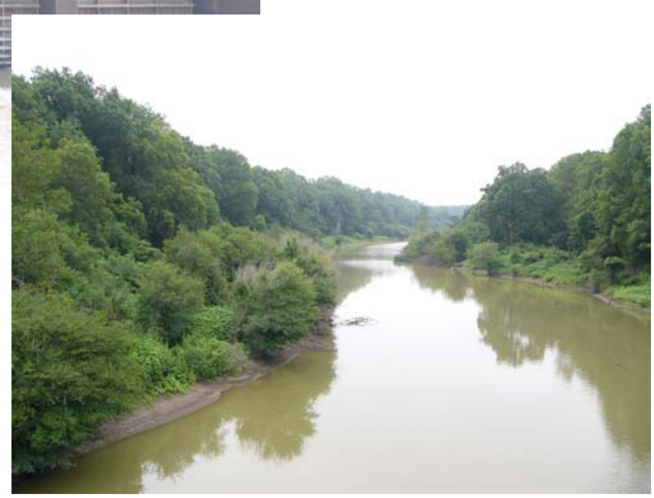
ATTACHMENT 2 TO APPENDIX 16

MODELING THE LOWER BIG SUNFLOWER RIVER DURING LOW-FLOW CONDITIONS

March 16, 2006

Final Project Report:

Modeling the Lower Big Sunflower River



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Submitted to the

U.S. Army Engineers District- Vicksburg

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Modeling the Big Sunflower River

1 INTRODUCTION

1.1 Objectives

Proposed modifications to the Sunflower River basin include raising the summer pool from between 68 and 70 feet, NGVD, to 70 to 73 feet, NGVD, at the Steele Bayou Structure. In addition, proposed maintenance dredging will lower the bottom elevation by 2 to 4 feet. The increased depth has the potential to lower DO levels in the summer pool. The objective of this work was to apply hydraulic and water quality models in order to estimate potential dissolved oxygen and organic enrichment impacts on the Sunflower River Basin due to project induced changes in the hydraulic regime.

1.2 Approach

The approach used in this project was to apply models to evaluate existing and recommended conditions. Recommended alternatives of two different projects were modeled here. The Big Sunflower River Maintenance Project has the dredging alternatives. In the model and report it is referred to as the existing and recommended plan. The Yazoo Backwater Reformulation Project has the increased water surface elevations (68.5, 70, and 73 feet). The flows modeled represent 3 low flow conditions and are not a direct component of either project.

This project is based in part upon a modeling study conducted by Mississippi State University for the Mississippi Department of Environmental Quality for the development of Total Maximum Daily Load (TMDL) limits for the Big Sunflower River (the TMDL study, Martin et al., 2003). Similarly to that study, the hydraulic characteristics of the system were first estimated using the HEC-RAS model. The hydraulic information was then used along with available water quality data to drive the water quality model WASP. The water quality model was used to estimate the potential impact of changes of hydraulic characteristics on dissolved oxygen conditions. As indicated above, hydraulic conditions included existing conditions and recommended conditions for two projects: dredging as part of the Big Sunflower River Maintenance Project, and increased water surface elevations (68.5, 70, and 73 feet at the Steele Bayou structure) as part of the Yazoo Backwater Reformulation Project. All possible combinations of these downstream water surface elevations and dredged conditions were analyzed under three low flow conditions. The flow conditions were not a direct component of either project but representative of critical low flow conditions for water quality. Eighteen combinations were analyzed, as tabulated below.

Table 1. Conditions analyzed

	Existing Conditions			Dredged Conditions		
200 cfs	68.5 ft	70 ft	73 ft	68.5	70 ft	73 ft
250 cfs	68.5 ft	70 ft	73 ft	68.5	70 ft	73 ft
300 cfs	68.5 ft	70 ft	73 ft	68.5	70 ft	73 ft

The most recent versions of the models were used (HEC-RAS Version 3.1.1 and WASP Version 7.1). The Vicksburg District using the HