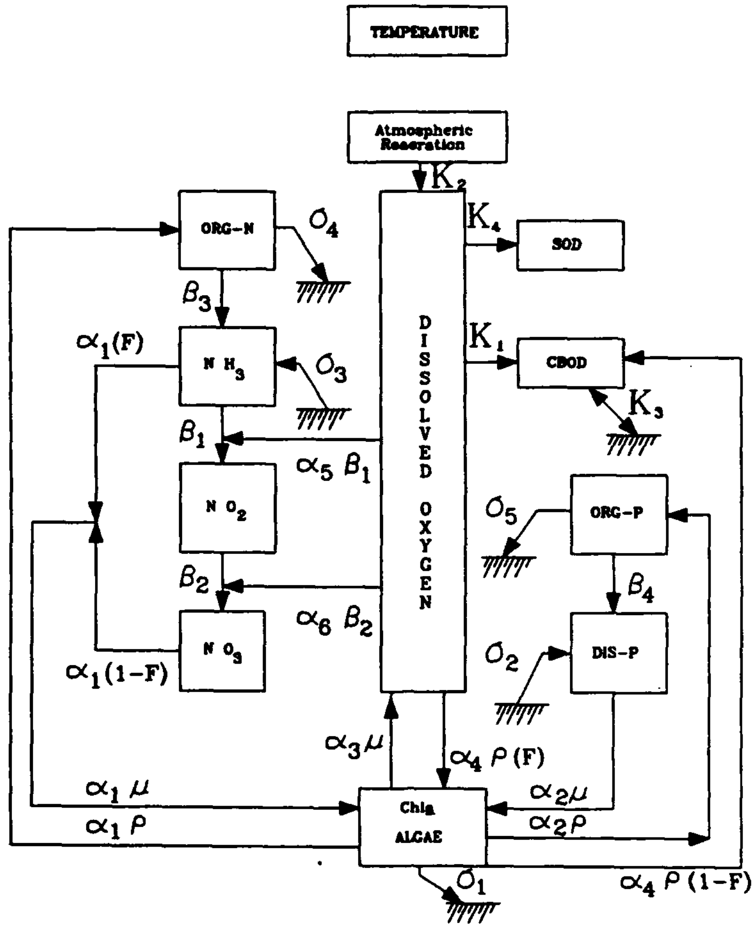
j. Dissolved inorganic phosphorus as P.

k. Coliforms.

l. Arbitrary nonconservative constituents.

m. Three conservative constituents.

Figure 2 shows the relationship or interactions (i.e., nutrient cycles, algae production, benthic sediment oxygen demand (SOD), carbonaceous oxygen uptake,



α_1 = Fraction of algal biomass that is nitrogen
α_2 = Fraction of algal biomass that is phosphorus
α_3 = O_2 production per unit of algal growth
α_4 = O_2 uptake per unit of algae respired
α_5 = O_2 uptake per unit of NH_3 oxidation
α_6 = O_2 uptake per unit of NO_2 oxidation
β_1 = Biological oxidation of NH_3 to NO_2
β_2 = Biological oxidation of NO_2 to NO_3
β_3 = Hydrolysis of organic N to ammonia
β_4 = mineralization of organic-P to dissolved-P

σ_1 = Algal settling rate
σ_2 = Benthos source rate for dissolved phosphorus
σ_3 = Benthos source rate for ammonia nitrogen
σ_4 = Organic nitrogen settling rate
σ_5 = Organic Phosphorus settling rate
μ = maximum algal growth rate
ρ = Algal respiration rate
K_1 = Carbonaceous deoxygenation rate constant
K_2 = Reaeration rate
K_3 = Loss of CBOD due to settling
K_4 = SOD

Figure 2. Interactions between water quality constituents

atmospheric reaeration and their effect on DO) between the major constituents. Coliforms and arbitrary nonconservative constituents are modeled as decaying substances that do not interact with other constituents, and conservative constituents do not decay or in any way interact with any other constituent.

20. The above constituents can be simulated in a steady-state mode (the time derivative of concentration is omitted from the mass balance equation, and the solution is computed in a single iteration) or dynamic mode

(meteorological data can change with time). The model is based on the time-dependent water quality constituent transport equation, allowing for description of advection, dispersion, and sources/sinks. This equation is referred to as the energy equation for temperature or the differential mass balance equation for other constituents.

21. Hydraulic conditions (flow rate and depth) used within the energy and mass balance equations are determined from steady, nonuniform flow conditions by satisfying continuity and using stage-discharge relationships or solving Manning's equation with channel geometry information. Steady flow implies that the flow, velocity, width, and depth at a given point in the stream network are constant with time. Nonuniform flow allows velocity, flow, width, and depth to change in the longitudinal direction from reach to reach.

22. QUAL2E approximates the river system by subdividing the stream system into reaches, which is the basic division of the model. Reaches represent portions of the river having similar channel geometry, hydraulic characteristics, and chemical/biological coefficients. Reaches are further divided into equally spaced units called computational elements. Figure 3 shows how QUAL2E conceptualizes a river basin (Brown and Barnwell 1987). Each computational element has inputs, outputs, and reaction terms. The energy and differential mass balance equations are solved simultaneously (implicitly) for each computational element.

23. Computational elements are connected in the direction of flow to form reaches; thus, the output from one element becomes the input to the next element downstream. QUAL2E recognizes seven element types depending on the type of input and/or output and the location in the stream network. The following tabulation identifies the flags (identifiers) for each computational element (Brown and Barnwell 1987).

Identifying Number	Type of Element
1	Headwater element
2	Ordinary element
3	Element upstream of junction on the main stem of river
4	Junction element
5	Last element in system
6	Element with a point source
7	Element with a withdrawal

24. A Type 1 element represents a headwater element of a tributary as well as the main stem of the river system, and as such must always be the first element in a reach. An ordinary or standard element (Type 2) is one

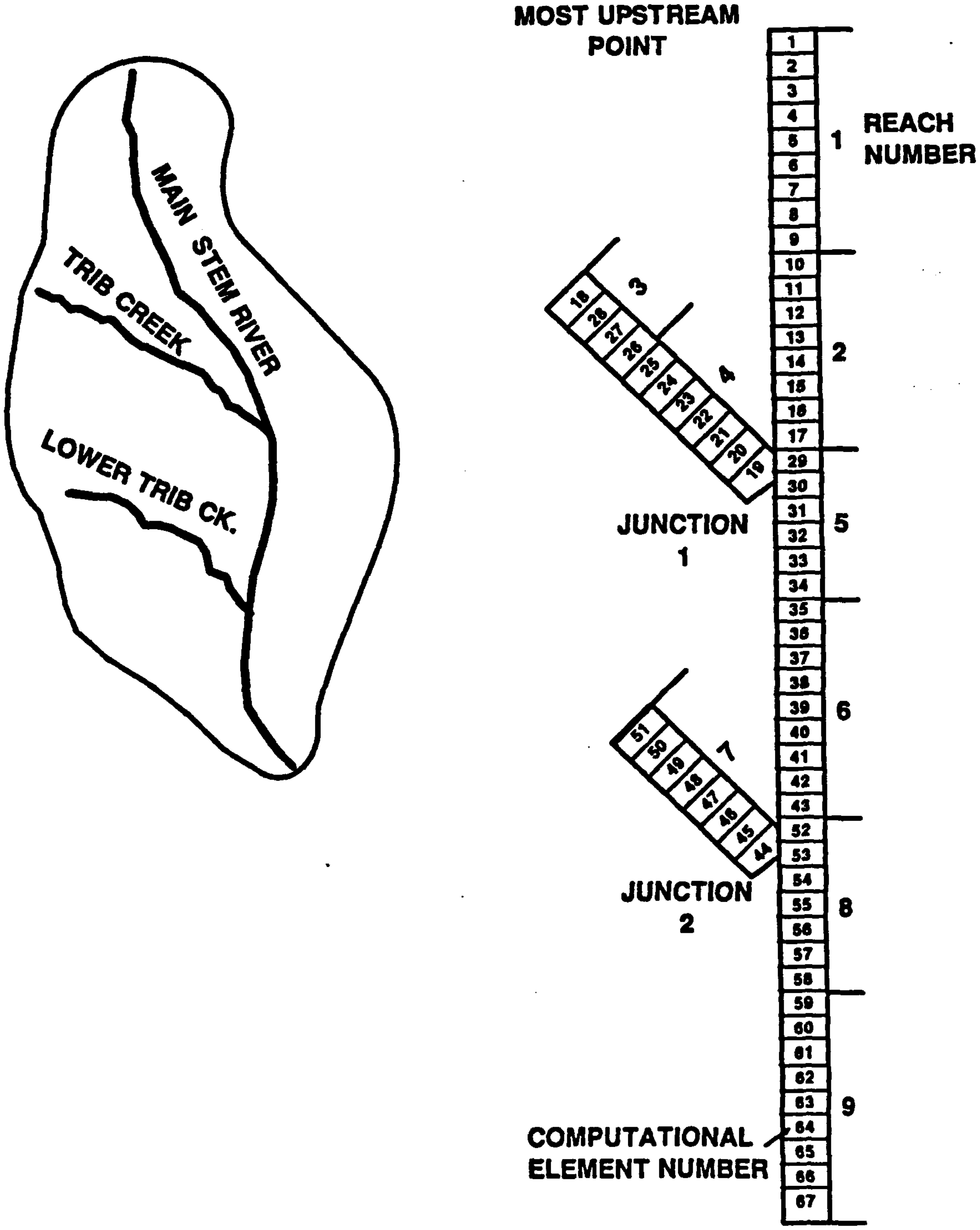


Figure 3. Stream network of computational elements and reaches

that cannot be classified as any other type of element; the only input permitted in a standard element is incremental inflow. The Type 3 element is used to designate an element on the main stem of the river just before a junction element (Type 4), which has the simulated tributary entering it. Element Type 5 represents the last element in the system, and should be the only one of this type. The remaining two types of elements (6 and 7) are those that have inputs (waste loads, returns, and unsimulated tributaries) and water withdrawals, respectively.

25. Longitudinal changes in water quality constituents are obtained by solving the differential mass and/or energy balance equation at the beginning of one of the headwater reaches and continuing downstream until a junction is encountered. Once a junction is encountered, the mass balance equations are solved for all the computational elements in the other reaches entering the junction before continuing beyond the junction. The result is a set of partial differential equations equal to the number of computational elements in the system. These partial differential equations are linked through the inputs and outputs of each element and are solved using an implicit finite difference procedure employing the Thomas algorithm (Brown and Barnwell 1987).

26. For this study, the stream network for calibration/verification and all scenario runs included approximately 810 miles of the Missouri River beginning at Gavins Point Dam (the most downstream dam in a series of dams, which also include Fort Randall, Big Bend, Oahe, Garrison, and Fort Peck listed in the order they occur in the upstream direction) and ending at the confluence of the Missouri and Mississippi Rivers (Figure 1). The system was then divided into reaches and further subdivided into elements. Nine reaches were subdivided into 162 elements equally spaced 5 miles apart for all simulations. Gavins Point Dam was the only headwater modeled; tributaries, wastewater treatment plants, and industrial discharges into the Missouri River were modeled as point sources. There were 35 point sources with 19 of them being major tributaries. Power plant discharges were modeled as additional heat sources.

Model Modifications

27. Modifications to the QUAL2E code were necessary to accomplish study needs and improve model performance. Modifications to the code were: (a) allowing the rating curves used to calculate depths and velocities to be

read per element rather than per reach, (b) increasing the number of point sources allowed, (c) modifying the read statement for hydraulic data to also include input values for delta temperatures and discharges coming from power plants, (d) adding heat source from power plants to temperature equation as a separate term, (e) adding contribution of algae that enter into organic carbon as CBOD, (f) and adding the temperature correction term (rate multiplier) for algae used in the CE-QUAL-R1 (Environmental Laboratory 1982) model.

28. Modifying QUAL2E to accept rating curves for each element instead of per reach helped to improve QUAL2E's predictability of the hydraulic characteristics of the lower Missouri River system. Normally, QUAL2E applies the same rating curve coefficients to each element within a reach; but since element lengths of 5 miles were used (which for most studies is a reach length), it was determined that a rating curve was needed at each element to better represent depth and velocities. HEC-2 (US Army Engineer Hydrologic Engineering Center (HEC) 1982) simulation results were available approximately every mile for hydraulic variables (i.e., depth, flow, and velocity) at five different flows. Five-mile averages of these data were used to develop the rating curves (discussed in Part III) for the study.

29. The second modification to QUAL2E allowed more point sources to be modeled. In the original code, a maximum of 25 point sources were allowed; but for the Missouri River study, 39 point sources were identified as necessary inputs to adequately model the water quality and account for the additional flow that comes from the point sources and tributaries in the system. These point sources included 19 major tributaries and 20 wastewater treatment facilities and industries along the Missouri River. When some of the tributaries and/or other facilities discharged into the same element, a flow weighted average was performed on all the water quality constituents and flows to get the appropriate combined loads coming into the element. After all necessary combinations were made, a total of 35 point sources were actually modeled instead of 39.

30. Discharge from power plants was treated as an additional heat source instead of a point source since no flow was actually lost or gained from the Missouri River. This required changes to the code to include the new input parameters (delta temperature and discharge) coming from power plants. These parameter values were included in the hydraulic data section of the input data set, and modifications were made to the subroutine that reads hydraulic information to include these new parameters. In addition, the new

heat source term had to be added to the temperature equation. The modified temperature equation is written as:

$$\frac{\partial T}{\partial t} = \frac{\partial (A_x D_L \frac{\partial T}{\partial X})}{A_x \partial X} - \frac{\partial (A_x \bar{u} T)}{A_x \partial X} + \frac{H_N}{\rho c d} + \frac{H_p}{\rho c V} \tag{1}$$

where

t = time

T = water temperature

A_x = x-section area

D_L = longitudinal dispersion coefficient

X = distance along stream

$\bar{u}$ = average velocity of flow

H_N = heat flux through air-water interface

ρ = density of water

c = heat capacity of water

d = depth of water

H_p = heat source of power plants

V = volume of water in computational element receiving power plant discharge

The new heat source term, H_p, was calculated as:

$$H_p = \rho c Q_P \Delta T_P \tag{2}$$

where

Q_p = discharge from power plants, cms

ΔT_p = temperature change (delta temperature) through power plant, °C

31. One of the major modifications to QUAL2E was to account for the algal contribution to CBOD concentration through algal respiration (which includes death and excretion) that goes into organic carbon as CBOD. Originally, in QUAL2E, algal respiration was modeled entirely as a DO sink with an immediate demand on DO. Now, algal respiration is fractioned into a portion that immediately exerts a demand on DO and a portion that is converted to CBOD that later exerts a demand on DO. The equation for CBOD with the algal component is:

$$\frac{dL}{dt} = -K_1 L - K_3 L + \alpha_4 (1-f) \rho A \tag{3}$$

where

L = the concentration of ultimate CBOD, mg/ℓ

K_1 = CBOD decay rate coefficient, day^{-1}

K_3 = loss rate of CBOD due to settling, day^{-1}

α_4 = the rate of oxygen uptake per unit of algal respired, mg-O/mg-A

$(1-f)$ = fraction of total algal respiration that goes into organic carbon as CBOD

f = fraction of total algal respiration that exerts an immediate DO demand

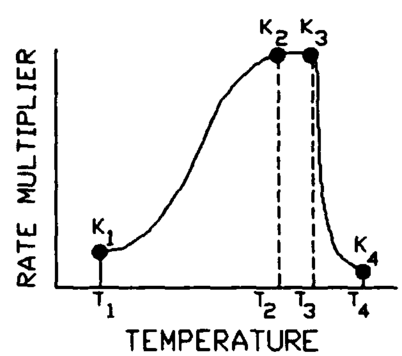
ρ = algal respiration rate, day^{-1}

A = algal biomass concentration, mg-A/L

The fraction of algal respiration going to organic carbon as CBOD was set to 0.70.

32. The final modification to QUAL2E was to replace the temperature correction term or rate multiplier for algae with the rate multiplier used in CE-QUAL-R1 (Environmental Laboratory 1982). The original correction term in QUAL2E did not account for mortality at the upper and lower temperature limits. Figure 4 illustrates, in general, how the biological process rate responds for an optimum temperature range (T_2 and T_3) for growth and diminishes at lower and higher temperatures (T_1 and T_4, respectively).

Figure 4. Rate multipliers for algal growth



The mathematical interpretation of this plot from Thornton and Lessem (1978) is written as:

$$f(T) = \begin{bmatrix} 0 & T<T_1 \\ \dfrac{K_1 e^{\lambda_1(T-T_1)}}{1 + K_1\left[e^{\lambda_1(T-T_1)} - 1\right]} \; \dfrac{K_4\ e^{\lambda_2(T_4-T)}}{1 + K_4\left[e^{\lambda_2(T_4-T)} - 1\right]} & T_1<T<T_4 \\ 0 & T_4<T \end{bmatrix} \tag{4}$$

where

$$\lambda_1 = \frac{1}{T_2-T_1} \ln \left[\frac{K_2(1-K_1)}{K_1(1-K_2)}\right] \tag{5}$$

$$\lambda_2 = \frac{1}{T_4-T_3} \ln \left[\frac{K_3(1-K_4)}{K_4(1-K_3)}\right] \tag{6}$$

The user supplies temperatures T_1 to T_4 and multiplier factors K_1 to K_4. Temperatures T_2 and T_3 are used to define the optimum growth range for algae and T_1 and T_4 represent mortality limits. The user supplied maximum reaction rates (for algal growth and respiration) are multiplied by f(T) (Equation 4) to determine rates corresponding to the water temperature of the element.

PART III: DATA REQUIREMENTS FOR QUAL2E

33. Numerical models require many types of data to adequately model a water body system. The types of data required to calibrate/verify QUAL2E for the lower Missouri River study were:

- a. Hydraulic data or channel geometry/flow conditions.
- b. Headwater boundary conditions.
- c. Point source and tributary loads.
- d. Meteorological data.
- e. Rate coefficients.
- f. Calibration/verification comparison data.

Because there was not enough data to calibrate or verify the model, the Omaha and Kansas City Districts conducted two snapshot samplings (taking measurements at all stations within a day) of water quality concentrations on the main stem Missouri River and 19 major tributaries. Appendix A contains the data collected. These data were used for headwater and tributary boundary conditions during calibration and verification. In addition, data were also collected on the main stem of the Missouri River and were used for comparison data.

34. Hydraulic data at approximately 1-mile intervals within the study reach were furnished to the MRD by the Omaha and Kansas City Districts from HEC-2 (HEC 1982) backwater computations. The types of hydraulic data furnished for each mile were flow, surface elevation, channel length between stations, area, top width, and velocity. These data were provided for five different constant flow rates (6,000, 9,000, 12,000, 18,000, and 25,000 cfs) through the Missouri River. Also furnished were the 5-mile averages of these data for slope, area, velocity, and depth. Using the averaged depth and velocity for all flow rates provided, rating curves for velocity and depth (respectively) were developed using the Statistical Analysis System (SAS) procedure, PROC NLIN (SAS Institute, Inc. 1988) for the equations below:

$$\bar{u} = aQ^{b} \tag{7}$$

and

$$d = \alpha Q^{\beta} \quad (8)$$

where

$\bar{u}$ = mean stream velocity, ft/sec

a = coefficient for velocity

Q = flow, cfs

b = exponent for velocity

d = depth, ft

α = coefficient for depth

β = exponent for depth

Coefficients and exponents for the velocity and depth rating curves were required by QUAL2E to calculate depths and velocities at each element. Using the velocity and flow of an element, the model calculated cross-sectional area.

35. Meteorological data required by QUAL2E were cloud cover, dry bulb and wet bulb temperature, air pressure, and wind speed and were obtained from the US Air Force Environmental Technical Applications Center in Asheville, NC. These data were obtained for the four first-order meteorological stations along the Missouri River. These stations were located at Sioux City, IA, Omaha, NE, Topeka, KS, and Columbia, MO.

36. Historical data of flow and water quality concentrations for all major tributaries and main stem stations of the Missouri River were obtained from CD ROM disks from EarthInfo in Boulder, CO, which contained US Geological Survey (USGS) data for stations all over the United States. Table 3 contains the tributary and main stem USGS stations numbers and data type (flow or water quality) for all data. The historical flow data were used to calculate the minimum 7-day running averaged flow with a recurrence interval of 10 years (7Q10) and the 2-year summer flow for period of record to be used for tributary flow boundary conditions in scenario runs. The water quality data were analyzed to find the maximum water quality concentrations that had occurred on tributaries to be used as water quality boundary conditions in scenario runs.

37. Data for flow and water quality concentrations of point sources (i.e., wastewater treatment plants and other dischargers) used in calibration and verification runs were obtained from the Permit Compliance System (PCS) of the Region Seven Environmental Protection Agency (EPA) office in Kansas City, KS. Permit limits for flow and water quality concentrations of these point

Table 3

Historical USGS Data for the Lower Missouri River Basin

Location	Station Number	Data Type
James River near Scotland, SD	06478500	Q
Vermillion River near Wakonda, SD	06479000	Q
Big Sioux River at Arkon, IA	06485500	Q and WQ
Big Sioux River at Sioux City, IA	06485950	WQ
Floyd River at James, IA	06600500	Q and WQ
Floyd River at Sioux City, IA	06600500	WQ
Little Sioux River near Turin, IA	06607500	Q and WQ
Boyer River at Logan, IA	06609500	Q
Boyer River near Denison, IA	06609400	WQ
Platte River at Louisville, NE	06805500	WQ
Platte River at Plattsmouth, NE	06805550	WQ
Nishnabotna River above Hamburg, IA	06810000	WQ
Little Nemaha River at Auburn, NE	06811500	Q
Nodaway River near Burlington, MO	06817500	Q
Nodaway River at Clarinda, IA	06817000	Q
Platte River at Sharp Station, MO	06821190	WQ
Platte River near Diagonal, IA	06821190	WQ
Kansas River at Desoto, KS	06892350	Q and WQ
Blue River near Kansas City, MO	06893500	Q
L. Blue River below Longview Dam, MO	06893793	Q
Grande River near Sumner, MO	06902000	WQ
Chariton River near Prairie Hill, MO	06926500	WQ
Lamine River at Clifton City, MO	06907000	Q
Osage River near St. Thomas, MO	06926500	Q
Osage River below St. Thomas, MO	06926510	WQ
Gasconade River at Jerome, MO	06933500	Q
Missouri River at Yankton, SD	06467500	Q
Missouri River at Sioux City, IA	06468600	Q
Missouri River at Decatur, NE	06601200	Q
Missouri River at Omaha, NE	06610000	Q
Missouri River at Nebraska City, NE	06807000	Q
Missouri River at Rulo, NE	06813500	Q
Missouri River at St. Joseph, MO	06818000	WQ
Missouri River at Kansas City, MO	06893000	Q
Missouri River at Waverly, MO	06895500	Q
Missouri River at Hermann, MO	06934500	WQ

Note: WQ = water quality, Q = flow.

sources were also obtained from this EPA office and used in scenario runs as point source boundary conditions. These point sources were identified by members of the Missouri Basin State Association as major dischargers into the Missouri River. Table 4 contains all the dischargers recommended and identified on the PCS. Other dischargers had been recommended but were not found in the PCS (Table 5). From discussions with EPA personnel at the Region Seven office, it was found that some dischargers were no longer operating and others did not directly discharge into the Missouri River; they either discharged to tributaries of the Missouri River or to holding ponds.

Table 4

Recommended Dischargers of the Missouri River Included in Modeling Effort

State	Industry
Kansas	K.C. Kaw Point STP
	Atchison STP
	Lansing STP
	Leavenworth STP
Missouri	K.C.-Birmingham STP
	K.C.-Blue River STP
	K.C.-Westside STP
	St. Joseph STP
	Little Blue River STP
	Jefferson City STP
	MSD-Missouri River STP
Nebraska	Bellevue STP
	Nebraska City STP
	Blair STP
	Dakota City STP
	IBP at Dakota City
	Omaha-Missouri River STP
	Omaha-Papillion Creek STP
	Plattsmouth STP
Iowa	Terra International, Inc.
	Sioux City STP
	Kind and Knox Gelatin
	Council Bluffs
	Glenwood
	Griffin Pipe

Note: STP refers to sewage treatment plant.

Table 5

Recommended Dischargers Not in EPA's Permits Compliance System

State	Industry
Kansas	Midwest Grain
Nebraska	Singer American JEBCO Consolidated Blenders, Inc. ASARCO-discharges to city sewer

38. Power plant loads during the August and September 1990 data collection were obtained through the MRD from all power plants along the Missouri River and were used in the calibration and verification simulations. Fully loaded conditions for delta temperatures and discharges of the power plants were used for scenario runs and were obtained through the MRD from the power plants. Table 6 contains delta temperature and discharge for each power plant discharging into the Missouri River.

Table 6

Power Plant Δ Temperatures and Discharges

Name	River-Mile	August 28, 1990 Δ T °C	August 28, 1990 Discharge cfs	September 12, 1990 Δ T °C	September 12, 1990 Discharge cfs	Fully Loaded Δ T °C	Fully Loaded Discharge cfs
Neal North Unit 3	718.4	8.33	610	7.22	610	8.89	613
Neal North Unit 1	718.3	11.11	160	8.33	160	13.89	160
Neal North Unit 2	718.3	11.11	265	10.56	265	15.00	265
Neal South Unit 4	716.7	7.22	705	8.33	705	8.33	707
OPPD Ft. Calh Nucl	645.9	0.00	802	12.22	802	12.78	802
OPPD No. Omaha Sta.	625.2	5.00	1,034	5.56	1,034	10.00	1,107
CB Energy Unit 3	606.0	11.11	558	8.33	688	12.22	688
CB Energy Units 1&2	606.0	8.33	179	3.89	136	8.33	179
OPPD Ne. City Plant	556.3	7.78	700	0.00	697	10.00	735
NPPD Cooper Nuclear	532.6	9.44	1,417	10.56	1,417	11.11	1,488
St.Joe Lake Rd.Sta.	446.0	0.00	91	7.22	156	9.17	150
KCPL-Iatan Station	411.1	9.44	829	8.33	829	8.33	829
Nearman Creek Sta.	378.6	8.89	319	7.78	352	9.44	319
Quindaro Station	373.4	0.56	325	3.89	325	12.22	325
KCPL G. Ave (summer)	365.7	6.11	301	0.00	0	14.44	510
KCP&L Hawthorne Sta.	358.4	11.11	374	11.11	374	16.67	374
Independence(std-by)	345.3		0		0	5.56	116
Sibley Power Station	336.4						
outfall 004		7.78	253	7.78	240	14.44	261
outfall 005		10.00	391	8.89	401	14.44	418
Chamois Power Sta.	117.1	10.00	105	9.44	105	10.00	109
Callaway Nuc. Sta.	115.5	7.22	16	6.67	15	5.56	22
Labadie Power Sta.	57.9	11.67	1,980	11.11	1,470	16.28	2,209

Note: August 28, 1990, data were used as power plant boundary conditions (A90) in scenario runs. Although Fort Calhoun and St. Joe Lake were not operating on August 28, their delta temperatures and discharge were set to 12.22 °C, 802 cfs and 9.17 °C, 156 cfs, respectively, for scenario runs.

PART IV: QUAL2E CALIBRATION/VERIFICATION

Background

39. Model calibration is an iterative process that requires comparison of model output with observed historical data for refining and adjusting model parameters until optimal model predictions are obtained. Water quality model calibration is actually a two-step process. First, calibrated hydraulic conditions must be in agreement with observed conditions. After the model is hydraulically calibrated, water quality calibration is performed until water quality predictions are in agreement with the observed water quality values. Once the calibration process is completed, a second data set, preferably with different flows and loadings, is used to verify that the model produces acceptable results. All model parameters (i.e., coefficients) remain the same. A calibrated and verified model can then be used to determine the effects of operational changes on downstream water quality.

Calibration

Hydraulic

40. Hydraulic calibration of QUAL2E was not necessary since hydraulic data were provided by the Omaha and Kansas City Districts and provided to the model. The hydraulic data came from HEC-2 backwater computations, where HEC-2 had been calibrated against observations. The HEC-2 results were used to develop (through regression) rating curves required by QUAL2E to compute, from discharge, depths and velocities needed at computational elements. Computed depths were compared with the HEC-2 results to see how accurately the rating curves estimated depths. Table 7 compares the computed (from the rating curves) and HEC-2 results for all discharges of interest at four river mile (RM) locations. On the average, computed depths were about 86 percent of the HEC-2 simulated depths for the four locations. This accuracy was considered acceptable.

41. During calibration, modeled flows downstream of the dam increased from 27,500 to 50,944 cfs at Hermann (RM 98) as a result of tributary and point source contributions. The modeled flow at Hermann was close (within about 91 and 94 percent) of the USGS gage flows of 56,898 and 43,400 cfs measured on August 28, 1990, and September 12, 1990, respectively. The

Table 7

Predicted Calibration Depths and HEC-2 Simulation Results at Four Locations in the Missouri River

Location	Computed Flow, cfs	Predicted Depth, ft	HEC-2 Depth, ft	% Within HEC-2
RM 800	6,000	3.352	3.739	90
	9,000	3.880	4.264	91
	12,000	4.303	4.631	93
	18,000	4.979	5.507	90
	25,000	5.601	6.239	90
RM 625	6,000	5.281	5.150	102
	9,000	6.232	6.291	99
	12,000	6.941	7.301	95
	18,000	8.141	9.122	89
	25,000	9.259	10.788	86
RM 367	6,000	5.550	5.271	105
	9,000	6.439	6.039	107
	12,000	7.150	7.059	101
	18,000	8.298	8.561	97
	25,000	9.351	10.060	93
RM 98	6,000	4.277	4.412	97
	9,000	5.030	5.389	93
	12,000	5.632	6.311	90
	18,000	6.124	7.961	77
	25,000	7.501	9.709	72

discrepancy in flow was most likely due to ungaged flows from smaller tributaries that were not included in the model. To account for these ungaged tributaries, lateral inflows were included with the flow set to the average difference between the modeled and observed flow for the two sample dates and was equally distributed over the reaches. Water quality concentrations for the lateral inflows were set to the same value as the gaged tributaries within a reach. With the inclusion of the lateral inflows, the modeled flow was very close to observed flow at Hermann, MO, for calibration and verification and was considered acceptable.

Water quality calibration

42. In addition to calibrating the model to simulate hydraulic conditions accurately, calibration was performed on all water quality constituents of concern and compared with observed Missouri River data. Measured water quality data available for calibration included temperature, DO, $CBOD_5$,

chlorophyll *a*, total kjeldahl nitrogen, total ammonia nitrogen, nitrate nitrogen, total phosphorus, and total inorganic phosphorus. Data collected during the snapshot sampling on August 28, 1990, (Appendix A) by the Omaha and Kansas City Districts or reported by power plants were used in the calibration runs as tributary and headwater boundary conditions (Table 8) and power plant loads (Table 6), respectively. In addition, measured data collected August 28, 1990, on the main stem Missouri River were used as comparison data to evaluate model predictability.

43. Model performance was also evaluated using the mean absolute error (MAE) and the root mean square error (RMSE). The MAE represents the average error (±) in model predictions as compared with observed data and is calculated as:

$$MAE = \frac{\sum |(PREDICTED - OBSERVED)|}{NUMBER\ OF\ OBSERVATIONS} \tag{9}$$

The RMSE is a measure of variability between predicted and observed values and is written as:

$$RMSE = \sqrt{\frac{\sum (PREDICTED - OBSERVED)^2}{NUMBER\ OF\ OBSERVATIONS}} \tag{10}$$

An RMSE value of 0.50 indicates that the predicted data are within ± 0.50 units of that observed 67 percent of the time. Table 9 contains the MAE and RMSE for each water quality constituent modeled for final calibration and verification.

44. Model calibration consisted of adjusting coefficients and comparing the predicted and observed concentrations. This was an iterative process that was repeated until reasonably close comparisons between observed and predicted concentrations were made. Reaction rates for processes (e.g., algal growth and respiration, organic nitrogen hydrolysis, nitrification, CBOD oxidation), were initially set based on recommendations by Brown and Barnwell (1987) except for CBOD. The initial oxidation rate for CBOD was calculated using linear regression (PROC REG, SAS Institute, Inc. 1988) from data collected

Table 8

Boundary Conditions for Headwater, Tributaries, and Other Point Sources Set for Calibration/Verification

Headwater	Parameter	Calibration	Verification
GP Dam	Flow, cfs	27,500	32,000
	Temperature, °C	25.60	24.10
	DO, mg/ℓ	7.34	7.10
	CBOD, mg/ℓ	1.00	1.90
	Organic nitrogen, mg/ℓ	0.58	0.44
	Ammonia nitrogen, mg/ℓ	0.02	0.02
	Nitrate nitrogen, mg/ℓ	0.02	0.05
	Diss. inorg. phosphorus, mg/ℓ	0.03	0.02
	Algae, μg/ℓ	1.00	1.00

Tributary/Other Point Sources	Parameter	Calibration	Verification
James River	Flow, cfs	66	20
	Temperature, °C	27.60	24.10
	DO, mg/ℓ	6.75	6.30
	CBOD, mg/ℓ	2.90	3.60
	Organic nitrogen, mg/ℓ	0.12	1.28
	Ammonia nitrogen, mg/ℓ	0.03	0.02
	Nitrate nitrogen, mg/ℓ	0.17	0.12
	Diss. inorg. phosphorus, mg/ℓ	0.05	0.05
	Algae, μg/ℓ	17.00	17.00
Vermillion River	Flow, cfs	13	6
	Temperature, °C	27.50	23.30
	DO, mg/ℓ	4.93	6.70
	CBOD, mg/ℓ	2.10	2.70
	Organic nitrogen, mg/ℓ	0.67	0.68
	Ammonia nitrogen, mg/ℓ	0.03	0.02
	Nitrate nitrogen, mg/ℓ	0.08	0.04
	Diss. inorg. phosphorus, mg/ℓ	0.05	0.04
	Algae, μg/ℓ	17.00	17.00
Sioux City STP	Flow, cfs	22	22
	Temperature, °C	15.60	15.60
	DO, mg/ℓ	4.10	4.10
	CBOD, mg/ℓ	5.00	5.00
	Organic nitrogen, mg/ℓ	13.50	13.50
	Ammonia nitrogen, mg/ℓ	20.00	20.00
	Nitrate nitrogen, mg/ℓ	10.00	10.00
	Diss. inorg. phosphorus, mg/ℓ	5.00	5.00
	Algae, μg/ℓ	0.00	0.00

(Continued)

Note: STP = Sewage Treatment Plant.

(Sheet 1 of 8)

Table 8 (Continued)

Tributary/Other Point Sources	Parameter	Calibration	Verification
Big Sioux River + Dakota City IBP + Terra International	Flow, cfs	580	279
	Temperature, °C	28.30	24.70
	DO, mg/ℓ	9.40	5.55
	CBOD, mg/ℓ	7.13	6.80
	Organic nitrogen, mg/ℓ	1.77	1.71
	Ammonia nitrogen, mg/ℓ	0.17	0.12
	Nitrate nitrogen, mg/ℓ	1.96	0.23
	Diss. inorg. phosphorus, mg/ℓ	0.12	0.04
	Algae, μg/ℓ	17.00	17.00
Floyd River	Flow, cfs	80	52
	Temperature, °C	27.30	24.80
	DO, mg/ℓ	8.49	6.70
	CBOD, mg/ℓ	13.80	3.60
	Organic nitrogen, mg/ℓ	3.13	1.12
	Ammonia nitrogen, mg/ℓ	0.03	0.02
	Nitrate nitrogen, mg/ℓ	0.15	0.08
	Diss. inorg. phosphorus, mg/ℓ	0.03	0.02
	Algae, μg/ℓ	17.00	17.00
Kind & Knox	Flow, cfs	4	4
	Temperature, °C	20.00	20.00
	DO, mg/ℓ	5.00	5.00
	CBOD, mg/ℓ	28.00	28.00
	Organic nitrogen, mg/ℓ	13.50	13.50
	Ammonia nitrogen, mg/ℓ	20.00	20.00
	Nitrate nitrogen, mg/ℓ	10.00	10.00
	Diss. inorg. phosphorus, mg/ℓ	5.00	5.00
	Algae, μg/ℓ	0.00	0.00
Little Sioux R.	Flow, cfs	760	386
	Temperature, °C	28.50	26.20
	DO, mg/ℓ	7.31	12.90
	CBOD, mg/ℓ	4.80	10.20
	Organic nitrogen, mg/ℓ	1.14	2.02
	Ammonia nitrogen, mg/ℓ	0.03	0.02
	Nitrate nitrogen, mg/ℓ	3.70	1.57
	Diss. inorg. phosphorus, mg/ℓ	0.09	0.01
	Algae, μg/ℓ	17.00	17.00
Blair STP	Flow, cfs	2	2
	Temperature, °C	15.60	15.60
	DO, mg/ℓ	5.00	5.00
	CBOD, mg/ℓ	12.76	12.76
	Organic nitrogen, mg/ℓ	13.50	13.50
	Ammonia nitrogen, mg/ℓ	20.00	20.00
	Nitrate nitrogen, mg/ℓ	6.60	6.60
	Diss. inorg. phosphorus, mg/ℓ	5.00	5.00
	Algae, μg/ℓ	0.00	0.00

(Continued)

(Sheet 2 of 8)

Table 8 (Continued)

Tributary/Other Point Sources	Parameter	Calibration	Verification
Boyer River	Flow, cfs	600	206
	Temperature, °C	28.90	26.10
	DO, mg/ℓ	6.64	5.55
	CBOD, mg/ℓ	3.50	6.20
	Organic nitrogen, mg/ℓ	1.14	1.37
	Ammonia nitrogen, mg/ℓ	0.04	0.02
	Nitrate nitrogen, mg/ℓ	7.80	5.20
	Diss. inorg. phosphorus, mg/ℓ	0.25	0.11
	Algae, μg/ℓ	17.00	17.00
Griffin Pipe	Flow, cfs	0.35	0.35
	Temperature, °C	33.90	33.90
	DO, mg/ℓ	5.00	5.00
	CBOD, mg/ℓ	30.00	30.00
	Organic nitrogen, mg/ℓ	13.50	13.50
	Ammonia nitrogen, mg/ℓ	20.00	20.00
	Nitrate nitrogen, mg/ℓ	6.60	6.60
	Diss. inorg. phosphorus, mg/ℓ	5.00	5.00
	Algae, μg/ℓ	0.00	0.00
Omaha Missouri River Plant STP	Flow, cfs	56	56
	Temperature, °C	26.10	24.40
	DO, mg/ℓ	5.00	5.00
	CBOD, mg/ℓ	7.00	22.00
	Organic nitrogen, mg/ℓ	13.50	13.50
	Ammonia nitrogen, mg/ℓ	6.90	6.00
	Nitrate nitrogen, mg/ℓ	9.00	8.10
	Diss. inorg. phosphorus, mg/ℓ	5.00	5.00
	Algae, μg/ℓ	0.00	0.00
Council Bluff STP	Flow, cfs	13	13
	Temperature, °C	26.70	26.70
	DO, mg/ℓ	5.20	5.20
	CBOD, mg/ℓ	10.00	10.00
	Organic nitrogen, mg/ℓ	13.50	13.50
	Ammonia nitrogen, mg/ℓ	12.00	12.00
	Nitrate nitrogen, mg/ℓ	10.00	10.00
	Diss. inorg. phosphorus, mg/ℓ	5.00	5.00
	Algae, μg/ℓ	0.00	0.00
Bellevue STP + Papillion Creek STP	Flow, cfs	84	84
	Temperature, °C	25.40	25.60
	DO, mg/ℓ	5.00	5.00
	CBOD, mg/ℓ	9.98	9.98
	Organic nitrogen, mg/ℓ	13.50	13.50
	Ammonia nitrogen, mg/ℓ	8.40	14.30
	Nitrate nitrogen, mg/ℓ	7.50	6.70
	Diss. inorg. phosphorus, mg/ℓ	5.00	5.00
	Algae, μg/ℓ	0.00	0.00

(Continued)

(Sheet 3 of 8)

Table 8 (Continued)

Tributary/Other Point Sources	Parameter	Calibration	Verification
Platte River (NE)	Flow, cfs	2,561	1,511
	Temperature, °C	27.00	24.00
	DO, mg/ℓ	6.00	7.20
	CBOD, mg/ℓ	6.30	9.20
	Organic nitrogen, mg/ℓ	1.16	1.50
	Ammonia nitrogen, mg/ℓ	0.02	0.02
	Nitrate nitrogen, mg/ℓ	0.11	0.04
	Diss. inorg. phosphorus, mg/ℓ	0.19	0.28
	Algae, μg/ℓ	17.00	17.00
Plattsmouth STP	Flow, cfs	2	2
	Temperature, °C	15.60	15.60
	DO, mg/ℓ	5.00	5.00
	CBOD, mg/ℓ	13.00	13.00
	Organic nitrogen, mg/ℓ	13.50	13.50
	Ammonia nitrogen, mg/ℓ	20.00	20.00
	Nitrate nitrogen, mg/ℓ	10.00	10.00
	Diss. inorg. phosphorus, mg/ℓ	5.00	5.00
	Algae, μg/ℓ	0.00	0.00
Glenwood	Flow, cfs	1	1
	Temperature, °C	24.40	24.40
	DO, mg/ℓ	5.00	5.00
	CBOD, mg/ℓ	16.10	16.10
	Organic nitrogen, mg/ℓ	13.50	13.50
	Ammonia nitrogen, mg/ℓ	20.00	20.00
	Nitrate nitrogen, mg/ℓ	10.00	10.00
	Diss. inorg. phosphorus, mg/ℓ	5.00	5.00
	Algae, μg/ℓ	0.00	0.00
Nebraska City STP	Flow, cfs	2	2
	Temperature, °C	15.60	15.60
	DO, mg/ℓ	5.00	5.00
	CBOD, mg/ℓ	14.40	14.40
	Organic nitrogen, mg/ℓ	13.50	13.50
	Ammonia nitrogen, mg/ℓ	20.00	20.00
	Nitrate nitrogen, mg/ℓ	10.00	10.00
	Diss. inorg. phosphorus, mg/ℓ	5.00	5.00
	Algae, μg/ℓ	0.00	0.00
Nishnabotna River	Flow, cfs	1,101	680
	Temperature, °C	27.50	25.00
	DO, mg/ℓ	6.00	7.40
	CBOD, mg/ℓ	4.20	4.00
	Organic nitrogen, mg/ℓ	1.57	0.92
	Ammonia nitrogen, mg/ℓ	0.03	0.02
	Nitrate nitrogen, mg/ℓ	6.05	3.45
	Diss. inorg. phosphorus, mg/ℓ	0.22	0.17
	Algae, μg/ℓ	17.00	17.00

(Continued)

Table 8 (Continued)

Tributary/Other Point Sources	Parameter	Calibration	Verification
Nemaha River	Flow, cfs	41	26
	Temperature, °C	29.00	27.00
	DO, mg/ℓ	9.80	8.00
	CBOD, mg/ℓ	8.30	6.40
	Organic nitrogen, mg/ℓ	1.86	1.28
	Ammonia nitrogen, mg/ℓ	0.02	0.02
	Nitrate nitrogen, mg/ℓ	0.09	0.07
	Diss. inorg. phosphorus, mg/ℓ	0.03	0.09
	Algae, μg/ℓ	17.00	17.00
Nodaway River	Flow, cfs	227	115
	Temperature, °C	30.50	27.50
	DO, mg/ℓ	7.30	5.90
	CBOD, mg/ℓ	14.10	6.20
	Organic nitrogen, mg/ℓ	1.56	1.35
	Ammonia nitrogen, mg/ℓ	0.05	0.02
	Nitrate nitrogen, mg/ℓ	0.19	0.08
	Diss. inorg. phosphorus, mg/ℓ	0.05	0.08
	Algae, μg/ℓ	17.00	17.00
St. Joseph STP	Flow, cms	42	42
	Temperature, °C	15.70	15.70
	DO, mg/ℓ	5.00	5.00
	CBOD, mg/ℓ	9.00	9.00
	Organic nitrogen, mg/ℓ	13.50	13.50
	Ammonia nitrogen, mg/ℓ	10.00	10.00
	Nitrate nitrogen, mg/ℓ	10.00	10.00
	Diss. inorg. phosphorus, mg/ℓ	5.00	5.00
	Algae, μg/ℓ	0.00	0.00
City of Atchison	Flow, cfs	6	6
	Temperature, °C	15.70	15.70
	DO, mg/ℓ	5.00	5.00
	CBOD, mg/ℓ	7.00	7.00
	Organic nitrogen, mg/ℓ	13.50	13.50
	Ammonia nitrogen, mg/ℓ	20.00	20.00
	Nitrate nitrogen, mg/ℓ	10.00	10.00
	Diss. inorg. phosphorus, mg/ℓ	5.00	5.00
	Algae, μg/ℓ	0.00	0.00
Platte River (MO)	Flow, cfs	224	121
	Temperature, °C	28.60	26.80
	DO, mg/ℓ	6.30	6.40
	CBOD, mg/ℓ	4.00	4.30
	Organic nitrogen, mg/ℓ	1.12	0.90
	Ammonia nitrogen, mg/ℓ	0.01	0.02
	Nitrate nitrogen, mg/ℓ	0.09	0.09
	Diss. inorg. phosphorus, mg/ℓ	0.06	0.06
	Algae, μg/ℓ	17.00	17.00

(Continued)

(Sheet 5 of 8)

Table 8 (Continued)

Tributary/Other Point Sources	Parameter	Calibration	Verification
Leavenworth STP	Flow, cfs	10	10
	Temperature, °C	21.70	21.70
	DO, mg/ℓ	5.00	5.00
	CBOD, mg/ℓ	13.10	13.10
	Organic nitrogen, mg/ℓ	13.50	13.50
	Ammonia nitrogen, mg/ℓ	20.00	20.00
	Nitrate nitrogen, mg/ℓ	10.00	10.00
	Diss. inorg. phosphorus, mg/ℓ	5.00	5.00
	Algae, μg/ℓ	0.00	0.00
Lansing STP	Flow, cfs	4	10
	Temperature, °C	15.70	15.70
	DO, mg/ℓ	5.00	5.00
	CBOD, mg/ℓ	3.00	3.00
	Organic nitrogen, mg/ℓ	13.50	13.50
	Ammonia nitrogen, mg/ℓ	0.06	0.06
	Nitrate nitrogen, mg/ℓ	10.00	10.00
	Diss. inorg. phosphorus, mg/ℓ	5.00	5.00
	Algae, μg/ℓ	0.00	0.00
Kansas River	Flow, cfs	5,193	2,041
	Temperature, °C	28.80	27.20
	DO, mg/ℓ	6.90	7.90
	CBOD, mg/ℓ	3.50	4.70
	Organic nitrogen, mg/ℓ	1.05	1.12
	Ammonia nitrogen, mg/ℓ	0.16	0.02
	Nitrate nitrogen, mg/ℓ	1.07	0.08
	Diss. inorg. phosphorus, mg/ℓ	0.29	0.16
	Algae, μg/ℓ	17.00	17.00
Big Blue River + Kansas City STP	Flow, cfs	81	79
	Temperature, °C	20.68	19.40
	DO, mg/ℓ	2.40	3.48
	CBOD, mg/ℓ	30.92	31.48
	Organic nitrogen, mg/ℓ	0.12	0.32
	Ammonia nitrogen, mg/ℓ	1.40	1.99
	Nitrate nitrogen, mg/ℓ	6.67	7.18
	Diss. inorg. phosphorus, mg/ℓ	4.25	5.96
	Algae, μg/ℓ	17.00	17.00
Kansas City-Birmingham STP	Flow, cfs	15	15
	Temperature, °C	15.60	15.60
	DO, mg/ℓ	5.00	5.00
	CBOD, mg/ℓ	14.00	14.00
	Organic nitrogen, mg/ℓ	13.50	13.50
	Ammonia nitrogen, mg/ℓ	15.00	15.00
	Nitrate nitrogen, mg/ℓ	10.00	10.00
	Diss. inorg. phosphorus, mg/ℓ	5.00	5.00
	Algae, μg/ℓ	0.00	0.00

(Continued)

(Sheet 6 of 8)

Table 8 (Continued)

Tributary/Other Point Sources	Parameter	Calibration	Verification
Little Blue River	Flow, cfs	10	20
	Temperature, °C	26.88	23.50
	DO, mg/ℓ	3.90	6.70
	CBOD, mg/ℓ	8.80	4.50
	Organic nitrogen, mg/ℓ	0.68	0.66
	Ammonia nitrogen, mg/ℓ	0.02	0.03
	Nitrate nitrogen, mg/ℓ	0.09	0.20
	Diss. inorg. phosphorus, mg/ℓ	0.04	0.02
	Algae, μg/ℓ	17.00	17.00
Grand River	Flow, cfs	561	473
	Temperature, °C	29.30	24.80
	DO, mg/ℓ	5.80	6.10
	CBOD, mg/ℓ	6.30	5.70
	Organic nitrogen, mg/ℓ	0.95	1.49
	Ammonia nitrogen, mg/ℓ	0.02	0.11
	Nitrate nitrogen, mg/ℓ	0.08	1.00
	Diss. inorg. phosphorus, mg/ℓ	0.04	0.03
	Algae, μg/ℓ	17.00	17.00
Chariton River	Flow, cfs	1,461	951
	Temperature, °C	29.20	24.80
	DO, mg/ℓ	6.80	7.90
	CBOD, mg/ℓ	5.60	4.40
	Organic nitrogen, mg/ℓ	1.26	1.98
	Ammonia nitrogen, mg/ℓ	0.02	0.14
	Nitrate nitrogen, mg/ℓ	0.30	0.66
	Diss. inorg. phosphorus, mg/ℓ	0.05	0.10
	Algae, μg/ℓ	17.00	17.00
Lamine River	Flow, cfs	23	9
	temperature, °C	28.60	26.40
	DO, mg/ℓ	5.60	5.40
	CBOD, mg/ℓ	7.40	10.60
	Organic nitrogen, mg/ℓ	1.58	1.60
	Ammonia nitrogen, mg/ℓ	0.07	0.10
	Nitrate nitrogen, mg/ℓ	0.39	0.82
	Diss. inorg. phosphorus, mg/ℓ	0.03	0.03
	Algae, μg/ℓ	17.00	17.00
Jefferson City STP	Flow, cfs	11	11
	Temperature, °C	15.70	15.70
	DO, mg/ℓ	5.00	5.00
	CBOD, mg/ℓ	34.76	34.76
	Organic nitrogen, mg/ℓ	13.50	13.50
	Ammonia nitrogen, mg/ℓ	20.00	20.00
	Nitrate nitrogen, mg/ℓ	10.00	10.00
	Diss. inorg. phosphorus, mg/ℓ	5.00	5.00
	Algae, μg/ℓ	0.00	0.00

(Continued)

(Sheet 7 of 8)

Table 8 (Concluded)

Tributary/Other Point Sources	Parameter	Calibration	Verification
Osage River	Flow, cfs	9,726	1,501
	Temperature, °C	28.30	27.30
	DO, mg/ℓ	6.30	6.10
	CBOD, mg/ℓ	3.00	2.70
	Organic nitrogen, mg/ℓ	1.01	1.10
	Ammonia nitrogen, mg/ℓ	0.02	0.10
	Nitrate nitrogen, mg/ℓ	0.22	0.76
	Diss. inorg. phosphorus, mg/ℓ	0.03	0.05
	Algae, μg/ℓ	17.00	17.00
Gasconade River	Flow, cfs	892	726
	Temperature, °C	26.80	29.20
	DO, mg/ℓ	6.60	7.00
	CBOD, mg/ℓ	3.40	7.20
	Organic nitrogen, mg/ℓ	0.63	1.05
	Ammonia nitrogen, mg/ℓ	0.01	0.16
	Nitrate nitrogen, mg/ℓ	0.07	1.07
	Diss. inorg. phosphorus, mg/ℓ	0.02	0.20
	Algae, μg/ℓ	17.00	17.00

(Sheet 8 of 8)

Table 9

The MAE and RMSE Values Calculated for All Water Quality Constituents for Calibration and Verification

Run	Constituent	MAE	RMSE	Range	Units
	Temperature	1.06	1.42	25.80 - 30.30	°C
	DO	0.58	0.71	5.80 - 8.10	mg/ℓ
Calibration	CBOD	1.70	2.94	1.00 - 11.90	mg/ℓ
	Organic nitrogen	0.39	0.52	0.20 - 2.20	mg/ℓ
	Ammonia nitrogen	0.07	0.18	0.02 - 0.80	mg/ℓ
	Nitrate nitrogen	0.12	0.21	0.02 - 0.80	mg/ℓ
	Diss. inorg-P	0.03	0.06	0.02 - 0.26	mg/ℓ
	Organic P	0.10	0.15	0.01 - 0.50	mg/ℓ
	Temperature	0.69	0.78	23.30 - 28.00	°C
	DO	0.48	0.54	7.10 - 8.00	mg/ℓ
Verification	CBOD	0.71	0.99	1.00 - 7.30	mg/ℓ
	Organic nitrogen	0.17	0.27	0.00 - 1.41	mg/ℓ
	Ammonia nitrogen	0.03	0.08	0.02 - 0.36	mg/ℓ
	Nitrate nitrogen	0.07	0.09	0.00 - 0.17	mg/ℓ
	Diss. inorg-P	0.01	0.02	0.02 - 0.09	mg/ℓ
	Organic P	0.05	0.06	0.01 - 0.20	mg/ℓ

Note: Diss. inorg-P = dissolved inorganic phosphorus, organic P = organic phosphorus.

during the August 28, 1990, field study (Table A3) at four RM locations (RM 735, RM 534, RM 329, and RM 50). The following regression equation was used:

$$\ln L = \ln L_o - Kt \tag{11}$$

where

L = remaining CBOD concentration, mg/ℓ

L_o = ultimate CBOD concentration, mg/ℓ

K = CBOD oxidation rate, 1/day

t = time elapsed, days

The oxidation rates calculated for the four locations are presented in Table 10.

Table 10

Regressed CBOD Oxidation Rates for Locations in the Missouri River

Location	K	R-square	Equation Significance
RM 735	0.11	0.95	0.0001
RM 534	0.10	0.92	0.0001
RM 329	0.13	0.94	0.0001
RM 50	0.12	0.93	0.0001

All estimated K's were similar in value, so an averaged K value of 0.12 was initially set for all reaches modeled. Table 11 lists final calibration reaction rates and coefficients.

45. Calibration of Missouri River water temperatures were performed first, since, as in any water quality model study, reaction rate terms for the other water quality constituents modeled are temperature dependent. Thus, to alleviate error in predicting other water quality constituents, accurately predicting water temperatures is extremely important. Initial water temperature predictions for the Missouri River were being over predicted for most of the river. This over prediction especially occurred in the lower reaches where differences were as much as 3.0 °C. Initially met conditions reported on August 28, 1990, for the four met stations (listed in Part III) were used for calibration. Inspection of meteorological data for each station prior to August 28, 1990, revealed that a cold front had moved through the upper reaches lowering air temperatures approximately 10 °C compared with the reported August 28 air temperature. Apparently, water temperatures were also cooled in these reaches, and during the August 28 data collection, this cooler water had moved to the lower reaches. This extreme variation in meteorological conditions violated an assumption of constant boundary conditions required for this study. It was assumed that meteorological conditions as well as other boundary conditions were essentially constant the 2 weeks before data collection. Thus, all met data required by QUAL2E were averaged for the 10 days prior and including August 28 in an attempt to capture some of variation in met conditions. Figure 5 presents the final calibration results for temperature while Table 9 contains the calculated MAE and RMSE values. Although temperatures were still overpredicted, the MAE was slightly more than

Table 11

Final Values for Reaction Rates Used in Calibration and Verification Simulations

Reaction Rate	Reach 1	2	3	4	5	6	7	8	9
Ratio of chlorophyll *a* to algal biomass (μg-Chla/mg-A)	25								
Fraction of algal biomass that is Nitrogen (mg-N/mg-A)	0.09								
Fraction of algal biomass that is Phosphorus (mg-P/mg-A)	0.02								
O_2 production per unit of agal growth (mg-O/mg-A)	1.6								
O_2 uptake per unit of algae respired (mg-O/mg-A)	2.30								
O_2 uptake per unit of NH_4 oxidation (mg-O/mg-N)	3.50								
O_2 uptake per unit of NO_2 oxidation (mg-O/mg-N)	1.20								
Maximum algal growth rate (day^{-1})	2.85								
Algal respiration rate (day^{-1})	0.25								
Michaelis-Menton half-saturation constant option for light (langleys/min)	2								

(Continued)

Note: Parameters were constant throughout reaches unless otherwise indicated.

(Sheet 1 of 3)

Table 11 (Continued)

Reaction Rate	Reach 1	2	3	4	5	6	7	8	9
Michaelis-Menton half-saturation constant for nitrogen (mg-N/ℓ)	0.045								
Michaelis-Menton half-saturation constant for phosphorus (mg-P/ℓ)	0.005								
Nonalgal light extinction coefficient (m^{-1})	0.50	1.0	1.5	2.0	3.0	3.0	3.5	4.0	4.5
Linear algal self-shading coefficient ($m^{-1}/\mu g$ Chla/ℓ)	.0088								
Nonlinear algal self-shading coefficient ($(m^{-1}/\mu g$ Chla/ℓ$)^{2/3}$)	.0088								
Algal preference factor for ammonia	0.7								
Algal settling rate (m/day)	0.15								
Benthos source rate for dissolved phosphorus (mg-P/m^2-day)	0.00								
Benthos source rate for dissolved ammonia nitrogen (mg-P/m^2-day)	0.00								
Organic nitrogen settling rate (day^{-1})	0.001								
Organic phosphorus settling rate (day^{-1})	0.00								
CBOD oxidation rate (day^{-1})	0.1								

(Continued)

(Sheet 2 of 3)

Table 11 (Concluded)

Reaction Rate	Reach 1	2	3	4	5	6	7	8	9
CBOD settling rate (day^{-1})	0.0								
SOD rate ($mg\text{-}O/m^2\text{-}day$)	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.05	0.05
Reaeration rate option	5								
Organic nitrogen hydrolysis rate to ammonia (day^{-1})	0.02								
Oxidation rate of NH_4 to NO_2 (day^{-1})	0.25								
Oxidation rate of NO_2 to NO_3	0.50								
Decay rate for organic-P to dissolved-P (day^{-1})	0.03	0.03	0.03	0.03	0.03	0.20	0.20	0.20	0.20

(Sheet 3 of 3)

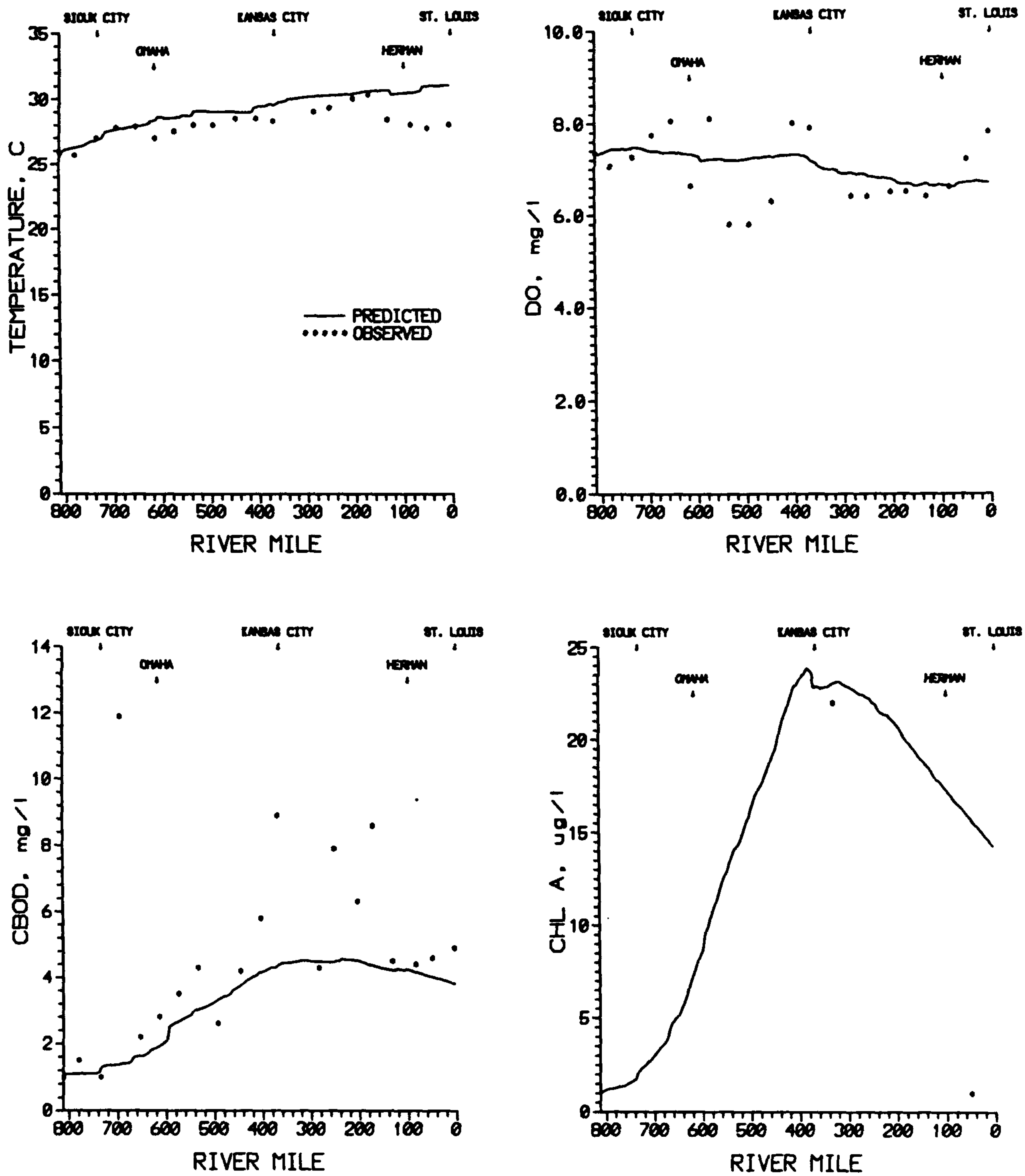


Figure 5. Final calibration results for all water quality constituents (Sheet 1 of 3)

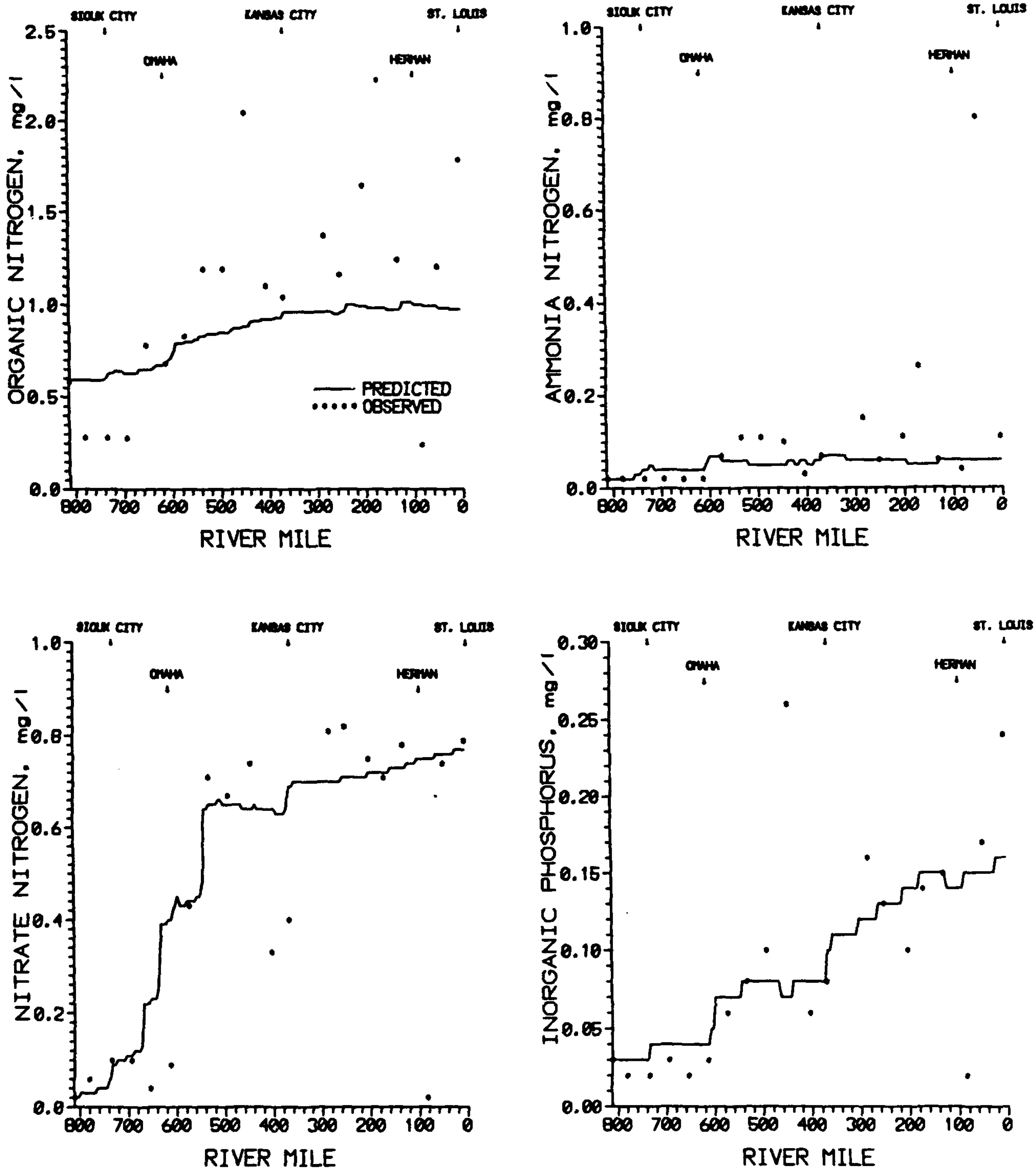


Figure 5. (Sheet 2 of 3)

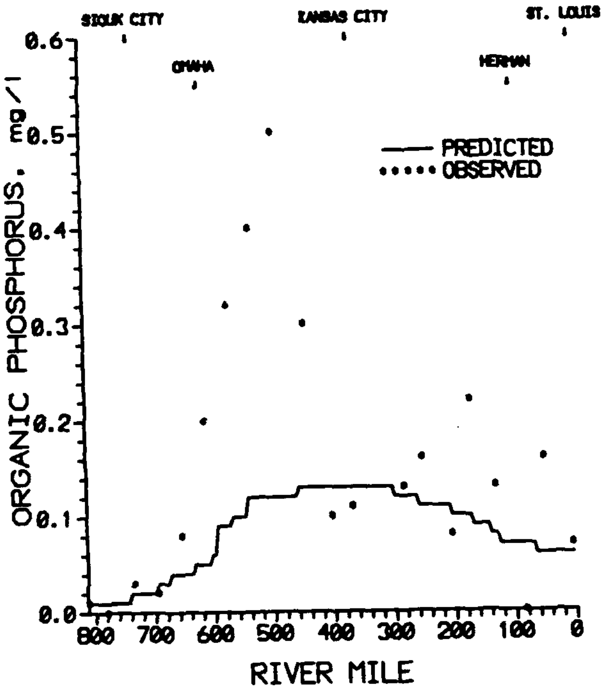


Figure 5. (Sheet 3 of 3)

1 °C, which was considered reasonable for the distance modeled in this study and the assumption of steady-state conditions. The value of these errors was greatly influenced by the discrepancies between predicted and observed water temperatures in the lower reaches that QUAL2E was unable to predict because of the prior cold front. Water temperatures in the upper reaches compared more favorably with observed data (Figure 5).

46. CBOD calibration began once temperature predictions were considered reasonable. Since CBOD boundary conditions and comparison (observed) data were 5-day values, the predicted values were output as $CBOD_5$ even though the predicted CBOD values are calculated as ultimate ($CBOD_u$). Low computed $CBOD_5$ concentrations shown in Figure 6 indicated that not all CBOD loads had been accounted for or that another process was contributing to CBOD concentrations. As identified in Figure 6, predicted $CBOD_5$ concentrations increased only slightly downstream while observed $CBOD_5$ concentrations increased downstream especially near RM 500. To try to account for these discrepancies, additional CBOD loads from minor wastewater treatment plants and industries discharging into the Missouri River were added to the CBOD loads. These additional loads only increased the $CBOD_5$ concentrations 0.2 mg/ℓ, which did not come close to the 4.5- to 6.5-mg/ℓ differences at some locations. Since increasing CBOD loads did not help account for these discrepancies, another possible explanation was that algae (calculated as biomass, dry weight, milligrams per liter) were contributing to CBOD concentrations through algal respiration, mortality, and excretion (discussed in the Model Modification section). Algae were not initially included as a modeled constituent since many people felt very little algae existed in the Missouri River during navigation season because of the faster flow velocities and high turbidity. However, this assumption had to be reconsidered after examining initial CBOD results. Additionally, the few chlorophyll *a* measurements for this study were similar to values reported by Reetz (1982) at RM miles 646 and 532 observed during the same time period as this study. Reetz (1982) found seven algal divisions (diatoms, green algae, blue-green algae, cryptophytes, chrysophytes, euglenoids, and dinoflagellates) comprised the algal community near the Fort Calhoun (RM 646) and Cooper Nuclear Stations (RM 532). In another study of the upper reaches below Gavins Point Dam, Carr (1988) also found similar algal divisions.

47. To verify if algae existed in the Missouri River during navigation season and was an appropriate constituent to include in this modeling study, the MRD requested the Omaha and Kansas City Districts to collect additional

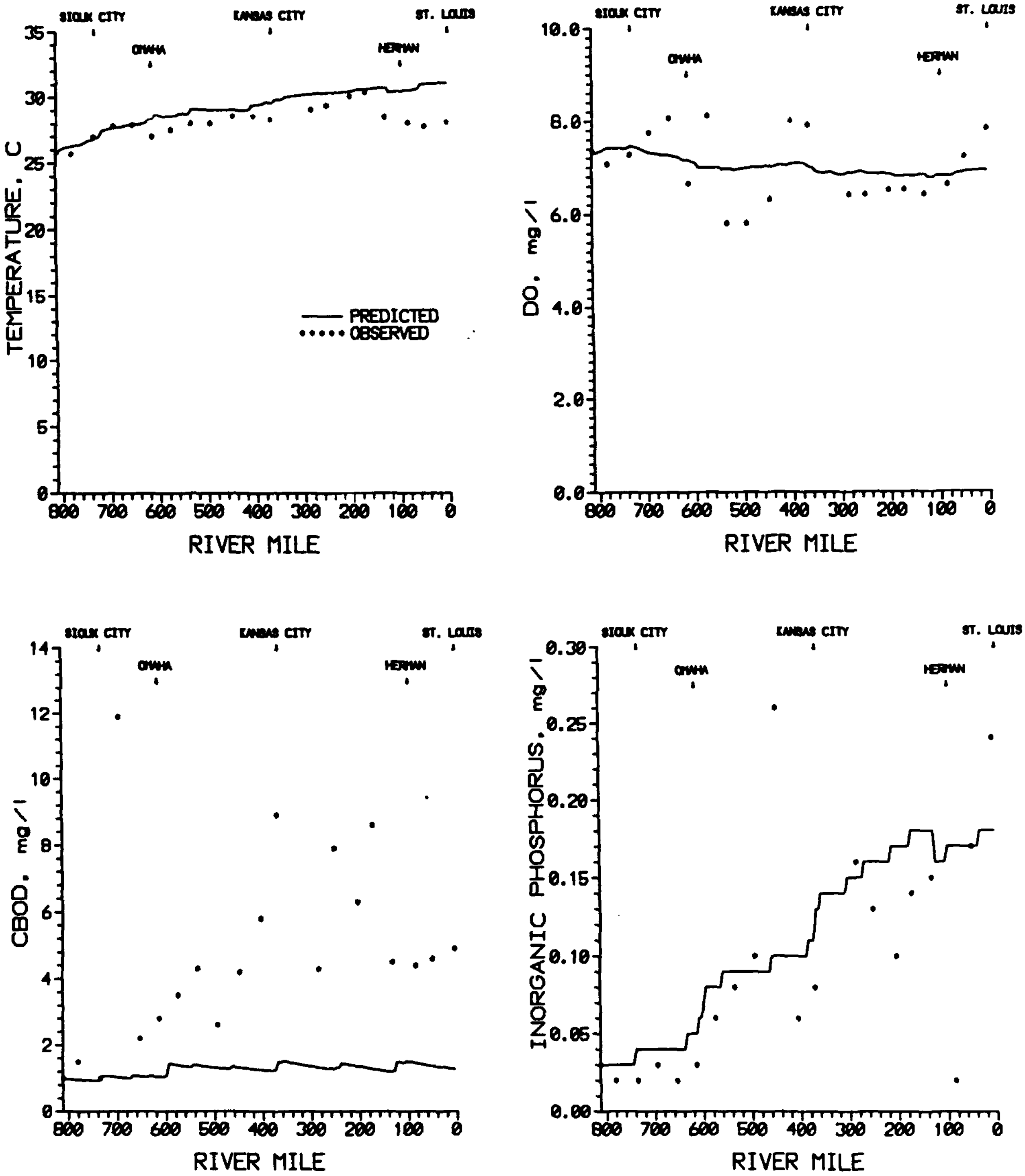


Figure 6. Initial calibration results for all water quality constituents (Continued)

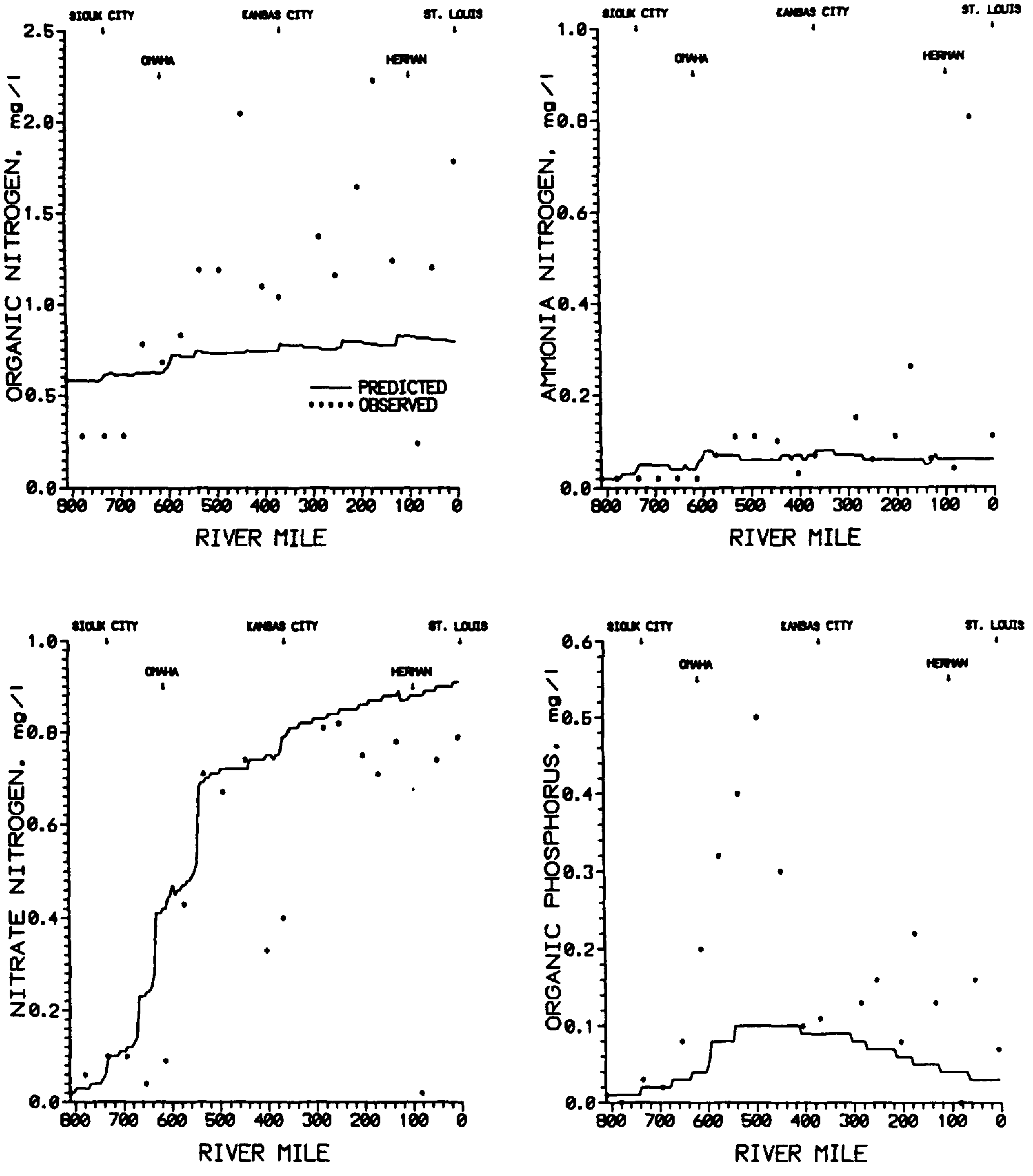


Figure 6. (Concluded)

chlorophyll *a* data at 11 locations in the Missouri River. These data were collected on September 11, 1991, and are presented in Table 12. Data in Table 12 suggest that algae are present in the Missouri River during navigation season and should be modeled.

Table 12

Chlorophyll *a* Data Measured September 11, 1991, by the Omaha and Kansas City Districts

River Mile	Concentration, μg/ℓ
805	< 1
691	7
672	6
590	10
498	19
398	12
366	11
294	28
197	42
98	33.5
St. Louis	209

48. The decision to model algae delayed the calibration of $CBOD_5$ since $CBOD_5$ concentrations are influenced by algal excretion and mortality. Calibration of algae consisted of adjusting values for the nonalgal light extinction, algal settling, ratio of chlorophyll *a* to algal biomass, algal specific growth, and respiration rates. In addition, the temperature limits (T_1-T_4) and temperature rate coefficients (K_1-K_4) required for the temperature correction term (Equation 4) for temperature dependent algal rates were also adjusted. Initial values for the nonalgal light extinction coefficient were estimated using observed Secchi depth measurements and the relationship shown in Figure 7 from the CE-QUAL-R1 manual (Environmental Laboratory 1982). Initial values for the other algal rates were set based on recommendations by Brown and Barnwell (1987). Table 11 contains final values for the rate terms and temperature limits associated with algal processes. Final calibration results for chlorophyll *a* shown in Figure 5 were considered reasonable based on the limited amount of available observed data on August 28, 1990. Calibrating algae proved to be very difficult with only a few observed chlorophyll *a* measurements available. The insufficient observed algal data throughout the

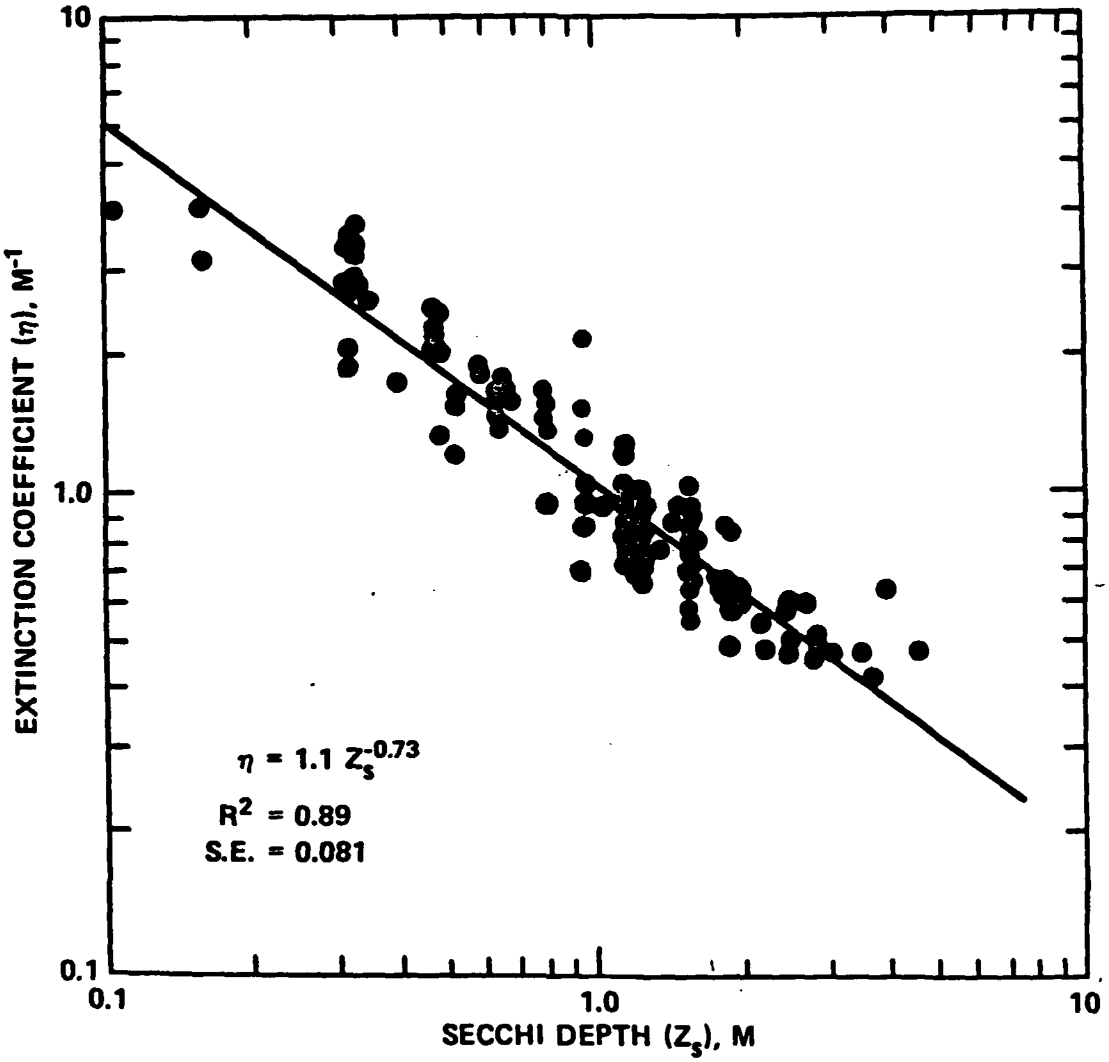


Figure 7. Relationship between the extinction coefficient and the Secchi disk depth (Williams et al. 1981)

Missouri River required the dynamics of algal growth and respiration through the system to be estimated based on observed CBOD dynamics through the system.

49. $CBOD_5$ was the next water quality constituent to be calibrated after algae predictions were deemed acceptable. Calibrating $CBOD_5$ was accomplished by adjusting the reaction rates of CBOD settling and oxidation. Initial CBOD settling rates were set based on recommendations of Brown and Barnwell (1987) and initial CBOD oxidation rates were set to the regressed K value discussed above. Final values for these rates are presented in Table 11. Figure 5 shows the final calibration results for $CBOD_5$ concentrations. Final $CBOD_5$ predictions plotted in Figure 5 were corrected for comparison with observed

measurements, which included algal organic carbon that can contribute to CBOD. In the model, CBOD and algae are separate variables; thus it is necessary to either substract algal effects from measured CBOD or add algal effects to computed CBOD. The latter correction is more reasonable. Therefore, ultimate algal CBOD was computed with Equation 12.

$$ult\ algal\ CBOD = \frac{\mu g\ chl\ a}{L} * \frac{0.05\ mg\ C}{\mu g\ chl\ a} * \frac{2.7\ mg\ DO}{mg\ C} \qquad (12)$$

Since observed CBOD data were 5-day CBOD values, ultimate algal CBOD was converted to 5-day algal CBOD using the equation:

$$algal\ CBOD_5 = algal\ CBOD_U * (1. - e^{(-5.\ \rho)}) \qquad (13)$$

where

algal $CBOD_5$ = 5-day algal CBOD, mg/ℓ

algal $CBOD_U$ = ultimate algal CBOD, mg/ℓ

ρ = modeled algal respiration rate, 1/day

Then algal $CBOD_5$ was added to modeled $CBOD_5$ for comparison with measured $CBOD_5$. The modeled $CBOD_5$ is computed from the model variable $CBOD_u$ using Equation 13 with K_1 (CBOD oxidation rate) in place of ρ. The MAE and RMSE values (Table 9) calculated for CBOD were 1.7 and 2.94, respectively. Although these errors are relatively high, the trend of predicted data followed the trend of observed data (i.e., concentrations increased in the downstream direction). Predicted CBOD results were not improved with further adjustments in rate constants. Table 11 contains the final values for CBOD oxidation and settling.

50. Calibration continued with the nitrogen cycle including total organic nitrogen, ammonia nitrogen, and nitrate nitrogen. First, organic nitrogen was calibrated by making adjustments to the reaction rates, i.e., organic nitrogen settling and hydrolysis of organic nitrogen to ammonia. As in the case of CBOD, initial organic nitrogen concentrations (Figure 6) were underpredicted with very little increase in the downstream direction as compared with observed data. Since organic nitrogen is a byproduct of algae, the inclusion of algae as a modeled variable helped improve organic nitrogen

predictions. Measured total organic nitrogen values (Figure 5) were obtained by subtracting total ammonia nitrogen from total kjeldahl nitrogen. Figure 5 shows the final calibration results for total organic nitrogen, and Table 9 presents calculated values of the MAE and RMSE, 0.39 and 0.52 (respectively). Table 11 contains final values for the reaction rates for organic nitrogen settling and hydrolysis. Final predictions for organic nitrogen were also corrected for algal composition to compare with observations as discussed above for CBOD. Algal organic nitrogen was computed from:

$$Algal\ ORG\text{-}N = \frac{\mu g\ chl\ a}{l} * \frac{0.02\ mg\ alg}{\mu g\ chl\ a} * \frac{0.09\ mg\ ORG\text{-}N}{mg\ alg} \tag{14}$$

Even though organic nitrogen concentrations were predicted lower than observed data in the lower reaches, the trend of increasing concentrations downstream was correctly predicted. Loads of organic nitrogen from sources such as feed lots or agricultural runoff could be contributing to the increase in organic nitrogen concentrations but could not be verified. Final calibration predictions of organic nitrogen were considered acceptable.

51. Ammonium nitrogen was calibrated next. Calibration of ammonia mainly consisted of adjusting the ammonia oxidation rate, benthos source rate, and the algal preference factor for ammonia. Initial values for these terms were set based on recommendations of Brown and Barnwell (1987). Ford (1982) states that Berner and many others found very low densities of benthos in the lower Missouri River because of physical constraints to colonization (e.g, shifting, unstable substrates, siltation, fluctuating water level, swift current, and the absence of rooted aquatic plants). For this reason, the benthos source rate was set to zero. Final values for the rates are shown in Table 11. Favorable predictions of ammonia nitrogen are shown in Figure 5, and the MAE and RMSE calculated were 0.07 and 0.18, respectively. The values of the errors were influenced by what appeared to be an outlier observed data point at RM 50.

52. The last constituent in the nitrogen cycle to be calibrated was nitrate nitrogen. Adjustments were made to the algal preference for nitrate. Before algae were included as a modeled constituent, the initial results of nitrate nitrogen in the lower reaches were being overpredicted (Figure 6). Modeling algae helped to improve calibration results for nitrate because algae

utilized nitrate as a food source removing the excess nitrate initially predicted. The final calibration results are shown in Figure 5 and the MAE and RMSE (Table 9) calculated were 0.12 and 0.21, respectively. These results compared favorably with the observed data.

53. With calibration of the nitrogen cycle complete, total organic and dissolved inorganic phosphorus were the next constituents to be calibrated. Adjustments were made to the mineralization and settling rate of organic phosphorus during calibration. As in the case of CBOD and organic nitrogen, initial organic phosphorus concentrations (Figure 6) were underpredicted. Since organic phosphorus is also a by-product of algae, the inclusion of algae as a modeled variable helped improve organic phosphorus predictions as well. Figure 5 shows the final calibration results for organic phosphorus, and Table 9 presents calculated values of the MAE and RMSE, 0.15 and 0.06 (respectively). Observed total organic phosphorus values in Figure 5 were obtained by substracting total inorganic phosphorus (particulate plus dissolved inorganic phosphorus) from total phosphorus (total organic plus total inorganic phosphorus). In Figure 5 the increase in organic phosphorus at approximately RM 500 was assumed to be caused by a storm event that had flushed organic matter into the Missouri River the week before data were collected. The modified version of QUAL2E was unable to capture this transient event since it is a steady-state model. Table 11 contains final values for the reaction rates for organic phosphorus settling and mineralization. Final predictions for organic phosphorus were also corrected for algal composition to compare with observations as discussed above for CBOD and organic nitrogen. Algal organic phosphorus was computed from:

$$Algal\ ORG\text{-}P = \frac{\mu g\ chl\ a}{l} * \frac{0.02\ mg\ alg}{\mu g\ chl\ a} * \frac{0.02\ mg\ ORG\text{-}P}{mg\ alg} \tag{14}$$

54. Calibration of dissolved inorganic phosphorus was performed once organic phosphorus was considered calibrated. As illustrated in Figure 2, inorganic dissolved phosphorus was gained through organic phosphorus mineralization and benthos source and lost through algal utilization as food. As discussed above, the benthos source rate was set to zero. Organic phosphorus mineralization was adjusted to an average value for the range specified by Brown and Barnwell (1987). Final values for the rates are shown in Table 11.

Figure 5 presents the final calibration results and shows favorable comparison with observed data. Although QUAL2E models dissolved inorganic phosphorus, comparisons of modeled values had to be made with total inorganic phosphorus (particulate plus dissolved) since this was what was measured. Based on the final results (Figure 5), the assumption that the predicted dissolved inorganic phosphorus and the measured total inorganic phosphorus were equivalent appeared to be reasonable. The MAE and RMSE values (Table 9) were calculated as 0.03 and 0.06, respectively.

55. DO was reserved as the final constituent to calibrate because, as shown in Figure 2, most of the other water quality constituents modeled exert a demand on DO. Once the demand by the other water quality constituents had been addressed through calibration of each, calibration of DO consisted of adjusting SOD and atmospheric reaeration (Figure 2). As discussed above, benthic sources in the lower Missouri River were found to be low; thus the SOD was set to a low value compared with rates used in other studies (Dortch et al. 1992). QUAL2E provides eight options for estimating a reaeration rate. Of the eight, five options were considered appropriate for the Missouri River system. Each of these five options were tested in the calibration runs, and the equation of Thackston and Krenkel (1969) was selected because it produced the best results. This equation is able to cover a range of depth scales greater than any of the other equations presently used (Thackston and Krenkel 1969). In addition this equation is also simpler and depends on hydraulic variables (i.e., slope) that are more easily and accurately measured.

56. Figure 5 depicts the final calibration results for DO. Around RM 550, Figure 5 shows a drop in observed DO concentrations that could not be predicted. Diel temperature data measured at two stations (RM 627 and 328.6) during the August 28, 1990, snapshot samplings showed a temperature change only of approximately 1 °C (Table A9) for a 24-hr period, which was not enough to cause the reduction in DO concentration at RM 550. Lower observed DO concentrations may have been caused by a local storm event (which occurred the week prior to data collection) flushing organic matter into the river from rural and urban areas. Tributary data collected on August 28, 1990, used for boundary conditions did not reflect this since no residual effects of the storm event remained. Consequently, QUAL2E was unable to predict the lower DO concentrations. Observed DO data also show increasing concentrations in the lower reaches around RM 100 probably resulting from the cooler water temperatures (Figure 5) in this reach. QUAL2E was unable to predict this trend since

predicted water temperatures in this reach were warmer than observed, allowing less solubility of DO in water. The MAE and RMSE values calculated were 0.58 and 0.71, respectively. Final calibration results were considered acceptable for DO.

Verification

57. Model performance was verified using data collected by the Omaha and Kansas City Districts on September 12, 1990, from the second snapshot sampling (Tables A5 and A6). This data was used as boundary conditions for the headwater (Gavins Point Dam) and major tributaries. Point source boundary conditions were set to data reported in the PCS on this date by industries discharging into the Missouri River, and power plant boundary conditions were also set to reported values on this date. Reaction rates for the verification simulation were set to the final values of the reaction rates from the calibration simulation (Table 11).

58. Figure 8 shows final verification results for all water quality constituents modeled. Final verification results compared favorably with observed data. As a matter of fact, verification results (Figure 8) as compared with calibration results (Figure 5) showed improved predictions for most water quality constituents. This is also demonstrated by the values of the MAE and RMSE calculated and shown in Table 9. Better verification results were probably due to more constant boundary conditions (a major assumption for steady-state modeling) the 2 weeks prior to data collection.

59. In Figure 9, calibration and verification algal predictions were plotted with the measured values from the September 11, 1991, sampling (Table 12). Figure 9 shows that similar trends in algal concentrations (especially for the verification predictions) were being predicted when compared with measured data. This indicated that the algal-related coefficients were adjusted to the appropriate values for algal growth and respiration.

60. In Figure 8, most of the observed DO data measured on September 12, 1990, were found to be supersaturated for the water temperatures measured on this date. Why these values were supersaturated was never determined. One theory was that water temperatures warmed up faster than the gas could escape causing DO measurements to be higher than what normally would occur for the water temperatures measured. Because of this, predicted DO concentrations

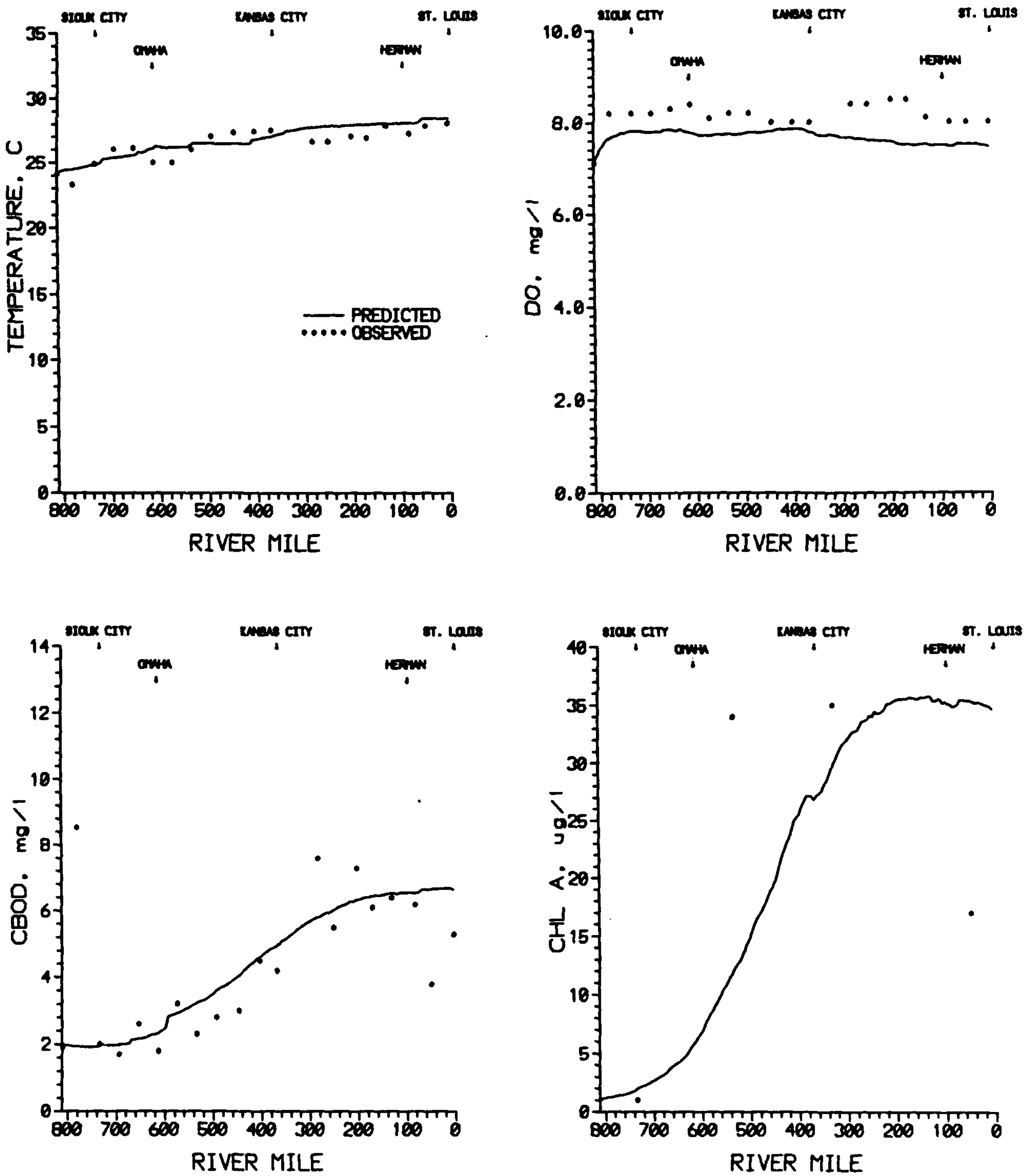


Figure 8. Verification results for all water quality constituents (Sheet 1 of 3)

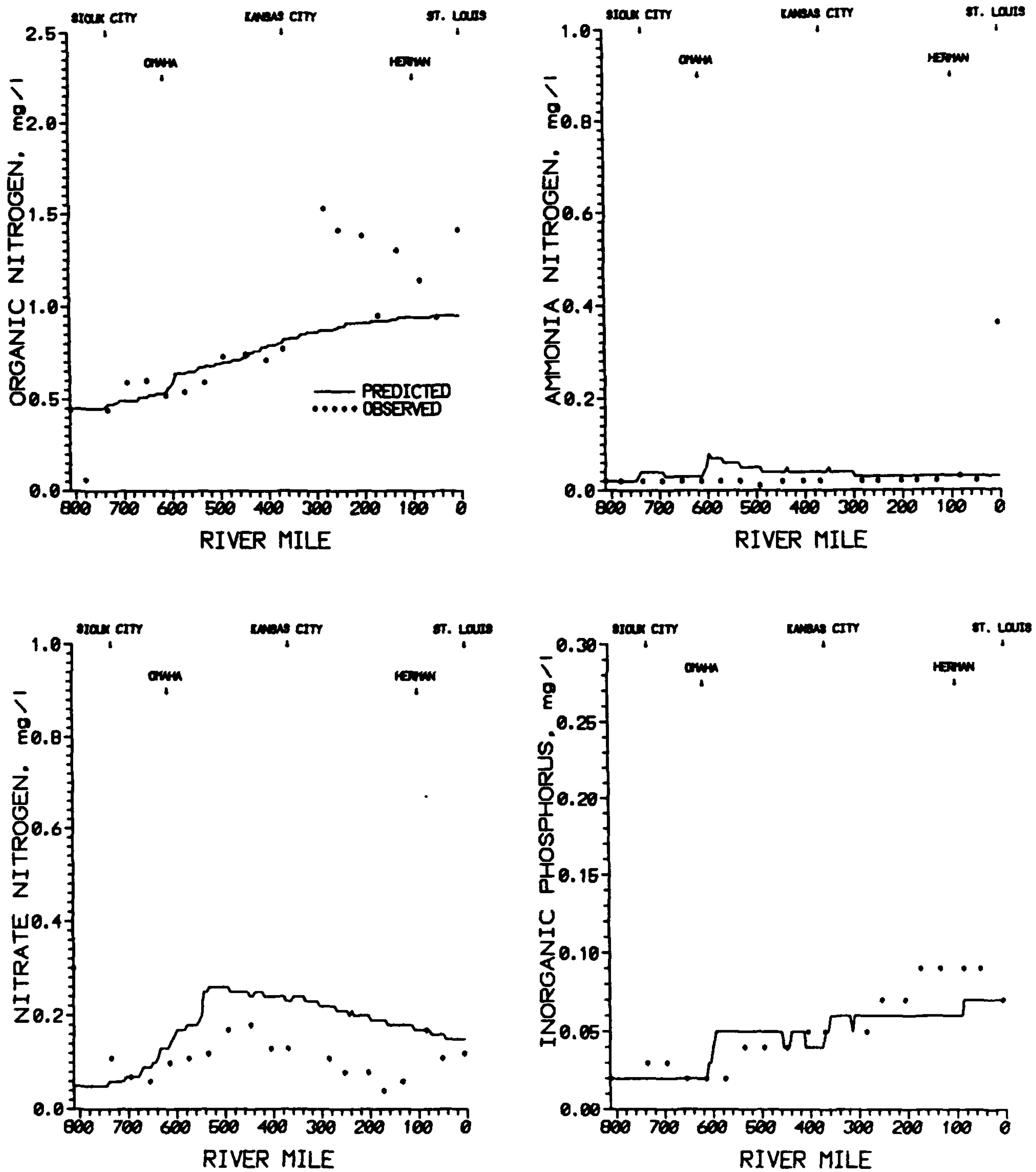


Figure 8. (Sheet 2 of 3)

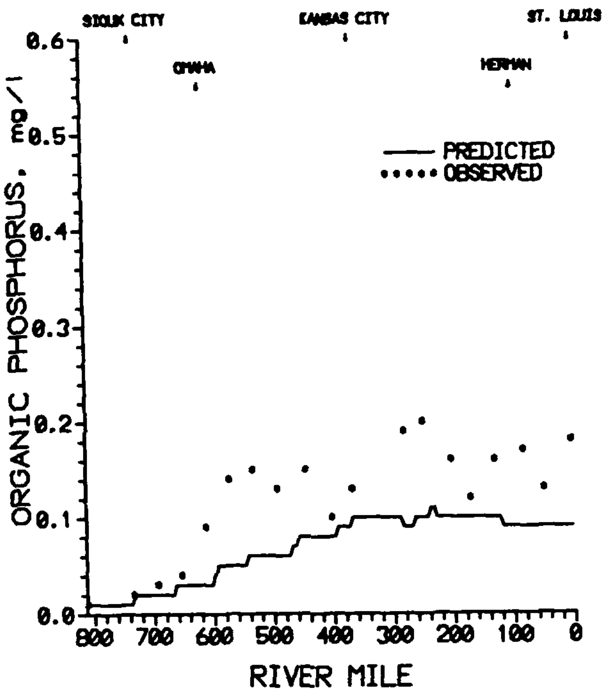


Figure 8. (Sheet 3 of 3)

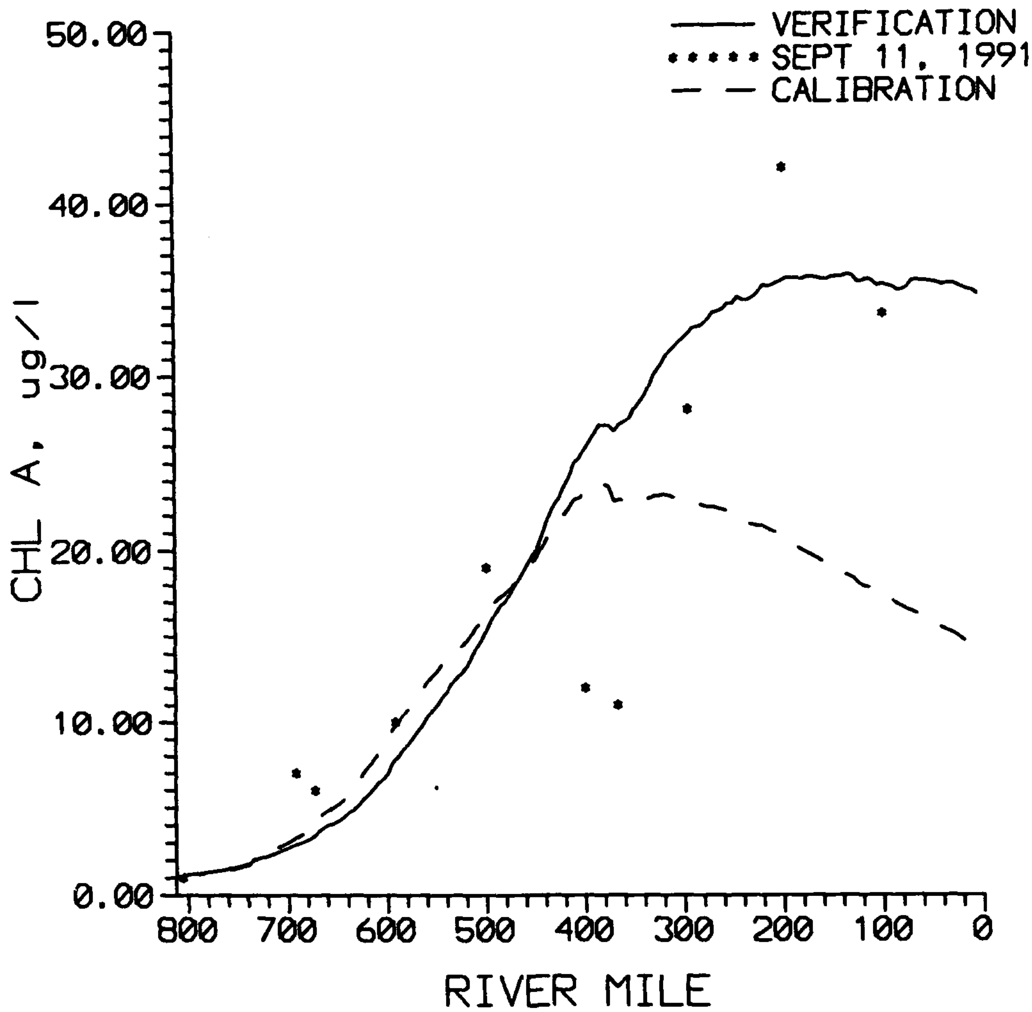


Figure 9. Calibration/verification algal predictions plotted with measured data (September 11, 1991)

were always approximately 0.4 mg/ℓ lower than observed even though predicted water temperatures were close to observed.

PART V: SCENARIO RESULTS

Overview

61. Scenario simulations were conducted following model calibration and verification. Scenario runs were made to examine the far field effects on water quality of operational changes (e.g., reduction in release flow in combination with a band of release temperatures) at Gavins Point Dam and changes to boundary conditions (i.e., meteorological, tributary, point source, and power plant loadings). Table 13 contains a list of the sets of scenario runs with the operations and boundary conditions considered for each set of runs. These scenarios were selected to coordinate with other operating scenarios being evaluated under the Phase 2 Master Manual Study and represent a wide range of possible operating conditions. All but one set of scenario runs were made for summer conditions since most of the concerns for deterioration in water quality are during hot, dry periods. One set of scenario runs was made for winter conditions.

62. The next section discusses boundary conditions (e.g., headwater, meteorological, tributary, point source, and power plant) set for scenario runs and base condition runs. Base condition is considered a "baseline" for comparison of reduced release flow results and other scenarios. Results for each set of scenario runs (Table 13) will be discussed in the final section of Part V.

Boundary Conditions for Scenarios

Headwater

63. Headwater boundary conditions for a range of release flows and temperatures for the scenario runs were provided by the MRD. These conditions are listed in Table 14. Boundary conditions for the other water quality constituents modeled (i.e., DO, CBOD, organic nitrogen, ammonia, nitrate nitrogen, dissolved inorganic phosphorus, and algae) were set to values measured during the snapshot sampling on August 28, 1990.

Table 13

Gavins Point Dam Operational Changes and Boundary Condition Changes Examined in Scenario Runs

Scenario #	GPDQ*	GPDT	Met Conditions	Trib Q	Trib Temp	Trib WQ	Power Plant
1	9000	23.9	14T10	7Q10	Max T	Max WQ	A90
	9000	26.7	14T10	7Q10	Max T	Max WQ	A90
	9000	29.4	14T10	7Q10	Max T	Max WQ	A90
	12000	23.9	14T10	7Q10	Max T	Max WQ	A90
	12000	26.7	14T10	7Q10	Max T	Max WQ	A90
	12000	29.4	14T10	7Q10	Max T	Max WQ	A90
	18000	23.9	14T10	7Q10	Max T	Max WQ	A90
	18000	26.7	14T10	7Q10	Max T	Max WQ	A90
	18000	29.4	14T10	7Q10	Max T	Max WQ	A90
	25000	23.9	14T10	7Q10	Max T	Max WQ	A90
	25000	26.7	14T10	7Q10	Max T	Max WQ	A90
	25000	29.4	14T10	7Q10	Max T	Max WQ	A90
2	9000	23.9	14T10	2-year	Max T	Max WQ	A90
	9000	26.7	14T10	2-year	Max T	Max WQ	A90
	9000	29.4	14T10	2-year	Max T	Max WQ	A90
	12000	23.9	14T10	2-year	Max T	Max WQ	A90
	12000	26.7	14T10	2-year	Max T	Max WQ	A90
	12000	29.4	14T10	2-year	Max T	Max WQ	A90
	18000	23.9	14T10	2-year	Max T	Max WQ	A90
	18000	26.7	14T10	2-year	Max T	Max WQ	A90
	18000	29.4	14T10	2-year	Max T	Max WQ	A90
	25000	23.9	14T10	2-year	Max T	Max WQ	A90
	25000	26.7	14T10	2-year	Max T	Max WQ	A90
	25000	29.4	14T10	2-year	Max T	Max WQ	A90
3	9000	23.9	Max	2-year	Max T	Max WQ	A90
	9000	26.7	Max	2-year	Max T	Max WQ	A90
	9000	29.4	Max	2-year	Max T	Max WQ	A90
	12000	23.9	Max	2-year	Max T	Max WQ	A90
	12000	26.7	Max	2-year	Max T	Max WQ	A90
	12000	29.4	Max	2-year	Max T	Max WQ	A90
	18000	23.9	Max	2-year	Max T	Max WQ	A90
	18000	26.7	Max	2-year	Max T	Max WQ	A90
	18000	29.4	Max	2-year	Max T	Max WQ	A90
	25000	23.9	Max	2-year	Max T	Max WQ	A90
	25000	26.7	Max	2-year	Max T	Max WQ	A90
	25000	29.4	Max	2-year	Max T	Max WQ	A90
4	9000	23.9	Max	2-year	Max T	Max WQ	NPP
	9000	26.7	Max	2-year	Max T	Max WQ	NPP
	9000	29.4	Max	2-year	Max T	Max WQ	NPP
	12000	23.9	Max	2-year	Max T	Max WQ	NPP
	12000	26.7	Max	2-year	Max T	Max WQ	NPP

(Continued)

* Definition of terms in table given on page 63.

(Sheet 1 of 3)

Table 13 (Continued)

Scenario #	GPDO*	GPDT	Met Conditions	Trib Q	Trib Temp	Trib WQ	Power Plant
	12000	29.4	Max	2-year	Max T	Max WQ	NPP
	18000	23.9	Max	2-year	Max T	Max WQ	NPP
4	18000	26.7	Max	2-year	Max T	Max WQ	NPP
	18000	29.4	Max	2-year	Max T	Max WQ	NPP
	25000	23.9	Max	2-year	Max T	Max WQ	NPP
	25000	26.7	Max	2-year	Max T	Max WQ	NPP
	25000	29.4	Max	2-year	Max T	Max WQ	NPP
5	9000	23.9	Max	2-year	Max T	Max WQ	MPL
	9000	26.7	Max	2-year	Max T	Max WQ	MPL
	9000	29.4	Max	2-year	Max T	Max WQ	MPL
	12000	23.9	Max	2-year	Max T	Max WQ	MPL
	12000	26.7	Max	2-year	Max T	Max WQ	MPL
	12000	29.4	Max	2-year	Max T	Max WQ	MPL
	18000	23.9	Max	2-year	Max T	Max WQ	MPL
	18000	26.7	Max	2-year	Max T	Max WQ	MPL
	18000	29.4	Max	2-year	Max T	Max WQ	MPL
	25000	23.9	Max	2-year	Max T	Max WQ	MPL
	25000	26.7	Max	2-year	Max T	Max WQ	MPL
	25000	29.4	Max	2-year	Max T	Max WQ	MPL
6	9000	23.9	14T10	7Q10	Max T	NA-Max WQ	A90
	9000	26.7	14T10	7Q10	Max T	NA-Max WQ	A90
	9000	29.4	14T10	7Q10	Max T	NA-Max WQ	A90
	12000	23.9	14T10	7Q10	Max T	NA-Max WQ	A90
	12000	26.7	14T10	7Q10	Max T	NA-Max WQ	A90
	12000	29.4	14T10	7Q10	Max T	NA-Max WQ	A90
	18000	23.9	14T10	7Q10	Max T	NA-Max WQ	A90
	18000	26.7	14T10	7Q10	Max T	NA-Max WQ	A90
	18000	29.4	14T10	7Q10	Max T	NA-Max WQ	A90
	25000	23.9	14T10	7Q10	Max T	NA-Max WQ	A90
	25000	26.7	14T10	7Q10	Max T	NA-Max WQ	A90
	25000	29.4	14T10	7Q10	Max T	NA-Max WQ	A90
7	9000	23.9	14T10	7Q10	Max T ↑ 30%	↑ 30%	A90
	9000	26.7	14T10	7Q10	Max T ↑ 30%	↑ 30%	A90
	9000	29.4	14T10	7Q10	Max T ↑ 30%	↑ 30%	A90
	12000	23.9	14T10	7Q10	Max T ↑ 30%	↑ 30%	A90
	12000	26.7	14T10	7Q10	Max T ↑ 30%	↑ 30%	A90
	12000	29.4	14T10	7Q10	Max T ↑ 30%	↑ 30%	A90
	18000	23.9	14T10	7Q10	Max T ↑ 30%	↑ 30%	A90
	18000	26.7	14T10	7Q10	Max T ↑ 30%	↑ 30%	A90
	18000	29.4	14T10	7Q10	Max T ↑ 30%	↑ 30%	A90
	25000	23.9	14T10	7Q10	Max T ↑ 30%	↑ 30%	A90
	25000	26.7	14T10	7Q10	Max T ↑ 30%	↑ 30%	A90
	25000	29.4	14T10	7Q10	Max T ↑ 30%	↑ 30%	A90
8	6000	2.0	NOV87	7Q10	4.0 °C	Max WQ	A90
	9000	2.0	NOV87	7Q10	4.0 °C	Max WQ	A90
	12000	2.0	NOV87	7Q10	4.0 °C	Max WQ	A90
9	9000	23.9	A28-S12	7Q10	Max T	Max WQ	A90

(Continued)

(Sheet 2 of 3)

Table 13 (Concluded)

Scenario #	GPDQ*	GPDT	Met Conditions	Trib Q	Trib Temp	Trib WQ	Power Plant
10	3000	23.9	Max	2-year	Max T	Max WQ	A90
	3000	26.7	Max	2-year	Max T	Max WQ	A90
	3000	29.4	Max	2-year	Max T	Max WQ	A90
	4000	23.9	Max	2-year	Max T	Max WQ	A90
	4000	26.7	Max	2-year	Max T	Max WQ	A90
	4000	29.4	Max	2-year	Max T	Max WQ	A90
	5000	23.9	Max	2-year	Max T	Max WQ	A90
	5000	26.7	Max	2-year	Max T	Max WQ	A90
	5000	29.4	Max	2-year	Max T	Max WQ	A90
	6000	23.9	Max	2-year	Max T	Max WQ	A90
	6000	26.7	Max	2-year	Max T	Max WQ	A90
	6000	29.4	Max	2-year	Max T	Max WQ	A90

Note: Boundary conditions (discharge and water quality concentrations) for industries discharging into the Missouri River were set to maximum permit limits for all scenarios.

Definition of Terms in Table:

- 14T10 - maximum 14-day averaged air temperature with 10-year recurrence period
- Max - maximum 14-day averaged air temperature in period of record
- NOV87 - met data taken from November 18, 1987
- 7Q10 - minimum 7 day averaged flow with a 10-year recurrence period
- 2-year - summer flow equaled or exceeded 50 percent of the time
- Max T - summer maximum historical tributary water temperature
- 4 °C - water temperatures on all tributaries set to 4 °C
- Max WQ - summer maximum historical tributary water quality concentrations, mg/ℓ
- NA-MAX WQ - maximum historical tributary water quality concentrations with no algae modeled
- ↑ 30% - increased MAX WQ 30 percent
- Max T ↑ 30% - increased Max T 30 percent
- A90 - power plant loads for August 28, 1990, loads plus two plants which had not been operating on this date
- NPP - no power plants operating
- MPL - power plants operating at their fully loaded capacity
- A28-S12 - Two-week met conditions for August 28, 1990, through September 12, 1990
- GPDQ - Gavins Point Dam release flow, cfs
- GPDT - Gavins Point Dam release temperature, °C

(Sheet 3 of 3)

Table 14

Release Rates and Temperatures Discharging from Gavins Point Dam during Scenario Runs

Flow Rates, cfs	Temperature, °C		
	Summer		
9,000	23.9	26.7	29.4
12,000	23.9	26.7	29.4
18,000	23.9	26.7	29.4
25,000	23.9	26.7	29.4
	Winter		
6,000	2.0		
9,000	2.0		
12,000	2.0		
	Summer		
3,000	23.9	26.7	29.4
4,000	23.9	26.7	29.4
5,000	23.9	26.7	29.4
6,000	23.9	26.7	29.4

Meteorological

64. Meteorological conditions selected for the scenario runs were chosen to create stressful conditions in the Missouri River system (i.e., drought conditions). Meteorological data selected were considered reasonable since they were chosen from actual historical basin met data. One of the major concerns of the study was the deterioration of water quality during extended hot, dry meteorological conditions in the basin; therefore, air temperature was assumed to be a good indicator of hot, warm, cool, etc., meteorological conditions. Historical air temperature data from the four met stations (listed in Part III) were analyzed for the appropriate data.

65. In the first sets of scenario runs (Table 13), the 14T10 was chosen for the meteorological boundary conditions. The 14T10 is defined as the maximum 14-day running average air temperature that for a given time period is expected to occur or be exceeded every 10 years. The 14-day running averages were used because the travel time through the Missouri River system is approximately 2 weeks during navigation season. The first step in finding the 14T10 was to compute the 14-day running averages of air temperature for the entire period of record for all met stations. Then, the 14-day maximum running average air temperature, 14T, was determined for the months of June through

September for each year of met data available. Using the 14T data found for each year, an exceedance frequency table was constructed, and the 14T10 for each met station was determined. Once the 14T10 was determined, the 14-day averaged met data for the other parameters required by QUAL2E were obtained for the same dates as the 14T10.

66. The 14T10 found for each met station was similar in value, and in addition, the 14-day averages for the other met data required by QUAL2E were also similar in value between stations. For this reason, a correlation analysis was performed on all 14-day running averaged met parameters required by QUAL2E (air temperature, cloud cover, wet bulb temperature, air pressure, and wind speed). The analysis was performed on each met parameter between stations to see if they were highly correlated. If so, then data from only one met station would be necessary to make the scenario runs. PROC CORR was the SAS procedure (SAS Institute, Inc. 1988) applied to each met parameter (14-day running average data) between met stations. Final results for each met parameter between stations indicated a high correlation with correlation coefficients for all parameters of 0.90 or better. Because of this, only the Topeka, Kansas, met station was used for meteorological boundary conditions in the scenario runs. The Topeka, KS, met station was chosen for the scenario runs since it had the warmest 14T10, while all the other met parameters were similar in value to the other stations.

67. Another met condition used in the scenario runs was the maximum 14-day running average of air temperature for the June through September time period each year for the period of record at the Topeka, KS, meteorological station (represented by Max in Table 13). The maximum 14-day running average of air temperature was approximately 4 °C greater than the 14T of the 14T10 met conditions. The 14-day averaged met data for the other parameters required by QUAL2E were obtained for the same dates as the maximum 14-day average of air temperature.

68. For the winter simulation, met conditions selected were for November 18, 1987. These data were chosen to keep water temperatures above the 1.67 °C temperature limit imposed by constants in the back radiation equation in QUAL2E.

69. During the time-varying simulation (Scenario 9), meteorological data were set to conditions that actually occurred during the 2-week period beginning August 28, 1990 (designated A28-S12 in Table 13). The time-varying

simulation required 3-hr averages of all meteorological parameters required by QUAL2E.

Tributaries

70. Initially, a minimum 7-day running average of flow during the June through September time period of each year having a 10-year recurrence period (7Q10) was used for tributary flow boundary conditions. This flow condition was chosen because flow from the tributaries would probably be very low during a period with very little or no rain (i.e., drought period). To find the 7Q10 flow conditions for all major tributaries, the same procedure for finding the 14T10 was employed. A minimum 7-day averaged flow (7Q) that had occurred during the June through September time frame for each year in the period of record was found. Using the 7Q data, an exceedance frequency table was constructed and the 7Q10 for each major tributary was determined. Table 15 contains the 7Q10 flow values calculated for each tributary used in the scenario runs.

71. The MRD wanted to test the sensitivity of the system to a variation in flow conditions on the tributaries, so a 2-year summer flow (June through September time period) was set as boundary conditions on all tributaries

Table 15

Tributary Flow Boundary Conditions Set in Scenario Runs

River	7Q10 cfs	2-Year Summer Q cfs
James	4	150
Vermillion	4	26
Big Sioux	61	458
Floyd	8	110
Little Sioux	88	557
Boyer	13	230
Platte	399	2,000
Nishnabotna	67	858
Nemaha	11	108
Nodaway	12	250
Platte	12	250
Kansas	857	5,697
Big Blue	101	101
Little Blue	3	7
Grand	32	600
Chariton	9	140
Lamine	1	40
Osage	489	3,370
Gasconade	350	816

included in the scenario runs. A 2-year summer flow for a tributary was considered to be a flow that had historically occurred or been exceeded 50 percent of the time. Table 15 also contains the 2-year summer flow values calculated for each tributary used in the scenario runs.

72. Tributary water quality boundary conditions for the scenario runs were set to maximum water quality concentrations that had been historically recorded during the June through September period for the entire period of record. The maximum water quality concentrations were chosen to create additional stress in the Missouri River system. The only water quality constituent not set to a maximum historical value was DO on all tributaries. The value for DO on the tributaries was set to a minimum historical value if available or what had been measured August 28, 1990. As for the other water quality constituent concentrations, the concentrations were set to values measured during the snapshot sampling August 28, 1990, if no historical data was available. Table 3 indicates which tributaries had water quality data available. These maximum water quality concentrations (except for DO) were also increased 30 percent to test the sensitivity of the system to changes tributary and point source loadings.

Point sources

73. Boundary conditions (flow and water quality concentrations) for wastewater treatment plants and other industries discharging into the Missouri River (Table 4) were set to maximum allowable permit limits to cause additional stress to the Missouri River system. For example, maximum permit limits for $CBOD_5$ concentration ranged from 30 to 45 mg/ℓ depending on the plant or industry. If a permit did not specify concentrations limits for water quality constituents modeled in this study (for example, ammonia), then concentrations were set to recommended values from Metcalf and Eddy, Inc. (1979).

Power plants

74. Initially power plant boundary conditions were to be set to fully loaded capacity for discharge and delta temperatures. However, this information was not available until late in the study (November 1991). Until these values were received, boundary conditions were set to reported values on August 28, 1990 (represented by A90 in Table 6). The MRD requested that two power plants (Fort Calhoun and St. Joe Lake Road Station) that had not been operating on August 28 also be included in the A90 boundary conditions. Their values for discharge and delta temperatures were provided by the MRD. Once

the MRD provided WES with fully loaded capacity data (MAX P L), a set of scenario runs was conducted (Scenario 5). The MRD also requested scenario runs with no power plants operating (NPP) set as boundary conditions (Scenario 4).

Boundary Conditions for Base Conditions

Base conditions

75. Scenario results were compared with "base condition" results, which were considered the baseline for comparison, to assess far field effects of operational changes from Gavins Point Dam on water quality in the Missouri River. The base condition run was considered the "baseline" for comparison with the reduced flow scenario runs. The only differences between the base condition runs and the scenario runs were the release rates and temperature discharged out of Gavins Point Dam. All other headwater water quality constituent concentrations being discharged from Gavins Point Dam were the same for base condition and scenario runs. Summer base release conditions from Gavins Point Dam (navigation season) were set to a release flow of 27,500 cfs and a release temperature of 25 °C. These were historically typical values for release flow and temperature at Gavins Point Dam during navigation season. For the winter simulation, base release conditions from Gavins Point Dam were set to a release flow of 17,000 cfs and a release temperature of 2.0 °C. All other boundary conditions for the base condition run (i.e., tributary flow and water quality, point source flow and water quality, power plant loads, and met conditions) were set to the same values as the scenario run with which it was compared. Table 16 shows the boundary conditions set for the base condition runs for each set of scenario runs.

Scenario Results

76. The following section will discuss the far field effects to downstream water quality for each set of scenario results. Table 13 contains a list of all the sets of scenario runs and their boundary conditions for each run. Appendix B contains Figures B1-B33, depicting results from each set of scenario runs. Boundary conditions set for tributary and point sources are presented in Appendix C.

Table 16

Boundary Conditions for Base Condition

Scenario #	GPDQ*	GPDT	Met Conditions	Trib Q	Trib Temp	Trib WQ	Power Plant
1	27500	25.0	14T10	7Q10	Max T	Max WQ	A90
2	27500	25.0	14T10	2-year	Max T	Max WQ	A90
3	27500	25.0	Max	2-year	Max T	Max WQ	A90
4	27500	25.0	Max	2-year	Max T	Max WQ	NPP
5	27500	25.0	Max	2-year	Max T	Max WQ	MPL
6	27500	25.0	14T10	7Q10	Max T	NA-Max WQ	A90
7	27500	25.0	14T10	7Q10	Max T	↑ 30%	A90
8	17000	2.0	NOV87	7Q10	4.0 °C	Max WQ	A90
9	27500	25.0	A28-S12	7Q10	Max T	Max WQ	A90
10	27500	25.0	Max	2-year	Max T	Max WQ	A90

Note: Boundary conditions (discharge and water quality concentrations) for industries discharging into the Missouri River were set to maximum permit limits for all scenarios.

* Definition of terms in table:

- 14T10 = maximum 14-day averaged air temperature with 10-year recurrence period
- Max = maximum 14-day averaged air temperature in period of record
- NOV87 = met data taken from November 18, 1987
- 7Q10 = minimum 7-day averaged flow with a 10-year recurrence period
- 2-year = summer flow equaled or exceeded 50 percent of the time
- Max T = summer maximum historical tributary water temperature
- 4 °C = water temperatures on all tributaries set to 4 °C
- Max WQ = summer maximum historical tributary water quality concentrations, mg/ℓ
- NA-MAX WQ = maximum historical tributary water quality concentrations with no algae modeled
- ↑ 30% = increased Max WQ 30 percent
- A90 = power plant loads for August 28, 1990, loads plus two plants that had not been operating on this date
- NPP = no power plants operating
- MPL = power plants operating at fully loaded capacity
- A28-S12 = 2-week met conditions for August 28, 1990, through September 12, 1990
- GPDQ = Gavins Point Dam release flow, cfs
- GPDT = Gavins Point Dam release temperature, °C

Scenario 1

77. Scenario 1 was simulated to examine the far fields effects of reducing release flows and increasing release temperatures on water quality in the Missouri River. Scenario 1 boundary conditions were set to extreme values to simulate the worst conditions that could possibly occur during a drought

period. The boundary conditions were set to 14T10 met conditions, maximum water quality concentrations on tributaries (except DO), 7Q10 tributary flows, maximum permit limits from point sources (i.e., water treatment plants) and A90 power plant loads (see definitions in Table 13 for abbreviations).

78. Results in Figure B1 demonstrated the effects of reducing release rates from Gavins Point Dam by comparing the results for release flows of 9,000, 12,000, 18,000, 25,000 cfs with the base condition results (release flow equaled to 27,500 cfs) represented by the solid line on all plots (labeled BASE SCEN). Figure B1 shows that by reducing flow from 27,500 to 9,000 cfs, water temperatures were substantially affected especially at the lower release rates. The greatest temperature difference occurred between the base condition run and the lowest reduced flow, and the maximum difference was approximately 1.3 °C. Because the release temperature of the reduced flow runs were less (23.9 °C) than the base condition release temperature (25.0 °C), the maximum water temperature differences downstream were slightly greater than they would have been if the release temperatures for all runs had been the same. Temperature results for the other reduced release rates analyzed approached base condition temperature results as the reduced flow value increased relative to the base condition release flow value.

79. Reduction in release flow rates also had an effect on the algae concentrations (CHL A in Figure B1) in the Missouri River. Algae concentrations more than doubled in the lower reaches of the Missouri River as the release flow was reduced to 9,000 cfs (around RM 100). This was believed to be simply due to the advection process and less dilution of nutrients. At the lower flows, velocity was reduced increasing residence time in the system which permitted more algal growth. As algae concentrations increased for all reduced flow runs, concentrations of the other water quality constituents that relate to algae (e.g., CBOD and organic nitrogen) also increased (Figure B1). The greatest concentration increases for these constituents occurred at the lowest release flow when compared with the base condition results. All constituent concentrations doubled or more than doubled at the lowest flow rate. Some of the increase in these constituent concentrations were attributed to increased algal concentrations, but some can also be attributed to less dilution of tributary and point source loads caused by the reduced release rates. Even though concentrations of constituents exerting a demand on DO have increased as release rates were reduced, DO concentrations in the Missouri River were affected only slightly ($\pm$ 0.4 mg/ℓ). Increased water temperatures

caused DO concentrations to decrease because increasing water temperatures decrease the solubility of DO. DO concentrations probably increased around RM 500 because of increased algal photosynthesis. Water temperatures in this reach did not have much impact on DO concentrations since differences in water temperatures between reduced flow runs was minimal.

80. The next set of release conditions examined in Scenario 1 (Table 13) was the same as discussed above except the release temperature was increased to 26.7 °C. Increasing the release temperature from Gavins Point Dam produced warmer water temperatures in the Missouri River between RM 811 and RM 600 when compared with temperature results in Figure B1 for all reduced flow runs. This indicates that the release flow slightly influences water temperatures through this portion of the study reach. As a result of warmer water temperatures, algae concentrations decreased since temperatures were more outside the optimum range for algal growth. With less algal growth, the concentrations of the other water quality constituents that relate to algae were also affected when compared with results in Figure B1. Since CBOD and organic nitrogen are organic materials partly resulting from the process of algal respiration, less algal growth reduced concentrations of these two constituents. Minimal reductions (0.01 mg/ℓ) in ammonia concentrations were noted as less organic nitrogen was available to convert to ammonia. Reduced algal growth resulted in increased nitrate and dissolved inorganic phosphorus concentrations because these constituents are utilized as sources of food by algae. DO concentrations were also slightly less (approximately 0.2 mg/ℓ for all reduced release flows) when compared with results in Figure B1. This was believed to be mostly due to the warmer water temperatures (especially in the upper reaches).

81. The final set of release conditions examined in Scenario 1 (Table 13) had the same flow conditions as above with an even higher release temperature of 29.4 °C. Again, Missouri River water temperatures were warmer especially in the upper reach between RM 811 and RM 600. Even though the release temperature was approximately 5.5 °C greater than the first release temperature discussed, the water temperatures in the lower Missouri River approached temperatures that had previously been predicted (Figure B1 and B2). This observation was made for all reduced flow conditions modeled. Warmer water temperatures caused an even greater decrease in algae concentrations especially in the reach, RM 811 to RM 200, as compared with results in Figures B1 and B2 (for all reduced flow conditions and release temperatures).

Reduction in algae concentration also caused reduction in other water quality constituent concentrations related to algae compared with Figure B2. Ammonia concentration remained essentially the same because ammonia was gained from less utilization by algae as food and lost from less hydrolysis of organic nitrogen to ammonia. Both nitrate and inorganic dissolved phosphorus increased because less algae utilized them for a food source. DO concentrations (Figure B3) in the upper reaches were also less (approximately 0.2 mg/ℓ) than the previous run (Figure B2) because of the warmer release temperature that affected the solubility of DO in water. In the lower reaches, DO concentrations slightly increased as release flow was reduced, possibly because of less exertion from CBOD.

Scenario 2

82. Scenario 2 was a sensitivity analysis looking at the effects of changing tributary boundary flow conditions from the minimum 7Q10 to a 2-year summer flow. All other boundary conditions remained the same as Scenario 1 (Table 13). The boundary conditions were 14T10 met conditions, maximum water quality concentrations on tributaries (except DO), 2-year summer tributary flows, maximum permit limits from point sources (i.e., water treatment plants) and A90 power plant loads (see definitions in Table 13 for abbreviations). Figures B4-B6 present the results for the three release temperatures, 23.9 °C, 26.7 °C, and 29.4 °C (respectively). Each figure contains results for all reduced flow conditions (9,000, 12,000, 18,000, and 25,000 cfs) plus the base condition results. The results of Figures B4 through B6 were compared with Scenario 1 results (Figures B1-B3) since boundary conditions for tributary flow were the only difference between the two scenarios.

83. Although changing tributary boundary flow conditions to 2-year summer tributary flows increased some tributary flows as much as 20 times (Table 15), Scenario 2 base condition temperature results (represented by the solid line in the plots in Figures B4-B6) were not much different from those of Scenario 1 (Figure B1-B3) for all release temperatures. Scenario 2 (Figure B4-B6) water temperature results for all reduced flow conditions and release temperatures were also similar to Scenario 1 results except near RM 400 and RM 60. Near these locations, power plants discharged into the Missouri River warming water temperatures. This is very noticeable at the lower reduced flows in Scenario 1 (Figure B1-B3) for all release temperatures. However, in Scenario 2, increased tributary flows helped dilute Missouri River

water temperatures, which produced cooler temperature results at these locations.

84. Increased tributary flow also had an impact on algae concentration and other water quality constituents interacting with algae. Again the following observations are made for all reduced flows modeled. Figures B4-B6 show a very noticeable reduction in algae concentrations (approximately 20-$\mu g/\ell$ maximum difference for the lowest flow condition (9,000 cfs)) as compared with Scenario 1 results (Figures B1-B3). This is probably the result of dilution of nutrients and greater advection in the Missouri River from increased tributary flows. Increased velocities in the Missouri River caused by the additional tributary flows decreased residence time in the river, reducing time for algal growth. As a result of reduction in algae concentrations, CBOD concentrations also decreased. As indicated in Figures B4-B6, the other water quality constituent concentrations increased because of increased tributary loads. Organic nitrogen appeared to increase solely because of increased tributary loads since reduced algae concentrations contributed less organic nitrogen. Ammonia slightly increased possibly for three reasons: (a) increased loads from the tributaries, (b) increased loads of organic nitrogen being converted to ammonia, and (c) less utilization by algae as a food source. Nitrate nitrogen and inorganic dissolved phosphorus increased for two possible reasons: (a) increased tributary loads and (b) less utilization by algae as a food source.

85. In general, DO concentration results for Scenario 2 (Figures B4-B6) in the upper reaches were very similar to Scenario 1 results (Figures B1-B3) for all release temperatures and reduced flows. However, Scenario 2 DO results were slightly reduced from Scenario 1 (approximately 0.2 mg/ℓ for all reduced flows) in the lower reaches below RM 500. This is possibly due to less DO produced from algal photosynthesis since there are less algae in the Missouri River in these reaches. Another possibility is that tributary DO concentrations in these reaches were lower than DO concentrations in the Missouri River. So when the increased flows from the tributaries were mixed with DO in the Missouri River, a lower main stem DO concentration resulted.

Scenario 3

86. Scenario 3 was a sensitivity analysis examining the far field effects of changing the meteorological conditions from the 14T10 to 14-day maximum met conditions (the maximum 14-day average of air temperature for the period of record). All other boundary conditions were the same as those of

Scenario 2 (Table 13). The boundary conditions were Max met conditions, maximum water quality concentrations on tributaries (except DO), 2-year tributary flows, maximum permit limits from point sources (i.e., water treatment plants) and A90 power plant loads (see definitions in Table 13 for abbreviations). Figures B7-B9 represent the results for the three release temperatures, 23.9 °C, 26.7 °C, and 29.4 °C (respectively). Each figure contains results for all reduced release flows (9,000, 12,000, 18,000, and 25,000 cfs) plus base condition results. Results for Scenario 3 are compared with results from Scenario 2 (Figures B4-B6) since the only difference between the two scenarios was the met condition used (Table 13).

87. Changing to maximum met conditions in Scenario 3 (Figures B7-B9) produced similar base condition temperature results (solid line) as those of Scenario 2 (Figures B4-B6) except they were approximately 0.3 °C warmer (maximum difference). Air temperature used in Scenario 3 met conditions were approximately 4 °C warmer than air temperature in Scenario 2. The system did not appear to be sensitive to this change in air temperature since only slightly warmer base condition water temperatures resulted in Scenario 3, and values for all other meteorological parameters were similar to those in Scenario 2. Scenario 3 (Figure B7-B9) water temperature results (for all release temperature and flow conditions) were also warmer (approximately 0.3 °C) than in Scenario 2 for the same reason discussed above. Although there was a large difference in air temperature between the two scenarios, water temperatures appeared to be impacted only minimally.

88. Since all water quality constituents modeled in this study were temperature dependent, warmer water temperatures in the Missouri River had an effect on all the water quality constituent concentrations. Warmer water temperatures in Scenario 3 through the Missouri River system decreased algae concentrations as seen in Figures B7-B9 for all release temperatures and reduced flows. Again as previously discussed, decreases in algae concentrations were attributed to warmer water temperatures being outside the optimum temperature growth range for algae. The greatest difference between algae concentrations for the two scenarios occurred at the 9,000-cfs flow condition for the two release temperatures (26.7 °C and 29.4 °C) and was an approximate 15-$\mu g/\ell$ difference (Figures B8 and B9). Less algal growth caused a reduction in the concentrations of CBOD and organic nitrogen. Ammonia concentrations essentially remained the same for both scenarios for all release temperatures

and reduced flows. Both nitrate and inorganic dissolved phosphorus increased because less algae were utilizing them as a food source.

89. In general, increased water temperatures in the Missouri River caused a very slight decrease in DO concentrations (approximately 0.2-mg/ℓ maximum difference) for all flow conditions and release temperature (Figure B7-B9) in comparison with Scenario 2 results (Figures B4-B6). Lower release flows showed the greatest differences in DO concentrations. Most of the decrease in DO concentrations were attributed to the warmer water temperatures.

Scenario 4

90. Scenario 4 was simulated to examine far field effects of power plant discharges on Missouri River water temperatures. This was done by comparing the temperature results from a set of scenario runs that had power plants operating (Scenario 3) with one that had no power plants operating (Scenario 4). Only far field effects (i.e., changes in water temperatures downstream of power plants assuming fully mixed laterally and vertically in the river) could be evaluated with this type of model. Near field effects (i.e., temperature changes in the mixing zone downstream of the discharge where lateral and/or vertical variations are considered) could not be evaluated in this study; a thermal jet-plume model would be required for this type of analysis. Far field effects on other water quality constituents were not examined in this set of scenario runs. Boundary conditions for this scenario were the same as Scenario 3 (Table 13) except no power plants were operating. Figures B10-B12 represent the temperature results for the three release temperatures, 23.9 °C, 26.7 °C, and 29.4 °C (respectively). On each plot, the solid line represents temperature results for Scenario 4 for the release flow indicated; the dashed line represents temperature results for Scenario 3 for the release flow indicated.

91. Figures B10-B12 reveal that power plant discharges along the Missouri River have a significant influence on water temperatures in the downstream direction. Scenario 4 results (solid line) show minimal changes in water temperature (approximately 0.2 °C) caused by tributary and other point source inflows at approximately RM 600 and RM 400. Temperature differences between the two scenarios were as much as 1.5 °C for the lowest release flow (9,000 cfs) and 1 °C for the highest release flow (25,000 cfs) for all release temperatures (Figure B10-B12). The higher release temperature (29.4 °C, Figure B15) produced slightly warmer water temperatures (approximately 0.2 °C

greater increase) when compared with the other release temperature results (23.9 °C and 26.7 °C, Figures B10 and B11, respectively). The figures also illustrate that between RM 300 and RM 120 where no power plants presently exist along the Missouri River, water temperatures approach values of those in Scenario 3 where no power plants were operating for all release temperatures, especially at the lower release temperatures. At approximately RM 60, discharge from the Labadie Power Plant created another temperature spike in Missouri River water temperatures. It would appear that if this plant had not been operating, water temperatures would have eventually become very close or equaled water temperatures of Scenario 3.

Scenario 5

92. Scenario 5 was simulated to examine far field effects on Missouri River water temperatures of operating power plants at their fully loaded capacity for delta temperatures and discharge. In Scenario 5, values of delta temperatures and discharge for fully loaded conditions were substituted in Scenario 3 instead of the A90 conditions, while all other boundary conditions were the same as Scenario 3 (Table 13). These boundary conditions were Max met conditions, maximum water quality concentrations on tributaries (except DO), 2-year tributary flows, maximum permit limits from point sources (i.e., water treatment plants) and maximum pump loads (see definitions in Table 13 for abbreviations). Figures B13-B15 present the water temperature results for the three release temperatures (23.9 °C, 26.7 °C, and 29.4 °C, respectively). The solid line on each plot represent the temperature results for Scenario 5, and the dash line represents the temperature results for Scenario 3. Each plot has the release flow indicated on the plot (i.e., 18,000 MAX P L indicates a flow of 18,000 cfs).

93. Figures B13-B15 show an increase in water temperatures in the Missouri River from using fully loaded capacity for delta temperature and discharge coming from power plants along the river. Although power plant discharge values for the two scenarios were similar (Table 6), delta temperature values for power plants in Scenario 5 were usually greater (sometimes as much as 10 °C) than in Scenario 3. The maximum Missouri River water temperature difference between Scenario 5 and Scenario 3 was approximately 0.6 °C for the release temperature of 29.4 °C and the release rate of 9,000 cfs (Figure B15). Results for the other release temperatures (23.9 °C and 26.7 °C, Figures B13 and B14, respectively) were cooler than the higher release temperature results by about 0.1 to 0.2 °C.

94. Figures B16-B18 present the results for the other water quality constituents modeled for the three release temperatures of 23.9 °C, 26.7 °C, and 29.4 °C, respectively. Each figure also contains all results for the reduced release flows (9,000, 12,000, 18,000, and 25,000 cfs) plus the base condition results. These results are compared with Scenario 3 water quality results (Figures B7-B9) to evaluate the effects caused by the increased water temperatures on the other water quality constituents. Comparisons are made with Scenario 3 results since all boundary conditions in Scenario 5 were the same except for the power plant boundary conditions (Table 13).

95. Warmer water temperatures in the Missouri River had the same effect on other water quality constituents modeled as discussed in Scenario 3. However, because water temperatures were warmer in this scenario than in Scenario 3, changes to other water quality concentrations were slightly more. Warmer water temperatures in Scenario 5 decreased in algae concentrations as seen in Figures B16-B18 for all release temperatures and reduced flows. Again as discussed for Scenario 3, decreases in algae concentrations were due to warmer water temperatures being outside the optimum temperature growth range. Maximum differences between algae concentrations for Scenarios 5 and 3 were greatest for the release temperature of 23.9 °C and flow of 9,000 cfs (Figure B16) with the maximum difference being approximately 10 $\mu g/\ell$. Results for algae at the higher release temperatures for the two scenarios showed less difference for all flow conditions because water temperatures in both scenarios were already outside the optimum temperature growth range. Less algae produced a reduction in concentrations of CBOD and organic nitrogen. Ammonia concentrations slightly increased as compared with Scenario 3 results for all release temperatures and reduced flows because of reduced algae concentrations using it for food. Both nitrate and inorganic dissolved phosphorus increased because less was utilized as a food source by algae.

96. In general, increases in water temperatures in the Missouri River (resulting from power plants operating fully loaded) caused a very slight decrease in DO concentrations (approximately 0.2 mg/ℓ) for all flow conditions and release temperatures (Figure B16-B18) when compared with Scenario 3 results (Figures B7-B9). Results for lower release flows showed greater impacts to DO concentrations on Figures B16-B18. Most decreases in DO concentrations were probably due to warmer water temperatures affecting solubility of DO in water. Another reason for decreased DO concentrations could be that

less DO was produced from algal photosynthesis since there was less algal growth.

Scenario 6

97. Scenario 6 was simulated to evaluate the water quality of the Missouri River when no algae were modeled. Originally, algae were not considered a necessary water quality constituent to model since many felt very little algae existed in the Missouri River. There also had been no historical algal problems reported. However, during calibration runs, algae had to be included as a modeled constituent to realistically predict the dynamics of other constituents modeled (which interact with algae). Toward the end of this study, chlorophyll *a* field measurements were collected at 11 stations in the Missouri River to verify that algae were an appropriate constituent to model. Scenario 6 was simulated prior to obtaining the field measurements to evaluate the sensitivity of the model results to algal effects.

98. Figures B19-B21 represent the results for the water quality constituents modeled for the three release temperatures of 23.9 °C, 26.7 °C, and 29.4 °C, respectively. Each figure also contains results for the reduced release flows (9,000, 12,000, 18,000, and 25,000 cfs) plus the base condition results. Comparisons are made between Scenarios 1 and 6 since the only difference was that Scenario 6 did not include algae as a modeled constituent. The boundary conditions were set to 14T10 met conditions, maximum water quality concentrations on tributaries (except DO), 7Q10 tributary flows, maximum permit limits from point sources (i.e., water treatment plants) and A90 power plant loads (see definitions in Table 13 for abbreviations).

99. Comparisons of Figures B19-B21 with Figures B1-B3 indicate that water temperature was not impacted, which is understandable; but all other water quality constituent concentrations increased or decreased depending on their interactions with algae. For example, concentrations of CBOD and organic nitrogen decreased as a result of no algae modeled. As pointed out previously, CBOD and organic nitrogen are organic materials which partly result from algae. In addition, when compared with observed data for these two constituents in the calibration and verification results (Figures 5 and 8, respectively), the concentration dynamics of both were not being realistically predicted (e.g., both observed data showed increased concentrations downstream). Nitrate nitrogen and inorganic dissolved phosphorus increased (compared with Scenario 1 results) in the downstream direction since they were no longer required by algae as a food source.

100. DO concentrations (Figures B19-B21) were reduced for all release temperatures especially as release flows were reduced. The maximum decease in DO concentration between the two scenarios was approximately 0.3 mg/ℓ for the reduced flow of 9,000 cfs for all release temperatures. Since constituents exerting a demand on DO were reduced (e.g., CBOD), decreased DO concentrations were attributed to not getting the additional DO from the algal photosynthesis process as in Scenario 1. Although changes in water temperatures do have an effect on DO concentrations, decreased DO concentrations could not be attributed to temperature since water temperature results for both scenarios were the same.

Scenario 7

101. Scenario 7 was a sensitivity analysis examining the far field effects increased tributary and other point source water quality concentrations have on Missouri River water quality (especially temperature and DO). All tributary and point source water quality constituent concentrations were increased by 30 percent except DO. DO concentrations remained the same as in Scenario 1. All other boundary conditions remained the same as in Scenario 1 (Table 13). Boundary conditions for this scenario were 14T10 met conditions, maximum water quality concentrations on tributaries increased 30 percent except DO, 7Q10 tributary flows, maximum permit limits from point sources increased 30 percent (i.e., water treatment plants), and A90 power plant loads (see definitions in Table 13 for abbreviations). Figures B22-B24 present the results for the three release temperatures, 23.9 °C, 26.7 °C, and 29.4 °C (respectively). Each figure contains results for all reduced release flow rates (9,000, 12,000, 18,000, and 25,000 cfs) plus base condition results. Comparison of results are made with Scenario 1 results since all boundary conditions were the same except for increased tributary and other point source water quality concentrations.

102. Increasing tributary and other point source water temperatures 30 percent in Scenario 7 (Figures B22-B24) produced similar base condition temperature results (solid line) as those of Scenario 1 (Figures B1-B3) except they were slightly warmer by approximately 0.3 °C at the maximum difference below RM 600 where major tributaries began entering the Missouri River. Scenario 7 water temperature results (for all release temperatures and reduced flows) were also warmer by approximately 0.3 °C at the maximum difference below RM 600 than in results from Scenario 1 because of the increased tributary and point source temperatures.

103. Normally, warmer water temperatures in the Missouri River would have reduced algae concentrations (as in Scenario 5); however, since algae concentrations were also increased, minimal (2 μg/ℓ) effects to algae concentrations are evident. Increased algae concentrations from tributaries and other point sources canceled the temperature effect when comparison was made with Scenario 1 algae results. Likewise, CBOD concentrations for Scenario 7 were slightly less (0.5 mg/ℓ) than Scenario 1 results (for all reduced release flows and release temperatures). Since there was very minimal changes in algal concentrations, CBOD concentrations were basically the same in both scenarios. Organic nitrogen, ammonia, nitrate, and inorganic dissolved phosphorus increased approximately 0.1, 0.02, 0.15, and 0.05 mg/ℓ, respectively, for all flow conditions at the release temperature of 29.4 °C (Figure B24) as compared with Scenario 1 results for these constituents (Figure B3) mostly from increased tributary and point source concentrations.

104. In general, increased water temperatures in the Missouri River caused a slight decrease in DO concentrations (less than 0.2 mg/ℓ maximum difference) for all reduced release flows and release temperatures (Figure B22-B24) in comparison with Scenario 1 results (Figures B1-B3). Most of the decrease in DO concentrations were caused by warmer water temperatures affecting the solubility of DO in water. Also, the increased concentrations of organic nitrogen and nitrate exert greater demands on DO.

Scenario 8

105. Scenario 8 was the only scenario simulated for winter conditions. Most of the concern for water quality deterioration was during navigation season when hot, dry periods could possibly drive DO concentrations to below state standards. The winter scenario run was simulated mostly because of concerns of power plant discharges causing extreme increases in water temperatures during winter season. Although QUAL2E could not address near field affects (i.e., water temperatures in the mixing zone), MRD requested a scenario that would address far field affects (i.e., after complete cross-sectional channel mixing) of the power plants on Missouri River water temperatures.

106. Choosing boundary conditions for this scenario was more difficult than for summer scenarios because of the limitation of QUAL2E to model water temperatures less than 1.67 °C. In QUAL2E, the constants in the back radiation equation were defined over the range of 1.67 to 57.2 °C, which limits the model to predict water temperatures below or above these values. Gavins Point

release temperatures were examined to find a release temperature close to this limiting value. A late November release temperature and flow (2 °C and 17,000 cfs, respectively) were chosen for the release boundary conditions from Gavins Point Dam for the base condition run. All other release water quality concentrations were set values measured on August 28, 1990. Boundary conditions for tributary water quality were set to historical maximum values for November if data was available. However, because of lack of historical data, most tributary boundary conditions were set to the same values as Scenario 1 (Table 13). Tributary temperatures were set to 4.0 °C unless historical data reported otherwise. The A90 boundary conditions were used for power plant loads. Finally, met conditions for November 18, 1987, were chosen for meteorological boundary conditions.

107. Figure B25 represents the water quality results for all constituents modeled for the release temperature of 2 °C. Each figure contains results for all reduced release flows (6,000, 9,000, and 12,000 cfs) plus base condition results. All comparisons are made between the reduced flow conditions and the base condition results (solid line).

108. As indicated in Figure B25, as release flow was reduced, Missouri River water temperatures increased. Water temperature increases were mainly due to less dilution of power plant discharges into the Missouri River. The maximum temperature difference occurred around RM 500 for the lowest release flow condition (6,000 cfs) and was approximately 2.0 °C warmer than the base condition results.

109. Water temperatures in November were too cool for algal growth as illustrated in Figure B25, as they were below the lower mortality limit (T_1) on the rate multiplier curve for algal growth (Figure 4). Because the model was calibrated during the summer season, green algae were assumed to be the dominant group; thus the temperature limits for the growth curve were set for this group although diatoms may be more prevalent during cooler seasons and have different temperature limits. The scenario results for algae concentration are more representative of green algae growth than diatom growth. Since only algal respiration was occurring and there was no algal growth, algal concentrations decreased as flow conditions were reduced as compared with the base condition results. Lower reduced flows had the lowest concentrations because increased residence time in the system allowed more respiration to occur. CBOD concentration increased as release rates were reduced mostly because of less dilution of the tributary and other point source loads. Algal

respiration contributed minimally to the increase in CBOD concentrations, but not enough to produce the 2-mg/ℓ difference between the lowest flow condition and the base condition results. Similarly, organic nitrogen, ammonia, nitrate, and inorganic dissolved phosphorus all increased when compared with base condition results (as much as 0.4, 0.3, 0.5, and 0.12 mg/ℓ, respectively) as release rates were reduced from less dilution of tributary and other point source loads. Decreases as much as 0.8 mg/ℓ presented no problems for DO because winter DO concentrations were very high as compared with summer concentrations.

Scenario 9

110. Scenario 9 was a time-varying simulation (i.e., diel, time-varying meteorological data and time-varying computed water quality variables) designed to produce an "algal crash" (unexpected death of all algae in the system). To initiate the algal crash, the algal growth rate was set to 0.0 day^{-1} while the algal respiration rate was increased tenfold to 2.5 day^{-1}. This scenario was simulated to stress the Missouri River system to examine the effect on DO concentrations. Concern was that if all algae died, would this cause a DO deficit or decrease DO concentrations below state standards. All boundary conditions for this scenario were the same as Scenario 1 (Table 13) except met conditions were set to conditions that actually occurred during the 2-week period beginning August 28, 1990. The boundary conditions for this scenario were the 2-week period of met data beginning August 28, 1990, maximum water quality concentrations on tributaries (except DO), 7Q10 tributary flows, maximum permit limits from point sources (i.e., water treatment plants) and A90 power plant loads (see definitions in Table 13 for abbreviations). Only two release flow conditions were examined, base release flow rate (27,500 cfs) and 9,000 cfs release flow. QUAL2E was run in diel mode, which means the time derivative of dependent variables was activated, thus time-varying results were obtained.

111. Results from Scenario 9 are shown in Figures B26 and B27. The solid line on plots in both figures represent the base condition results, and the dashed line represents the 9,000 release rate results. Figure B26 depicts DO concentration changes with respect to time at three RM locations (RM 606 Omaha, NE, RM 351 Kansas City, KS, and RM 81 Hermann, MO). Figure B27 depicts DO concentration changes downstream of Gavins Point Dam to the mouth of the Missouri River system for two time periods during the simulation (day 2 and day 12 for 12:00 noon).

112. In Figure B26, DO concentrations decreased after the first day of simulation at all locations for both flow conditions, and then began to recover. The lowest DO concentrations for the base release rate at the three locations were approximately 7.0, 6.42 and 6.2 mg/ℓ, respectively, and the lowest DO concentrations for the 9,000 cfs release flow at the three locations were approximately 6.68, 5.67, and 4.84 mg/ℓ, respectively. The most downstream locations (RM 351 and RM 81) showed the greatest decrease in DO concentration especially at the lower flow (9,000 cfs). This was attributed to more algal respiration creating a greater demand on DO since there was more algal growth in the lower reaches of the river. Results shown in Figure B26 also demonstrated that the worst of the algae crash had occurred by the second day of the simulation, and the system was recovering by the third day. Figure B27a shows the total effect to the Missouri River system from the algal crash on the second day of simulation. Comparisons of Figures B27a and B27b illustrated how the system was recovering after 12 days of simulation. In both figures (B27a and B27b), the lower release flow run produced lower DO concentrations. Lower DO concentrations were attributed to water quality constituents exerting a greater demand through processes such as algal respiration, CBOD oxidation, hydrolysis of organic nitrogen to ammonia, and oxidation to nitrate. Also, at the lower release flow, less dilution of tributary and other point source loads caused greater DO demand. Although DO concentrations were lower in this scenario as compared with any other scenario, the lowest DO concentration predicted was on the borderline of state standards.

Scenario 10

113. Scenario 10 was simulated to examine further reductions of release flows from Gavins Point Dam. All previous summer scenarios discussed examined reduced release flows of 9,000, 12,000, 18,000, and 25,000 cfs; this scenario examined reduced release flows of 3,000, 4,000, 5,000, and 6,000 cfs. All other boundary conditions remained the same as those of Scenario 3. The boundary conditions for this scenario were Max met conditions, maximum water quality concentrations on tributaries (except DO), 2-year tributary flows, maximum permit limits from point sources (i.e., water treatment plants) and A90 power plant loads (see definitions in Table 13 for abbreviations). The MRD requested this scenario to represent the "worst case" scenario because these flows were well below recommended releases during navigation season. The 2-year summer tributary flows were also chosen since more adverse water quality loadings would result inducing more stress to the system. Figures B28-B30

present the results for the three release temperatures, 23.9 °C, 26.7 °C, and 29.4 °C (respectively). Each figure contains results for all reduced release flows (3,000, 4,000, 5,000, and 6,000 cfs) plus base condition results. Results from Scenario 10 are compared with Scenario 3 results (Figures B7-B9) since all boundary conditions were the same except for reduced release flows out of Gavins Point Dam.

114. Base condition temperature results (solid line) for both scenarios (for all release temperatures) were exactly the same since release conditions out of Gavins Point Dam as well as all other boundary conditions (e.g., tributary, point source, power plant, and met) were the same. Water temperature results for all reduced release flows shown in Figure B28 were very similar in values through the Missouri River. This is also noted for the water temperature results for all reduced release flows at the higher release temperatures (Figures B29 and B30) as well. Since the difference in flow between each reduced release flow run was only approximately 1,000 cfs as compared with flow differences as much as 7,000 cfs in Scenario 3, variation between water temperature results were minimal for all reduced release rates. This was also demonstrated for the other water quality constituents. Comparisons were made for water temperature results from all reduced flow rate runs in Scenario 10 results (since they were essentially the same values) with water temperature results for the lowest flow rate results (9,000 cfs) in Scenario 3 to see the far field effects of further reductions to water temperatures. From Figures B28-B30 water temperature results for all reduced flows and release temperatures showed further increases in water temperatures compared with Scenario 3 (an additional 1.2 °C for the higher release temperature) in the upper reaches around RM 700 where a power plant discharges into the Missouri River. Below RM 300, water temperatures for all flow conditions approach similar values in both scenarios probably because there were no power plants in this reach influencing water temperatures until RM 60. At this location, the Labadie Power Plant discharges into the Missouri River and slightly warmed water temperatures (approximately 0.1 °C) in Scenario 10 (Figures B28-B30) when compared with results in Scenario 3 (Figures B7-B9).

115. As with water temperature predictions, concentrations of the other water quality constituents did not vary as much between reduced flow runs for all release temperatures (Figure B28-B30) as compared with water quality results from Scenario 3 (Figures B7-B9). Comparisons between constituent concentration results were made between all reduced release rate results in

Scenario 10 to the 9,000 cfs reduced flow results in Scenario 3 to determine effects of further reduction of flow to water quality concentrations. Beginning with algae, algal concentrations for all reduced flow runs and release temperatures (Figures B28-B30) were increased approximately 20 $\mu g/\ell$ below RM 500 as compared with algae concentrations from Scenario 3 (Figures B7-B9). The increases were attributed to less dilution at the lower flows and also to less advection, which decreased velocities and increased residence time for more algal growth in the Missouri River. Likewise, CBOD, organic nitrogen, and ammonia concentrations increased (2.0, 0.5, and 0.2 mg/ℓ, respectively) mostly from less dilution at the lower reduced flows. CBOD and organic nitrogen also increased to some extent because of increased algal concentrations. Although algae use ammonia as a food source, more ammonia was being replaced than utilized. Nitrate and inorganic dissolved phosphorus increased (0.8 and 0.07 mg/ℓ, respectively) as compared with Scenario 3 results for these constituents simply from less dilution of tributary and point source inflows at the lower release flows. Normally, their concentrations would have decreased from increased algae concentrations since, as in the case of ammonia, algae utilize these constituents for food.

116. In general, increased water temperatures in the Missouri River caused a very slight decrease in DO concentrations (approximately 0.4 mg/ℓ at the maximum difference, Figure B30) for all flow conditions and release temperature (Figure B28-B30) in comparison to Scenario 3 results (Figures B7-B9). Most decreases in DO concentrations were due to the warmer water temperatures (especially in the upper reaches) affecting the solubility of DO in water. In the lower reaches, more algal photosynthesis occurring as a result of increased algal concentrations may be contributing to less differences in DO concentrations at the lowest flows.

PART VI: SUMMARY AND CONCLUSIONS

117. A modified version of the stream water quality model, QUAL2E, was applied to approximately 810 miles of the Missouri River from Gavins Point Dam to the mouth to determine impacts of Gavins Point Dam releases. Model results were analyzed to determine the far field effects of reducing historical seasonal flows for a range of release temperatures on key water quality constituents (i.e., temperature, DO, CBOD, etc.) in the Missouri River. In addition, sensitivity analyses were simulated to examine how sensitive the Missouri River system was to changes in boundary conditions (e.g., tributary flow and water quality concentrations).

118. Data required to calibrate and verify QUAL2E were collected by the Omaha and Kansas City Districts in August and September 1990 because there were insufficient historical data available. Once QUAL2E was deemed satisfactorily calibrated and verified, 10 sets of scenario runs were simulated with results for all scenario runs graphically presented in Appendix B. The resulting water quality concentrations were examined to see if by reducing flows, any state standards (Appendix D) for water quality were violated.

119. From the 10 scenarios simulated, the following conclusions were derived from examination of results:

a. Reduction in release flows out of Gavins Point Dam from a base condition of 27,500 to 9,000 cfs and extreme boundary conditions set for other forcing functions produced increases in water temperatures as much as 1.3 °C. Although water temperatures were increased, their values were well below the 32.2 °C temperature limit for Missouri River water temperatures. Temperature changes in the mixing zone downstream of power plants discharges could not be addressed in this study because QUAL2E assumes inflows to be completely mixed within the channel cross section upon entering.

b. Reduction in release flows out of Gavins Point Dam from a base condition of 27,500 to 9,000 cfs and extreme boundary conditions set for other forcing functions increased all water quality constituent concentrations in the Missouri River except DO concentrations. As release flows were reduced, concentrations of algae, CBOD, organic nitrogen, ammonia nitrogen, nitrate nitrogen, and dissolved inorganic phosphorus were increased twofold or slightly more for some constituents (Figure B1). Most constituent concentrations increased from less dilution of tributary and other point source loads and less advection; but, to some extent, concentrations increased as a result of their interactions with algae. For instance, CBOD and organic nitrogen concentrations increased in some degree from increases in algae. Even though concentrations more than doubled in value, none of the state standard limits for these constituents were violated. DO concentrations for the most part were reduced with a maximum reduction being approximately 0.4 mg/ℓ. This reduction was considered minimal, and reduced DO concentrations were well above state standards for DO (Appendix D).

c. Increases in release temperatures from Gavins Point Dam for the same release flow conditions and boundary conditions discussed above produced increases in water temperatures downstream of the dam. The maximum temperature increases occurred immediately downstream of the dam since this reach has no tributaries or other point sources impacting water temperatures and continued to RM 600. Below RM 600, water temperatures were essentially the same. Water quality concentrations were also affected by the increases in water temperatures as their reaction rates are temperature dependent. Increases in release temperatures of 26.7 °C and above from Gavins Point Dam violated the state standard of South Dakota for maximum water temperature in the Missouri River. The reach where maximum temperature violations occurred extended from Gavins Point Dam to just upstream of Sioux City, Iowa (RM 810 to 735). Since the maximum water temperature in the Missouri River for this reach cannot exceed 26.7 °C (Table D8), violations occur mostly because of increased release temperatures, not from reduction in flows.

d. Results from the sensitivity analyses of changing tributary flow boundary conditions from 7Q10 to 2-year summer flows showed very little impact to water temperatures except around RM 400 and RM 60 where power plants discharge into the Missouri River. At these locations, 2-year summer flow helped to dilute the power plant discharges especially at the lower release flows, cooling water temperatures slightly. Overall, changes in water temperatures were not sensitive to 2-year summer flow increases from the tributaries. Other water quality constituents proved to be more sensitive to tributary flow changes than temperature. As a matter of fact, for all other water quality constituents modeled, concentrations increased because of increased loads. Nitrate nitrogen had the greatest concentration increase (which occurred at the lowest reduced release flow) and was approximately 0.4 mg/ℓ. Water quality concentrations were well below state standards for these constituents.

e. Sensitivity analyses where tributary and other point source water quality concentrations were increased by 30 percent produced very minimal changes to water temperatures and other water quality constituents. Water temperatures were increased by 0.3 °C at the maximum difference, while algae (as chlorophyll *a*) and CBOD concentrations were essentially unchanged. The other constituents modeled showed only slight increases in concentrations. Again, water quality concentrations were well below state standards for these constituents.

f. Sensitivity analysis performed on meteorological boundary conditions for the 14T10 and maximum 14-day air temperatures demonstrated that the system was not very sensitive to changes in air temperatures. Although air temperature changed as much as 4 °C between scenarios, water temperatures were only increased 0.3 °C. Increases in water temperature affected other water quality concentrations because of their temperature dependency. Changes in constituent concentrations were small since temperature increases were minimal.

g. Comparisons of water temperature results for scenarios with and without power plants operating definitely illustrated that power plant discharges significantly impact water temperatures in the Missouri River far more than tributaries or other point sources. Water temperatures were increased as much as 1.5 °C for the lowest reduced release flow modeled (9,000 cfs) during summer navigation season. Although water temperatures were increased, their values were still below 32.2 °C, the maximum allowable water temperature in the Missouri River. These water temperature results were from scenarios using the A90 power plant boundary conditions. When results from a scenario run using fully loaded capacity for power plant discharges were compared with these results, water temperatures were increased an additional 0.6 °C. This was still not enough to cause water temperatures to be above the 32.2 °C maximum water temperature limit.

h. For winter simulations, reduced flows produced increases in water temperatures as much as 2 °C, and again water quality concentrations increased as release flows were reduced from Gavins Point Dam. Increased water quality concentrations did not violate any state standard.

i. DO concentrations predicted in the time-varying (i.e., diel) simulation where boundary conditions were set to extreme values and an algal crash was initiated were on the borderline of state standard limits for the lowest reduced release flow modeled (9,000 cfs). If algal concentrations had been greater, DO concentrations more than likely would have been decreased below state standards for a short period (perhaps 1 day).

j. Further reductions in release flows (Scenario 10) caused additional increases in water temperatures as much as 1.2 °C, but did not violate the maximum allowable temperature limit imposed on Missouri River water temperatures (Appendix D). Water quality concentrations of the other constituents were also increased, mostly from less dilution of tributary and point source loadings. Increased water quality concentrations did not violate state standards set for these constituents.

120. Overall, results from all scenario runs indicate that water temperature and water quality concentrations were impacted by reducing flows in the Missouri River, yet temperatures and water quality concentrations for all constituents were well within standards for state limits.

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APPENDIX A: CALIBRATION/VERIFICATION DATA

Table A1

Calibration Data Collected by the Omaha and Kansas City Districts

August 28, 1990

Location		Time	Temp °C	pH SU	D.O. mg/ℓ	Cond. µmhos	SD cm
			Omaha Sampling				
Gavins Point Dam	Approx. RM 811	0735	25.8	8.3	7.34	781	
James River	Approx. RM 801	0810	27.6	7.9	6.75	1363	
RM 780		0840	25.7	8.3	7.07	794	
Vermillion River	Approx. RM 772	0900	27.5	7.8	4.93	1485	
*RM 735		1045	27.0	8.3	7.27	789	40
Big Sioux River	Approx. RM 734	1100	28.4	8.3	9.45	848	
Floyd River	Approx. RM 731	1135	27.3	8.0	8.49	724	
RM 694		1350	27.8	8.3	7.74	791	
Little Sioux R.	Approx. RM 669	1505	28.5	8.1	7.31	618	
RM 654		1545	27.9	8.4	8.05	786	
Boyer River	Approx. RM 635	1635	28.9	8.0	6.64	544	
RM 614		0750	27.0	8.4	6.5	766	
Platte River	Approx. RM 595	0830	27.0	8.4	6.0	766	
RM 574		0915	27.5	8.1	6.1	784	
Nishnabotna R.	Approx. RM 542	1020	27.5	8.1	6.0	594	
*RM 534		1100	28.0	8.1	5.8	754	10
Nemaha River	Approx. RM 495	1215	29.0	8.1	9.8	556	
RM 494		1230	28.0	8.0	5.8	754	
			Kansas City Sampling				
Nodaway River	Approx. RM 463	1610	30.5	8.5	7.3	348	
RM 446.5		1510	28.5	8.2	6.3	695	
RM 404		1255	28.5	8.5	8.0	740	
Platte River	Approx. RM 391	1140	28.6	7.6	6.3	393	
RM 369		1025	28.3	8.4	7.9	744	
Kansas River	Approx. RM 367	1010	28.8	8.2	6.9	519	
Big Blue River	Approx. RM 357	0925	28.3	7.2	2.4	1490	
Little Blue R.	Approx. RM 339	0825	26.8	7.2	3.9	564	
Fishing River	Approx. RM 334						
*RM 329		0730	29.0	8.2	6.7	704	15.2
Crooked River	Approx. RM 314						
RM 284		0900	29.0	7.7	6.4	700	
Grand River	Approx. RM 250	1105	29.3	7.0	5.8	333	
RM 252		1050	29.3	7.7	6.4	694	
Chariton River	Approx. RM 239	1140	29.2	7.4	6.8	271	
RM 204		1420	30.0	7.6	6.5	667	
Lamine River	Approx. RM 202	1440	28.6	7.2	5.6	415	
RM 172		1610	30.3	7.6	6.5	662	
Perche Creek	Approx. RM 170	1630	27.6	6.8	7.3	609	

(Continued)

* Sites where 20-day carbonaceous biochemical oxygen demand (CBOD) samples were collected.

Table A1 (Concluded)

Location		Time	Temp °C	pH SU	D.O. mg/ℓ	Cond. µmhos	SD cm
Osage River	Approx. RM 130	1525	28.3	7.7	6.3	265	109.7
RM 132		1506	28.4	8.0	6.4	680	12.2
Gasconade River	Approx. RM 104	1325	29.2	8.3	7.0	340	48.8
RM 84		1220	28.0	7.9	6.6	630	9.1
*RM 50		1014	27.7	7.9	7.2	605	9.1
RM 4		0803	28.0	7.8	7.3	560	9.1

Table A2

Observed Water Quality Data Collected by Omaha District on August 28, 1990

Analysis	Units	Station*												
		1	2	3	4	5	6	7	8	9	10	11	12	13
Total suspended solids	mg/ℓ	8	33	20	65	23	68	180	34	140	59	381	392	320
Dissolved organic carbon	mg/ℓ	2.9	8.2	2.9	2.7	2.8	5.2	4.8	2.7	3.7	2.8	3.5	3.7	2.9
Total organic carbon	mg/ℓ	3.2	8.7	3.4	3.6	2.9	6.1	11.7	3.8	4.6	3.2	4.0	3.4	3.2
Total ammonia nitrogen	mg/ℓ	<.02	0.03	<.02	0.03	<.02	0.02	0.03	<.02	0.03	<.02	0.04	0.11	0.07
Total kjeldahl nitrogen	mg/ℓ	0.6	1.5	0.3	0.7	0.3	2.5	3.2	0.3	1.7	0.8	1.8	1.3	0.9
Nitrate nitrogen	mg/ℓ	0.02	0.17	0.06	0.08	0.10	1.37	0.15	0.10	3.7	0.04	7.8	0.71	0.43
Nitrite nitrogen	mg/ℓ	<.01	<.01	0.06	<.01	<.01	0.10	0.12	<.01	0.09	<.01	<.01	<.01	<.01
CBOD 5 day	mg/ℓ	<1.0	2.9	1.5	2.1	<1.0	6.7	13.8	11.9	4.8	2.2	3.5	2.8	3.5
CBOD 20 day	mg/ℓ	--	--	--	--	--	--	--	--	--	--	--	--	--
Total recoverable phosphorus	mg/ℓ	0.04	0.17	0.02	0.14	0.05	0.49	0.48	0.05	0.36	0.10	0.72	0.48	0.38
Total inorganic phosphorus	mg/ℓ	0.03	0.05	0.02	0.05	0.02	0.12	0.03	0.03	0.09	0.02	0.25	0.08	0.06
Chlorophyll	µg/ℓ	<1	<1	--	--	--	--	--	--	--	--	--	--	--
Pheophytin	µg/ℓ	<1	<1	--	--	--	--	--	--	--	--	--	--	--

(Continued)

* Stations are identified on page A6.

AD-A259 186 PREDICTED WATER QUALITY IMPACTS FROM REDUCING FLOW OUT OF GAVINS POINT DAM ON THE MISSOURI RIVER(U) ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS ENV 2/2

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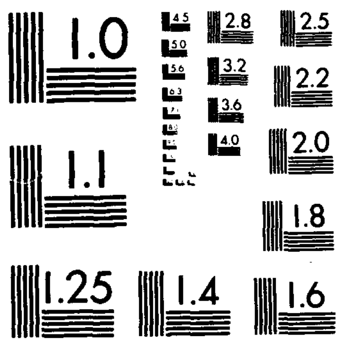


RESOLUTION TEST CHART

Table A2 (Concluded)

Analysis	Units	Station 14	15	16	17	18
Total suspended solids	mg/ℓ	522	134	97	539	111
Dissolved organic carbon	mg/ℓ	2.7	2.9	3.8	2.5	4.6
Total organic carbon	mg/ℓ	3.1	3.2	5.2	3.2	4.7
Total ammonia nitrogen	mg/ℓ	0.11	<.02	0.04	0.03	0.02
Total kjeldahl nitrogen	mg/ℓ	1.3	0.7	1.9	1.6	1.8
Nitrate nitrogen	mg/ℓ	0.67	0.22	0.09	6.05	0.11
Nitrite nitrogen	mg/ℓ	<.01	0.07	0.09	<.01	0.10
CBOD 5 day	mg/ℓ	4.3	2.6	8.3	4.2	6.3
CBOD 20 day	mg/ℓ	--	--	--	--	
Total recoverable phosphorus	mg/ℓ	0.60	0.23	0.29	0.86	0.64
Total inorganic phosphorous	mg/ℓ	0.10	0.03	0.03	0.22	0.19
Chlorophyll	µg/ℓ	--	--	--	--	--
Pheophytin	µg/ℓ	--	--	--	--	--

Note: < = Less than detection limit.

Station No.	Sample Identification	Station No.	Sample Identification	Station No.	Sample Identification
1.	Gavins Point Dam (811 mile)	7.	Floyd River (731 mile)	13.	River (574 mile)
2.	James River (801 mile)	8.	River (694 mile)	14.	River (494 mile)
3.	Clay Country Parks (780 mile)	9.	Little Sioux River (669 mile)	15.	River (614 mile)
4.	Vermillion River (722 mile)	10.	River (654 mile)	16.	Nemaha River
5.	River (735 mile)	11.	Boyer River (635 mile)	17.	Nishnabotna
6.	Big Sioux River (734 mile)	12.	River (534 mile)	18.	Platte River

Table A3

Observed Water Quality Data Collected by Kansas City District on August 28, 1990

Analysis	Units	Station*													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Total suspended solids	mg/ℓ	54	147	66	122	66	58	68	23	370	39	326	325	263	17
Dissolved organic carbon	mg/ℓ	5.8	4.2	4.6	3.4	5.5	6.8	3.5	5.5	6.4	6.8	4.0	3.7	4.8	2.6
Total organic carbon	mg/ℓ	6.5	5.0	8.5	4.3	5.6	7.2	4.2	6.3	8.0	8.4	5.0	5.2	4.7	2.2
Total ammonia nitrogen	mg/ℓ	0.08	0.16	0.05	0.07	0.01	3.40	0.03	0.10	0.14	0.54	0.11	0.80	0.10	0.04
Total kjeldahl nitrogen	mg/ℓ	1.64	1.21	1.61	1.11	1.13	3.45	0.69	1.70	2.12	2.60	1.89	2.00	1.20	0.28
Nitrate nitrogen	mg/ℓ	0.17	1.07	0.19	0.40	0.09	1.68	0.20	0.82	0.66	1.90	0.79	0.74	0.76	<.02
Nitrite nitrogen	mg/ℓ	<.01	<.01	0.05	<.01	<.01	0.08	<.01	<.01	<.01	0.98	<.01	<.01	<.01	<.01
CBOD 5 day	mg/ℓ	6.3	3.5	14.1	8.9	4.0	6.8	8.8	7.4	5.6	9.1	4.9	4.6	7.2	4.4
CBOD 20 day	mg/ℓ	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Total recoverable phosphorus	mg/ℓ	0.12	0.29	0.24	0.19	0.13	6.20	0.06	0.05	0.30	0.32	0.37	0.33	0.31	0.02
Total ortho phosphorus	mg/ℓ	0.03	0.25	0.05	0.08	0.06	4.25	0.02	0.03	0.10	0.19	0.24	0.17	0.20	0.02
Chlorophyll	μg/ℓ	--	--	--	--	--	--	--	--	--	--	--	<1	--	--
Pheophytin	μg/ℓ	--	--	--	--	--	--	--	--	--	--	--	<1	--	--

(Continued)

* Stations are identified on page A8.

Table A3 (Concluded)

Analysis	Units	Station 15	16	17	18	19	20	21	22	23	21
Total suspended solids	mg/ℓ	24	199	174	200	172	154	121	142	495	
Dissolved organic carbon	mg/ℓ	3.8	4.1	5.5	4.8	4.9	3.8	3.6	3.6	3.4	
Total organic Carbon	mg/ℓ	4.6	4.4	7.7	5.8	4.6	5.2	4.3	4.1	4.1	
Total ammonia nitrogen	mg/ℓ	0.04	0.06	0.26	0.11	0.06	0.15	0.19	0.03	0.10	
Total kjeldahl nitrogen	mg/ℓ	0.43	1.30	2.48	1.75	1.22	1.52	1.65	1.13	2.14	
Nitrate nitrogen	mg/ℓ	0.21	0.78	0.71	0.75	0.82	0.81	0.65	0.33	0.74	
Nitrite nitrogen	mg/ℓ	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	
CBOD 5 day	mg/ℓ	3.0	4.5	8.6	6.3	7.9	4.3	4.0	5.8	4.2	
CBOD 20 day	mg/ℓ	--	--	--	--	--	--	--	--	--	
Total recoverable phosphorus	mg/ℓ	0.09	0.28	0.26	0.22	0.26	0.26	0.26	0.16	0.56	
Total ortho phosphorus	mg/ℓ	0.05	0.15	0.04	0.14	0.10	0.13	0.16	0.06	0.26	
Chlorophyll	μg/ℓ	--	--	--	--	--	--	22	--	--	*21
Pheophytin	μg/ℓ	--	--	--	--	--	--	23	--	--	*22

* Note: Duplicate sample for Station 21 for chlorophyll.

Station No.	Sample Identification	Station No.	Sample Identification	Station No.	Sample Identification
1	Grand River	9	Chariton River	17	River (172 mile)
2	Mouth Kansas River (367.4 mile)	10	Perche Creek	18	River (204 mile)
3	Mouth Nodaway River (463 mile)	11	River (4 mile)	19	River (252 mile)
4	Mouth Missouri River (391.1 mile)	12	River (50 mile)	20	River (284 mile)
5	Mouth Platte River (391.1 mile)	13	River (104.4 mile)	21	River (329 mile
6	Mouth Blue River (358 mile)	14	River (84 mile)	22	Missouri River (404 mile)
7	Mouth L. Blue (339.4 mile)	15	Osage River (130 mile)	23	Missouri River (446.5 mile)
8	Lamine River	16	River (132 mile)		

Table A4

20-Day CBOD Data for August 28, 1990, Samples at Four River Locations

Test Parameter CBOD, day	Sample Identification* 3	10	12	21	Units
1	<1.0	<1.0	<1.0	<1.0	mg/ℓ
2	<1.0	<1.0	1.0	<1.0	mg/ℓ
3	<1.0	<1.0	1.6	2.6	mg/ℓ
4	1.2	<1.0	2.2	3.4	mg/ℓ
5	1.4	1.7	3.6	4.5	mg/ℓ
6	2.1	3.0	4.1	5.6	mg/ℓ
7	2.5	3.3	5.1	6.4	mg/ℓ
8	3.1	3.9	5.6	7.0	mg/ℓ
9	3.1	3.9	5.6	7.0	mg/ℓ
10	3.3	4.8	6.3	8.0	mg/ℓ
11	3.5	5.3	6.3	8.2	mg/ℓ
12	3.6	5.2	6.3	8.2	mg/ℓ
13	3.7	5.2	6.5	8.2	mg/ℓ
14	3.7	5.7	6.7	8.3	mg/ℓ
15	3.9	5.8	6.5	8.7	mg/ℓ
16	3.9	5.8	7.1	8.7	mg/ℓ
17	3.9	6.2	7.2	8.9	mg/ℓ
18	4.3	7.2	7.9	9.8	mg/ℓ
19	4.8	8.2	8.5	10.4	mg/ℓ
20	4.8	8.2	8.5	10.4	mg/ℓ

* Sample number 3 = RM 735, number 10 = RM 534, number 12 = RM 50, and number 21 = RM 329.

Table A5

Verification Data Collected by the Omaha and Kansas City Districts

on September 12, 1990

Location		Time	Temp °C	pH SU	D.O. mg/ℓ	Cond. µmhos	SD cm
			Omaha Sampling				
Gavins Point Dam	Approx. RM 811	0730	24.1	8.19	7.1	801	
James River	Approx. RM 801	0800	24.5	8.0	6.3	1352	
RM 780		0830	23.3	8.2	7.1	805	
Vermillion River	Approx. RM 772	0900	23.3	7.8	6.7	1650	
*RM 735		1030	24.9	8.2	7.4	800	60
Big Sioux River	Approx. RM 734	1045	24.9	7.7	5.6	914	
Floyd River	Approx. RM 731	1105	24.8	8.2	6.7	785	
RM 694		1330	26.0	8.2	7.3	800	
Little Sioux R.	Approx. RM 669	1435	26.2	8.5	12.9	580	
RM 654		1530	26.1	8.3	7.6	803	
Boyer River	Approx. RM 635	1615	26.1	8.6	16.13	645	
RM 614		0815	25.0	8.4	6.4	821	
Platte River	Approx. RM 595	0845	24.0	8.7	7.2	858	
RM 574		0915	25.0	8.1	6.3	821	
Nishnabotna R.	Approx. RM 542	1050	25.0	8.3	7.4	721	
*RM 534		1115	26.0	8.2	8.0	718	30
Nemaha River	Approx. RM 495	1230	27.0	8.2	8.0	718	
RM 494		1235	27.0	8.2	7.0	814	
			Kansas City Sampling				
Nodaway River	Approx. RM 463		27.5	7.5	5.9	495	
RM 446.5			27.3	8.0	8.5	777	
RM 404			27.4	8.0	8.2	776	
Platte River	Approx. RM 391		26.8	7.0	6.4	538	
RM 369			27.5	8.0	7.9	774	
Kansas River	Approx. RM 367		27.2	7.9	6.6	683	
Big Blue River	Approx. RM 357		25.5	7.1	1.2	575	
Little Blue R.	Approx. RM 339		23.5	7.1	6.7	568	
Fishing River	Approx. RM 334						
*RM 329			27.9	8.0	7.2	765	33.5
Crooked River	Approx. RM 314						
RM 284			26.6	8.4	8.3	720	
Grand River	Approx. RM 250		24.8	7.6	6.1	550	
RM 252			26.6	8.4	8.3	750	
Chariton River	Approx. RM 239		24.8	7.8	7.9	300	
RM 204			27.0	8.5	8.2	760	
Lamine River	Approx. RM 202		26.4	8.0	5.4	600	
RM 172			26.9	8.5	8.0	775	
Perche Creek	Approx. RM 170		23.9	7.4	12.8	900	
Osage River	Approx. RM 130		27.3	7.3	6.1	273	
RM 132			27.8	8.1	8.2	738	

(Continued)

* Sites where 20-day CBOD samples were collected.

Table A5 (Concluded)

Location		Time	Temp °C	pH SU	D.O. mg/ℓ	Cond. µmhos	SD cm
Gasconade River	Approx. RM 104		26.8	7.7	6.6	330	
RM 84			27.2	8.0	7.2	717	
*RM 50			27.8	8.0	7.5	720	42.6
RM 4			27.8	8.0	7.6	709	

Table A6

Observed Water Quality Data Collected by Omaha District on September 12, 1990

Analysis	Units	Station* 1	2	3	4	5	6	7	8	9	10	11	12	13	14
Total suspended solids	mg/ℓ	52	74	8	75	17	46	50	6	15	15	66	25	45	52
Dissolved organic carbon	mg/ℓ	3.1	3.6	3.0	2.4	2.7	3.5	3.0	2.9	6.5	3.6	2.6	3.3	5.1	3.4
Total organic carbon	mg/ℓ	3.3	6.1	3.3	2.7	3.1	3.6	3.2	3.2	7.3	3.3	2.7	3.1	6.9	5.0
Total ammonia nitrogen	mg/ℓ	<.02	<.02	<.02	<.02	<.02	<.02	<.01	<.02	<.02	<.02	<.02	<.02	<.02	<.02
Total kjeldahl nitrogen	mg/ℓ	0.54	1.52	0.56	0.94	0.61	1.3	0.74	0.46	1.3	0.65	0.70	0.46	1.75	1.14
Nitrate nitrogen	mg/ℓ	0.10	0.04	0.11	3.45	0.12	0.07	0.17	0.30	0.12	0.08	0.04	0.11	0.02	0.08
Nitrite nitrogen	mg/ℓ	<.01	0.05	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
CBOD 5 day	mg/ℓ	1.8	9.2	3.2	4.0	2.3	6.4	2.8	1.9	3.6	3.7	2.7	2.0	6.3	3.6
CBOD 20 day	mg/ℓ	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Total recoverable phosphorus	mg/ℓ	0.11	0.60	0.16	0.33	0.19	0.29	0.17	0.03	0.14	0.08	0.12	0.05	0.29	0.15
Total inorganic phosphorus	mg/ℓ	0.02	0.28	0.02	0.17	0.04	0.09	0.04	0.02	0.05	0.02	0.04	0.03	0.04	0.02
Chlorophyll	μg/ℓ	--	--	--	--	34	--	--	--	--	--	--	<1	--	--
Pheophytin	μg/ℓ	--	--	--	--	<1	--	--	--	--	--	--	<1	--	--

(Continued)

* Stations are identified on page A13.

Table A6 (Concluded)

Analysis	Units	Station 15	16	17	18
Total suspended solids	mg/ℓ	22	46	22	51
Dissolved organic carbon	mg/ℓ	3.3	3.5	2.9	2.7
Total organic carbon	mg/ℓ	3.3	5.9	3.3	3.9
Total ammonia nitrogen	mg/ℓ	<.02	<.02	<.02	<.02
Total kjeldahl nitrogen	mg/ℓ	0.61	2.04	0.62	1.39
Nitrate nitrogen	mg/ℓ	0.07	1.57	0.06	5.20
Nitrite nitrogen	mg/ℓ	<.01	0.06	<.01	<.01
CBOD 5 Day	mg/ℓ	1.7	10.2	2.6	6.2
CBOD 20 Day	mg/ℓ	--	--	--	--
Total recoverable phosphorus	mg/ℓ	0.06	0.19	0.06	0.38
Total inorganic phosphorous	mg/ℓ	0.03	0.01	0.02	0.11
Chlorophyll	μg/ℓ	--	--	--	--
Pheophytin	μg/ℓ	--	--	--	--

Note: < = Less than detection limit.

Station No.	Sample Identification	Station No.	Sample Identification
1.	River (614 mile)	10.	Clay County Park River (780 mile)
2.	Platte River	11.	Vermillion River (772 mile)
3.	River (574 mile)	12.	River (735 mile)
4.	Nishnabotna River	13.	Big Sioux River (734 mile)
5.	River (534 mile)	14.	Floyd River (731 mile)
6.	Nemaha River	15.	River (694 mile)
7.	River (494 mile)	16.	Little Sioux River (669 mile)
8.	Gavins Point Dam River (811 mile)	17.	River (654 mile)
9.	James River (801 mile)	18.	River (635 mile)

Table A7

Observed Water Quality Data Collected by Kansas City District on September 12, 1990

Analysis	Units	Station*													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Total suspended solids	mg/ℓ	37	29	186	46	27	65	93	10	81	27	49	33	113	68
Dissolved organic carbon	mg/ℓ	5.0	3.9	5.6	3.8	2.1	3.7	4.0	5.3	4.2	4.8	3.5	4.8	3.3	3.2
Total organic carbon	mg/ℓ	6.4	4.9	8.2	4.3	2.8	4.8	5.1	6.2	5.5	5.6	4.5	5.5	3.7	3.8
Total ammonia nitrogen	mg/ℓ	0.36	<.02	<.02	<.02	0.01	<.02	<.02	0.07	<.02	<.02	<.02	<.02	<.02	<.02
Total kjeldahl nitrogen	mg/ℓ	1.77	1.03	1.28	0.96	0.64	1.32	1.43	1.65	1.55	0.97	0.70	0.92	0.79	0.73
Nitrate nitrogen	mg/ℓ	0.12	0.22	0.30	0.11	0.07	0.06	0.08	0.39	0.11	0.08	0.09	0.09	0.13	0.13
Nitrite nitrogen	mg/ℓ	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.39	<.01	<.01	<.01	<.01	<.01	<.01
CBOD 5 day	mg/ℓ	5.3	2.7	4.4	3.8	3.4	6.4	5.5	10.6	7.6	5.7	4.5	4.3	4.2	4.5
CBOD 20 day	mg/ℓ	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Total recoverable phosphorus	mg/ℓ	0.25	0.07	0.34	0.22	0.06	0.25	0.27	0.11	0.24	0.10	0.16	0.15	0.18	0.15
Total ortho phosphorus	mg/ℓ	0.07	0.03	0.05	0.09	0.02	0.09	0.07	0.03	0.05	0.04	0.04	0.06	0.05	0.05
Chlorophyll	μg/ℓ	--	--	--	--	--	--	--	--	--	--	17	--	--	--
Pheophytin	μg/ℓ	--	--	--	--	--	--	--	--	--	--	22	--	--	--

(Continued)

* Stations are identified on page A15.

Table A7 (Concluded)

Analysis	Units	Station 15	16	17	18	19	20	21	22	23
Total suspended solids	mg/ℓ	94	68	64	85	45	79	24	101	102
Dissolved organic carbon	mg/ℓ	4.1	4.6	5.4	3.5	4.0	3.9	6.5	4.0	4.4
Total organic carbon	mg/ℓ	5.2	4.5	6.3	3.9	5.0	5.3	8.1	4.3	5.1
Total ammonia nitrogen	mg/ℓ	<.02	<.02	3.70	<.02	0.02	<.02	5.00	<.02	0.03
Total kjeldahl nitrogen	mg/ℓ	1.40	0.97	4.18	0.76	1.14	1.37	5.58	0.90	1.17
Nitrate nitrogen	mg/ℓ	0.08	0.04	0.63	0.18	0.08	0.08	2.60	0.10	0.17
Nitrite nitrogen	mg/ℓ	<.01	<.01	0.17	<.01	<.01	<.01	1.56	<.01	<.01
CBOD 5 day	mg/ℓ	7.3	6.1	8.0	3.0	4.7	6.2	5.7	4.1	6.2
CBOD 20 day	mg/ℓ	--	--	--	--	--	--	--	--	--
Total recoverable phosphorus	mg/ℓ	0.23	0.21	0.30	0.19	0.29	0.33	6.00	0.23	0.26
Total Ortho phosphorus	mg/ℓ	0.07	0.09	0.04	0.04	0.16	0.08	5.96	0.08	0.09
Chlorophyll	μg/ℓ	--	--	--	--	--	--	--	35	--
Pheophytin	μg/ℓ	--	--	--	--	--	--	--	21	--

Station No.	Sample Identification	Station No.	Sample Identification	Station No.	Sample Identification
1	River (4 mile)	10	Grand River	19	Kansas River (367.4 mile)
2	Osage River	11	Mouth L. Blue River (339.4 mile)	20	Mouth Nodaway River (463 mile)
3	Chariton River	12	Mouth Platte River (391.1 mile)	21	Mouth Blue River (358 mile)
4	River (50 mile)	13	River (369 mile)	22	River (258 mile)
5	Gasconade River	14	River (404 mile)	23	River (84 mile)
6	River (132 mile)	15	River (204 mile)		
7	River (252 mile)	16	River (172 mile)		
8	Lamine River	17	Perche Creek		
9	River (284 mile)	18	River (446.5 mile)		

Table A8

20 Day CBOD Data for September 12, 1990 Samples at Four River Locations

Test Parameter CBOD, day	Sample Identification* 4	5	12	22	Units
1	<1.0	<1.0	<1.0	<1.0	mg/ℓ
2	<1.0	<1.0	<1.0	<1.0	mg/ℓ
3	1.4	<1.0	<1.0	2.5	mg/ℓ
4	2.0	1.9	1.3	3.5	mg/ℓ
5	3.4	1.2	2.7	4.1	mg/ℓ
6	3.4	3.2	2.7	4.3	mg/ℓ
7	4.2	4.0	3.6	6.3	mg/ℓ
8	5.4	5.8	4.8	7.7	mg/ℓ
9	6.2	6.3	4.9	8.2	mg/ℓ
10	6.6	6.5	5.4	8.2	mg/ℓ
11	6.7	6.4	5.5	9.6	mg/ℓ
12	7.5	7.4	6.4	9.7	mg/ℓ
13	7.5	7.8	6.7	11.3	mg/ℓ
14	8.5	8.1	6.7	11.3	mg/ℓ
15	9.1	8.8	7.4	11.6	mg/ℓ
16	9.2	9.1	7.8	11.5	mg/ℓ
17	9.8	9.1	7.8	11.5	mg/ℓ
18	10.4	10.2	8.7	12.4	mg/ℓ
19	10.5	10.2	8.7	12.4	mg/ℓ
20	10.5	10.2	9.1	12.6	mg/ℓ

* Sample number 4 = RM 50, number 5 = RM 534, number 12 = RM 735, and number 22 = RM 358.

Table A9

Diel Temperature and DO Measurements at Two Stations in the Missouri River Collected August 28, 1990

RM 627			RM 328.6		
Time	Temp	DO	Time	Temp	DO
1110	27.5	6.3	1152	29.44	5.86
1210	27.5	6.3	1252	29.51	5.82
1310	27.5	6.4	1352	29.70	5.80
1410	27.6	6.5	1452	29.84	5.82
1510	27.7	6.7	1552	29.96	5.80
1610	27.7	6.8	1652	30.04	5.79
1710	27.8	6.8	1752	30.07	5.78
1810	27.8	6.9	1852	30.05	5.77
1910	27.8	6.9	1952	30.00	5.77
2010	27.7	6.8	2052	29.92	5.79
2110	27.7	6.7	2152	29.85	5.78
2210	27.6	6.7	2252	29.76	5.78
2310	27.5	6.6	2352	29.66	5.79
0010	27.5	6.5	0052	29.57	5.79
0110	27.4	6.5	0152	29.49	5.80
0210	27.2	6.4	0252	29.39	5.81
0310	26.9	6.4	0352	29.31	5.82
0410	26.7	6.4	0452	29.23	5.82
0510	26.6	6.4	0552	29.15	5.86
0610	26.6	6.3	0652	29.07	5.84
0710	26.4	6.3	0752	29.00	5.84
0810	26.5	6.3	085[illegible]	28.98	5.86
0910	26.5	6.3	0952	28.98	5.88
1010	26.5	6.4	1052	29.07	5.89
1110	26.6	6.4	1152	29.17	5.91
1145	26.6	6.4	1252	29.29	5.94

Table A10

Diel Temperature and DO Measurements at Two Stations in the Missouri River Collected September 12, 1990

RM 627			RM 328.6		
Time	Temp	DO	Time	Temp	DO
1230	25.8	6.4	1120	28.18	7.69
1330	26.0	6.5	1220	28.28	7.97
1430	26.0	6.6	1320	28.40	8.24
1530	26.1	6.8	1420	28.51	8.47
1630	26.2	6.9	1520	28.59	8.73
1730	26.2	7.0	1620	28.65	8.88
1830	26.2	7.2	1720	28.69	9.05
1930	26.3	7.0	1820	28.66	9.03
2030	26.3	6.9	1920	28.65	8.95
2130	26.3	6.9	2020	28.59	8.77
2230	26.2	6.8	2120	28.56	8.62
2330	26.1	6.8	2220	28.50	8.47
0030	26.0	6.7	2320	28.44	8.27
0130	26.0	6.7	0020	28.36	8.20
0230	26.0	6.7	0120	28.25	8.05
0330	25.9	6.7	0220	28.13	7.94
0430	25.7	6.7	0320	28.06	7.84
0530	25.7	6.7	0420	27.99	7.76
0630	25.5	6.7	0520	27.93	7.64
0730	25.4	6.6	0620	27.83	7.62
0830	25.4	6.6	0720	27.73	7.51
0930	25.4	6.7	0820	27.64	7.53
1030	25.4	6.7	0920	27.58	7.62
1130	25.5	6.8	1020	27.55	7.76
1230	25.7	6.9	1120	27.54	8.01

APPENDIX B: SCENARIO RESULTS

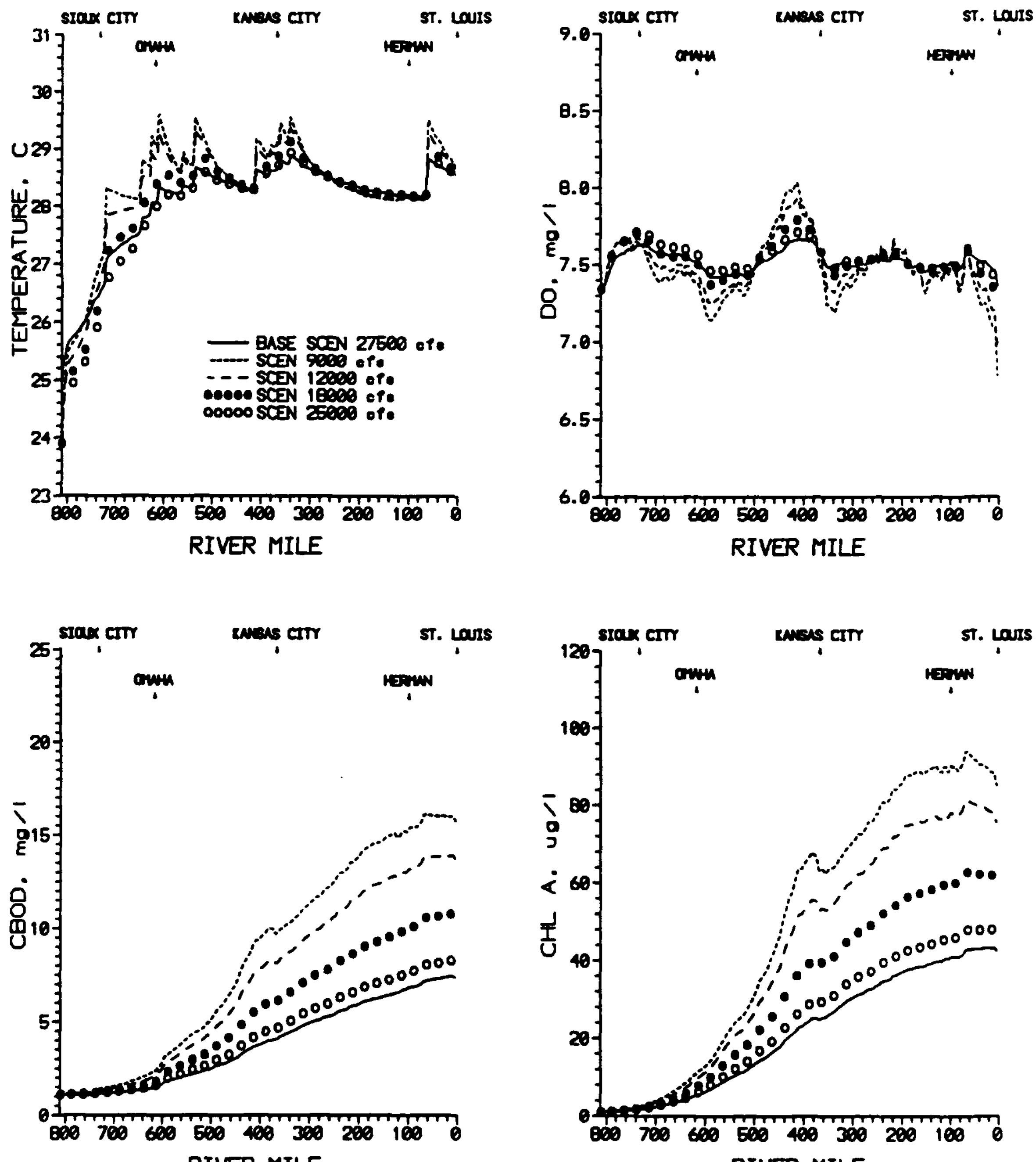


Figure B1. Scenario 1 water quality results for the release temperature of 23.9 °C and all flow conditions. Boundary conditions for this scenario were set to 14T10 met conditions, maximum water quality concentrations on tributaries, 7Q10 tributary flows, maximum permit limits from point sources (i.e., water treatment plants), and A90 power plant loads (see definitions in Table 13 for abbreviations) (Continued)

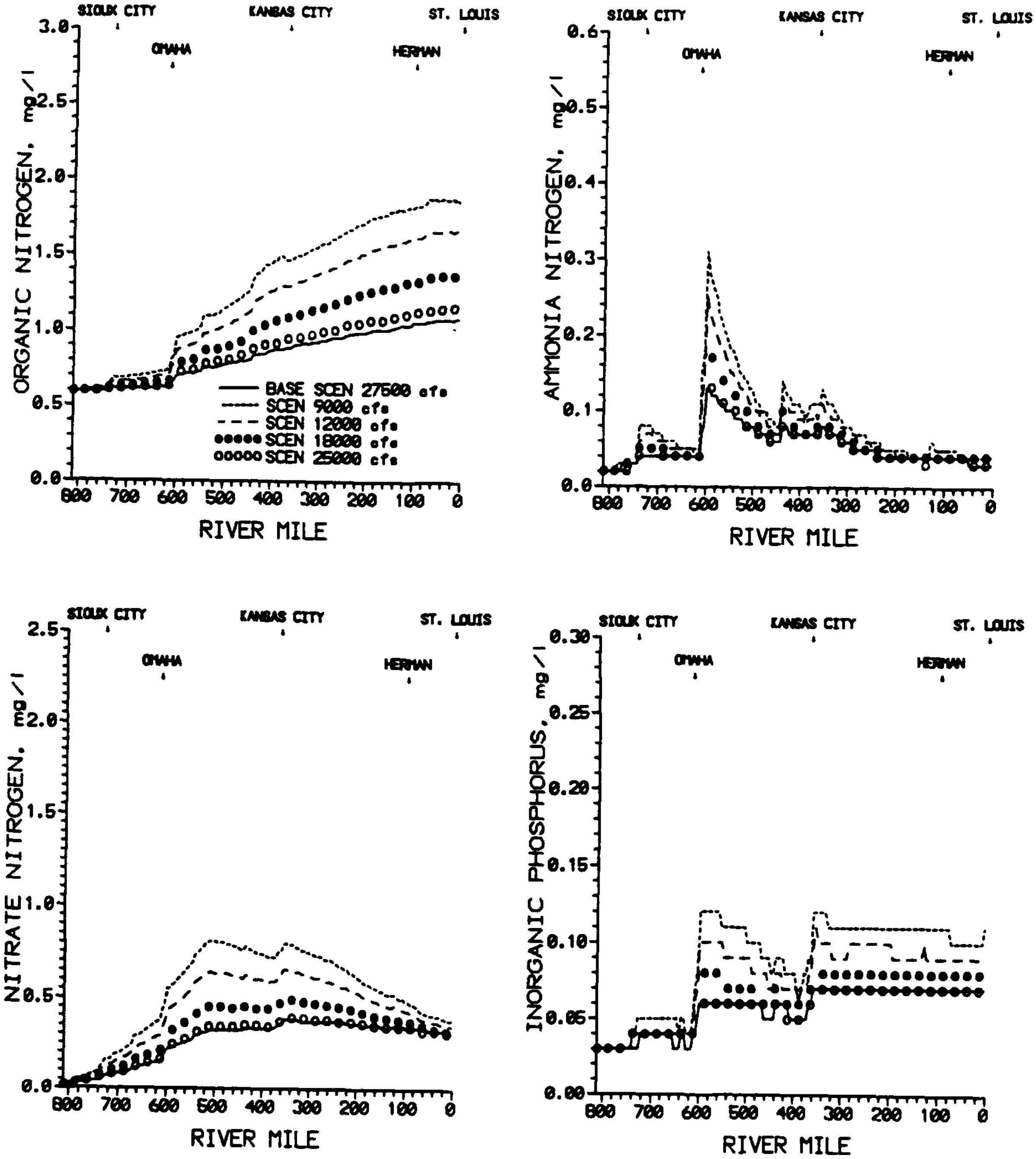


Figure B1. (Concluded)

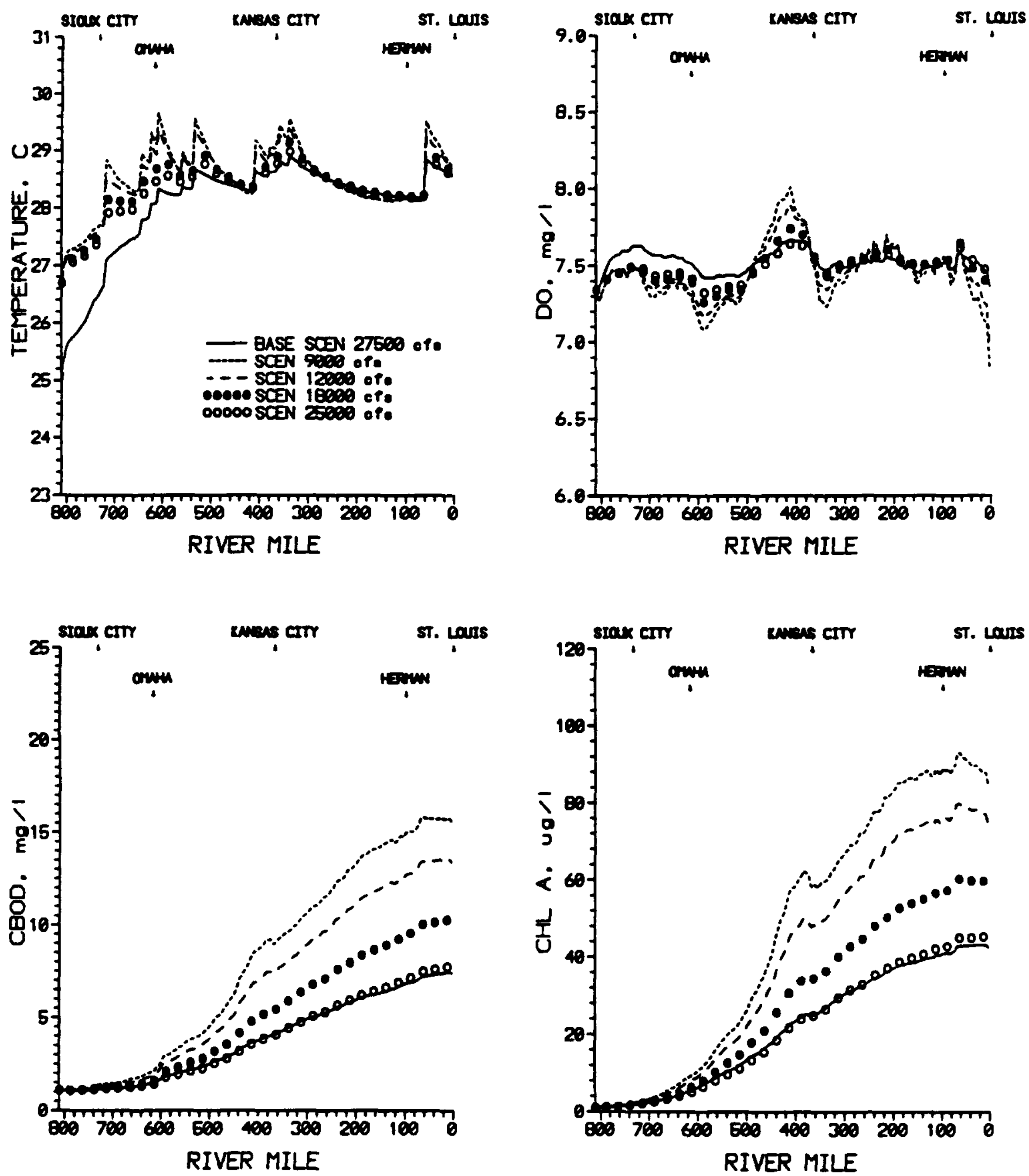


Figure B2. Scenario 1 water quality results for the release temperature of 26.7 °C and all flow conditions. Boundary conditions for this scenario were set to 14T10 met conditions, maximum water quality concentrations on tributaries, 7Q10 tributary flows, maximum permit limits from point sources (i.e., water treatment plants), and A90 power plant loads (see definitions in Table 13 for abbreviations) (Continued)

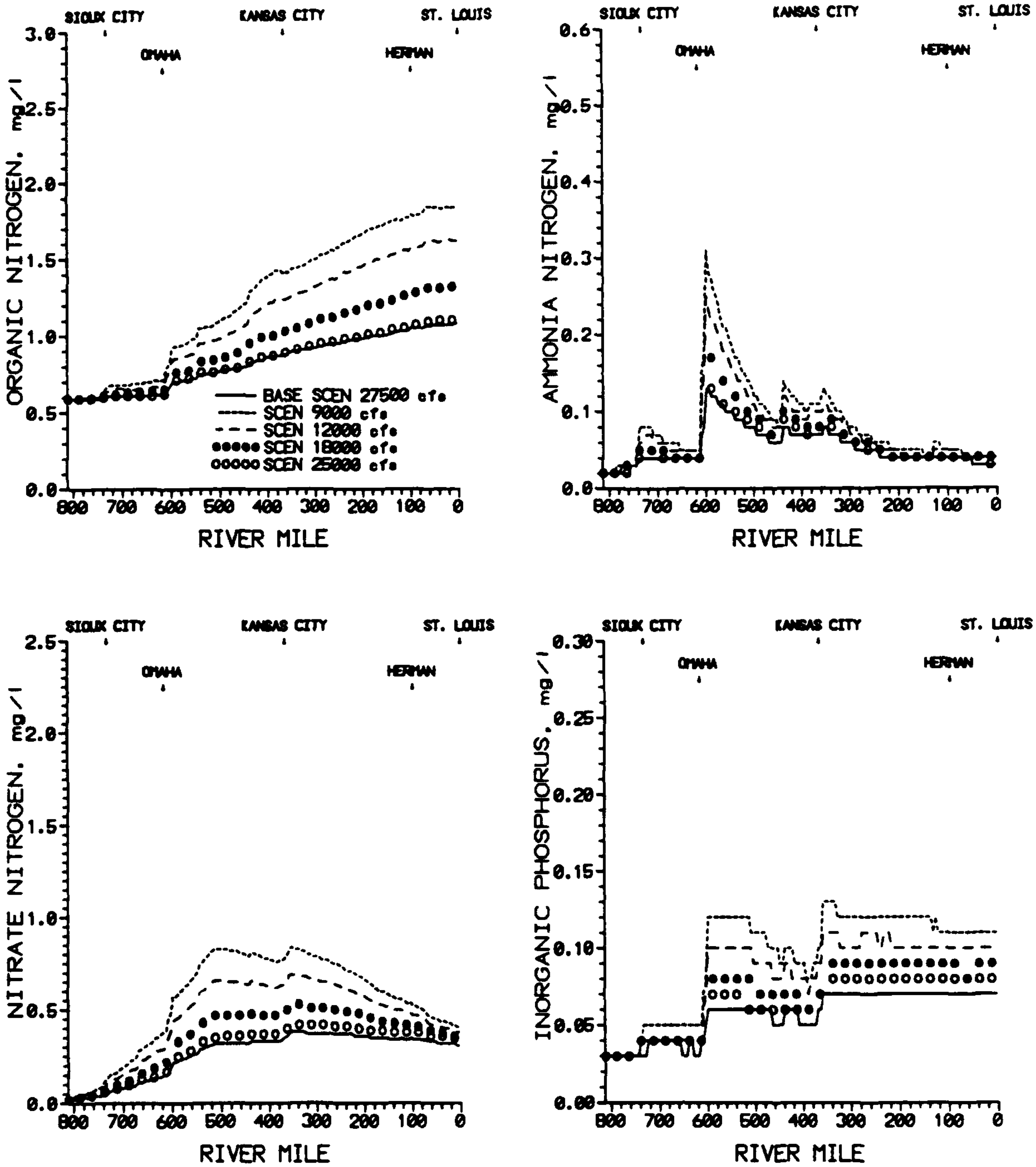


Figure B2. (Concluded)

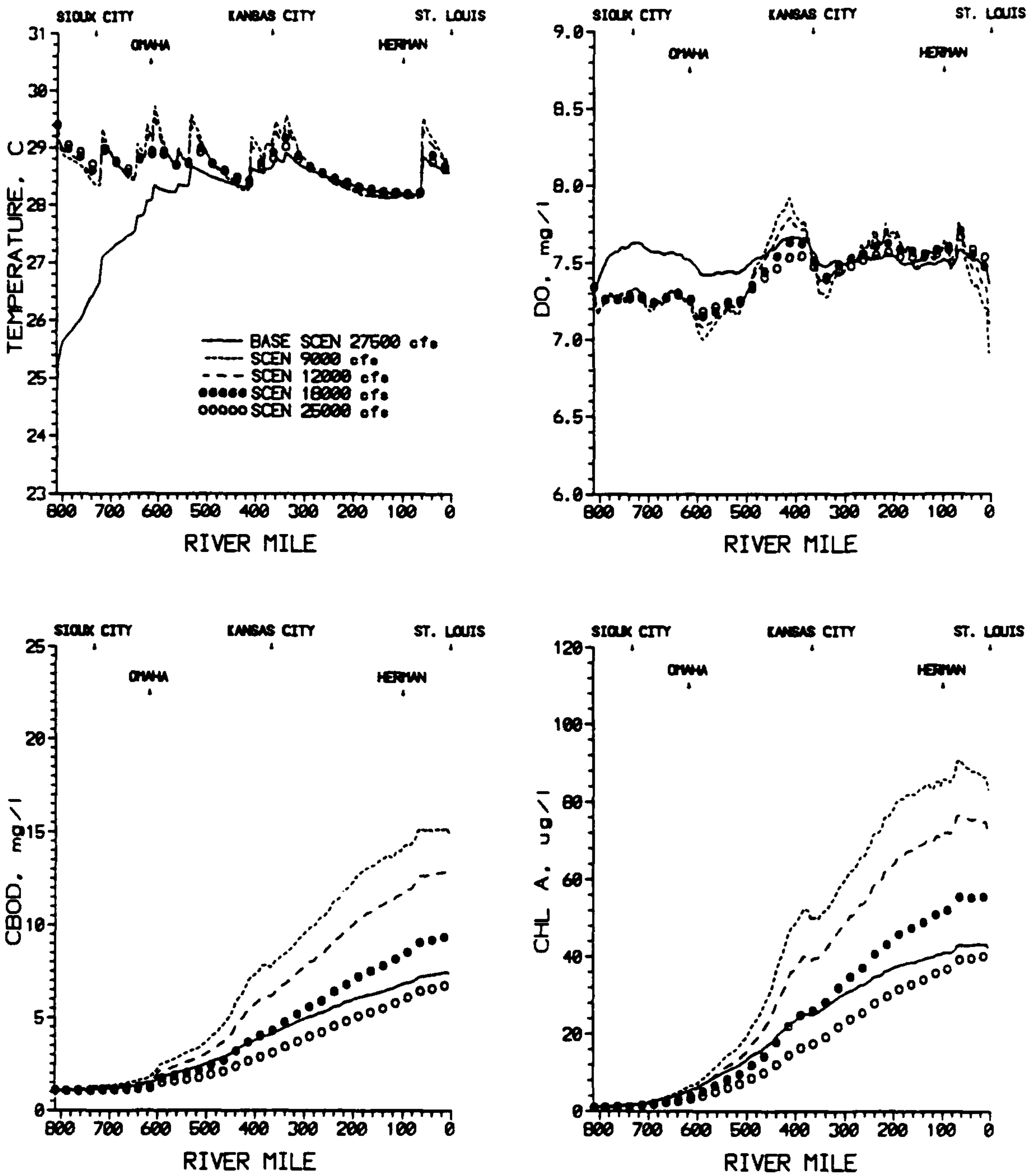


Figure B3. Scenario 1 water quality results for the release temperature of 29.4 °C and all flow conditions. Boundary conditions for this scenario were set to 14T10 met conditions, maximum water quality concentrations on tributaries, 7Q10 tributary flows, maximum permit limits from point sources (i.e., water treatment plants), and A90 power plant loads (see definitions in Table 13 for abbreviations) (Continued)

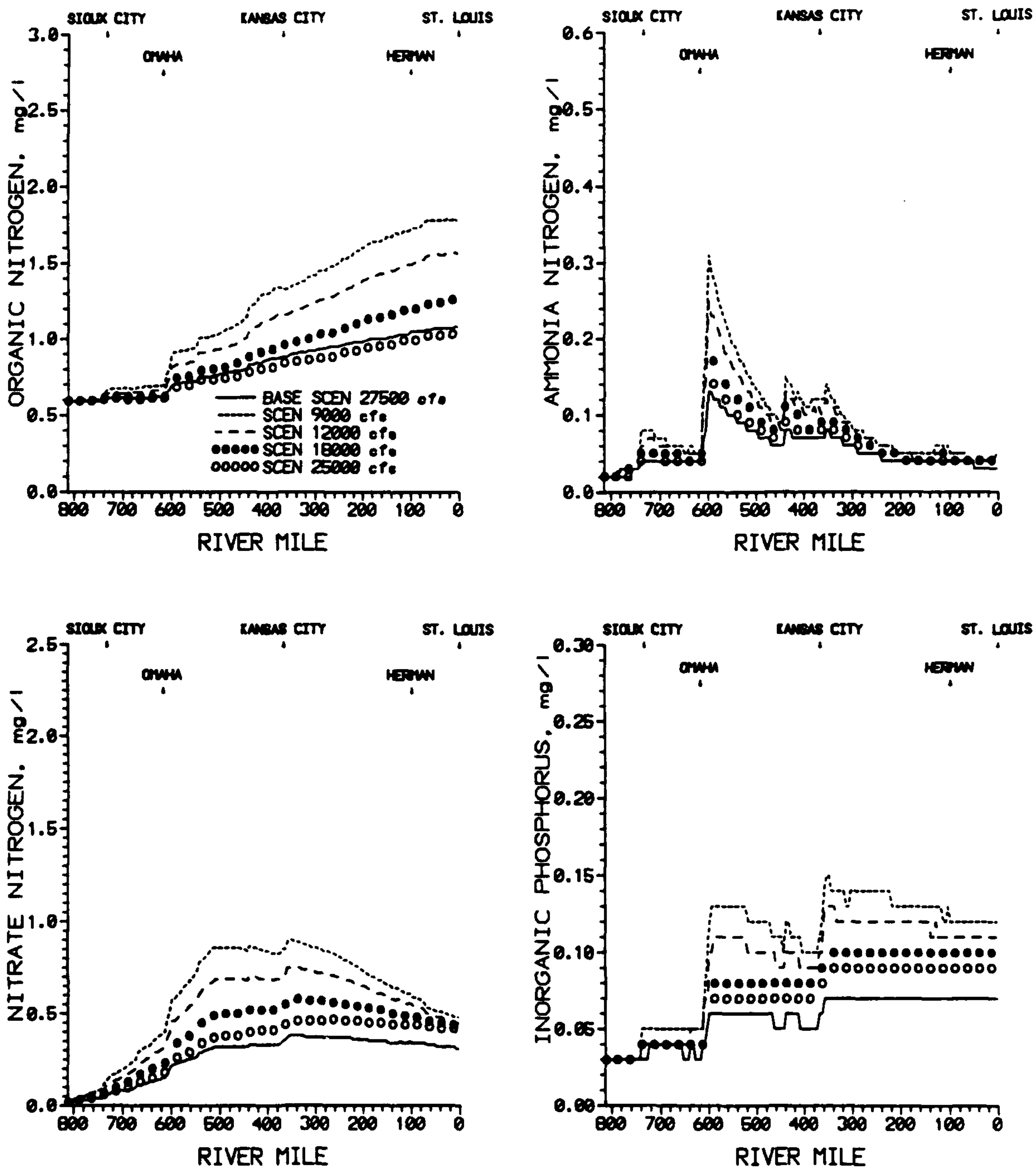


Figure B3. (Concluded)

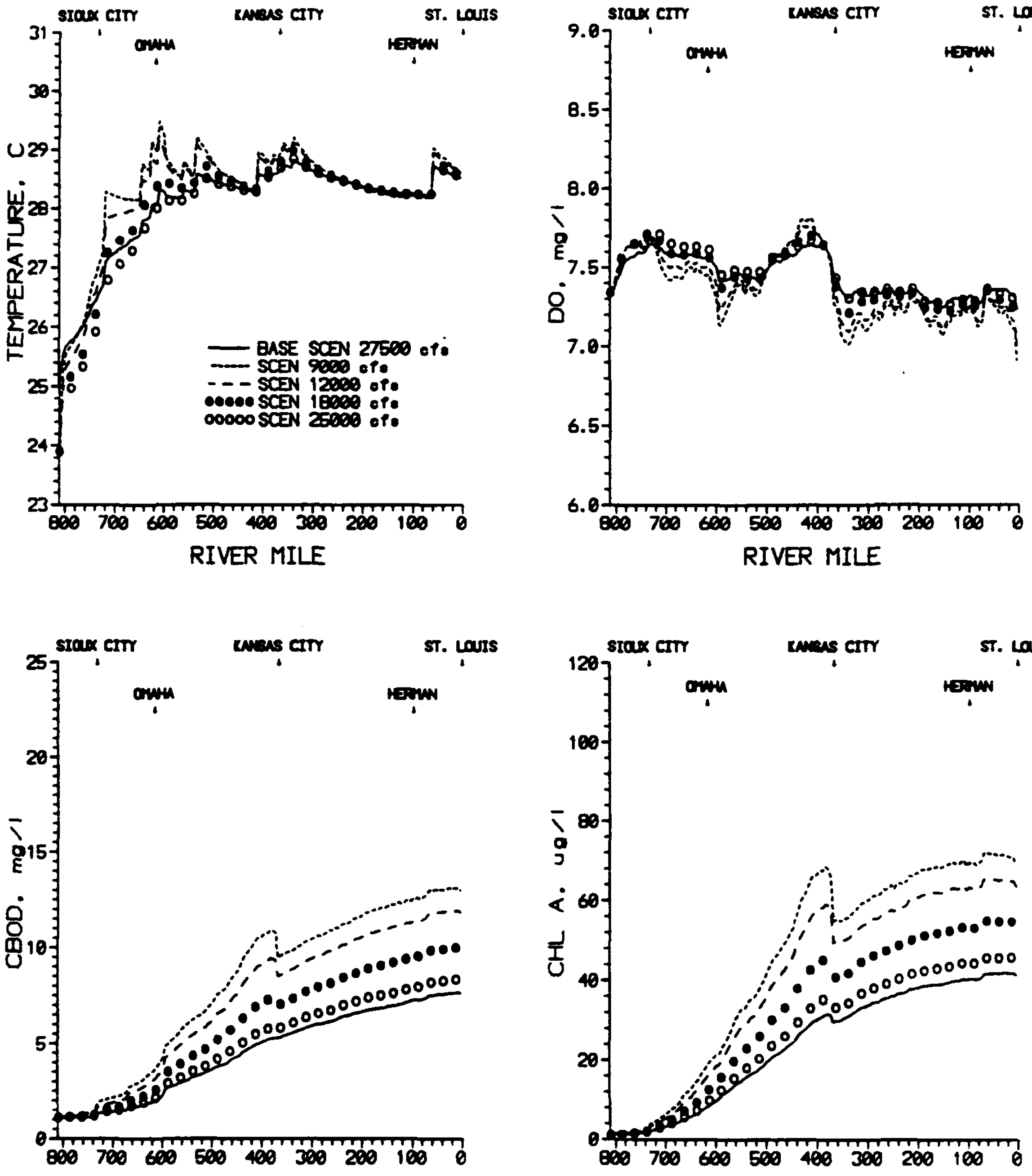


Figure B4. Scenario 2 water quality results for the release temperature of 23.9 °C and all flow conditions. Boundary conditions for this scenario were set to 14T10 met conditions, maximum water quality concentrations on tributaries, 2-year tributary flows, maximum permit limits from point sources (i.e., water treatment plants), and A90 power plant loads (see definitions in Table 13 for abbreviations) (Continued)

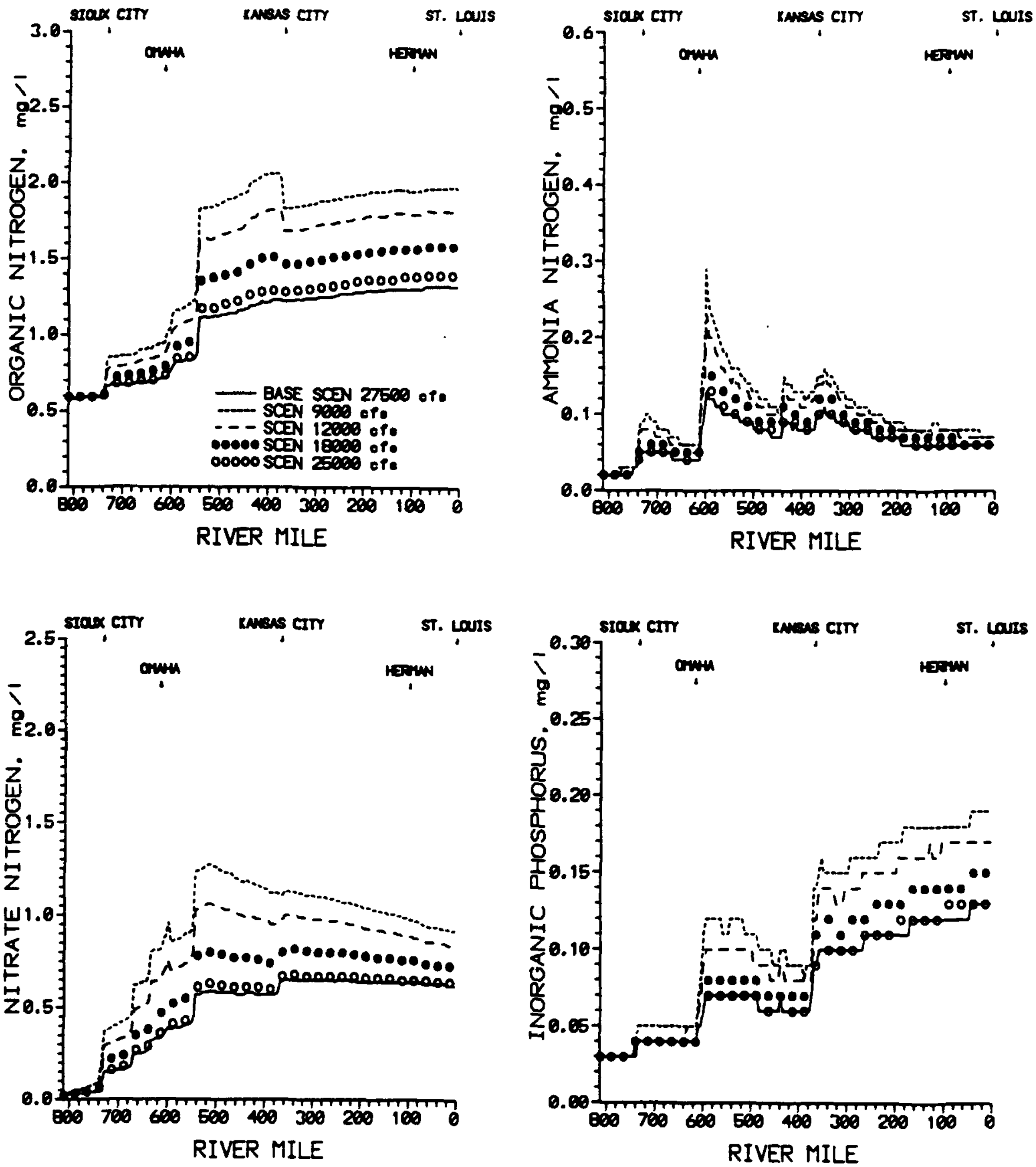


Figure B4. (Concluded)

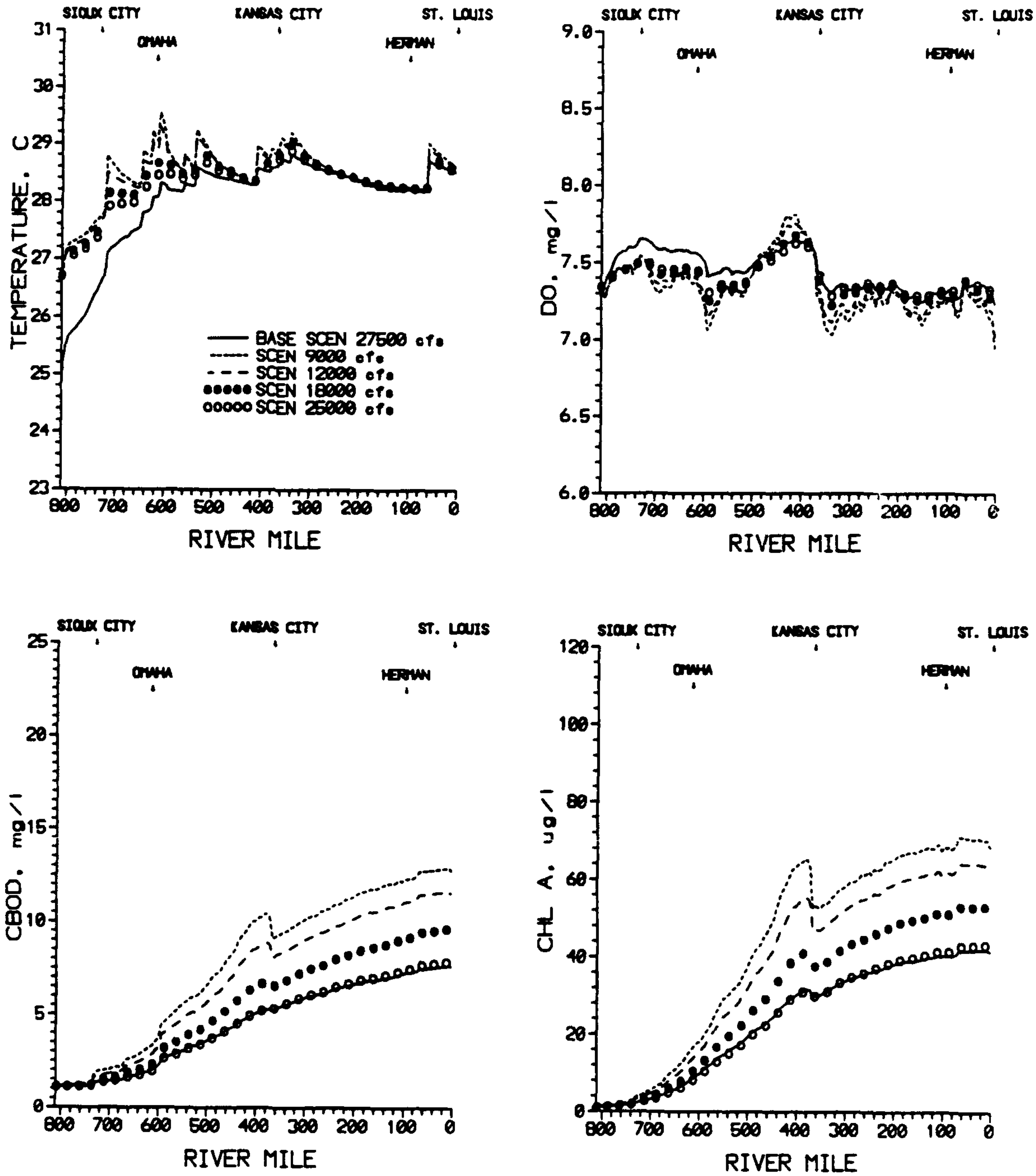


Figure B5. Scenario 2 water quality results for the release temperature of 26.7 °C and all flow conditions. Boundary conditions for this scenario were set to 14T10 met conditions, maximum water quality concentrations on tributaries, 2-year tributary flows, maximum permit limits from point sources (i.e., water treatment plants), and A90 power plant loads (see definitions in Table 13 for abbreviations) (Continued)

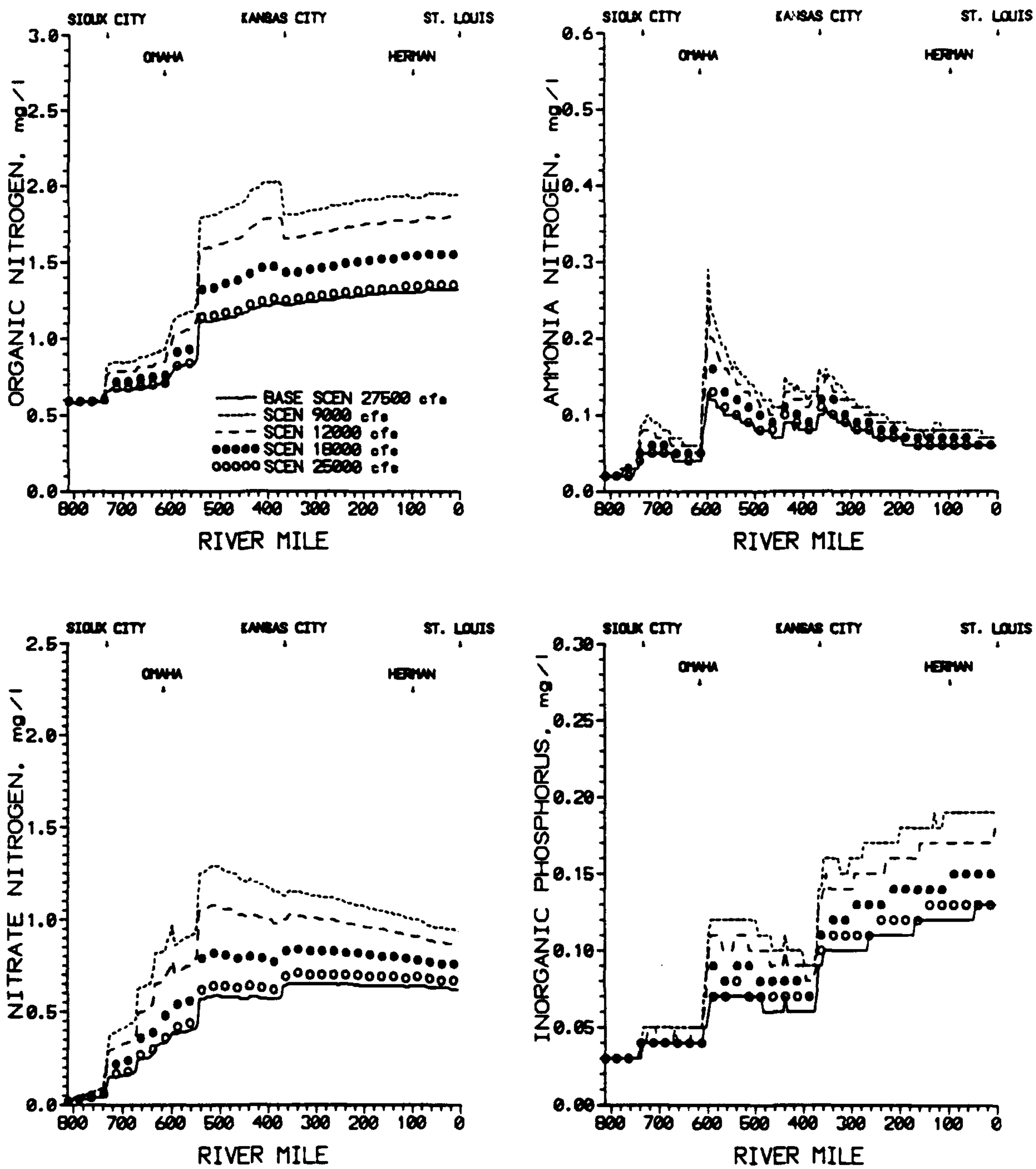


Figure B5. (Concluded)

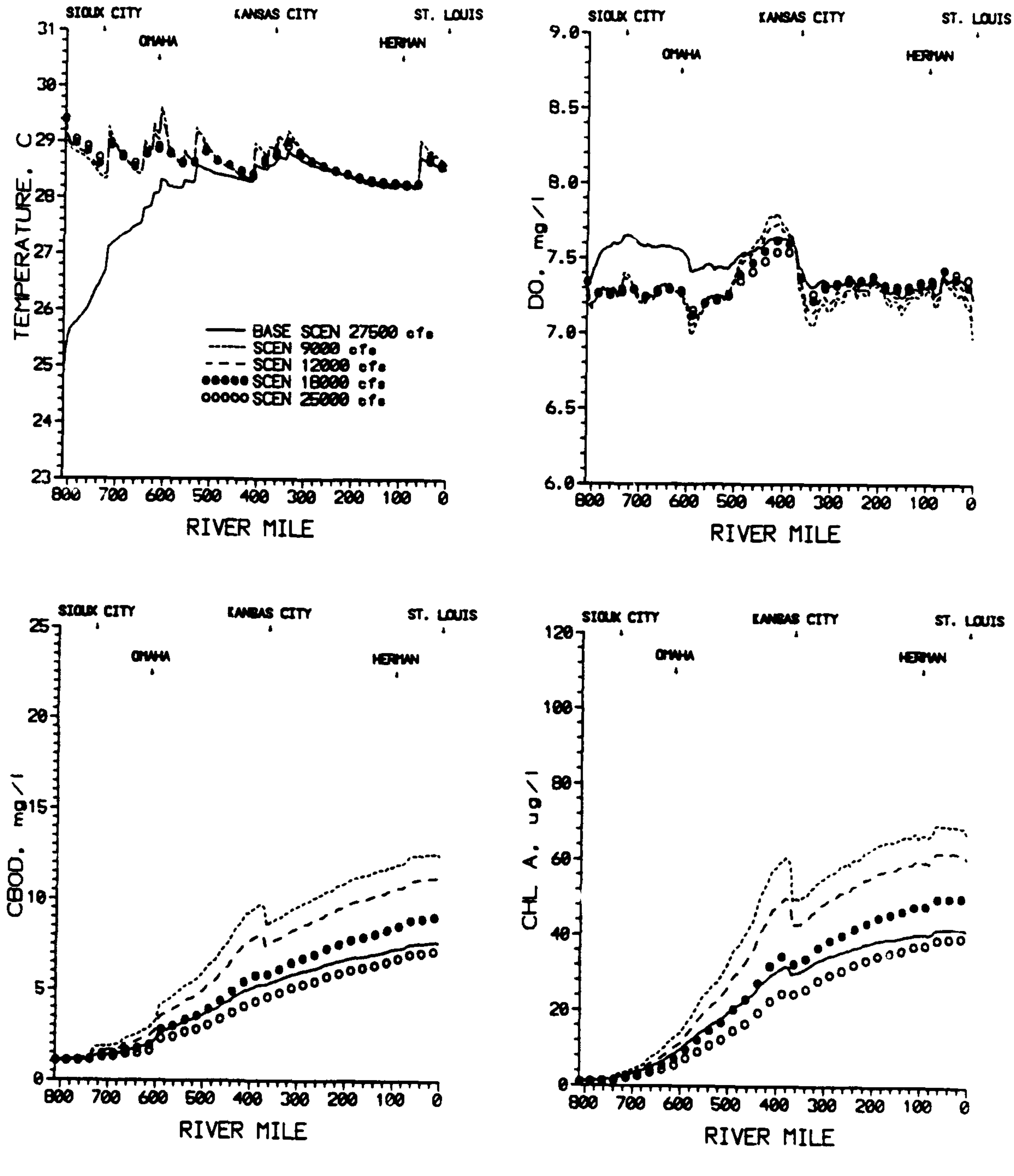


Figure B6. Scenario 2 water quality results for the release temperature of 29.4 °C and all flow conditions. Boundary conditions for this scenario were set to 14T10 met conditions, maximum water quality concentrations on tributaries, 2-year tributary flows, maximum permit limits from point sources (i.e., water treatment plants), and A90 power plant loads (see definitions in Table 13 for abbreviations) (Continued)

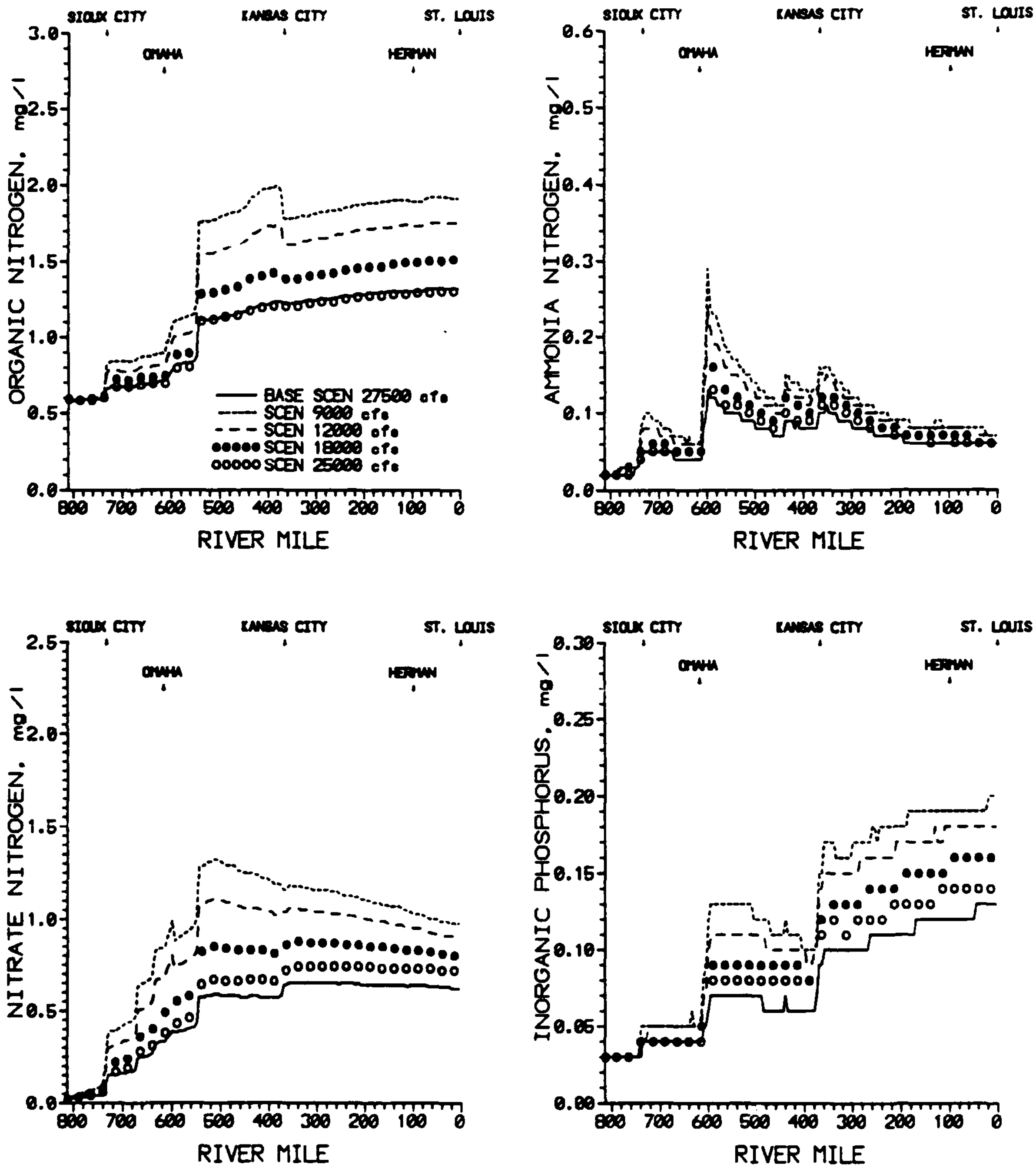


Figure B6. (Concluded)

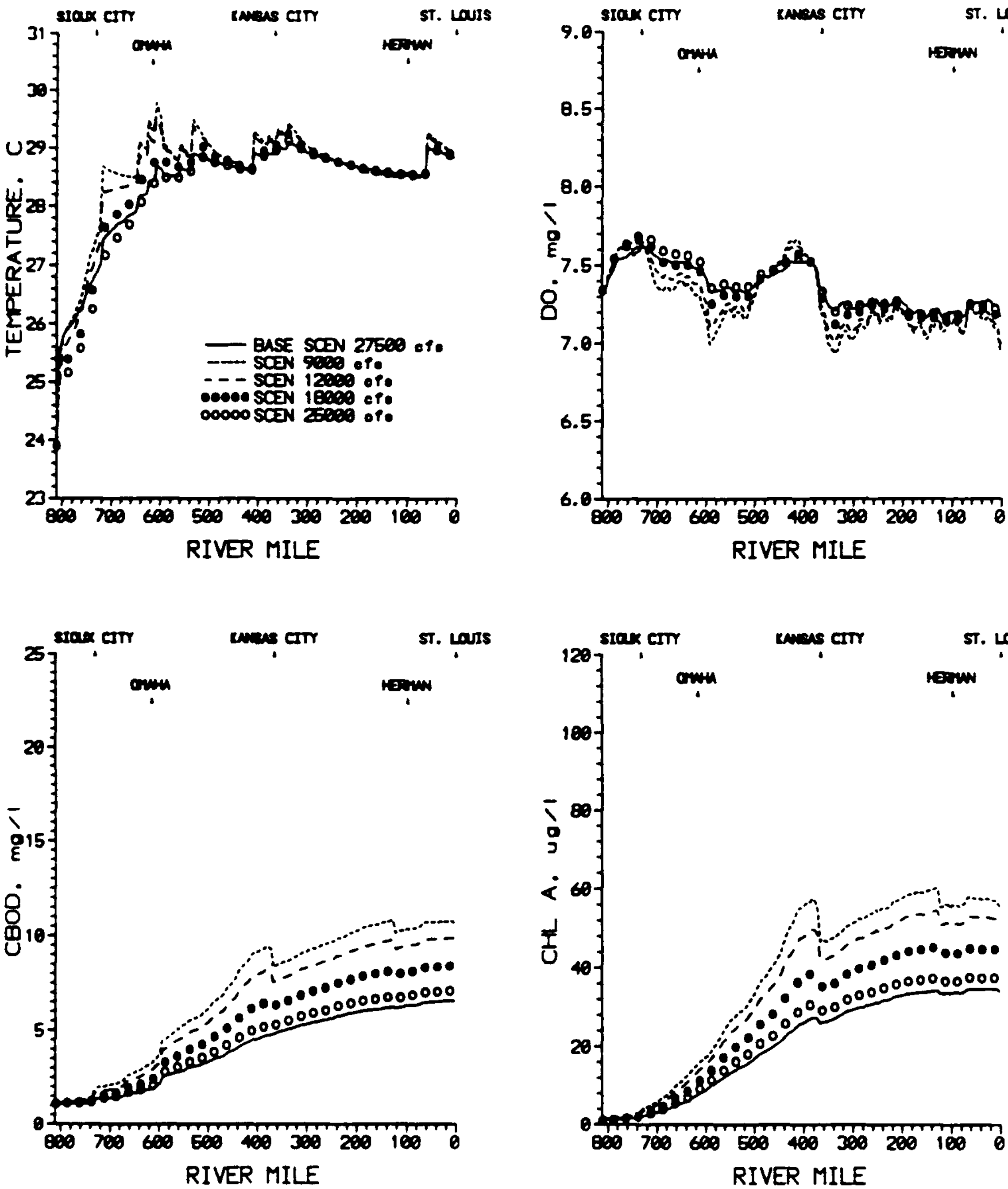
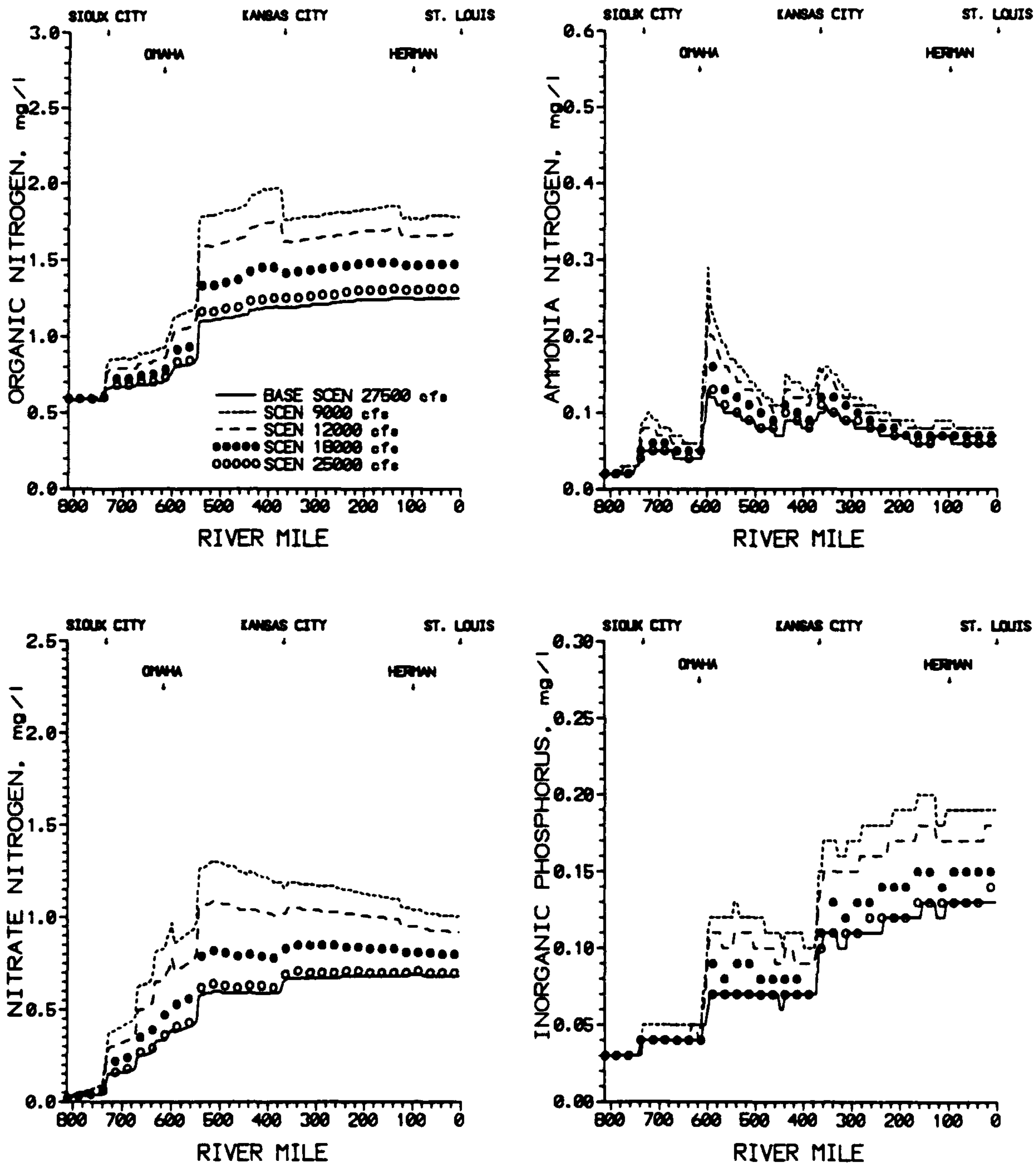


Figure B7. Scenario 3 water quality results for the release temperature of 23.9 °C and all flow conditions. Boundary conditions for this scenario were set to maximum met conditions, maximum water quality concentrations on tributaries, 2-year tributary flows, maximum permit limits from point sources (i.e., water treatment plants), and A90 power plant loads (see definitions in Table 13 for abbreviations) (Continued)



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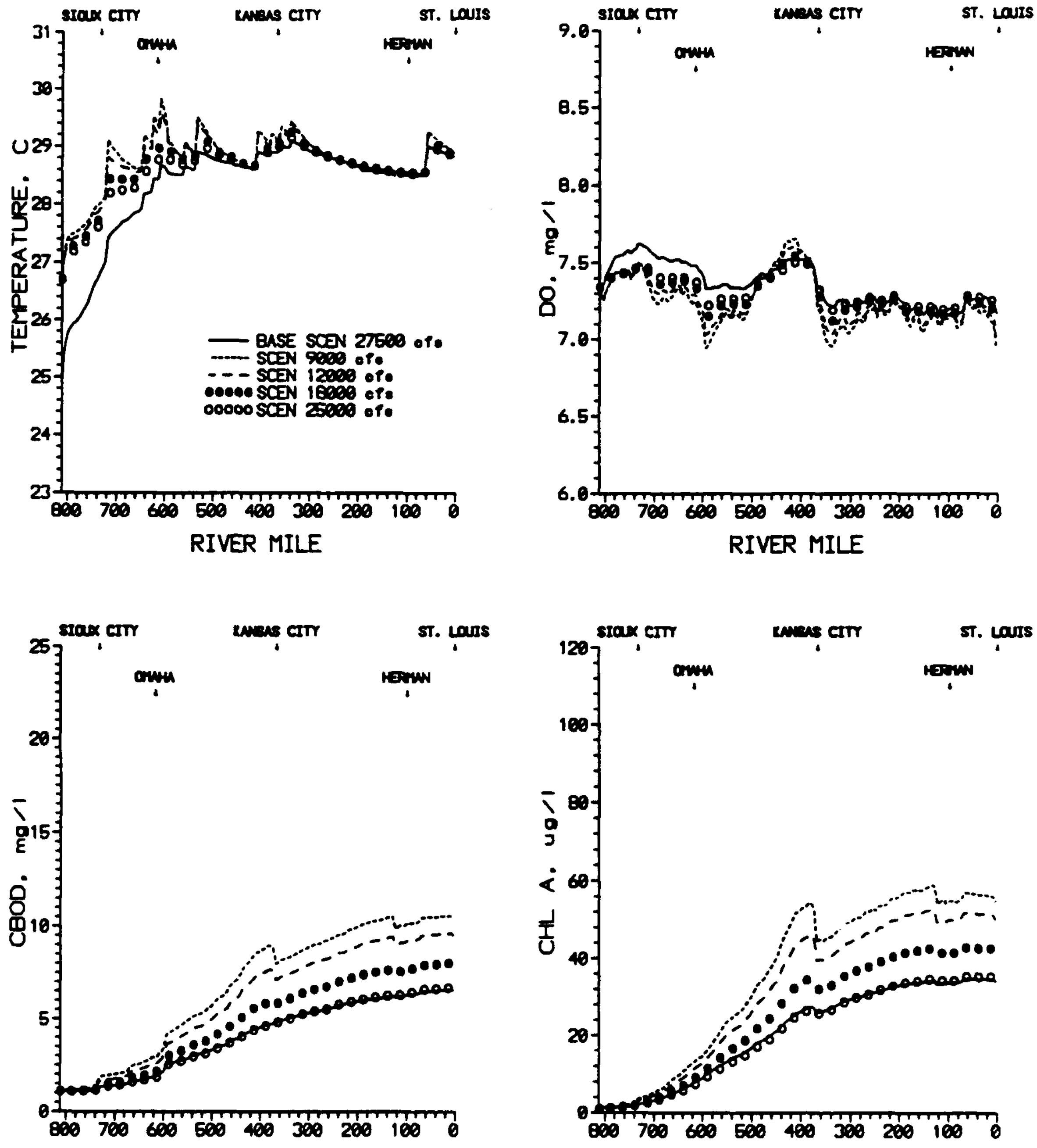
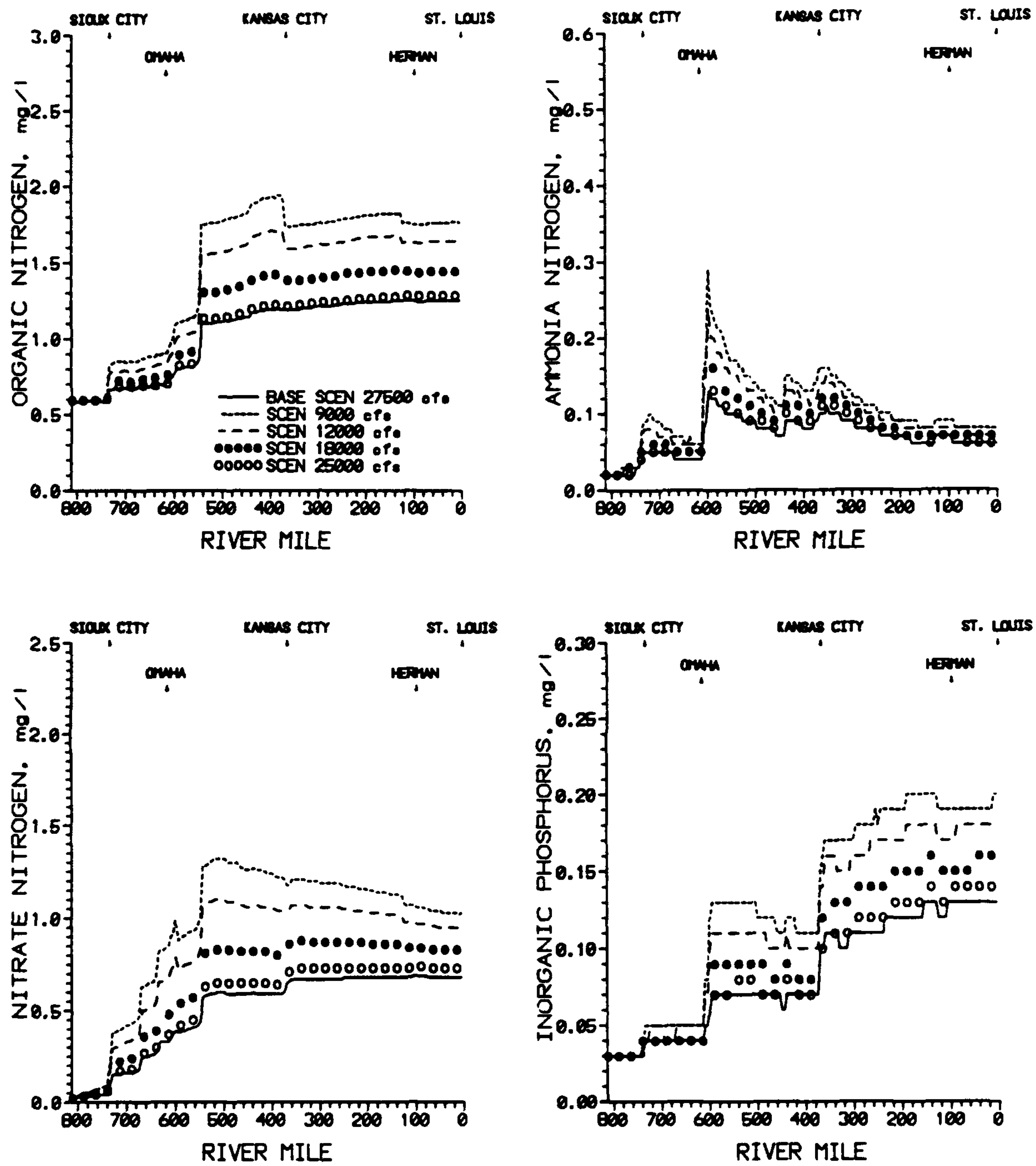


Figure B8. Scenario 3 water quality results for the release temperature of 26.7 °C and all flow conditions. Boundary conditions for this scenario were set to maximum met conditions, maximum water quality concentrations on tributaries, 2-year tributary flows, maximum permit limits from point sources (i.e., water treatment plants), and A90 power plant loads (see definitions in Table 13 for abbreviations) (Continued)



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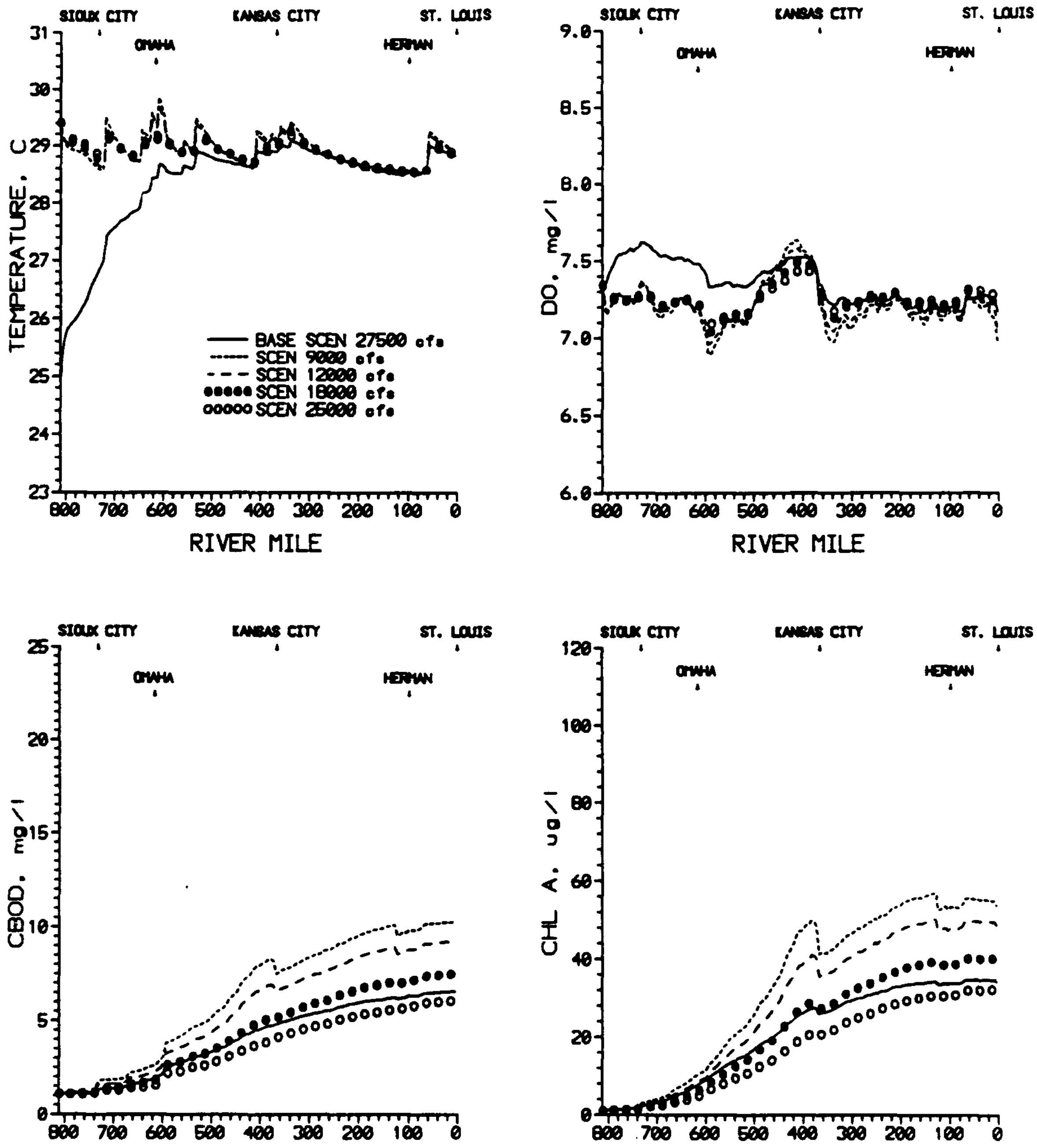
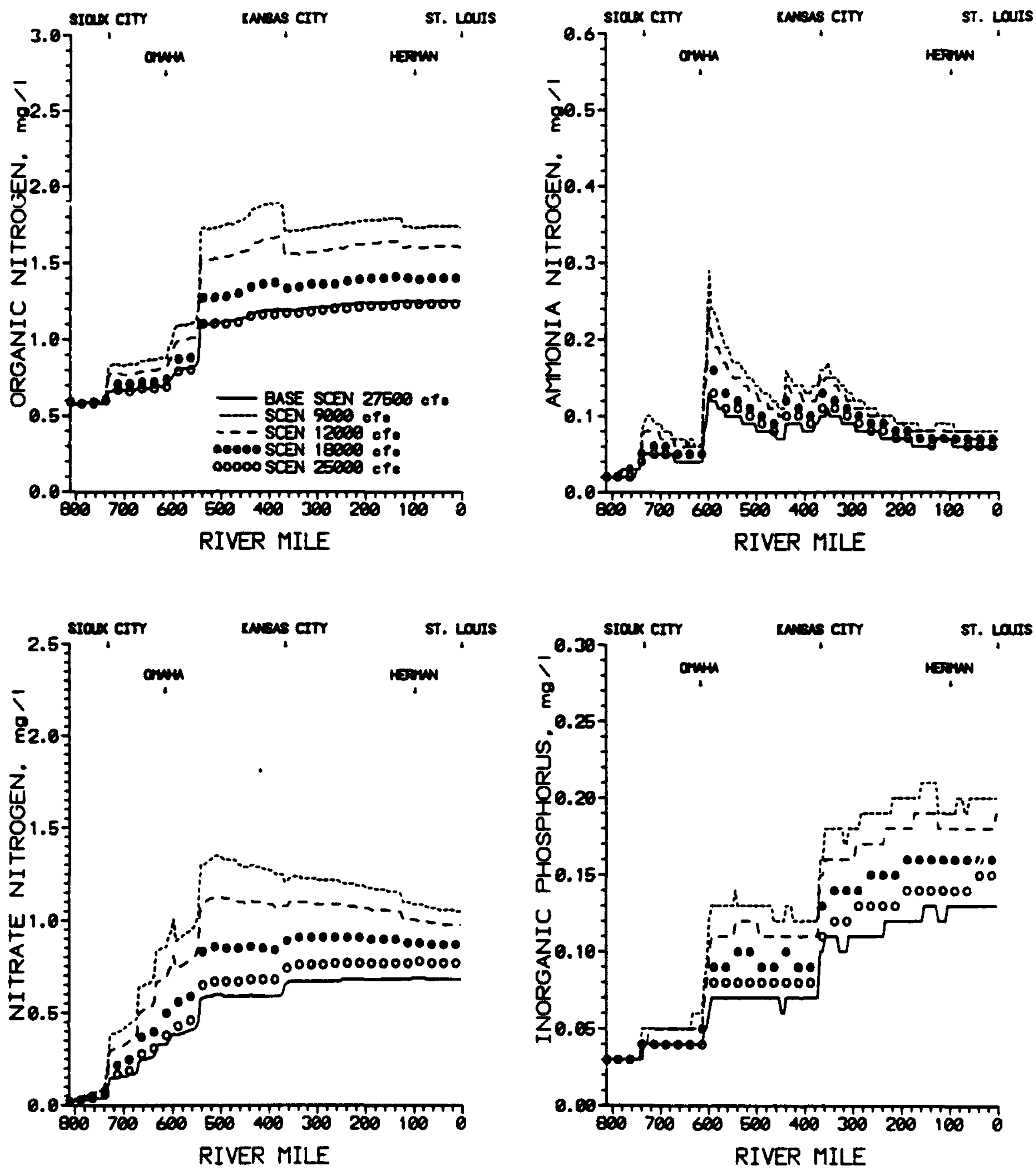


Figure B9. Scenario 3 water quality results for the release temperature of 29.4 °C and all flow conditions. Boundary conditions for this scenario were set to maximum met conditions, maximum water quality concentrations on tributaries, 2-year tributary flows, maximum permit limits from point sources (i.e., water treatment plants), and A90 power plant loads (see definitions in Table 13 for abbreviations) (Continued)



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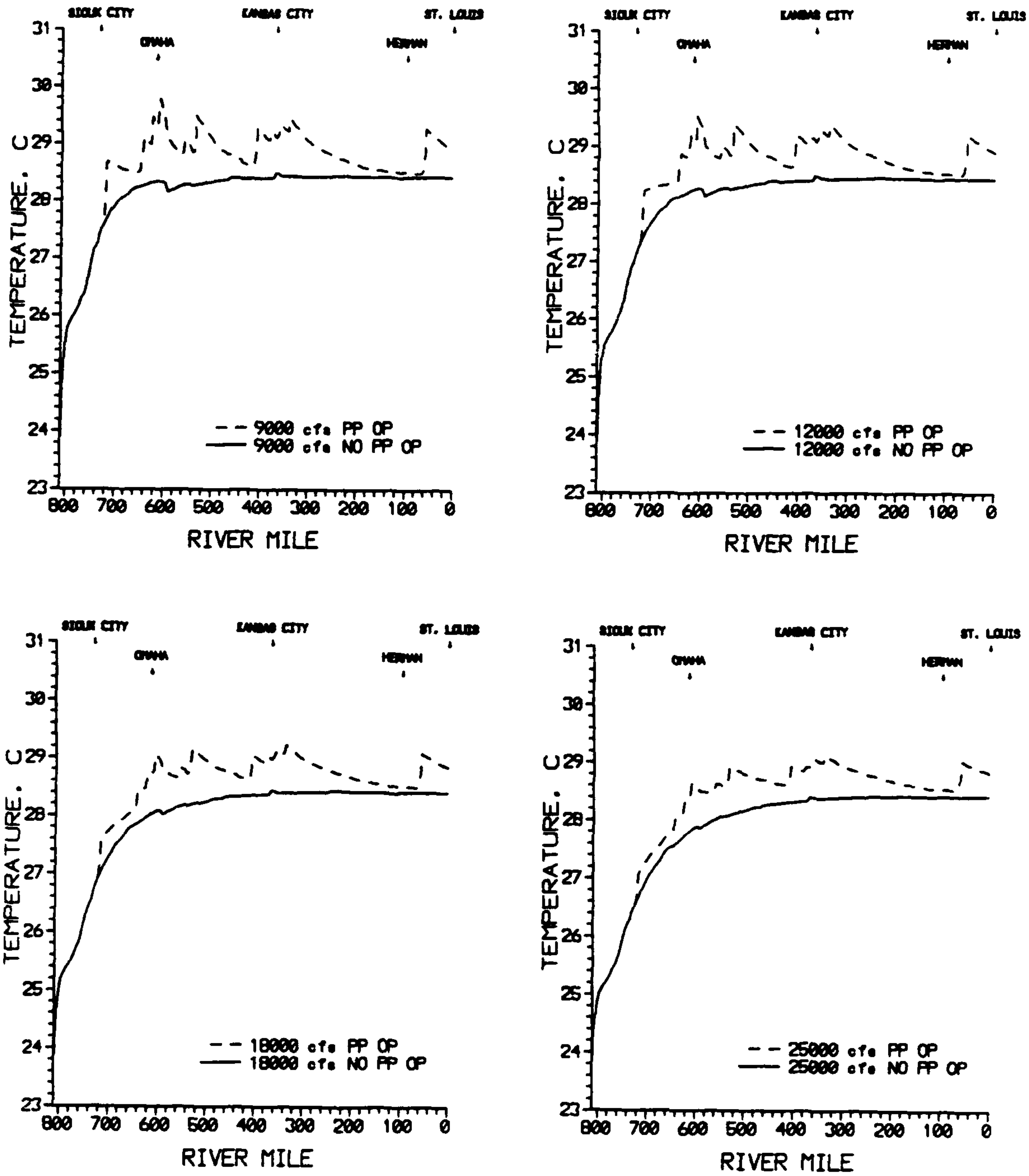


Figure B10. Scenario 4 water quality results for the release temperature of 23.9 °C and all flow conditions. Boundary conditions for this scenario were set to maximum met conditions, maximum water quality concentrations on tributaries, 2-year tributary flows, maximum permit limits from point sources (i.e., water treatment plants), and no power plants operating (NPP) (see definitions in Table 13 for abbreviations)

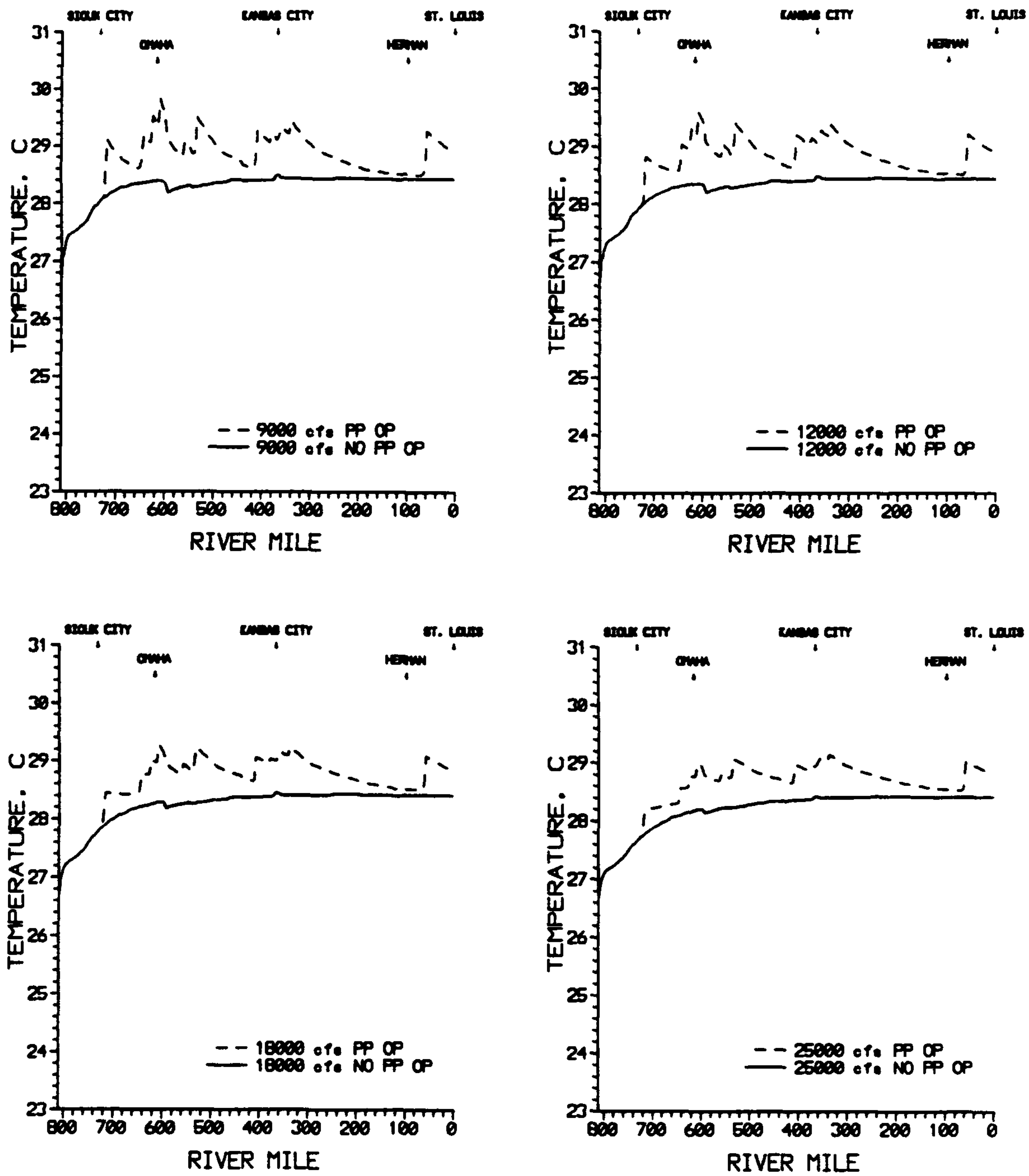


Figure B11. Scenario 4 water quality results for the release temperature of 26.7 °C and all flow conditions. Boundary conditions for this scenario were set to maximum met conditions, maximum water quality concentrations on tributaries, 2-year tributary flows, maximum permit limits from point sources (i.e., water treatment plants), and no power plants operating (NPP) (see definitions in Table 13 for abbreviations)

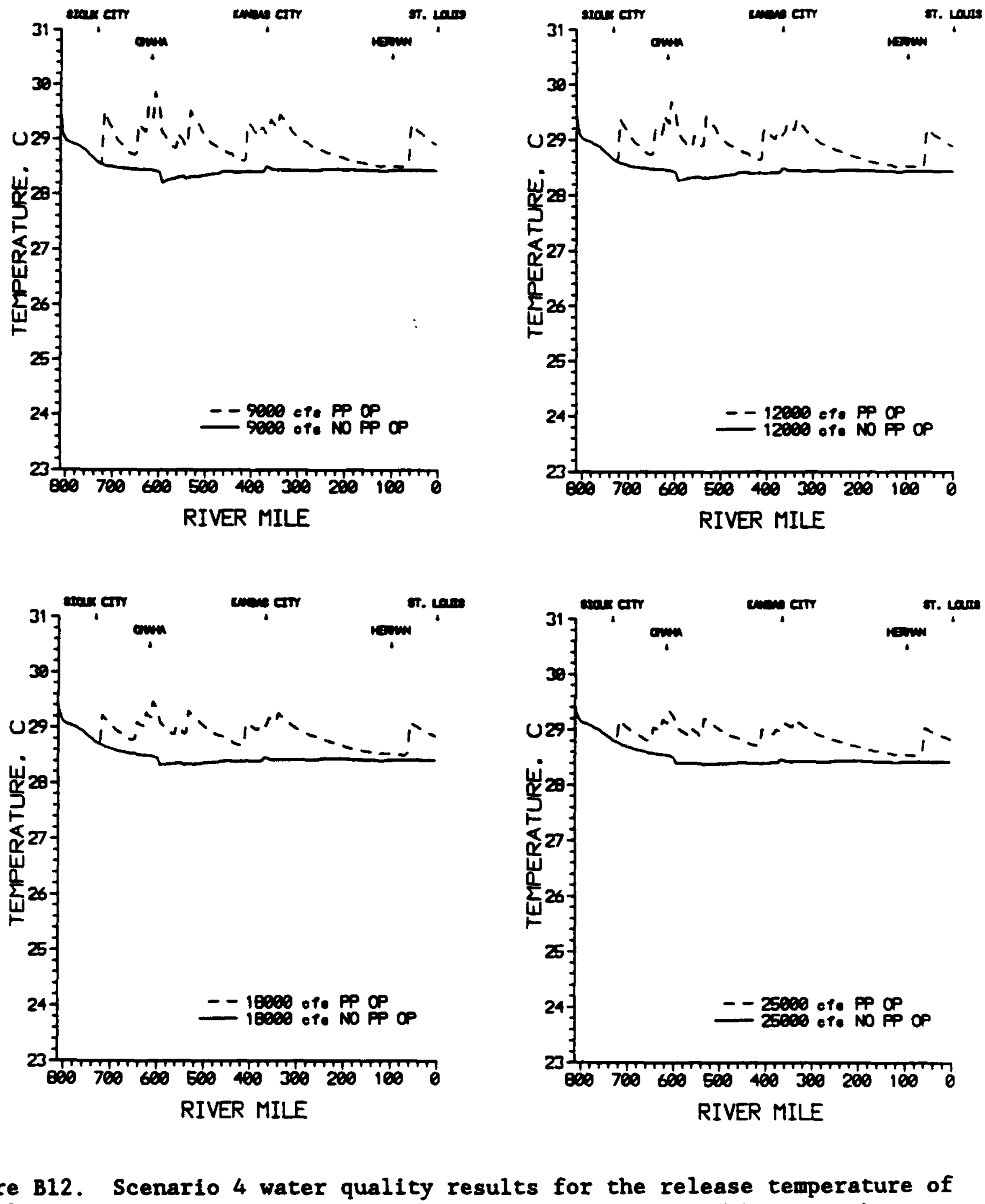


Figure B12. Scenario 4 water quality results for the release temperature of 29.4 °C and all flow conditions. Boundary conditions for this scenario were set to maximum met conditions, maximum water quality concentrations on tributaries, 2-year tributary flows, maximum permit limits from point sources (i.e., water treatment plants), and no power plants operating (NPP) (see definitions in Table 13 for abbreviations)

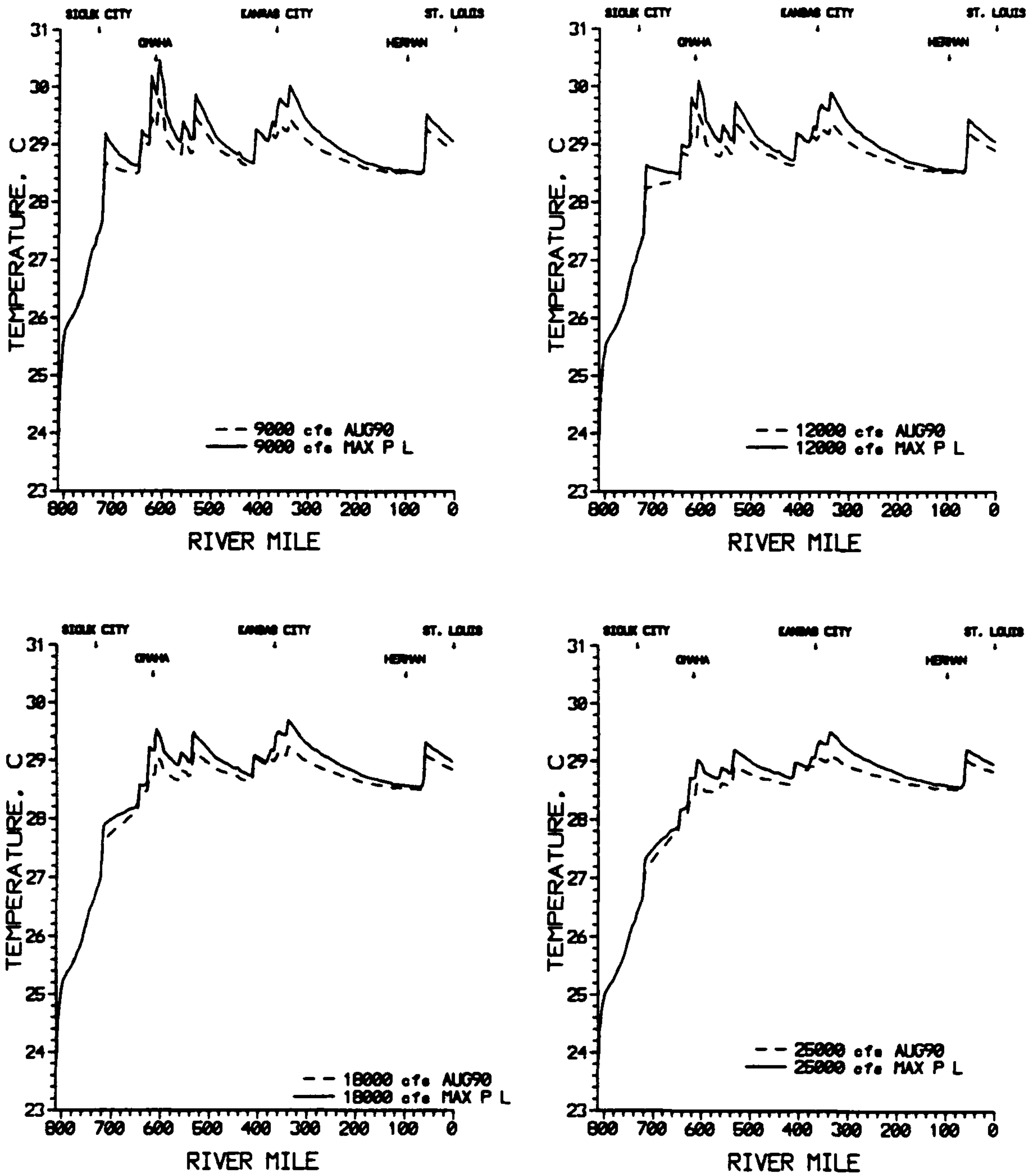


Figure B13. Scenario 5 temperature results for the release temperature of 23.9 °C and all flow conditions. Boundary conditions for this scenario were set to maximum met conditions, maximum water quality concentrations on tributaries, 2-year tributary flows, maximum permit limits from point sources (i.e., water treatment plants), and power plants operating fully loaded (see definitions in Table 13)

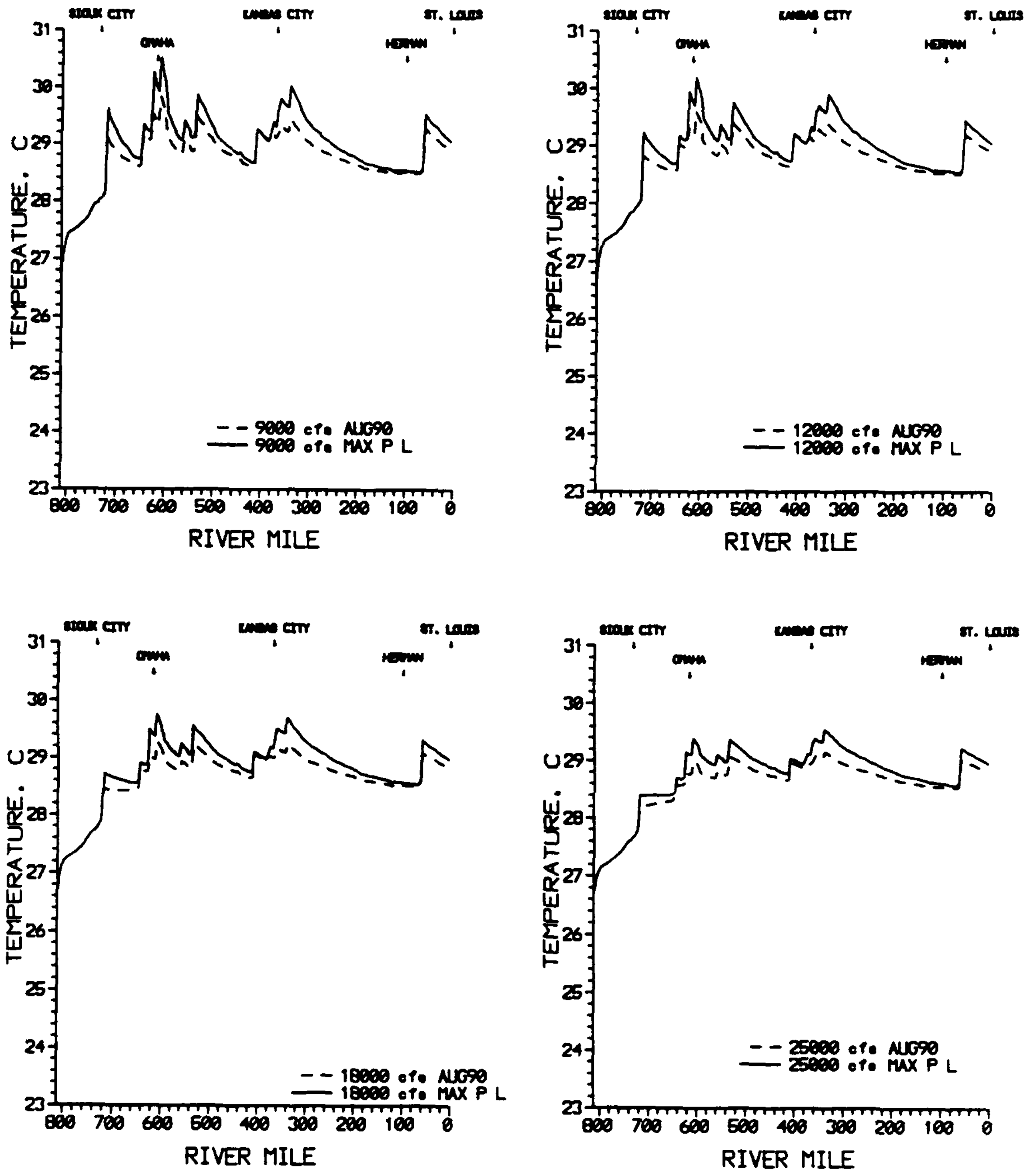


Figure B14. Scenario 5 temperature results for the release temperature of 26.7 °C and all flow conditions. Boundary conditions for this scenario were set to maximum met conditions, maximum water quality concentrations on tributaries, 2-year tributary flows, maximum permit limits from point sources (i.e., water treatment plants), and power plants operating fully loaded (see definitions in Table 13)

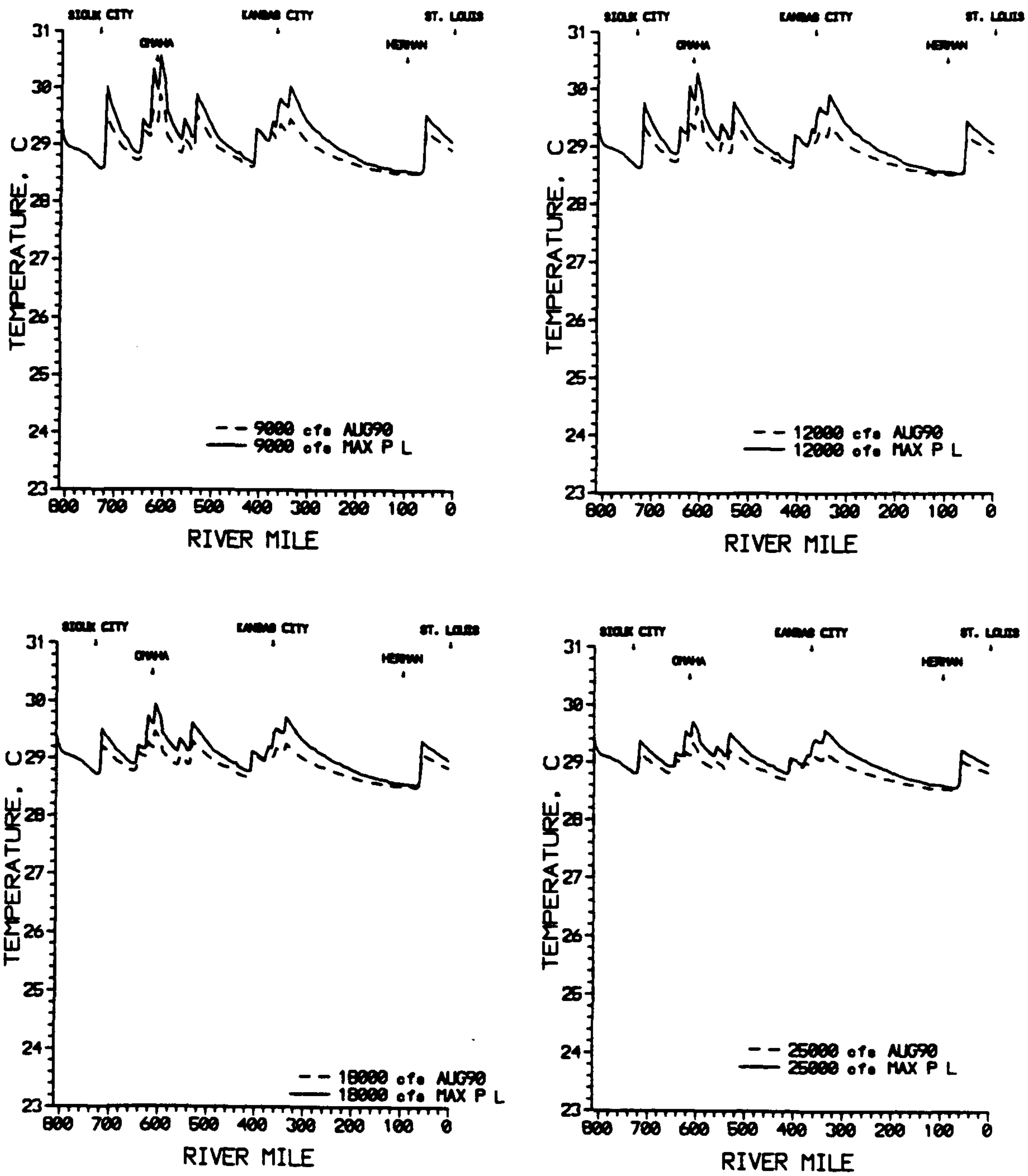


Figure B15. Scenario 5 temperature results for the release temperature of 29.4 °C and all flow conditions. Boundary conditions for this scenario were set to maximum met conditions, maximum water quality concentrations on tributaries, 2-year tributary flows, maximum permit limits from point sources (i.e., water treatment plants), and power plants operating fully loaded (see definitions in Table 13)

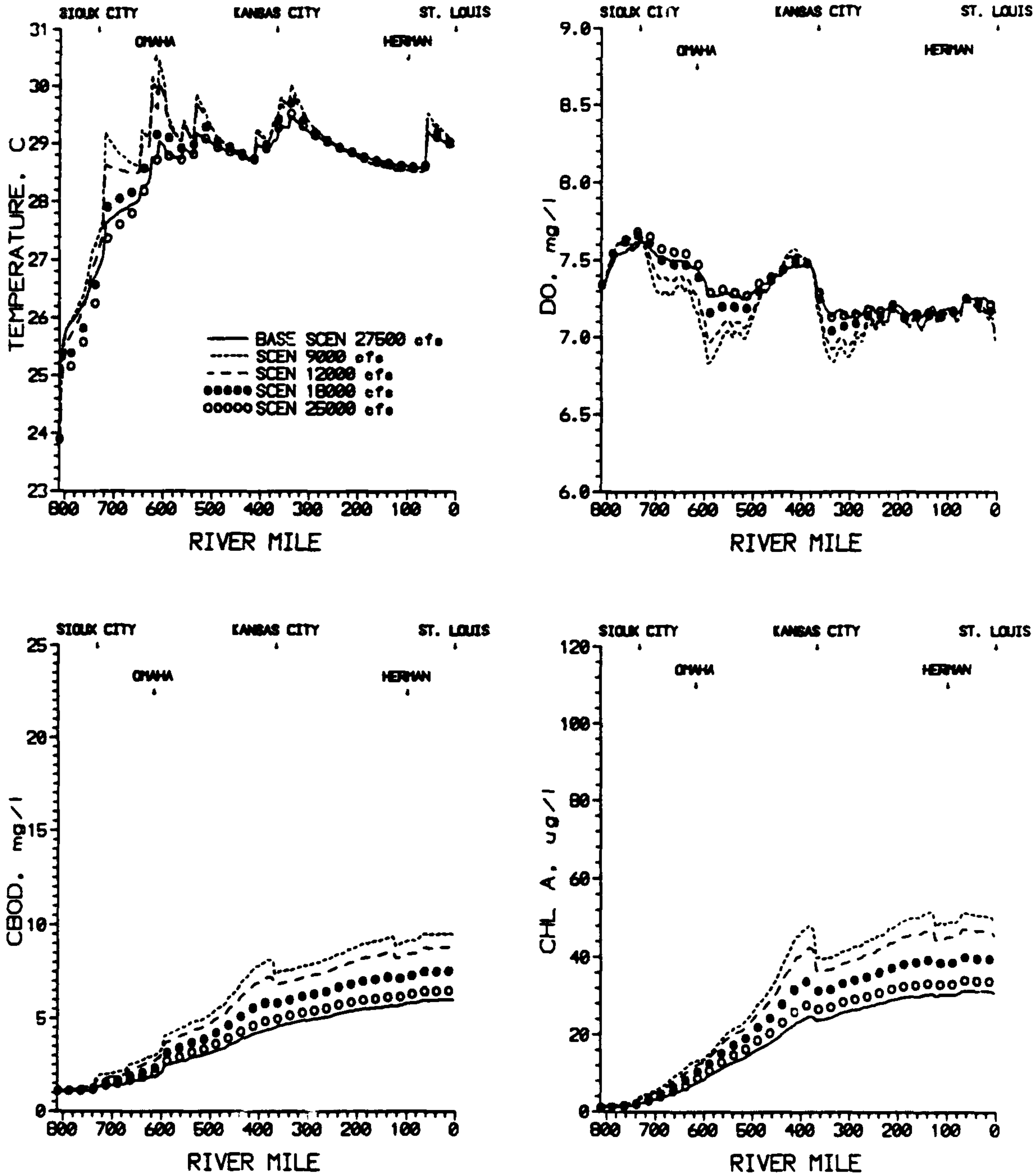


Figure B16. Scenario 5 water quality results for the release temperature of 23.9 °C and all flow conditions. Boundary conditions for this scenario were set to maximum met conditions, maximum water quality concentrations on tributaries, 2-year tributary flows, maximum permit limits from point sources (i.e., water treatment plants), and power plants operating fully loaded (see definitions in Table 13) (Continued)

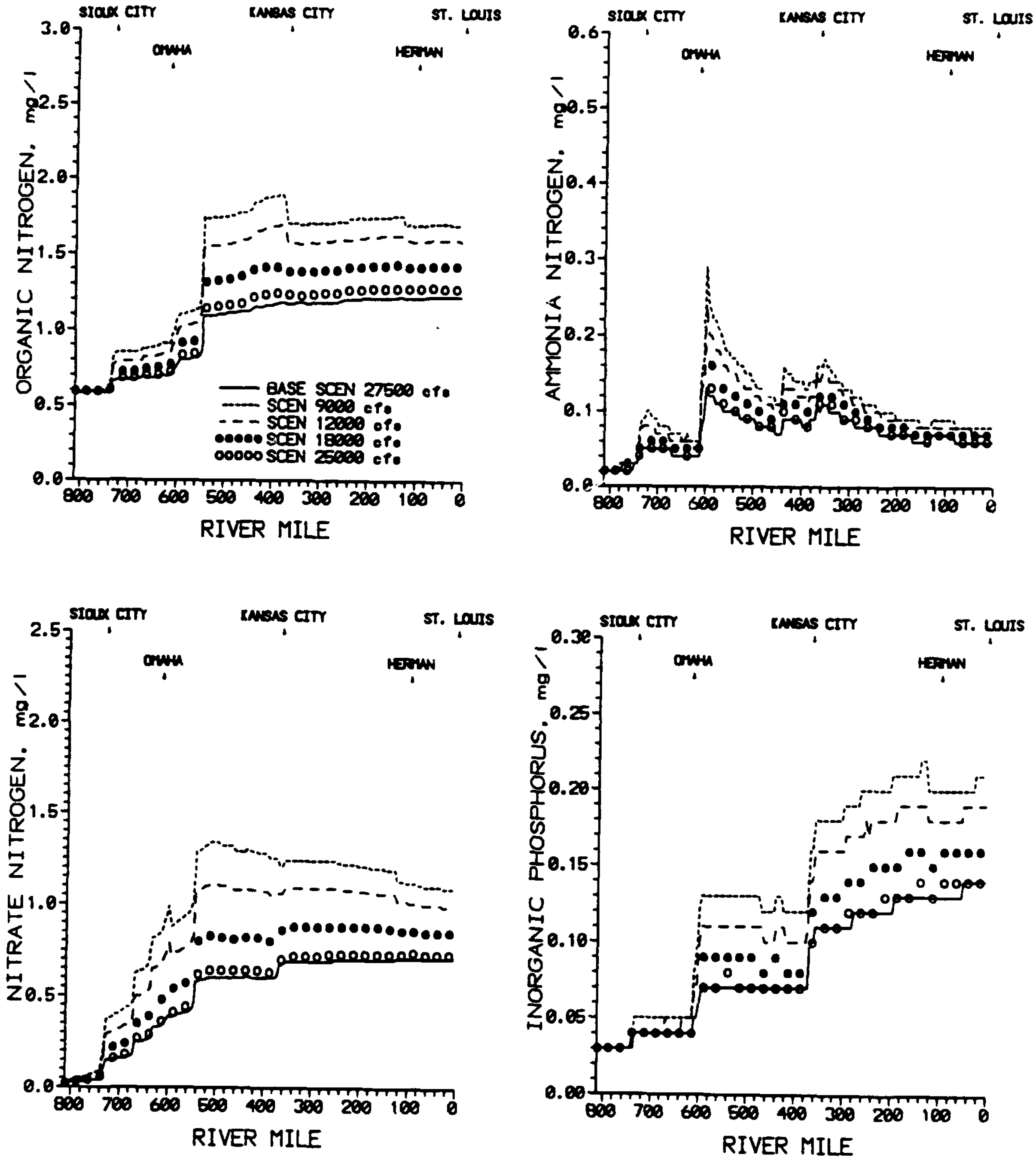


Figure B16. (Concluded)

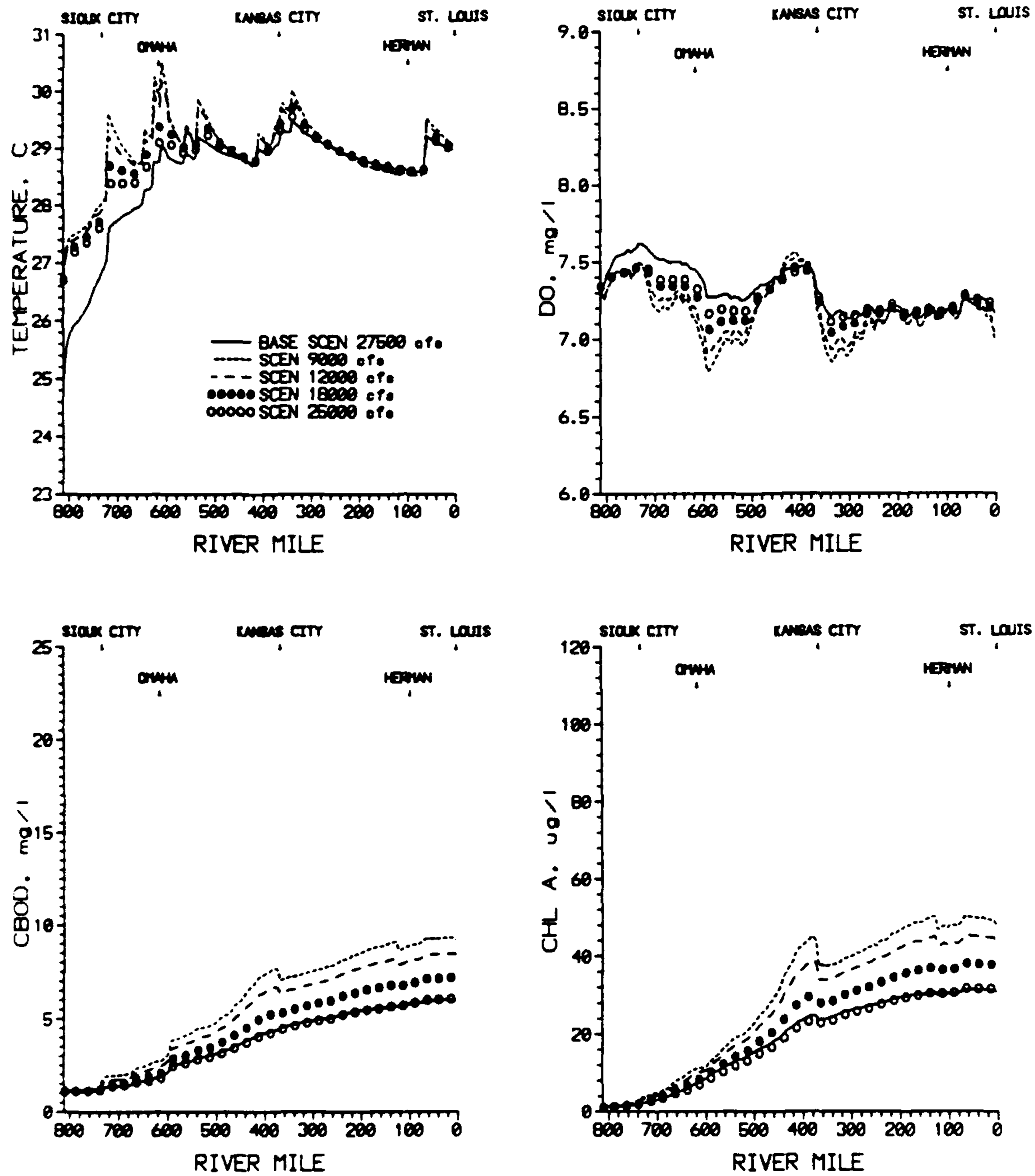
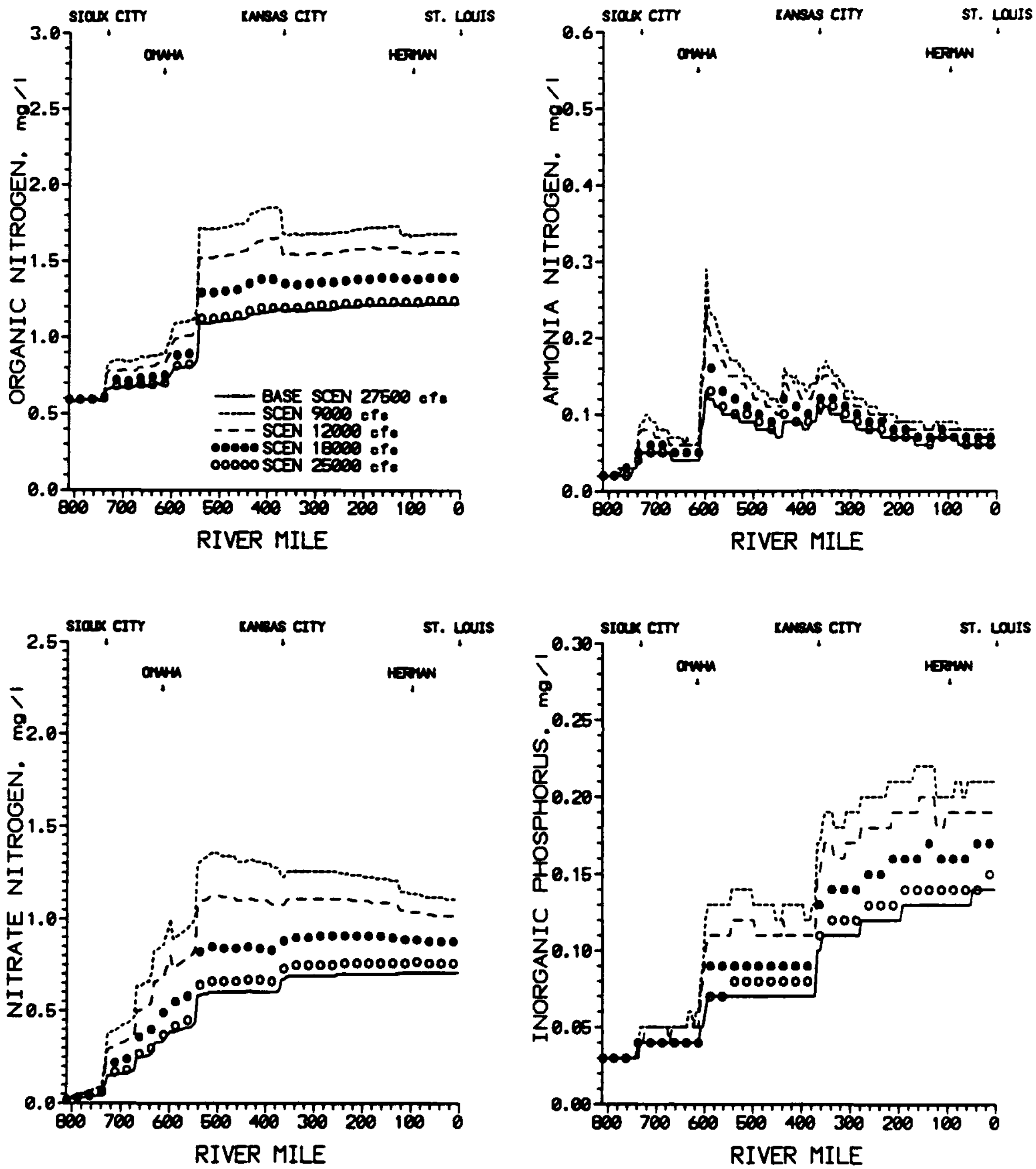


Figure B17. Scenario 5 water quality results for the release temperature of 26.7 °C and all flow conditions. Boundary conditions for this scenario were set to maximum met conditions, maximum water quality concentrations on tributaries, 2-year tributary flows, maximum permit limits from point sources (i.e., water treatment plants), and power plants operating fully loaded (see definitions in Table 13) (Continued)



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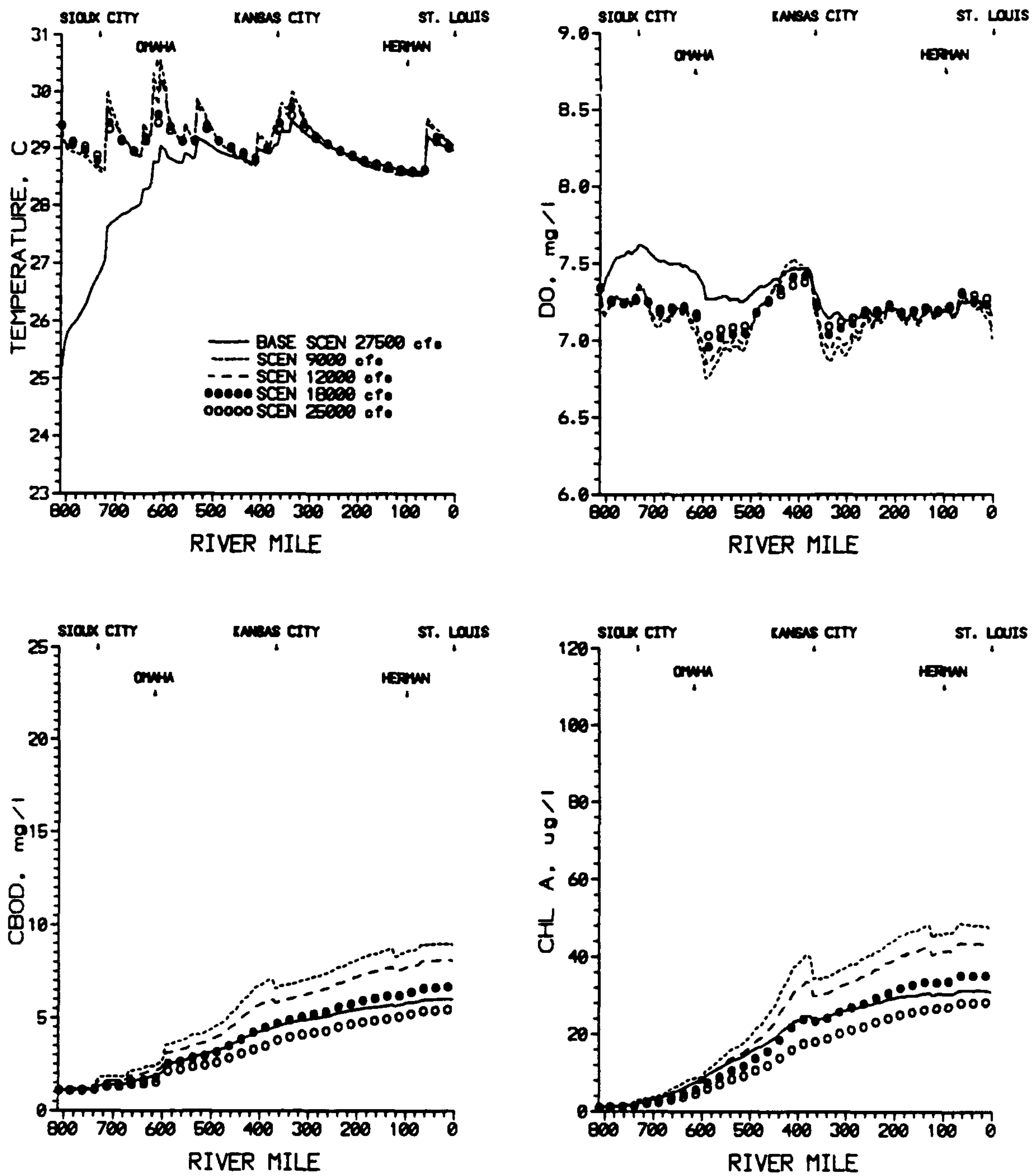


Figure B18. Scenario 5 water quality results for the release temperature of 29.4 °C and all flow conditions. Boundary conditions for this scenario were set to maximum met conditions, maximum water quality concentrations on tributaries, 2-year tributary flows, maximum permit limits from point sources (i.e., water treatment plants), and power plants operating fully loaded (see definitions in Table 13) (Continued)

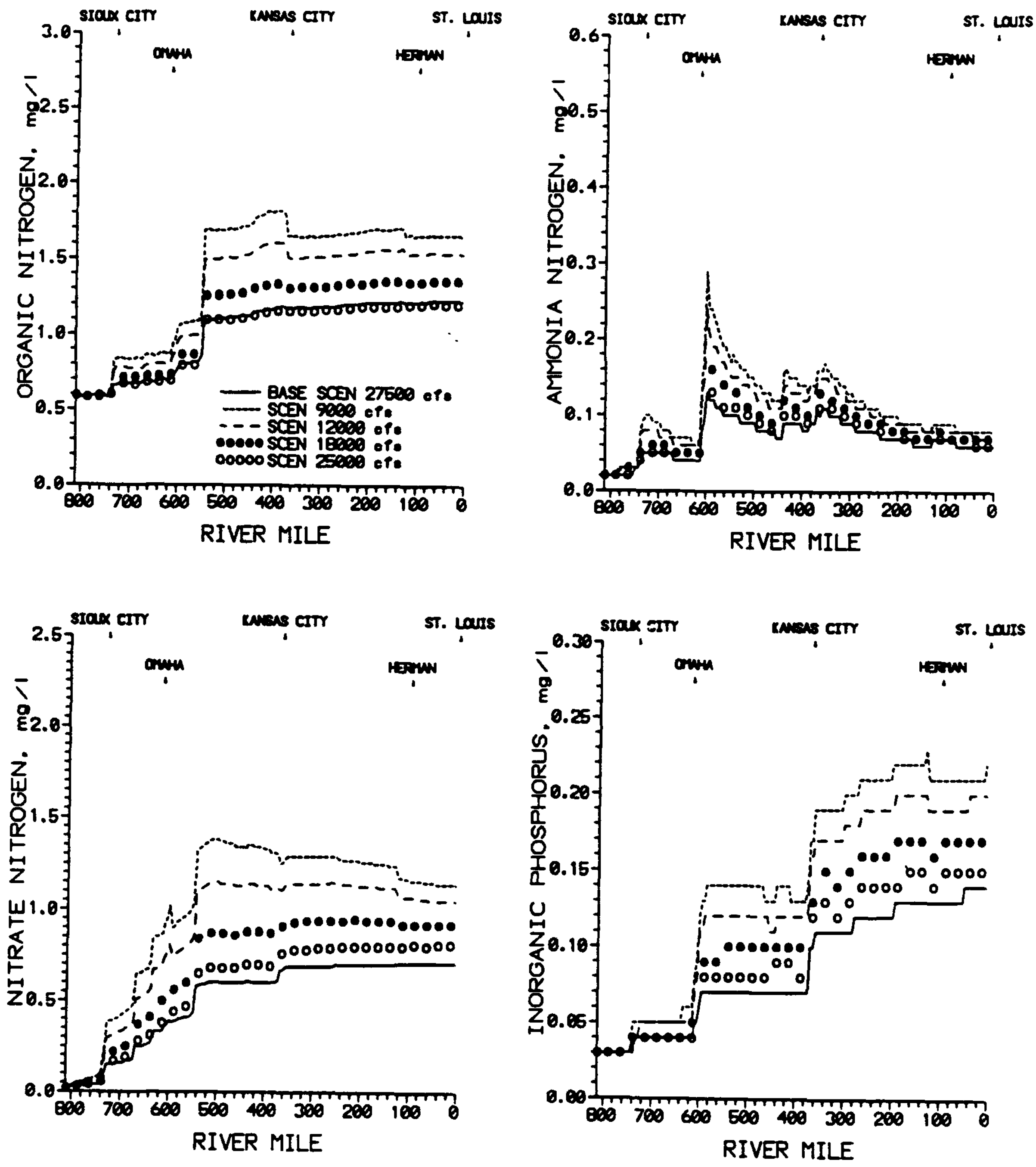


Figure B18. (Concluded)

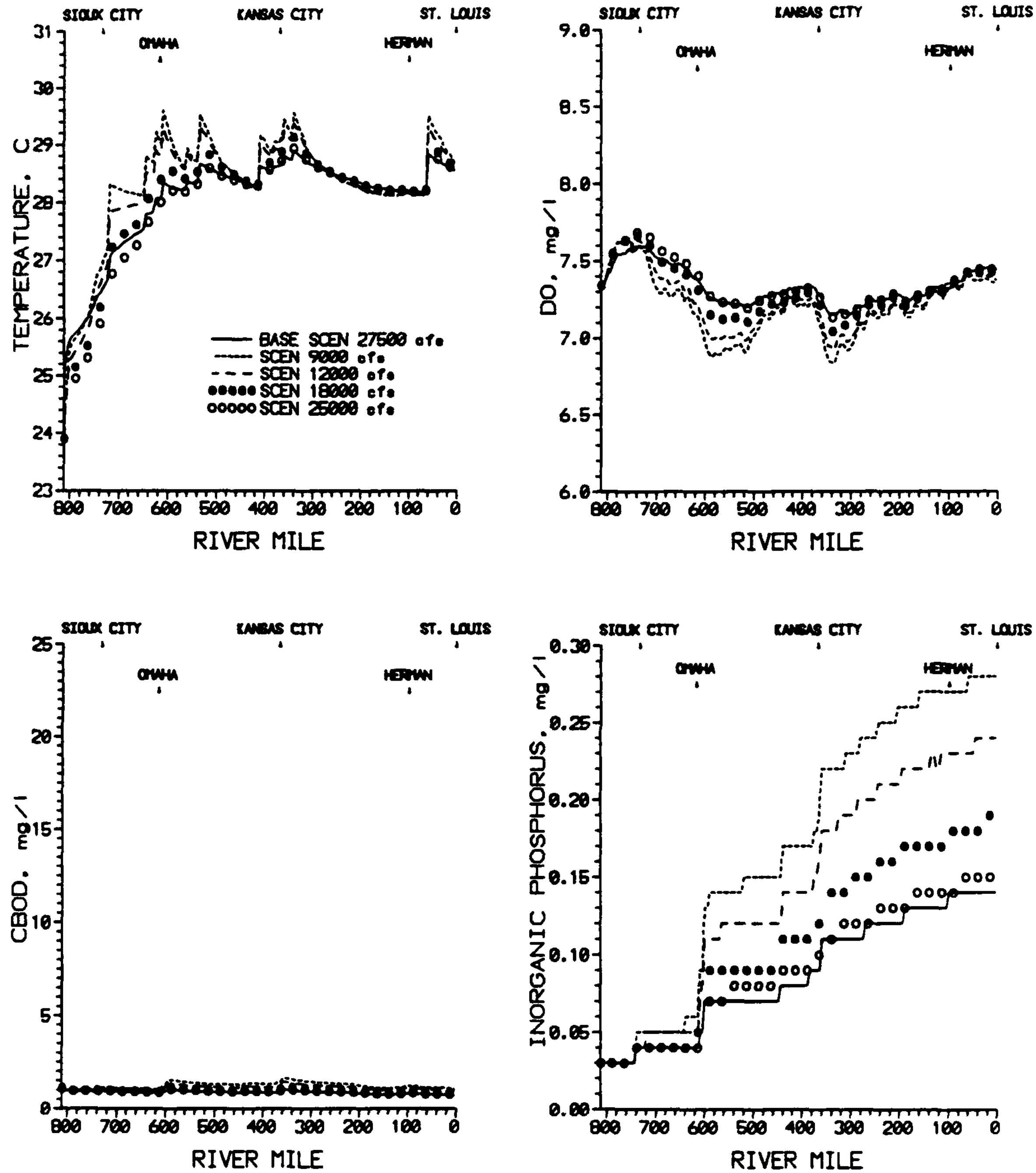
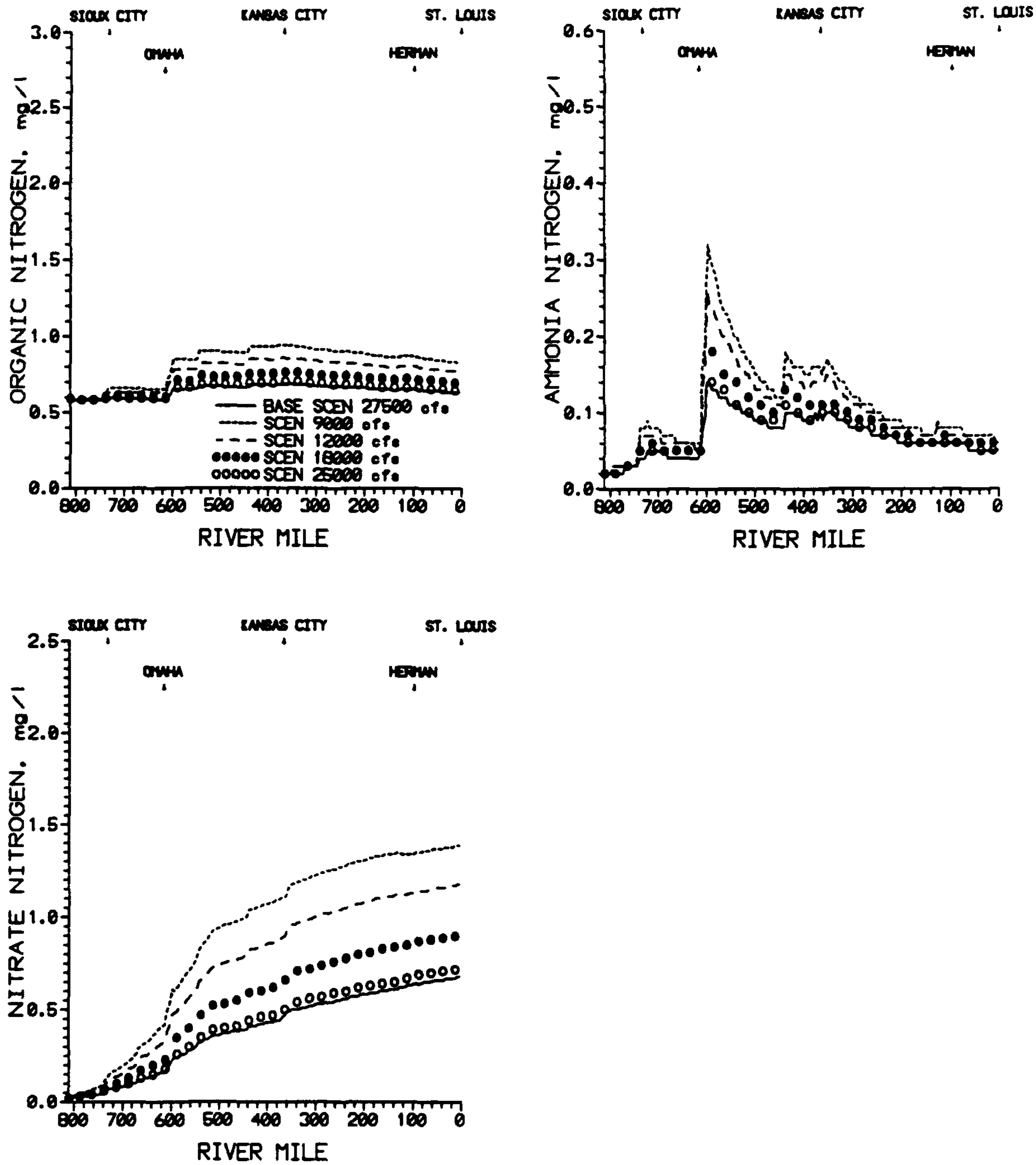


Figure B19. Scenario 6 water quality results (no algae modeled) for the release temperature of 23.9 °C and all flow conditions. Boundary conditions for this scenario were set to 14T10 met conditions, maximum water quality concentrations on tributaries, 7Q10 tributary flows, maximum permit limits from point sources (i.e., water treatment plants), and A90 power plant loads (see definitions in Table 13) (Continued)



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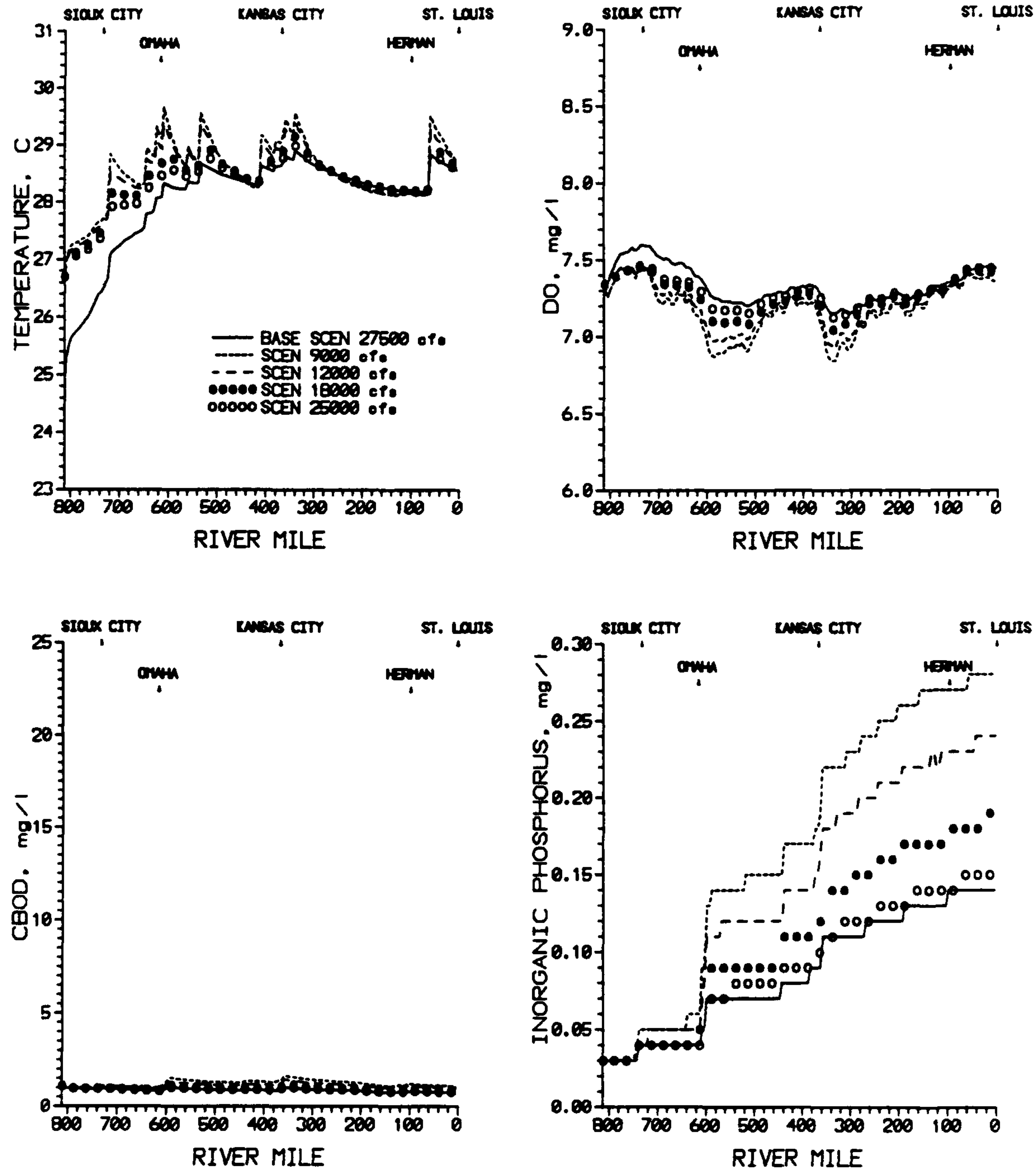
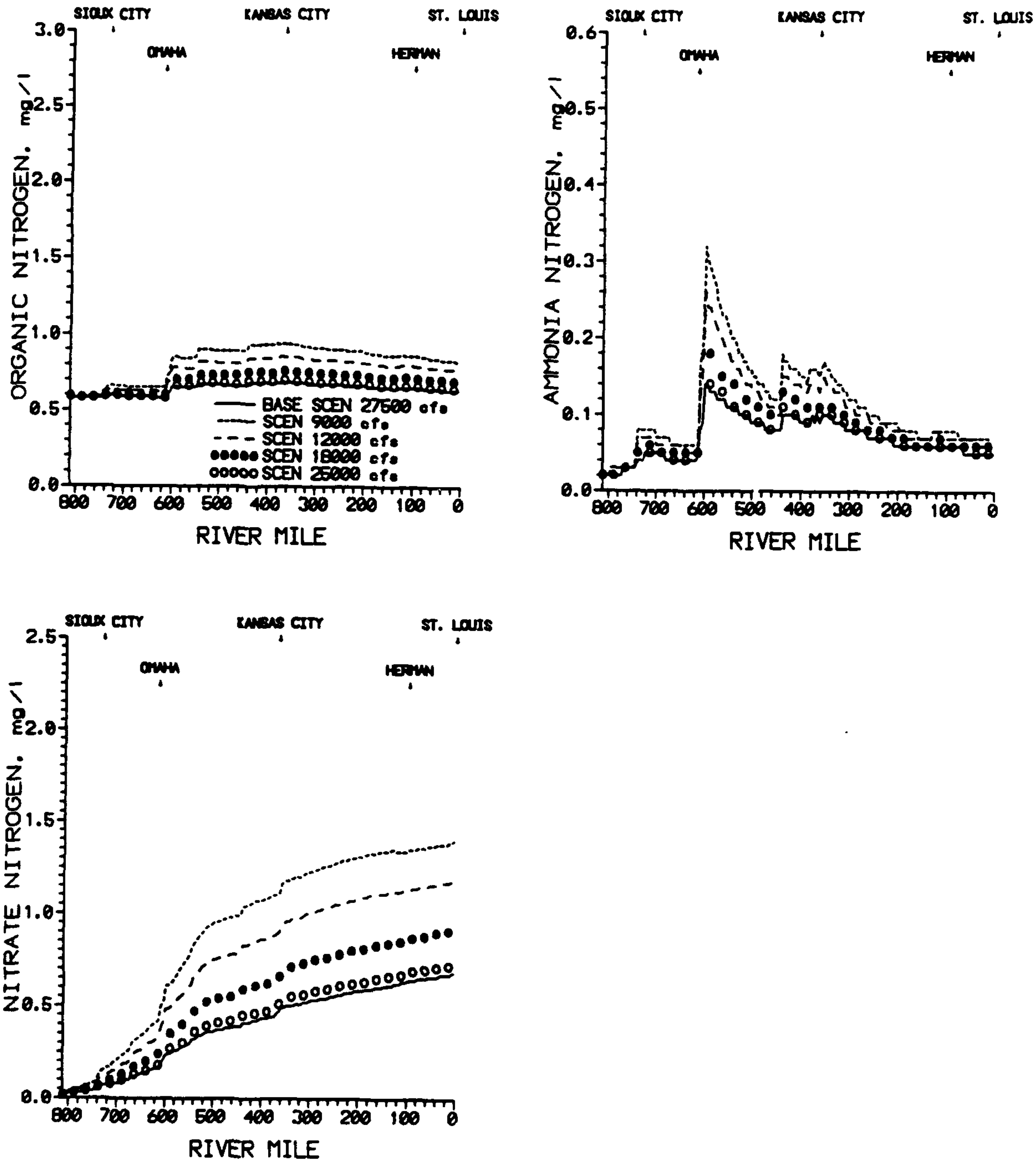


Figure B20. Scenario 6 water quality results (no algae modeled) for the release temperature of 26.7 °C and all flow conditions. Boundary conditions for this scenario were set to 14T10 met conditions, maximum water quality concentrations on tributaries, 7Q10 tributary flows, maximum permit limits from point sources (i.e., water treatment plants), and A90 power plant loads (see definitions in Table 13) (Continued)



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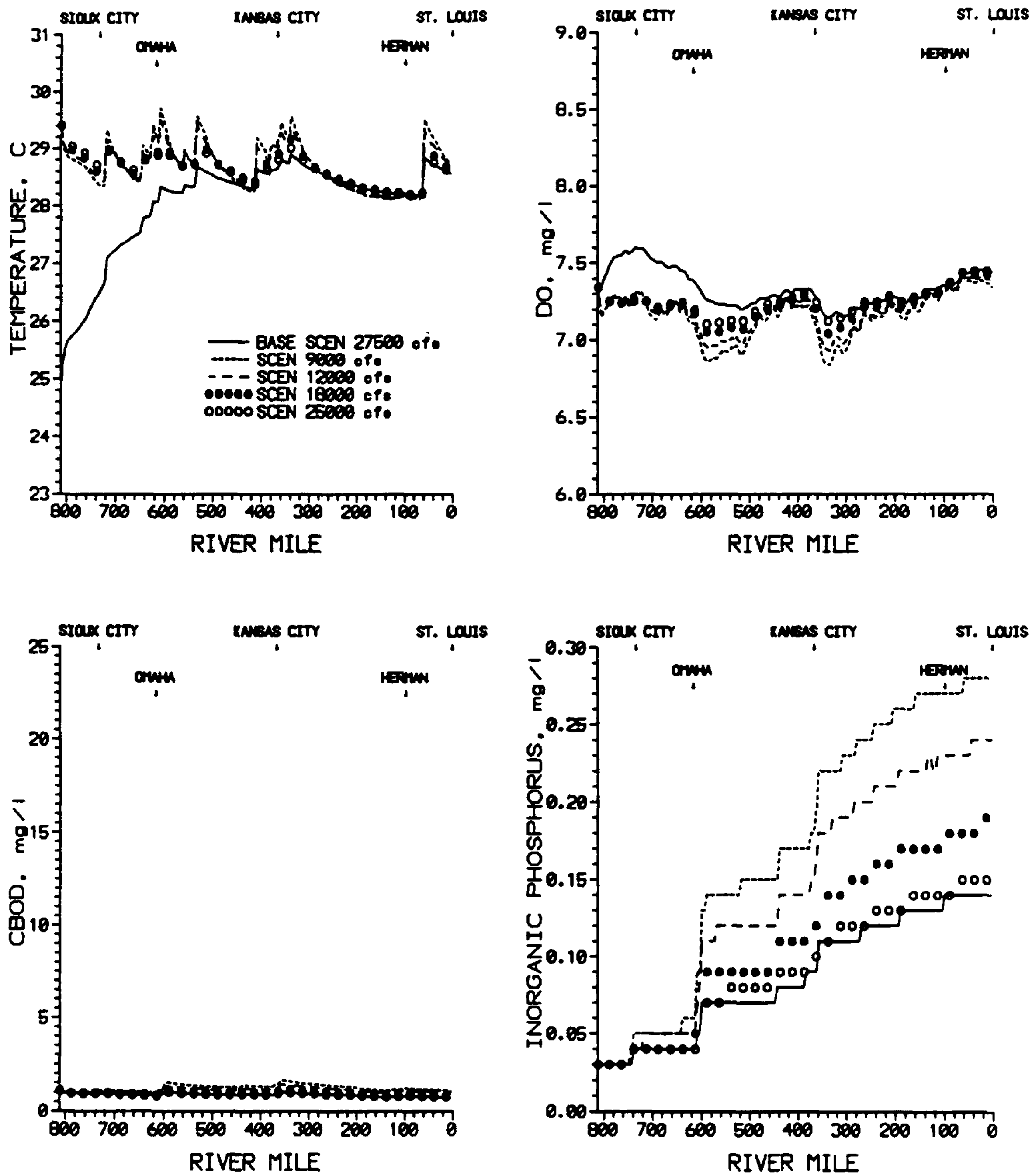
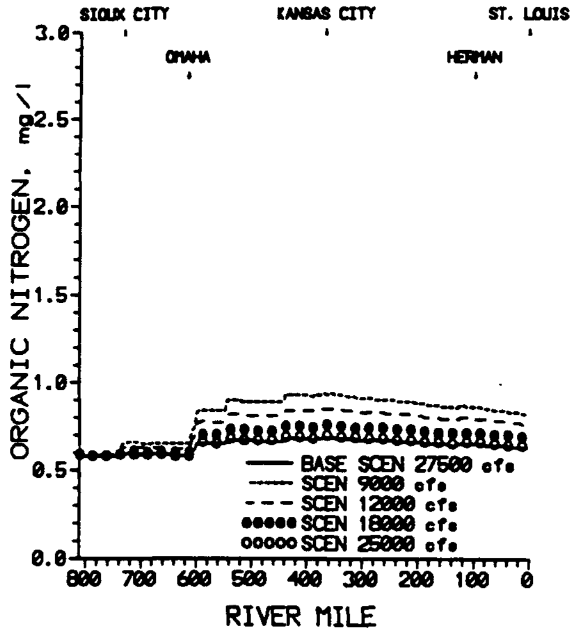
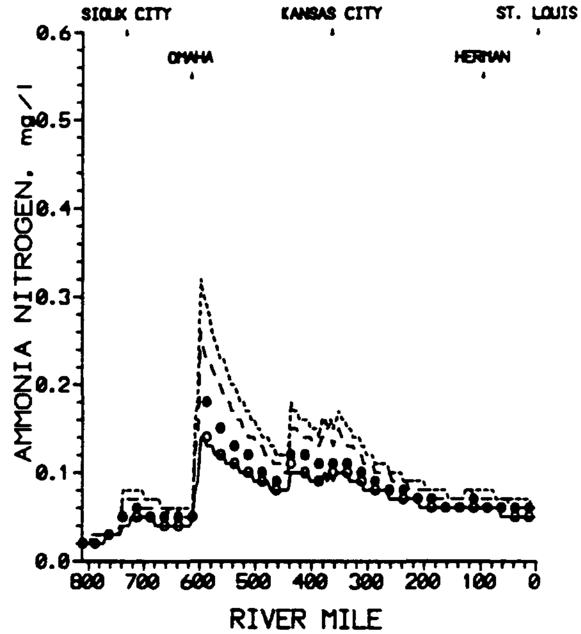
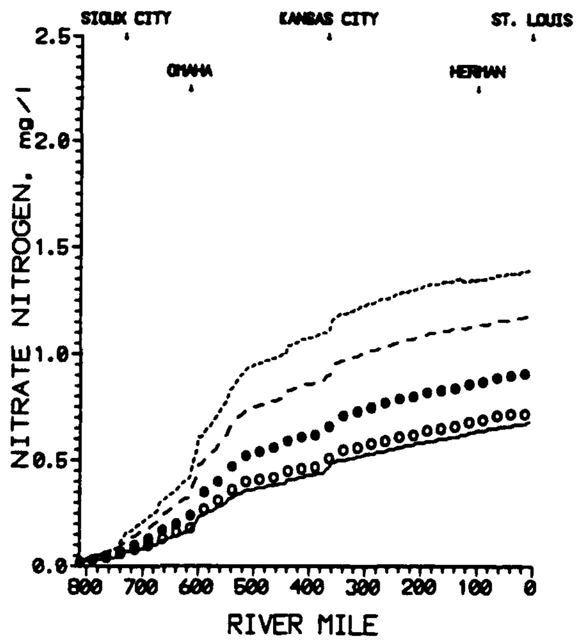


Figure B21. Scenario 6 water quality results (no algae modeled) for the release temperature of 29.4 °C and all flow conditions. Boundary conditions for this scenario were set to 14T10 met conditions, maximum water quality concentrations on tributaries, 7Q10 tributary flows, maximum permit limits from point sources (i.e., water treatment plants), and A90 power plant loads (see definitions in Table 13) (Continued)







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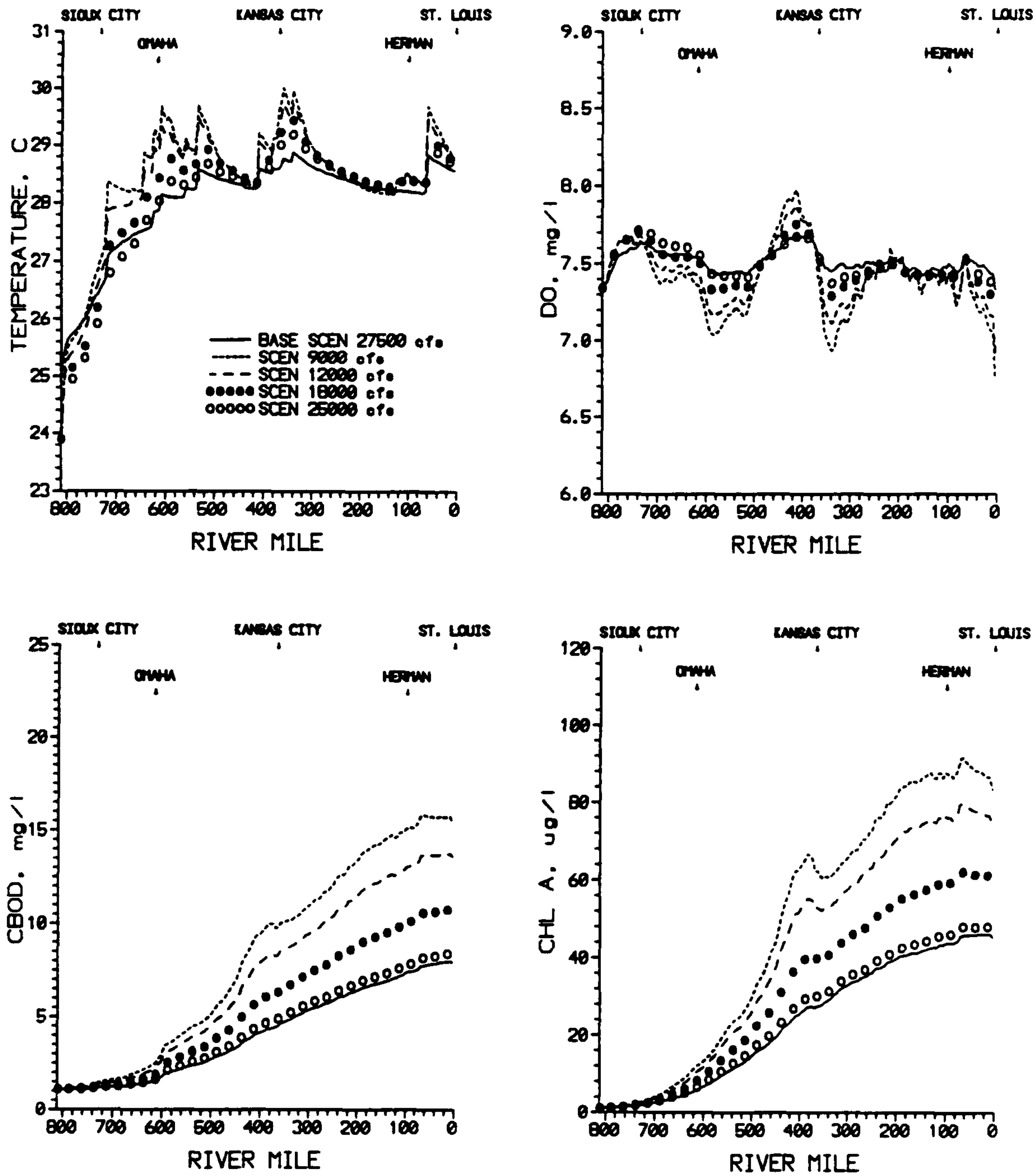
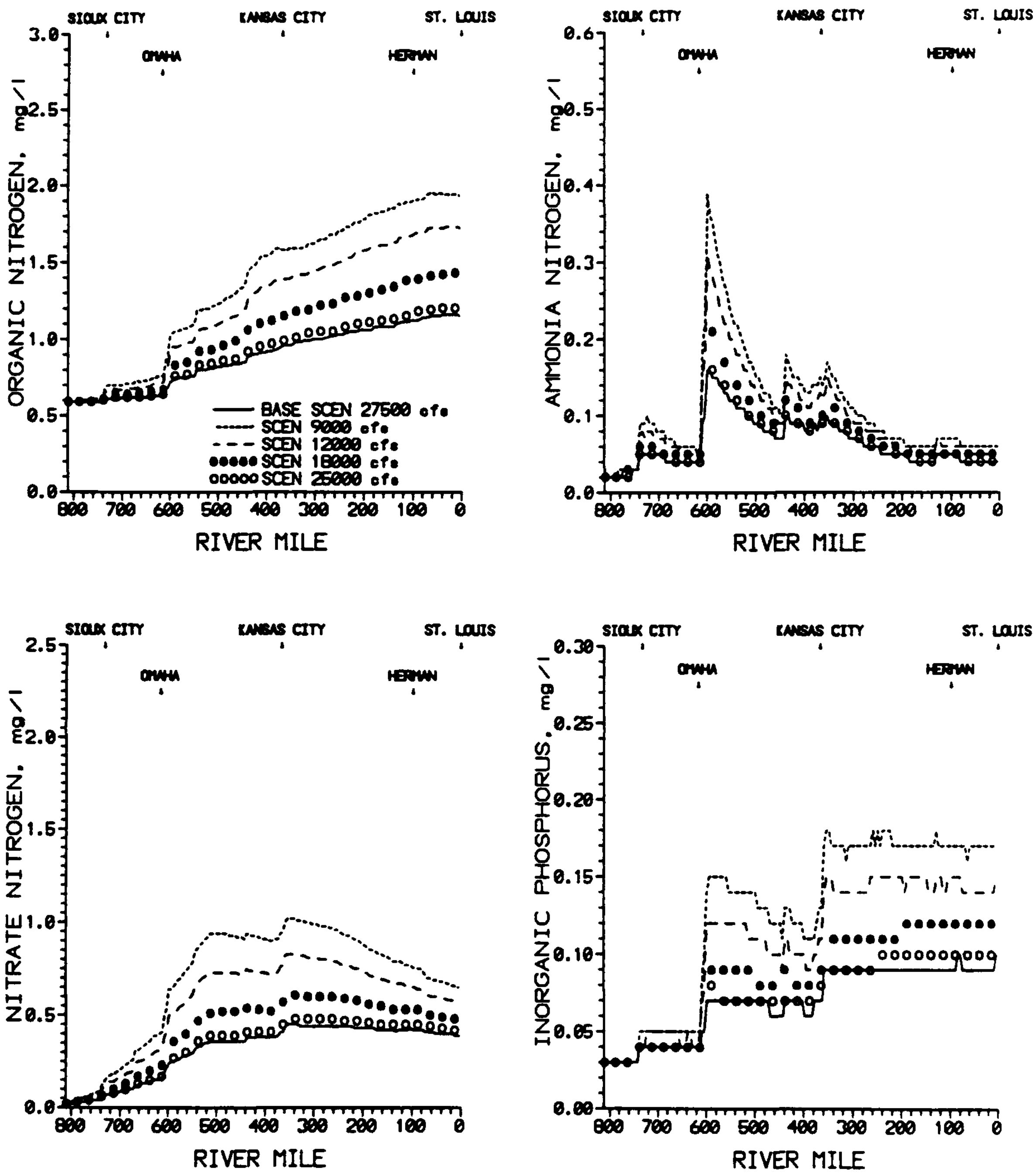


Figure B22. Scenario 7 water quality results for the release temperature of 23.9 °C and all flow conditions. Boundary conditions for this scenario were set to 14T10 met conditions, maximum water quality concentrations on tributaries increased 30 percent, 7Q10 tributary flows, maximum permit limits from point sources (i.e., water treatment plants), and A90 power plant loads (see definitions in Table 13) (Continued)



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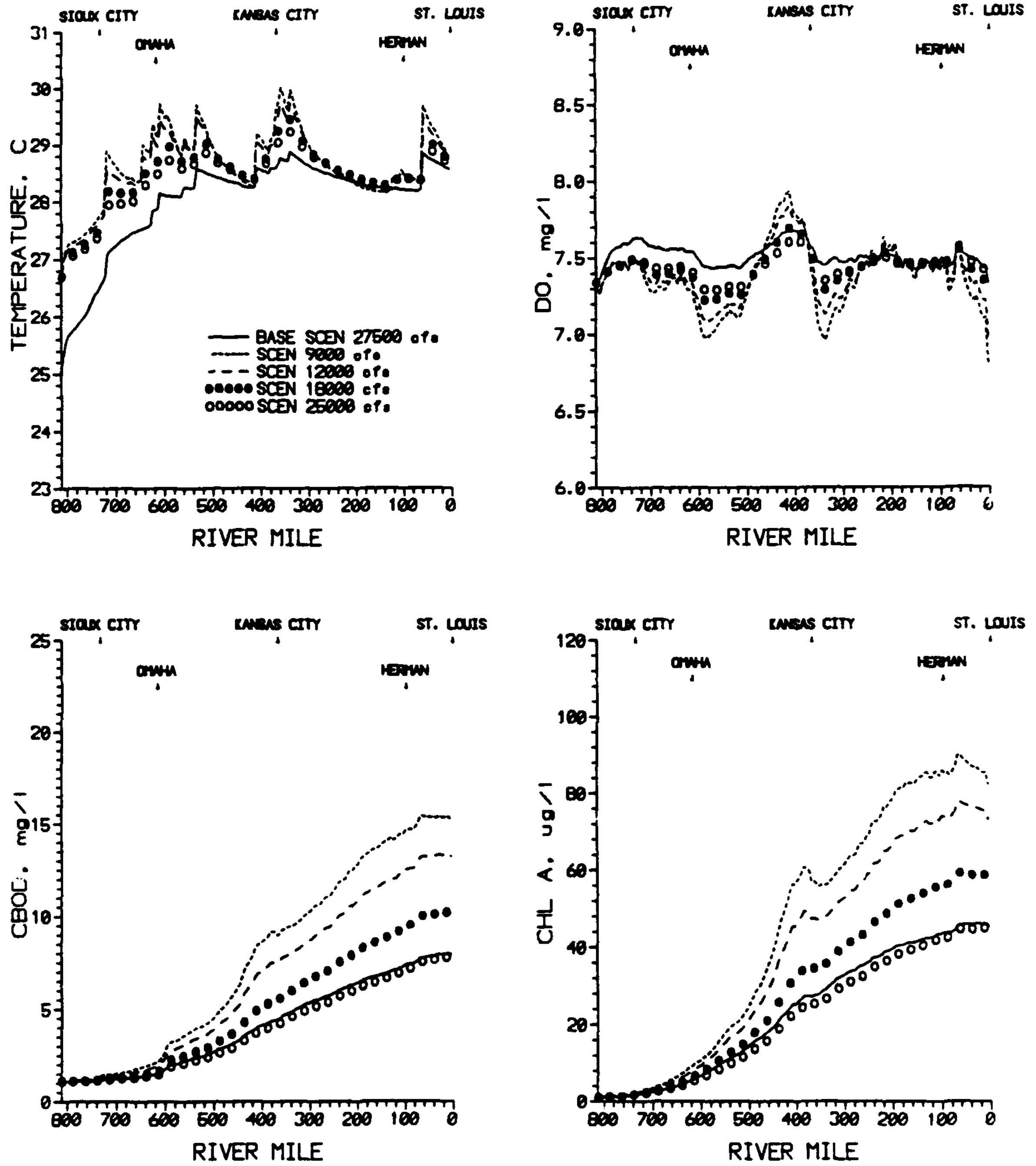


Figure B23. Scenario 7 water quality results for the release temperature of 26.7 °C and all flow conditions. Boundary conditions for this scenario were set to 14T10 met conditions, maximum water quality concentrations on tributaries increased 30 percent, 7Q10 tributary flows, maximum permit limits from point sources (i.e., water treatment plants), and A90 power plant loads (see definitions in Table 13) (Continued)

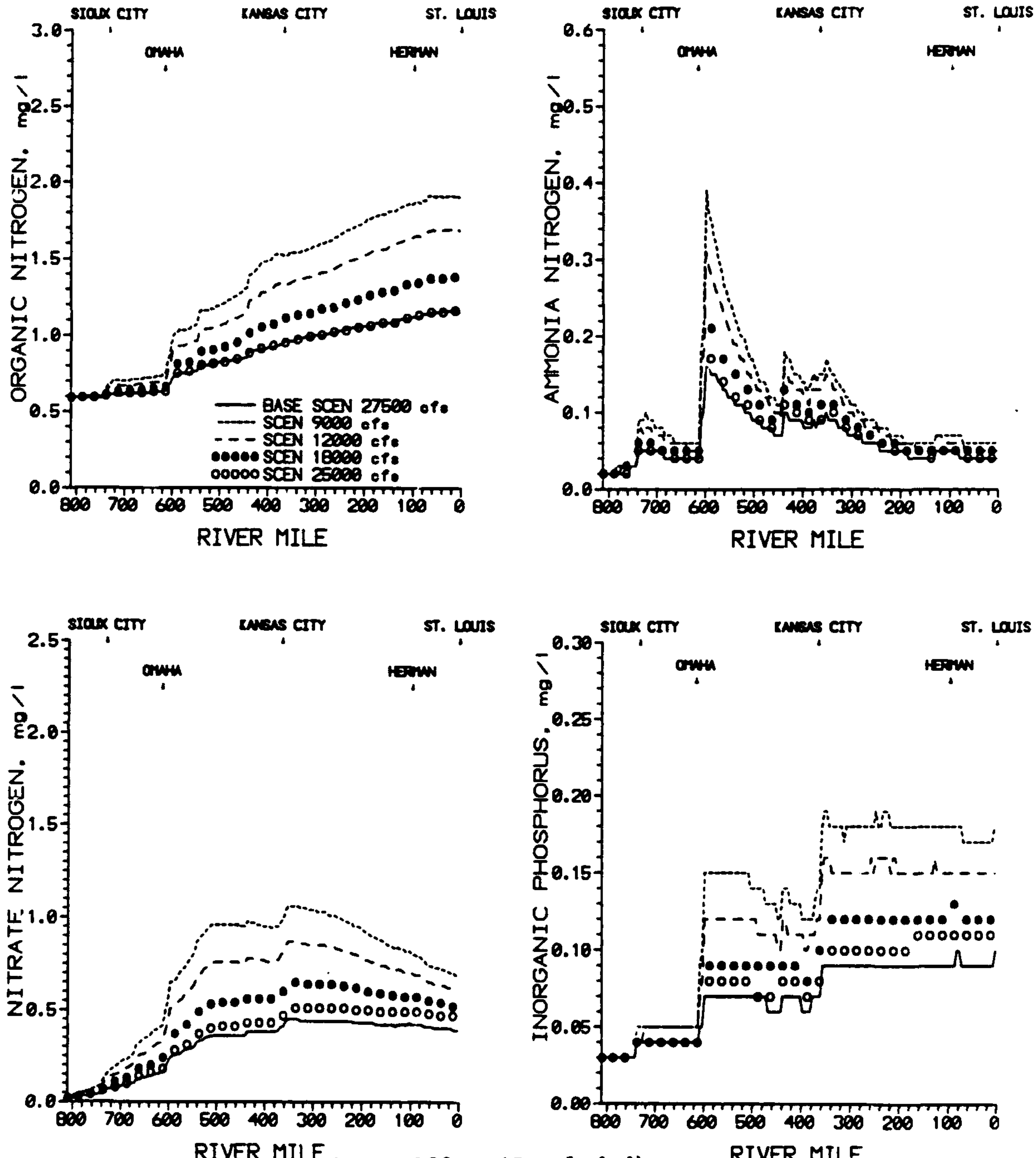


Figure B23. (Concluded)

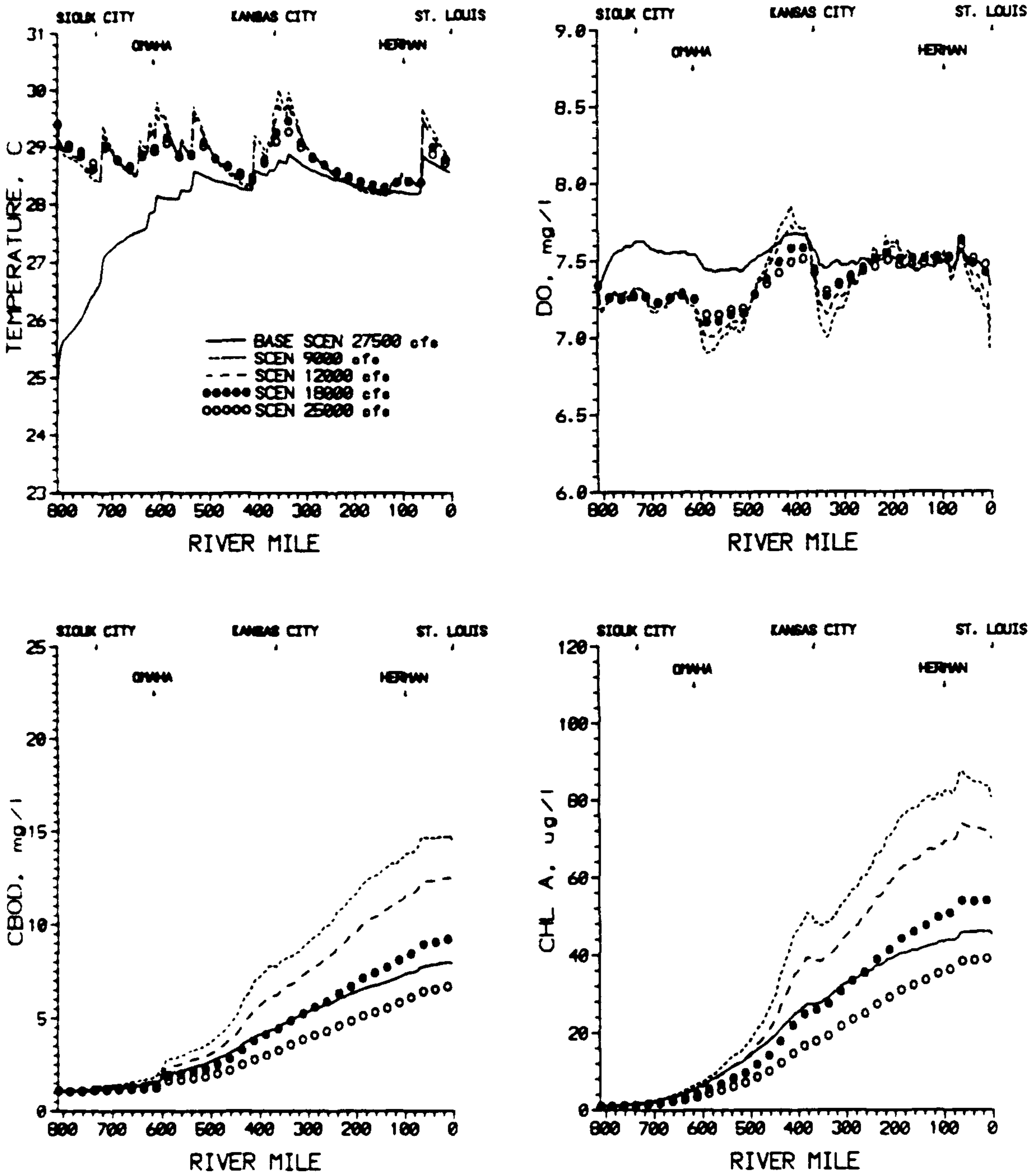
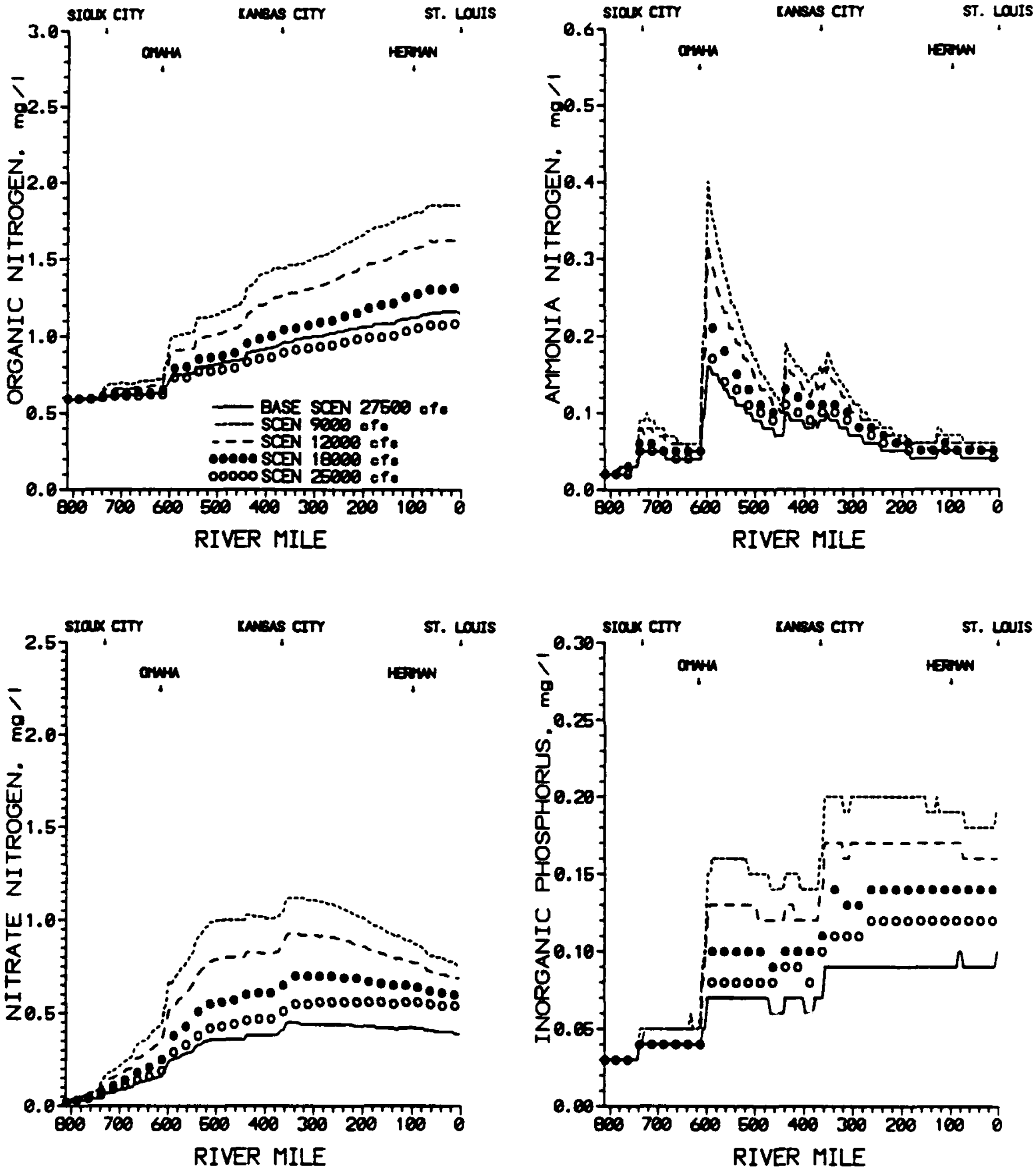


Figure B[illegible]. Scenario 7 water quality results for the release temperature of 29.4 °C and all flow conditions. Boundary conditions for this scenario were set to 14T10 met conditions, maximum water quality concentrations on tributaries increased 30 percent, 7Q10 tributary flows, maximum permit limits from point sources (i.e., water treatment plants), and A90 power plant loads (see definitions in Table 13) (Continued)



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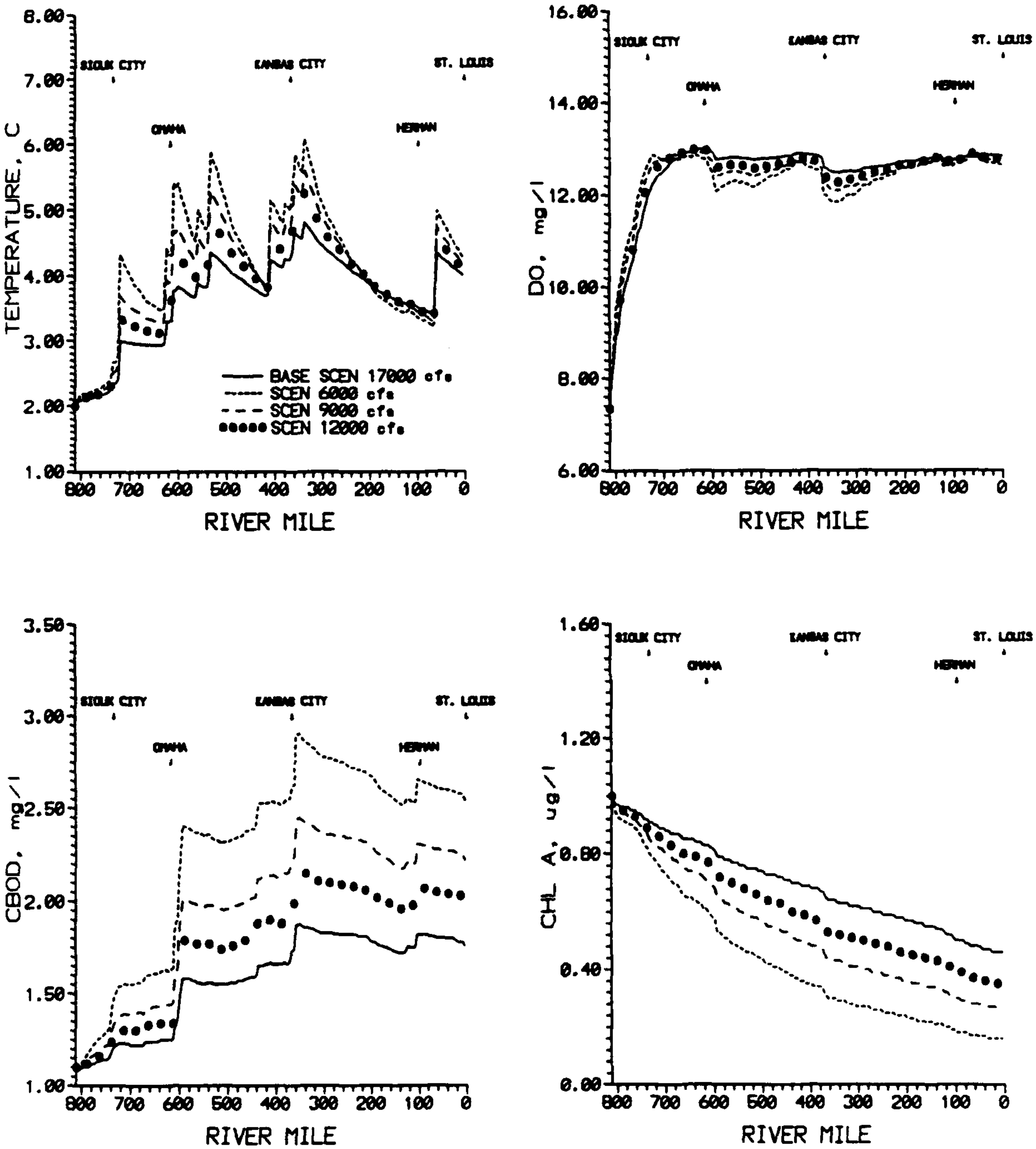
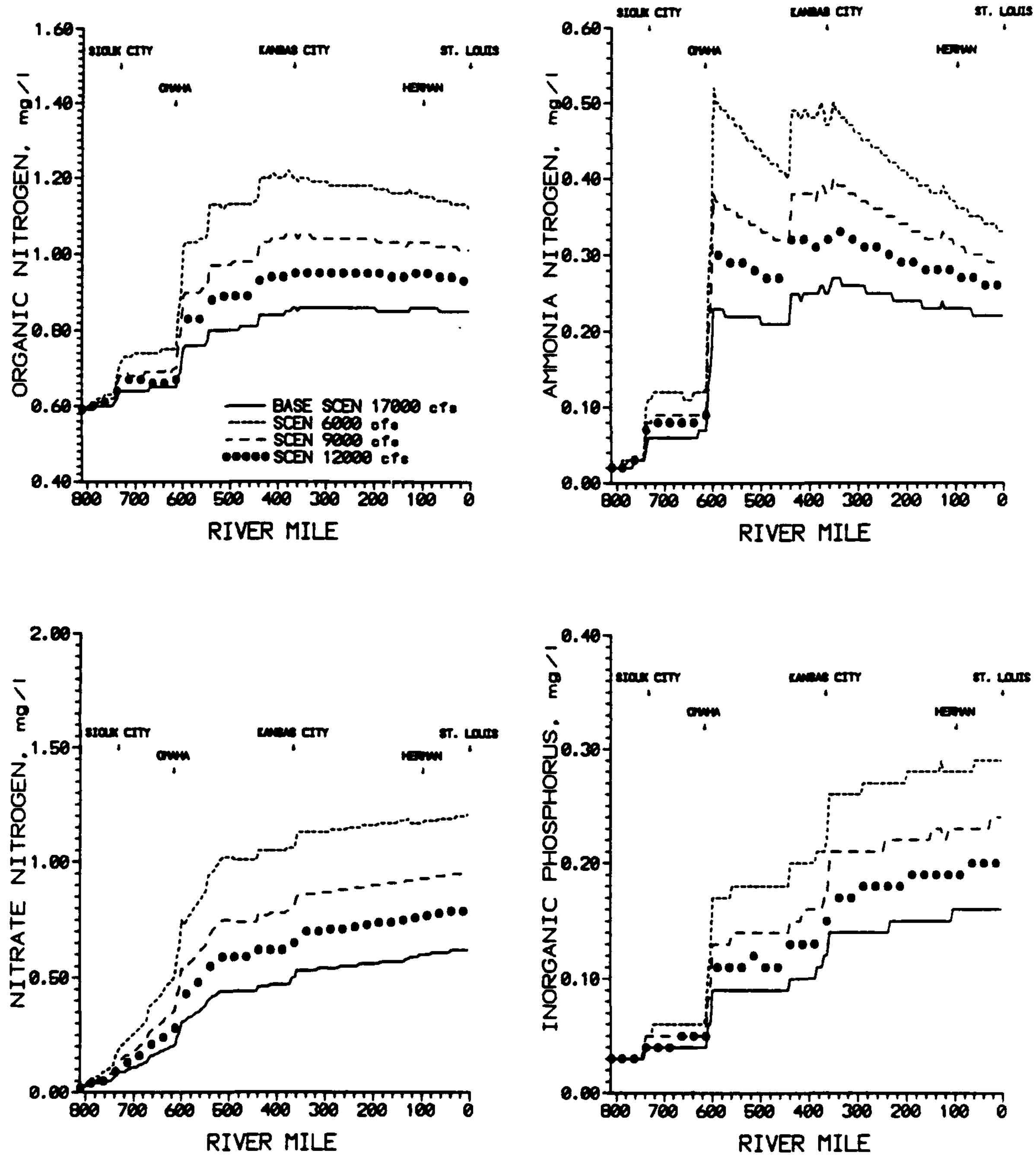


Figure B25. Scenario 8 water quality results for the release temperature of 2.0 °C and all flow conditions. Boundary conditions for this scenario were set to NOV87 met conditions, maximum water quality concentrations on tributaries, 7Q10 tributary flows, maximum permit limits from point sources (i.e., water treatment plants), and A90 power plant loads (see definitions in Table 13) (Continued)



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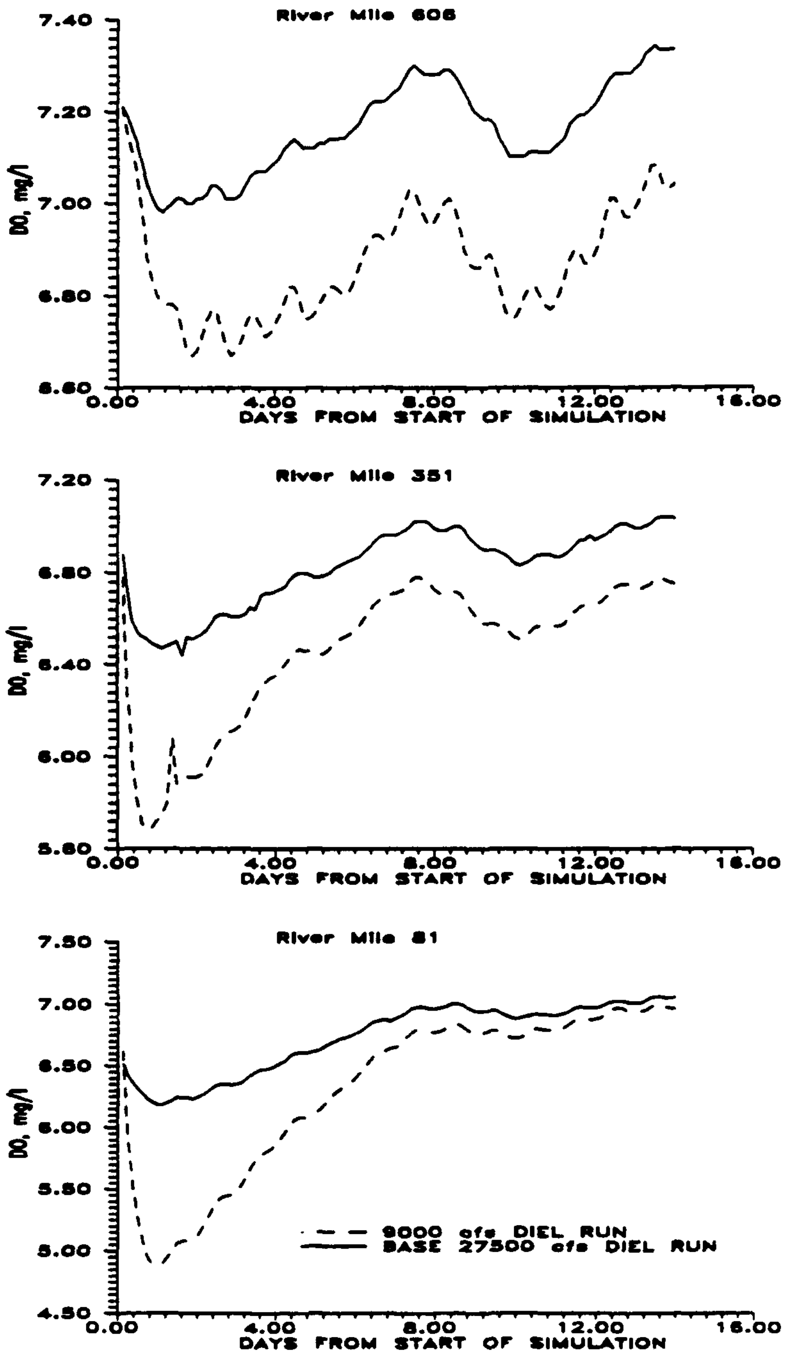
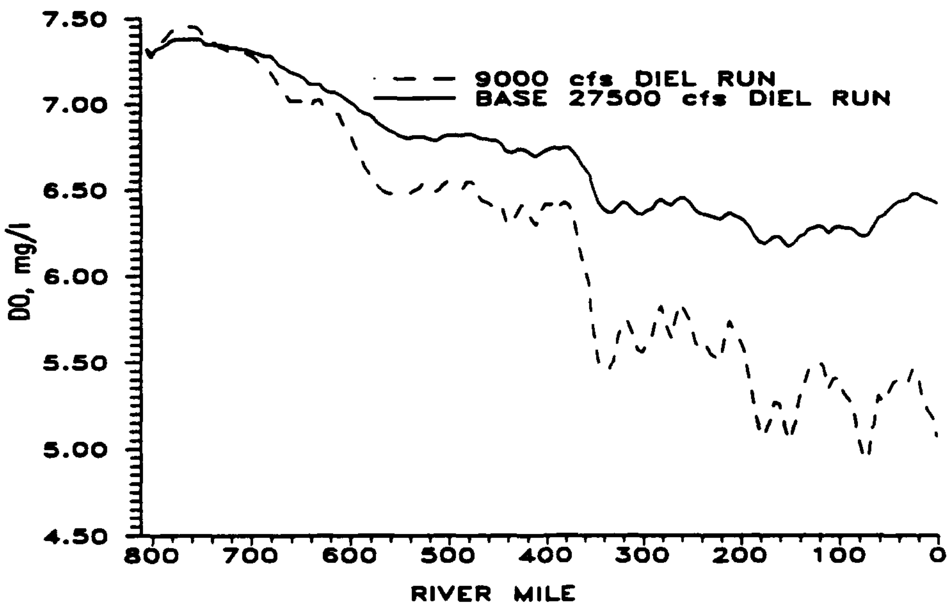


Figure B26. Scenario 9 DO results at three locations for the release temperature of 2[illegible] 9 °C and all flow conditions. Boundary conditions for this scenario were set to A28-S12 met conditions, maximum water quality concentrations on tributaries, 7Q10 tributary flows, maximum permit limits from point sources (i.e., water treatment plants), and A90 power plant loads (see definitions in Table 13)

a. Simulation day 2



b. Simulation day 12

Figure B27. Scenario 9 DO simulation day 2 and day 12 results in the Missouri River for the release temperature of 23.9 °C and all flow conditions. Boundary conditions for this scenario were set to A28-S12 met conditions, maximum water quality concentrations on tributaries, 7Q10 tributary flows, maximum permit limits from point sources (i.e., water treatment plants), and A90 power plant loads (see definitions in Table 13)

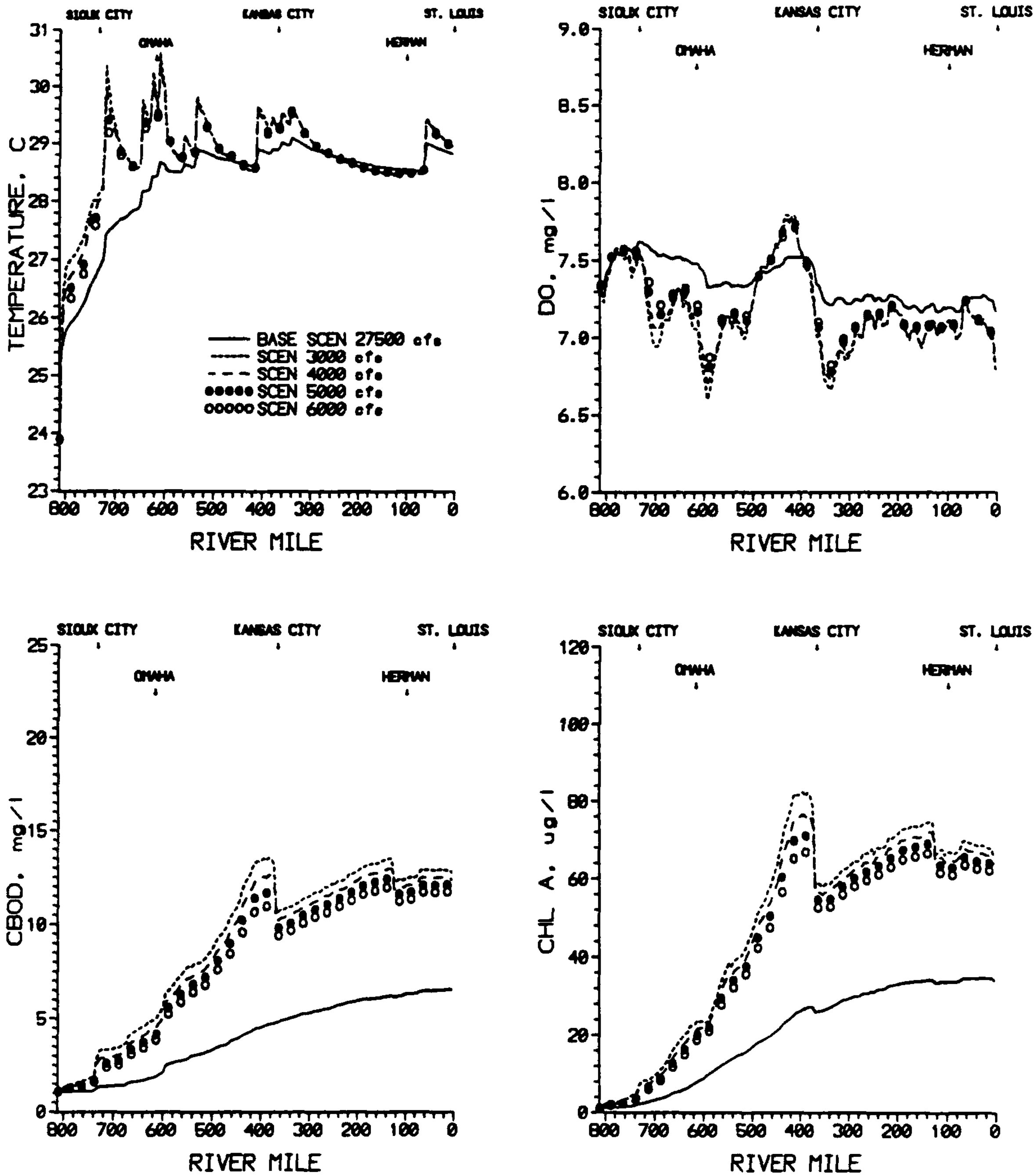


Figure B28. Scenario 10 water quality results for the release temperature of 23.9 °C and all flow conditions. Boundary conditions for this scenario were set to maximum met conditions, maximum water quality concentrations on tributaries, 2-year tributary flows, maximum permit limits from point sources (i.e., water treatment plants), and A90 power plant loads (see definitions in Table 13 for abbreviations) (Continued)

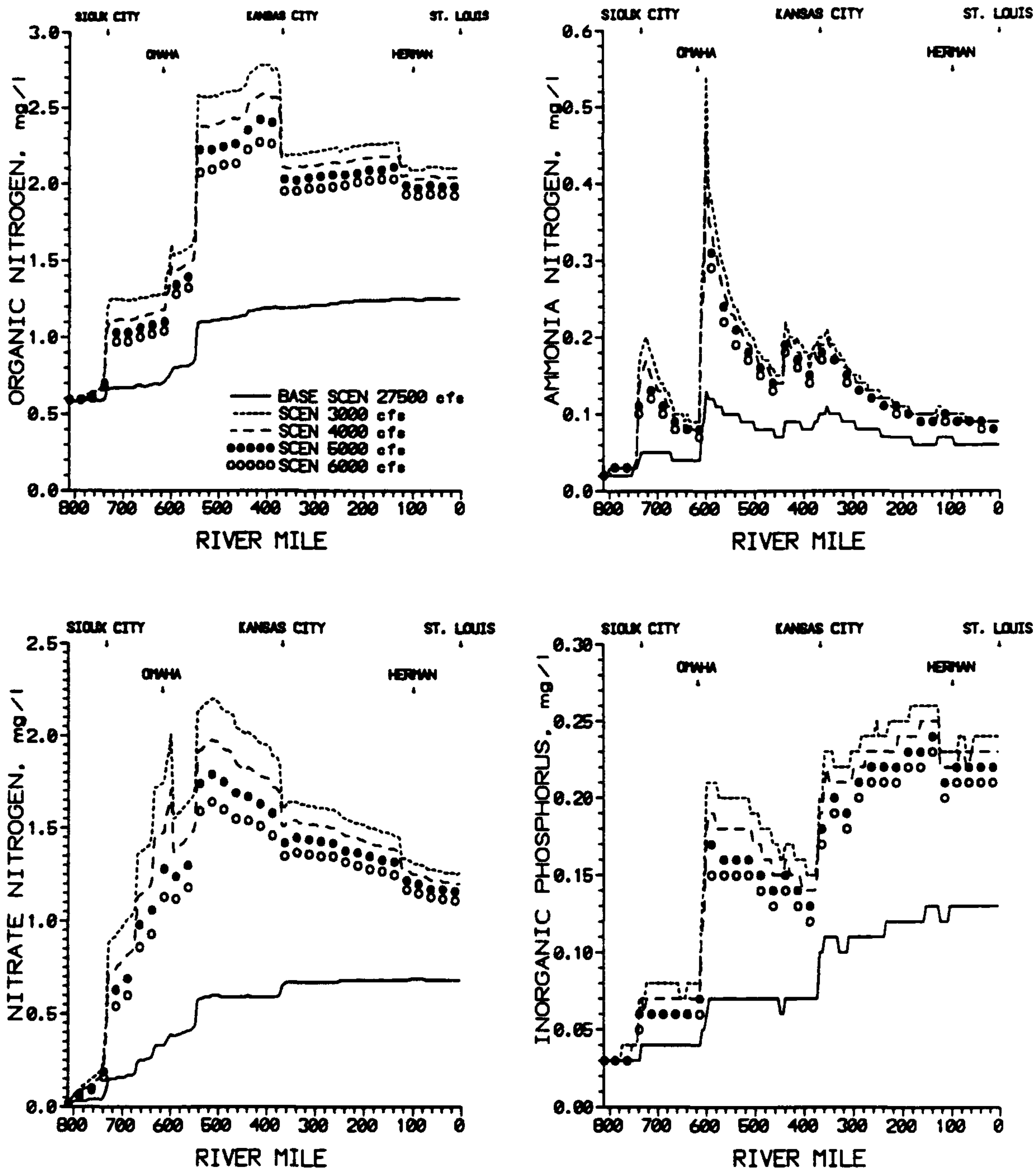


Figure B28. (Concluded)

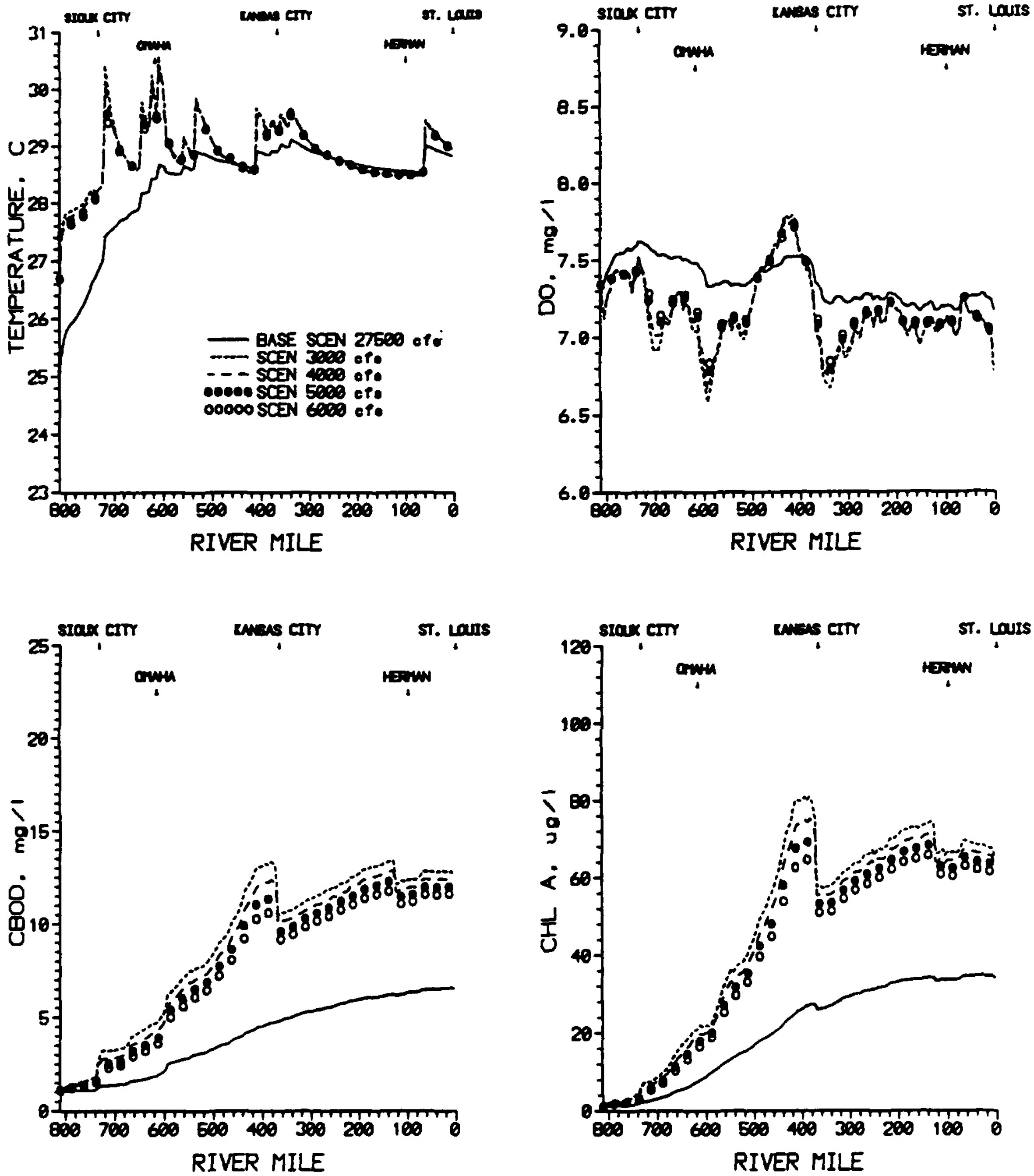


Figure B29. Scenario 10 water quality results for the release temperature of 26.7 °C and all flow conditions. Boundary conditions for this scenario were set to maximum met conditions, maximum water quality concentrations on tributaries, 2-year tributary flows, maximum permit limits from point sources (i.e., water treatment plants), and A90 power plant loads (see definitions in Table 13 for abbreviations) (Continued)

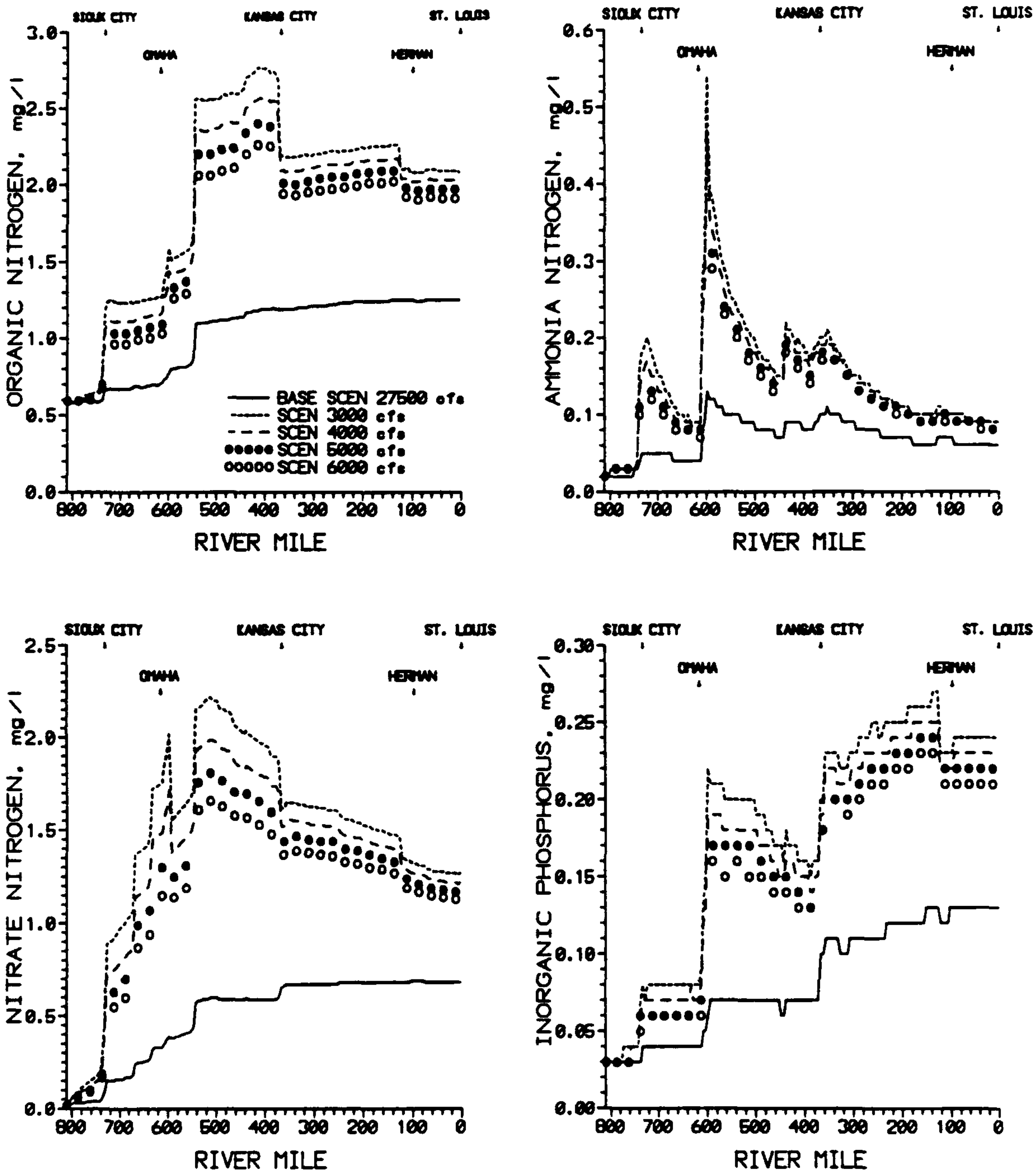


Figure B29. (Concluded)

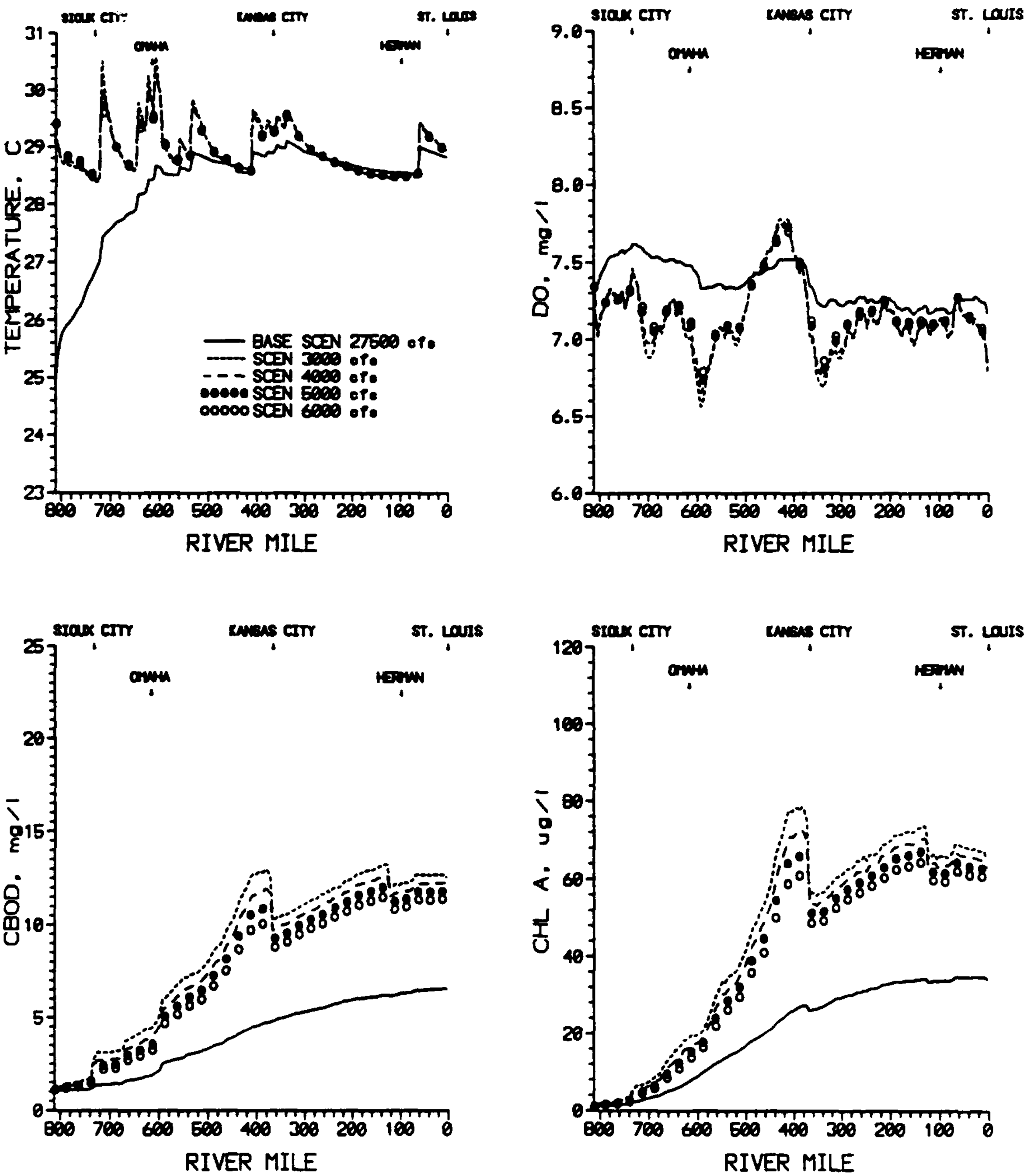


Figure B30. Scenario 10 water quality results for the release temperature of 29.4 °C and all flow conditions. Boundary conditions for this scenario were set to maximum met conditions, maximum water quality concentrations on tributaries, 2-year tributary flows, maximum permit limits from point sources (i.e., water treatment plants), and A90 power plant loads (see definitions in Table 13 for abbreviations) (Continued)

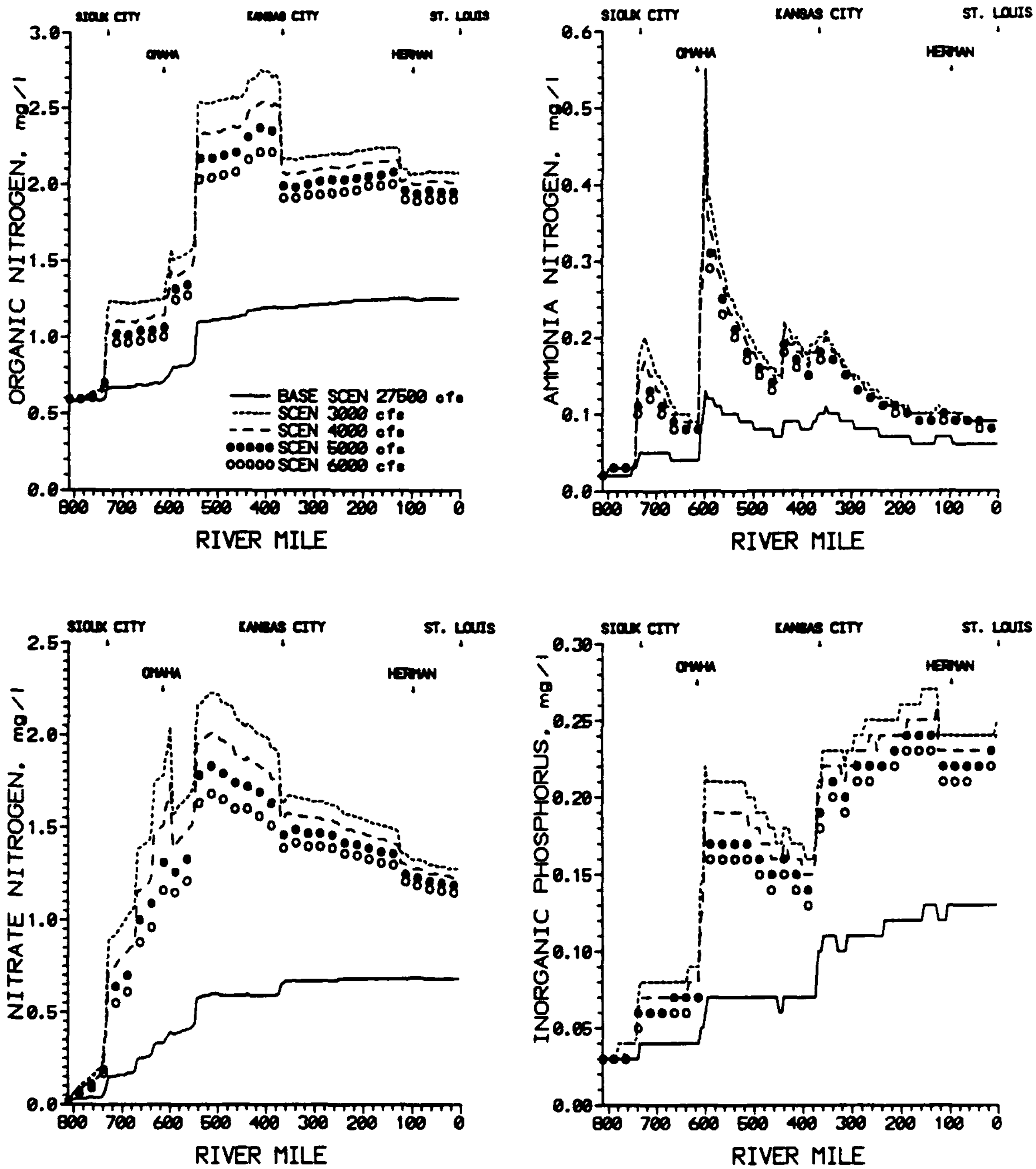


Figure B30. (Concluded)

APPENDIX C: SCENARIO BOUNDARY CONDITIONS

Table C1

Meteorological Boundary Conditions Set in Scenario Runs

Met Boundary Condition	Cloud Cover	Air Temp °C	Wet Bulb Temp °C	Air Pressure millibars	Wind Speed mile/hour
14T10	0.28	29.69	23.20	992.46	9.4
Max	0.27	33.50	23.72	992.26	10.8
Nov87	0.30	2.66	0.44	998.60	6.6
A28-S12*	0.70	32.27	25.35	970.97	2.9
	0.53	26.30	23.22	971.50	2.4
	0.37	24.42	21.47	971.70	2.0
	0.20	21.24	19.92	971.83	1.1
	0.20	23.69	20.96	973.27	1.4
	0.20	29.47	23.87	973.70	2.8
	0.77	32.09	26.77	973.40	2.9
	0.77	31.71	26.94	973.00	3.3
	0.70	29.47	25.55	973.20	2.9
	0.70	25.37	22.81	974.27	3.0
	0.53	21.80	20.96	974.27	2.0
	0.20	19.75	19.28	974.60	2.0
	0.37	19.73	19.60	975.57	2.0
	0.07	27.79	23.31	976.00	1.3
	0.07	32.29	22.96	974.57	2.5
	0.20	33.04	22.92	973.70	4.2
	0.20	30.22	22.05	974.07	3.3
	0.00	24.27	20.38	975.10	1.3
	0.00	20.50	18.70	975.03	0.8
	0.00	18.63	17.71	974.90	0.9
	0.13	20.68	19.10	974.93	1.2
	0.13	28.90	22.38	974.60	3.5
	0.07	32.80	23.93	972.97	3.4
	0.00	33.38	23.78	970.87	5.5
	0.07	29.64	22.47	970.23	4.7
	0.00	26.11	21.39	970.40	4.8
	0.00	24.25	20.48	970.47	4.6
	0.00	23.09	19.75	969.10	4.6
	0.13	23.67	19.62	969.77	5.7
	0.00	28.52	21.71	970.33	5.0
	0.00	34.89	23.82	971.27	3.7
	0.00	36.75	25.26	971.73	2.2
	0.00	30.97	25.37	972.60	2.2
	0.00	25.74	23.30	974.37	1.9
	0.13	23.30	22.03	975.30	1.8
	0.20	21.43	20.70	976.00	1.8
		22.01	21.13	977.67	2.1

(Continued)

* Note: A28-S12 represent the actual 3-hr averaged meteorological data for the 2-week period beginning August 28, 1990.

(Sheet 1 of 3)

Table C1 (Continued)

Met Boundary Condition	Cloud Cover	Air Temp °C	Wet Bulb Temp °C	Air Pressure millibars	Wind Speed mile/hour
	0.53	28.54	23.89	978.90	3.7
	0.70	32.46	25.18	978.30	4.2
	0.20	33.00	25.80	978.07	3.4
	0.53	29.29	25.05	978.50	2.1
		27.05	24.53	978.83	3.1
A28-S12	0.80	26.67	24.57	979.90	3.7
	0.80	24.42	22.64	979.70	2.6
	0.80	22.92	21.09	981.37	1.4
	0.80	24.81	21.95	982.00	2.4
	0.80	24.62	21.88	980.57	4.1
	0.80	27.23	23.39	980.50	3.4
	0.70	26.30	23.58	979.70	2.9
	0.70	25.20	23.50	979.90	2.9
	0.77	23.30	21.93	979.53	2.1
	0.77	22.38	20.81	978.80	2.1
	0.77	22.55	20.14	979.37	2.4
	0.73	28.00	22.34	979.27	3.5
	0.70	32.42	23.82	978.20	4.2
	0.70	33.79	22.96	976.90	4.9
	0.20	29.27	22.61	976.90	3.0
	0.20	26.67	21.84	977.30	3.8
	0.07	25.54	20.87	977.77	3.1
	0.00	22.01	19.71	978.30	3.1
	0.00	24.06	20.18	979.50	2.4
	0.00	31.15	22.44	980.27	3.4
	0.00	35.28	23.39	979.73	4.3
	0.00	35.65	23.26	979.30	4.0
	0.00	30.18	22.98	979.37	2.0
	0.00	24.64	21.90	980.03	0.5
	0.00	23.13	21.28	979.90	1.5
	0.00	21.97	20.40	979.27	1.8
	0.00	23.48	21.04	979.00	2.0
	0.00	31.15	23.48	978.60	2.2
	0.13	35.26	24.15	976.63	4.2
	0.20	35.65	23.76	974.03	4.4
	0.20	31.36	23.30	972.97	2.9
	0.20	27.63	21.99	972.40	3.5
	0.00	24.98	20.94	971.47	2.7
	0.00	23.13	19.86	970.43	3.0
	0.00	23.48	20.10	970.90	2.4
	0.00	30.58	22.53	970.90	3.5
	0.00	35.45	23.59	970.87	4.7
	0.20	35.99	23.73	970.77	3.8
	0.20	30.59	23.63	971.83	3.4
	0.20	24.40	21.45	972.70	1.9
	0.20	21.06	19.73	973.03	1.8

(Continued)

(Sheet 2 of 3)

Table C1 (Concluded)

Met Boundary Condition	Cloud Cover	Air Temp °C	Wet Bulb Temp °C	Air Pressure millibars	Wind Speed mile/hour
	0.20	19.58	18.61	973.50	2.3
	0.70	19.41	19.00	974.30	2.1
	0.70	26.28	22.51	974.80	1.4
	0.70	31.70	23.41	974.00	1.3
	0.37	32.46	22.66	973.40	1.2
	0.70	28.17	21.41	974.67	1.3
	0.53	22.75	18.89	976.20	2.4
A28-S12	0.70	19.41	17.01	976.27	2.4
	0.70	17.88	16.09	976.20	1.6
	0.20	17.34	16.20	976.23	2.0
	0.13	24.02	19.13	976.57	1.6
	0.13	28.34	20.44	975.33	1.7
	0.20	29.46	20.20	973.83	2.0
	0.07	24.64	17.40	973.37	1.8
	0.00	17.71	15.51	974.00	0.7
	0.00	15.66	14.56	973.73	0.6
	0.00	14.54	13.85	973.60	0.0
	0.37	14.93	14.47	973.97	1.4
	0.53	25.91	20.46	973.70	1.7
	0.37	31.51	21.34	972.83	2.5
	0.70	32.83	20.76	972.50	1.8
	0.77	25.91	19.75	973.27	1.9
	0.80	22.96	19.39	975.33	1.6
	0.77	20.14	18.05	975.97	1.4
	0.37	17.51	16.05	976.53	1.0
	0.20	17.17	16.15	977.90	2.2
	0.00	25.74	20.42	978.40	1.2
	0.00	33.38	21.60	978.07	1.7
	0.13	34.16	21.34	977.00	2.8

(Sheet 3 of 3)

Table C2

Boundary Conditions for Tributaries, and Other Point Sources Set for Scenario Runs

Tributary/Other Point Sources	Parameter	Max WQ	Max WQ ↑ 30%
James River	7Q10 Flow, cfs	4.00	4.00
	2-year sum flow, cfs	150.00	150.00
	Temperature, °C	27.60	35.90
	DO, mg/ℓ	6.75	6.75
	CBOD, mg/ℓ	2.90	3.77
	Organic nitrogen, mg/ℓ	0.12	0.16
	Ammonia nitrogen, mg/ℓ	0.03	0.04
	Nitrate nitrogen, mg/ℓ	0.17	0.22
	Diss. inorg. phosphorus, mg/ℓ	0.05	0.07
	Algae, μg/ℓ	17.00	22.10
Vermillion River	Flow, cfs	3.53	3.53
	2-year sum flow, cfs	25.78	25.78
	Temperature, °C	27.50	35.80
	DO, mg/ℓ	4.93	4.93
	CBOD, mg/ℓ	2.10	2.73
	Organic nitrogen, mg/ℓ	0.67	0.87
	Ammonia nitrogen, mg/ℓ	0.03	0.04
	Nitrate nitrogen, mg/ℓ	0.08	0.10
	Diss. inorg. phosphorus, mg/ℓ	0.05	0.07
	Algae, μg/ℓ	17.00	22.10
Sioux City STP	Flow, cfs	22.00	22.00
	2-year sum flow, cfs	22.00	22.00
	Temperature, °C	15.60	20.30
	DO, mg/ℓ	4.10	4.10
	CBOD, mg/ℓ	30.00	39.00
	Organic nitrogen, mg/ℓ	13.50	17.55
	Ammonia nitrogen, mg/ℓ	20.00	26.00
	Nitrate nitrogen, mg/ℓ	10.00	13.00
	Diss. inorg. phosphorus, mg/ℓ	5.00	6.50
	Algae, μg/ℓ	0.00	0.00
Big Sioux River	Flow, cfs	61.00	61.00
+ Dakota City IBP	2-year sum flow, cfs	458.00	458.00
+ Terra	Temperature, °C	28.30	36.80
International	DO, mg/ℓ	9.40	9.40
	CBOD, mg/ℓ	7.13	9.27
	Organic nitrogen, mg/ℓ	4.40	5.72
	Ammonia nitrogen, mg/ℓ	0.47	0.61
	Nitrate nitrogen, mg/ℓ	1.96	2.55
	Diss. inorg. phosphorus, mg/ℓ	0.12	0.16
	Algae, μg/ℓ	17.00	22.10

(Continued)

(Sheet 1 of 9)

Table C2 (Continued)

Tributary/Other Point Sources	Parameter	Max WQ	Max WQ ↑ 30%
Floyd River	Flow, cfs	8.00	8.00
	2-year sum flow, cfs	110.00	110.00
	Temperature, °C	27.30	35.50
	DO, mg/ℓ	8.49	8.49
	CBOD, mg/ℓ	13.80	17.94
	Organic nitrogen, mg/ℓ	3.13	4.07
	Ammonia nitrogen, mg/ℓ	0.76	0.99
	Nitrate nitrogen, mg/ℓ	16.00	20.80
	Diss. inorg. phosphorus, mg/ℓ	0.03	0.04
	Algae, μg/ℓ	17.00	22.10
Kind & Knox	Flow, cfs	4.00	4.00
	2-year sum flow, cfs	4.00	4.00
	Temperature, °C	20.00	26.00
	DO, mg/ℓ	5.00	5.00
	CBOD, mg/ℓ	30.00	39.00
	Organic nitrogen, mg/ℓ	13.50	17.55
	Ammonia nitrogen, mg/ℓ	20.00	26.00
	Nitrate nitrogen, mg/ℓ	10.00	13.00
	Diss. inorg. phosphorus, mg/ℓ	5.00	6.50
	Algae, μg/ℓ	0.00	0.00
Little Sioux R.	Flow, cfs	88.00	88.00
	2-year sum flow, cfs	557.00	557.00
	Temperature, °C	28.50	37.10
	DO, mg/ℓ	7.31	7.31
	CBOD, mg/ℓ	4.80	6.24
	Organic nitrogen, mg/ℓ	1.14	1.48
	Ammonia nitrogen, mg/ℓ	0.03	0.04
	Nitrate nitrogen, mg/ℓ	3.70	4.81
	Diss. inorg. phosphorus, mg/ℓ	0.09	0.12
	Algae, μg/ℓ	17.00	22.10
Blair STP	Flow, cfs	2.00	2.00
	2-year sum flow, cfs	2.00	2.00
	Temperature, °C	15.60	20.30
	DO, mg/ℓ	5.00	5.00
	CBOD, mg/ℓ	30.00	39.00
	Organic nitrogen, mg/ℓ	13.50	17.55
	Ammonia nitrogen, mg/ℓ	20.00	26.00
	Nitrate nitrogen, mg/ℓ	10.00	13.00
	Diss. inorg. phosphorus, mg/ℓ	5.00	6.50
	Algae, μg/ℓ	0.00	0.00

(Continued)

(Sheet 2 of 9)

Table C2 (Continued)

Tributary/Other Point Sources	Parameter	Max WQ	Max WQ ↑ 30%
Boyer River	Flow, cfs	13.00	13.00
	Ave. sum flow, cfs	230.00	230.00
	Temperature, °C	28.90	37.60
	DO, mg/ℓ	6.64	6.64
	CBOD, mg/ℓ	3.50	4.55
	Organic nitrogen, mg/ℓ	1.14	1.48
	Ammonia nitrogen, mg/ℓ	0.04	0.05
	Nitrate nitrogen, mg/ℓ	7.80	10.14
	Diss. inorg. phosphorus, mg/ℓ	0.25	0.33
	Algae, μg/ℓ	17.00	22.10
Griffin Pipe	Flow, cfs	0.50	0.50
	2-year sum flow, cfs	0.50	0.50
	Temperature, °C	33.90	44.10
	DO, mg/ℓ	5.00	5.00
	CBOD, mg/ℓ	30.00	39.00
	Organic nitrogen, mg/ℓ	13.50	17.55
	Ammonia nitrogen, mg/ℓ	20.00	26.00
	Nitrate nitrogen, mg/ℓ	10.00	13.00
	Diss. inorg. phosphorus, mg/ℓ	5.00	6.50
	Algae, μg/ℓ	0.00	0.00
Omaha Missouri River Plant STP	Flow, cfs	56.00	56.00
	2-year sum flow, cfs	56.00	56.00
	Temperature, °C	26.10	33.90
	DO, mg/ℓ	5.00	5.00
	CBOD, mg/ℓ	30.00	39.00
	Organic nitrogen, mg/ℓ	13.50	17.55
	Ammonia nitrogen, mg/ℓ	20.00	26.00
	Nitrate nitrogen, mg/ℓ	10.00	13.00
	Diss. inorg. phosphorus, mg/ℓ	5.00	6.50
	Algae, μg/ℓ	0.00	0.00
Council Bluff STP	Flow, cfs	13.00	13.00
	2-year sum flow, cfs	13.00	13.00
	Temperature, °C	26.70	34.70
	DO, mg/ℓ	5.20	5.20
	CBOD, mg/ℓ	30.00	39.00
	Organic nitrogen, mg/ℓ	13.50	17.55
	Ammonia nitrogen, mg/ℓ	20.00	26.00
	Nitrate nitrogen, mg/ℓ	10.00	13.00
	Diss. inorg. phosphorus, mg/ℓ	5.00	6.50
	Algae, μg/ℓ	0.00	0.00

(Continued)

(Sheet 3 of 9)

Table C2 (Continued)

Tributary/Other Point Sources	Parameter	Max WQ	Max WQ ↑ 30%
Bellevue STP + Papillion Creek STP	7Q10 flow, cfs	84.00	84.00
	Ave. sum flow, cfs	84.00	84.00
	Temperature, °C	25.40	25.60
	DO, mg/ℓ	5.00	5.00
	CBOD, mg/ℓ	30.00	39.00
	Organic nitrogen, mg/ℓ	13.50	17.55
	Ammonia nitrogen, mg/ℓ	20.00	26.00
	Nitrate nitrogen, mg/ℓ	10.00	13.00
	Diss. inorg. phosphorus, mg/ℓ	5.00	6.50
	Algae, µg/ℓ	0.00	0.00
Platte River (NE)	Flow, cfs	399.00	399.00
	2-year sum flow, cfs	2,000.00	2,000.00
	Temperature, °C	27.00	35.10
	DO, mg/ℓ	6.00	6.00
	CBOD, mg/ℓ	6.30	8.19
	Organic nitrogen, mg/ℓ	1.16	1.51
	Ammonia nitrogen, mg/ℓ	0.02	0.03
	Nitrate nitrogen, mg/ℓ	0.11	0.14
	Diss. inorg. phosphorus, mg/ℓ	0.19	0.25
	Algae, µg/ℓ	17.00	22.10
Plattsmouth STP	Flow, cfs	2.00	2.00
	2-year sum flow, cfs	2.00	2.00
	Temperature, °C	15.60	20.30
	DO, mg/ℓ	5.00	5.00
	CBOD, mg/ℓ	30.00	39.00
	Organic nitrogen, mg/ℓ	13.50	17.55
	Ammonia nitrogen, mg/ℓ	20.00	26.00
	Nitrate nitrogen, mg/ℓ	10.00	13.00
	Diss. inorg. phosphorus, mg/ℓ	5.00	6.50
	Algae, µg/ℓ	0.00	0.00
Glenwood	Flow, cfs	1.00	1.00
	2-year sum flow, cfs	1.00	1.00
	Temperature, °C	24.40	31.70
	DO, mg/ℓ	5.00	5.00
	CBOD, mg/ℓ	30.00	39.00
	Organic nitrogen, mg/ℓ	13.50	17.55
	Ammonia nitrogen, mg/ℓ	20.00	26.00
	Nitrate nitrogen, mg/ℓ	10.00	13.00
	Diss. inorg. phosphorus, mg/ℓ	5.00	6.50
	Algae, µg/ℓ	0.00	0.00

(Continued)

(Sheet 4 of 9)

Table C2 (Continued)

Tributary/Other Point Sources	Parameter	Max WQ	Max WQ ↑ 30%
Nebraska City STP	Flow, cfs	2.00	2.00
	2-year sum flow, cfs	2.00	2.00
	Temperature, °C	15.60	20.30
	DO, mg/ℓ	5.00	5.00
	CBOD, mg/ℓ	30.00	39.00
	Organic nitrogen, mg/ℓ	13.50	13.50
	Ammonia nitrogen, mg/ℓ	20.00	26.00
	Nitrate nitrogen, mg/ℓ	10.00	13.00
	Diss. inorg. phosphorus, mg/ℓ	5.00	6.50
	Algae, μg/ℓ	0.00	0.00
Nishnabotna River	Flow, cfs	67.00	67.00
	2-year sum flow, cfs	858.00	858.00
	Temperature, °C	27.50	35.80
	DO, mg/ℓ	6.00	6.00
	CBOD, mg/ℓ	4.20	5.46
	Organic nitrogen, mg/ℓ	11.00	14.30
	Ammonia nitrogen, mg/ℓ	0.28	0.36
	Nitrate nitrogen, mg/ℓ	6.05	7.87
	Diss. inorg. phosphorus, mg/ℓ	0.22	0.29
	Algae, μg/ℓ	17.00	22.10
Nemaha River	Flow, cfs	11.00	11.00
	2-year sum flow, cfs	108.00	108.00
	Temperature, °C	29.00	37.70
	DO, mg/ℓ	9.80	9.80
	CBOD, mg/ℓ	8.30	10.79
	Organic nitrogen, mg/ℓ	1.86	2.42
	Ammonia nitrogen, mg/ℓ	0.04	0.05
	Nitrate nitrogen, mg/ℓ	0.09	0.25
	Diss. inorg. phosphorus, mg/ℓ	0.03	0.04
	Algae, μg/ℓ	17.00	22.10
Nodaway River	Flow, cfs	12.00	12.00
	2-year sum flow, cfs	250.00	250.00
	Temperature, °C	30.50	39.70
	DO, mg/ℓ	7.30	7.30
	CBOD, mg/ℓ	14.10	18.33
	Organic nitrogen, mg/ℓ	1.56	2.03
	Ammonia nitrogen, mg/ℓ	0.05	0.06
	Nitrate nitrogen, mg/ℓ	0.19	0.25
	Diss. inorg. phosphorus, mg/ℓ	0.05	0.07
	Algae, μg/ℓ	17.00	22.10

(Continued)

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Table C2 (Continued)

Tributary/Other Point Sources	Parameter	Max WQ	Max WQ ↑ 30%
St. Joseph STP	Flow, cfs	42.00	42.00
	2-year sum flow, cfs	42.00	42.00
	Temperature, °C	15.70	20.30
	DO, mg/ℓ	5.00	5.00
	CBOD, mg/ℓ	30.00	39.00
	Organic nitrogen, mg/ℓ	13.50	17.55
	Ammonia nitrogen, mg/ℓ	20.00	26.00
	Nitrate nitrogen, mg/ℓ	10.00	13.00
	Diss. inorg. phosphorus, mg/ℓ	5.00	6.50
	Algae, μg/ℓ	0.00	0.00
Atchison STP	Flow, cfs	6.00	6.00
	2-year sum flow, cfs	6.00	6.00
	Temperature, °C	15.70	20.30
	DO, mg/ℓ	5.00	5.00
	CBOD, mg/ℓ	30.00	39.00
	Organic nitrogen, mg/ℓ	13.50	17.55
	Ammonia nitrogen, mg/ℓ	20.00	26.00
	Nitrate nitrogen, mg/ℓ	10.00	13.00
	Diss. inorg. phosphorus, mg/ℓ	5.00	6.50
	Algae, μg/ℓ	0.00	0.00
Platte River (MO)	Flow, cfs	12.00	12.00
	2-year sum flow, cfs	250.00	250.00
	Temperature, °C	28.60	37.20
	DO, mg/ℓ	6.30	6.30
	CBOD, mg/ℓ	4.00	5.20
	Organic nitrogen, mg/ℓ	1.12	1.47
	Ammonia nitrogen, mg/ℓ	0.01	0.02
	Nitrate nitrogen, mg/ℓ	0.09	0.12
	Diss. inorg. phosphorus, mg/ℓ	0.06	0.08
	Algae, μg/ℓ	17.00	22.10
Leavenworth STP	Flow, cfs	10.00	10.00
	2-year sum flow, cfs	10.00	10.00
	Temperature, °C	21.70	28.20
	DO, mg/ℓ	5.00	5.00
	CBOD, mg/ℓ	30.00	39.00
	Organic nitrogen, mg/ℓ	13.50	17.55
	Ammonia nitrogen, mg/ℓ	20.00	26.00
	Nitrate nitrogen, mg/ℓ	10.00	13.00
	Diss. inorg. phosphorus, mg/ℓ	5.00	6.50
	Algae, μg/ℓ	0.00	0.00

(Continued)

Table C2 (Continued)

Tributary/Other Point Sources	Parameter	Max WQ	Max WQ ↑ 30%
Lansing STP	Flow, cfs	4.00	4.00
	2-year sum flow, cfs	4.00	4.00
	Temperature, °C	15.70	15.70
	DO, mg/ℓ	5.00	5.00
	CBOD, mg/ℓ	30.00	39.00
	Organic nitrogen, mg/ℓ	13.50	17.55
	Ammonia nitrogen, mg/ℓ	20.00	26.00
	Nitrate nitrogen, mg/ℓ	10.00	13.00
	Diss. inorg. phosphorus, mg/ℓ	5.00	6.50
	Algae, μg/ℓ	0.00	0.00
Kansas River	Flow, cfs	857.00	857.00
	2-year sum flow, cfs	5,697.00	5,697.00
	Temperature, °C	28.80	37.40
	DO, mg/ℓ	6.90	6.90
	CBOD, mg/ℓ	3.50	4.55
	Organic nitrogen, mg/ℓ	1.05	1.37
	Ammonia nitrogen, mg/ℓ	0.25	0.33
	Nitrate nitrogen, mg/ℓ	1.07	1.39
	Diss. inorg. phosphorus, mg/ℓ	0.29	0.38
	Algae, μg/ℓ	17.00	22.10
Big Blue River + Kansas City STP	Flow, cfs	101.00	101.00
	2-year sum flow, cfs	101.00	101.00
	Temperature, °C	20.68	26.90
	DO, mg/ℓ	2.40	2.40
	CBOD, mg/ℓ	30.92	40.20
	Organic nitrogen, mg/ℓ	0.12	0.16
	Ammonia nitrogen, mg/ℓ	1.40	1.82
	Nitrate nitrogen, mg/ℓ	6.67	8.67
	Diss. inorg. phosphorus, mg/ℓ	4.25	5.53
	Algae, μg/ℓ	17.00	22.10
Kansas City-Birmingham STP	Flow, cfs	15.00	15.00
	2-year sum flow, cfs	15.00	15.00
	Temperature, °C	15.60	20.30
	DO, mg/ℓ	5.00	5.00
	CBOD, mg/ℓ	30.00	39.00
	Organic nitrogen, mg/ℓ	13.50	17.55
	Ammonia nitrogen, mg/ℓ	20.00	26.00
	Nitrate nitrogen, mg/ℓ	10.00	13.00
	Diss. inorg. phosphorus, mg/ℓ	5.00	6.50
	Algae, μg/ℓ	0.00	0.00

(Continued)

(Sheet 7 of 9)

Table C2 (Continued)

Tributary/Other Point Sources	Parameter	Max WQ	Max WQ ↑ 30%
Little Blue River	Flow, cfs	3.00	3.00
	2-year sum flow, cfs	7.00	7.00
	Temperature, °C	26.88	34.80
	DO, mg/ℓ	3.90	3.90
	CBOD, mg/ℓ	8.80	11.44
	Organic nitrogen, mg/ℓ	0.66	0.86
	Ammonia nitrogen, mg/ℓ	0.03	0.04
	Nitrate nitrogen, mg/ℓ	0.20	0.26
	Diss. inorg. phosphorus, mg/ℓ	0.02	0.03
	Algae, μg/ℓ	17.00	22.10
Grand River	Flow, cfs	32.00	32.00
	2-year sum flow, cfs	600.00	600.00
	Temperature, °C	29.30	38.10
	DO, mg/ℓ	5.80	5.80
	CBOD, mg/ℓ	6.30	8.19
	Organic nitrogen, mg/ℓ	1.49	1.94
	Ammonia nitrogen, mg/ℓ	0.11	0.14
	Nitrate nitrogen, mg/ℓ	1.00	1.30
	Diss. inorg. phosphorus, mg/ℓ	0.03	0.04
	Algae, μg/ℓ	17.00	22.10
Chariton River	Flow, cfs	9.00	9.00
	2-year sum flow, cfs	140.00	140.00
	Temperature, °C	29.20	38.00
	DO, mg/ℓ	6.80	6.80
	CBOD, mg/ℓ	5.60	7.28
	Organic nitrogen, mg/ℓ	1.98	2.57
	Ammonia nitrogen, mg/ℓ	0.14	0.18
	Nitrate nitrogen, mg/ℓ	0.66	0.86
	Diss. inorg. phosphorus, mg/ℓ	0.10	0.13
	Algae, μg/ℓ	17.00	22.10
Lamine River	Flow, cfs	1.00	1.00
	2-year sum flow, cfs	40.00	40.00
	Temperature, °C	28.60	37.20
	DO, mg/ℓ	5.60	5.60
	CBOD, mg/ℓ	7.40	9.62
	Organic nitrogen, mg/ℓ	1.60	2.08
	Ammonia nitrogen, mg/ℓ	0.10	0.13
	Nitrate nitrogen, mg/ℓ	0.82	1.07
	Diss. inorg. phosphorus, mg/ℓ	0.03	0.04
	Algae, μg/ℓ	17.00	22.10

(Continued)

Table C2 (Concluded)

Tributary/Other Point Sources	Parameter	Max WQ	Max WQ ↑ 30%
Jefferson City STP	Flow, cfs	11.00	11.00
	2-year sum flow, cfs	11.00	11.00
	Temperature, °C	15.70	15.70
	DO, mg/ℓ	5.00	5.00
	CBOD, mg/ℓ	45.00	58.50
	Organic nitrogen, mg/ℓ	13.50	17.55
	Ammonia nitrogen, mg/ℓ	20.00	26.00
	Nitrate nitrogen, mg/ℓ	10.00	13.00
	Diss. inorg. phosphorus, mg/ℓ	5.00	6.50
	Algae, μg/ℓ	0.00	0.00
Osage River	Flow, cfs	489.00	489.00
	2-year sum flow, cfs	3,370.00	3,370.00
	Temperature, °C	28.30	36.80
	DO, mg/ℓ	6.30	6.30
	CBOD, mg/ℓ	3.00	3.90
	Organic nitrogen, mg/ℓ	1.10	1.43
	Ammonia nitrogen, mg/ℓ	0.10	0.13
	Nitrate nitrogen, mg/ℓ	0.76	0.99
	Diss. inorg. phosphorus, mg/ℓ	0.05	0.07
	Algae, μg/ℓ	17.00	22.10
Gasconade River	Flow, cfs	350.00	350.00
	2-year sum flow, cfs	816.00	816.00
	Temperature, °C	29.20	38.00
	DO, mg/ℓ	7.00	7.00
	CBOD, mg/ℓ	7.20	9.36
	Organic nitrogen, mg/ℓ	1.05	1.37
	Ammonia nitrogen, mg/ℓ	0.16	0.21
	Nitrate nitrogen, mg/ℓ	1.07	1.39
	Diss. inorg. phosphorus, mg/ℓ	0.20	0.26
	Algae, μg/ℓ	17.00	22.10

(Sheet 9 of 9)

APPENDIX D: STATE STANDARDS FOR WATER QUALITY

Table D1

Iowa State Standards for Water Quality

Constituent	Standard
Temperature	No heat shall be added to the Missouri River that would cause an increase of more than 3 °C. The rate of temperature change shall not exceed 1 °C per hour. In no case shall heat be added that would raise the stream temperature above 32 °C.
Dissolved oxygen	5.0 mg/ℓ
$CBOD_5$	None
Organic nitrogen	None
Ammonia nitrogen	See Table D2
Nitrate nitrogen	45 mg/ℓ at class C location (potable water intake)
Organic P	None
Diss Inorg-P	None

Note: Organic P = Organic Phosphorus, Diss Inorg-P = Dissolved Inorganic Phosphorus.

Table D2

Iowa Criteria for Ammonia Nitrogen

Temp. °C		pH											
		6.5	7.0	7.2	7.4	7.6	7.8	8.0	8.2	8.4	8.6	8.8	9.0
1.0	Acute	49.0	39.5	33.8	27.6	21.4	15.8	11.2	7.1	4.5	2.9	1.8	1.2
	Chronic	9.8	7.9	6.8	5.5	4.3	3.2	2.2	1.4	0.9	0.6	.4	.2
5.0	Acute	46.4	37.4	32.1	26.2	20.3	15.0	10.6	6.8	4.3	2.8	1.8	1.2
	Chronic	9.3	7.5	6.4	5.2	4.1	3.0	2.1	1.4	0.9	.6	.4	.2
10.0	Acute	44.0	35.5	30.5	24.9	19.3	14.3	10.1	6.5	4.1	2.7	1.8	1.2
	Chronic	8.8	7.1	6.1	5.1	3.9	2.9	2.0	1.3	0.8	.5	.4	.2
15.0	Acute	42.3	34.1	29.3	24.0	18.6	13.8	9.8	6.3	4.1	2.7	1.8	1.2
	Chronic	8.5	6.8	5.9	4.8	3.7	2.8	2.0	1.3	0.3	.5	.4	.2
20.0	Acute	41.2	33.3	28.6	23.4	18.2	13.5	9.7	6.2	4.1	2.7	1.8	1.2
	Chronic	8.2	6.7	5.7	4.7	3.6	2.7	1.9	1.2	0.8	.5	.4	.2
25.0	Acute	40.7	32.9	28.3	23.2	18.1	13.5	9.7	6.3	4.2	2.7	1.8	1.2
	Chronic	8.1	6.6	5.7	4.6	3.6	2.7	1.9	1.3	0.8	.5	.4	.2
30.0	Acute	20.4	16.5	14.2	11.7	9.1	6.8	5.2	3.3	2.2	1.5	1.1	.8
	Chronic	4.1	3.3	2.8	2.3	1.8	1.4	1.0	0.7	0.4	.3	.2	.2

Table D3

Nebraska State Standards for Water Quality

Constituent	Standard
Temperature	The temperature of a receiving water shall not be increased by a total of more than 3 °C from natural outside the mixing zone. For the Missouri River, from the South Dakota-Nebraska state line near Fort Randall to Sioux City, Iowa, the maximum temperature limit is 29 °C with an allowable change of 2 °C from natural. For cold waters the maximum limit is 22 °C with an allowable change of 3 °C from natural. For warm waters, the maximum limit is 32 °C.
Dissolved oxygen	One-day minimum of not less than 5.0 mg/ℓ for early-life stages (applies April 1 through September 30). One-day minimum of not less than 3.0 mg/ℓ for all life stages other than early-life stages (applies from October 1 through March 31). Seven-day mean minimum of not less than 4.0 mg/ℓ (applies from October 1 through March 31. Seven-day mean of not less than 6.0 mg/ℓ for early-life stages (applies from April 1 through September 30).
$CBOD_5$	Low flow based percent calculation
Organic nitrogen	None
Ammonia nitrogen	See Table D4
Nitrate nitrogen	10 mg/ℓ
Organic P	None
Diss Inorg-P	None

Note: Organic P = Organic Phosphorus, Diss Inorg-P = Dissolved Inorganic Phosphorus.

Table D4

Nebraska Criteia for Ammonia Nitrogen

Temperature °C	pH 6.60	6.80	7.00	7.20	7.40	7.60	7.80	8.00	8.20	8.40	8.60	8.80	9.00
One-hour Average Criteria for Un-ionized Ammonia: Class A - Warmwater Aquatic Life													
0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.08	0.08	0.08	0.08	0.08	0.08	0.08
	43.99	40.74	36.47	31.28	25.53	19.77	14.58	10.31	6.54	4.16	2.66	1.71	1.11
2.00	0.02	0.02	0.03	0.05	0.06	0.07	0.09	0.10	0.10	0.10	0.10	0.10	0.10
	42.73	39.58	35.43	30.39	24.80	19.22	14.18	10.03	6.37	4.06	2.60	1.67	1.09
4.00	0.02	0.03	0.04	0.05	0.07	0.09	0.10	0.11	0.11	0.11	0.11	0.11	0.11
	41.61	38.54	34.50	29.60	24.16	18.73	13.82	9.79	6.22	3.97	2.54	1.65	1.08
6.00	0.02	0.03	0.05	0.06	0.08	0.10	0.11	0.13	0.13	0.13	0.13	0.13	0.13
	40.62	37.62	33.68	28.90	23.59	18.29	13.51	9.57	6.09	3.89	2.50	1.63	1.07
8.00	0.03	0.04	0.05	0.07	0.09	0.11	0.13	0.15	0.15	0.15	0.15	0.15	0.15
	38.74	36.81	32.96	28.28	23.10	17.91	13.23	9.38	5.98	3.83	2.47	1.67	1.07
10.00	0.03	0.04	0.06	0.08	0.11	0.13	0.15	0.17	0.17	0.17	0.17	0.17	0.17
	38.97	36.10	32.32	27.74	22.66	17.58	13.00	9.22	5.89	3.78	2.45	1.61	1.08
12.00	0.03	0.05	0.07	0.09	0.12	0.15	0.17	0.19	0.19	0.19	0.19	0.19	0.19
	38.30	35.48	31.77	27.27	22.28	17.30	12.80	9.09	5.81	3.74	2.43	1.61	1.08
14.00	0.04	0.06	0.08	0.11	0.14	0.17	0.20	0.22	0.22	0.22	0.22	0.22	0.22
	37.72	34.94	31.30	26.87	21.97	17.06	12.63	8.99	5.76	3.71	2.43	1.61	1.10
16.00	0.04	0.06	0.09	0.12	0.16	0.20	0.23	0.26	0.26	0.26	0.26	0.26	0.26
	37.23	34.50	30.90	26.54	21.70	16.86	12.50	8.90	5.72	3.70	2.43	1.63	1.12
18.00	0.05	0.07	0.10	0.14	0.18	0.22	0.26	0.29	0.29	0.29	0.29	0.29	0.29
	36.83	34.12	30.58	26.26	21.49	16.71	12.39	8.85	5.70	3.70	2.44	1.65	1.15
20.00	0.06	0.08	0.12	0.16	0.21	0.26	0.30	0.34	0.34	0.34	0.34	0.34	0.34
	36.50	33.83	30.32	26.05	21.32	16.59	12.32	8.81	5.69	3.71	2.47	1.68	1.19
22.00	0.07	0.10	0.14	0.19	0.24	0.30	0.35	0.39	0.39	0.39	0.39	0.39	0.39
	36.25	33.60	30.12	25.89	21.20	16.51	12.28	8.80	5.70	3.74	2.50	1.72	1.23
24.00	0.08	0.11	0.16	0.21	0.28	0.34	0.40	0.44	0.44	0.44	0.44	0.44	0.44
	36.08	33.44	29.99	25.79	21.13	16.47	12.27	8.82	5.73	3.78	2.55	1.77	1.28
26.00	0.08	0.12	0.17	0.23	0.30	0.36	0.43	0.48	0.48	0.48	0.48	0.48	0.48
	33.57	31.13	27.92	24.02	19.70	15.37	11.47	8.26	5.40	3.58	2.43	1.71	1.26
28.00	0.08	0.12	0.17	0.23	0.30	0.36	0.43	0.48	0.48	0.48	0.48	0.48	0.48
	29.21	27.09	24.31	20.92	17.17	13.42	10.03	7.25	4.75	3.18	2.18	1.55	1.15
30.00	0.08	0.12	0.17	0.23	0.30	0.36	0.43	0.48	0.48	0.48	0.48	0.48	0.48
	25.46	23.62	21.20	18.26	15.00	11.74	8.80	6.38	4.20	2.83	1.96	1.41	1.07
Four-day Average Criteria for Un-ionized Ammonia: Class A - Warmwater Aquatic Life													
0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	2.13	2.13	2.13	2.13	2.13	2.13	1.82	1.29	0.82	0.52	0.33	0.21	0.14
2.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02
	2.75	2.75	2.75	2.76	2.76	2.76	2.36	1.67	1.06	0.68	0.43	0.28	0.18
4.00	0.00	0.00	0.00	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02
	2.68	2.68	2.68	2.68	2.69	2.69	2.30	1.63	1.04	0.66	0.42	0.27	0.18
6.00	0.00	0.00	0.00	0.01	0.01	0.01	0.05	0.02	0.02	0.02	0.02	0.02	0.02
	2.62	2.62	2.62	2.62	2.62	2.63	2.25	1.59	1.01	0.65	0.42	0.27	0.18

(Continued)

Table D4 (Concluded)

Temperature °C	pH 6.60	6.80	7.00	7.20	7.40	7.60	7.80	8.00	8.20	8.40	8.60	8.80	9.00
8.00	0.00	0.00	0.00	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
	2.56	2.56	2.56	2.56	2.57	2.57	2.20	1.56	1.00	0.64	0.41	0.27	0.18
10.00	0.00	0.00	0.01	0.01	0.01	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	2.51	2.51	2.51	2.51	2.52	2.53	2.16	1.54	0.98	0.63	0.41	0.27	0.18
12.00	0.00	0.00	0.01	0.01	0.01	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	2.47	2.47	2.47	2.47	2.48	2.49	2.13	1.51	0.97	0.62	0.40	0.27	0.18
14.00	0.00	0.00	0.01	0.01	0.02	0.02	0.03	0.04	0.04	0.04	0.04	0.04	0.04
	2.43	2.43	2.43	2.44	2.44	2.45	2.10	1.50	0.96	0.62	0.40	0.27	0.18
16.00	0.00	0.00	0.01	0.01	0.02	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04
	2.40	2.40	2.40	2.41	2.41	2.42	2.08	1.48	0.95	0.62	0.40	0.27	0.19
18.00	0.00	0.01	0.01	0.01	0.02	0.03	0.04	0.05	0.05	0.05	0.05	0.05	0.05
	2.37	2.37	2.38	2.38	2.39	2.40	2.06	1.47	0.95	0.62	0.41	0.27	0.19
20.00	0.00	0.01	0.01	0.02	0.02	0.04	0.05	0.06	0.06	0.06	0.06	0.06	0.06
	2.35	2.35	2.36	2.36	2.37	2.38	2.05	1.47	0.95	0.62	0.41	0.28	0.20
22.00	0.00	0.01	0.01	0.02	0.02	0.04	0.05	0.06	0.06	0.06	0.06	0.06	0.06
	2.03	2.03	2.04	2.04	2.05	2.07	1.76	1.28	0.83	0.54	0.36	0.25	0.18
24.00	0.00	0.01	0.01	0.02	0.02	0.04	0.05	0.06	0.06	0.06	0.06	0.06	0.06
	1.76	1.76	1.77	1.77	1.78	1.79	1.55	1.11	0.72	0.48	0.32	0.22	0.16
26.00	0.00	0.01	0.01	0.02	0.02	0.04	0.05	0.06	0.06	0.06	0.06	0.06	0.06
	1.53	1.53	1.54	1.54	1.55	1.56	1.35	0.97	0.64	0.42	0.29	0.20	0.15
28.00	0.00	0.01	0.01	0.02	0.02	0.04	0.05	0.06	0.06	0.06	0.06	0.06	0.06
	1.33	1.33	1.34	1.34	1.34	1.36	1.18	0.85	0.56	0.37	0.26	0.18	0.14
30.00	0.00	0.01	0.01	0.02	0.02	0.04	0.05	0.06	0.06	0.06	0.06	0.06	0.06
	1.16	1.16	1.17	1.17	1.18	1.19	1.04	0.75	0.50	0.33	0.23	0.17	0.13

Table D5

Missouri State Standards for Water Quality

Constituent	Standard
Temperature	No heat shall be added to the Missouri River that would cause an increase of more than 3 °C. The rate of temperature change shall not exceed 1 °C per hour. In no case shall heat be added that would raise the stream temperature above 32 °C.
Dissolved oxygen	5.0 mg/ℓ
$CBOD_5$	None
Organic nitrogen	None
Ammonia nitrogen	See Table D6
Nitrate nitrogen	10 mg/ℓ
Organic P	None
Diss Inorg-P	None

Note: Organic P = Organic Phosphorus, Diss Inorg-P = Dissolved Inorganic Phosphorus.

Table D6

Missouri Criteria for Ammonia Nitrogen

Temp. °C	pH 6.6	6.8	7.0	7.2	7.4	7.6	7.8	8.0	8.2	8.4	8.6	8.8	9.0
Chronic Criteria for Total Ammonia: General Warmwater Fishery (mg/ℓ)													
4	2.5	2.5	2.5	2.5	2.5	2.5	2.1	1.8	0.9	0.6	0.4	0.3	0.2
6	2.4	2.4	2.4	2.4	2.4	2.4	2.1	1.5	0.9	0.6	0.4	0.2	0.2
8	2.3	2.3	2.3	2.3	2.3	2.4	2.0	1.4	0.9	0.6	0.4	0.2	0.2
10	2.3	2.3	2.3	2.3	2.3	2.3	2.0	1.4	0.9	0.6	0.4	0.2	0.2
12	2.3	2.3	2.3	2.3	2.3	2.3	2.0	1.4	0.9	0.6	0.4	0.2	0.2
14	2.2	2.2	2.2	2.2	2.2	2.2	2.0	1.4	0.9	0.6	0.4	0.2	0.2
16	2.2	2.2	2.2	2.2	2.2	2.2	1.9	1.4	0.9	0.6	0.4	0.2	0.2
18	2.2	2.2	2.2	2.2	2.2	2.2	1.9	1.3	0.9	1.6	0.4	0.3	0.2
20	2.1	2.2	2.2	2.2	2.2	2.2	1.9	1.3	0.9	0.6	0.4	0.3	0.2
22	1.9	1.9	1.9	1.9	1.9	1.9	1.6	1.2	0.8	0.5	0.3	0.2	0.2
24	1.6	1.6	1.6	1.6	1.6	1.6	1.4	1.0	0.7	0.4	0.3	0.2	0.1
26	1.4	1.4	1.4	1.4	1.4	1.4	1.2	0.9	0.6	0.4	0.3	0.2	0.1
28	1.2	1.2	1.2	1.2	1.2	1.2	1.1	0.8	0.5	0.3	0.2	0.2	0.1
30	1.1	1.1	1.1	1.1	1.1	1.1	0.9	0.7	0.5	0.3	0.2	0.2	0.1
Acute Criteria for Total Ammonia: General; Warmwater Fishery (mg/ℓ)													
4	50.6	46.9	42.0	36.0	29.4	22.8	16.8	11.9	7.6	4.8	3.1	2.0	1.3
6	49.4	45.8	41.0	35.2	28.7	22.3	16.4	11.6	7.4	4.7	3.0	2.0	1.3
8	48.3	44.8	40.1	34.4	28.1	21.8	16.1	11.4	7.3	4.7	3.0	2.0	1.3
10	47.4	44.0	39.3	33.7	27.6	21.4	15.8	11.2	7.2	4.6	3.0	2.0	1.3
12	46.6	43.2	38.7	33.2	27.1	26.0	15.6	11.1	7.1	4.6	3.0	2.0	1.3
14	45.9	42.5	38.1	32.7	26.7	20.8	15.4	10.9	7.0	4.5	3.0	2.0	1.3
16	45.3	42.0	37.6	32.3	26.4	20.5	15.2	10.8	7.0	4.5	3.0	2.0	1.4
18	44.8	41.5	37.2	32.0	26.1	20.3	15.1	10.8	7.0	4.5	3.0	2.0	1.4
20	44.4	41.2	36.9	31.7	25.9	20.2	15.0	10.7	6.9	4.5	3.0	2.0	1.4
22	44.1	40.9	36.6	31.5	25.8	20.1	14.9	10.7	6.9	4.6	3.0	2.1	1.5
24	43.9	40.7	36.5	31.4	25.7	20.0	14.9	10.7	7.0	4.6	3.1	2.2	1.6
26	40.8	37.9	34.0	29.0	24.0	18.7	14.0	10.0	6.6	4.4	3.0	2.1	1.5
28	35.5	33.0	29.6	25.5	20.9	16.3	12.2	8.8	5.8	3.9	2.7	1.9	1.4
30	31.0	28.7	25.8	22.2	18.3	14.3	10.7	7.8	5.1	3.4	2.4	1.7	1.3

Table D7

Kansas State Standards for Water Quality

Constituent	Standard
Temperature	No heat shall be added to the Missouri River that would cause an increase of more than 3 °C. The rate of temperature change shall not exceed 1 °C per hour. In no case shall heat be added that would raise the stream temperature above 32 °C.
Dissolved oxygen	No less than 5.0 mg/ℓ
$CBOD_5$	None
Organic nitrogen	None
Ammonia nitrogen	Artificial sources shall not cause the un-ionized ammonia concentration of surface water to exceed 0.07 mg/ℓ as NH_3-N.
Nitrate nitrogen	10 mg/ℓ
Organic P	None
Diss Inorg-P	None

Note: Organic P = Organic Phosphorus, Diss Inorg-P = Dissolved Inorganic Phosphorus.

Table D8

South Dakota State Standards for Water Quality

Constituent	Standard
Temperature	No heat shall be added to the Missouri River that would cause an increase of more than 2 °C. The rate of temperature change shall not exceed 1 °C per hour. In no case shall heat be added that would raise the stream temperature above 27 °C. There may be no induced temperature change over spawning beds.
Dissolved oxygen	No less than 5.0 mg/ℓ
$CBOD_5$	None
Organic nitrogen	None
Ammonia nitrogen	Artificial sources shall not cause the un-ionized ammonia concentration of surface water to exceed 0.04 mg/ℓ as NH_3-N.
Nitrate nitrogen	50 mg/ℓ
Organic P	None
Diss Inorg-P	None

Note: Organic P = Organic Phosphorus, Diss Inorg-P = Dissolved Inorganic Phosphorus.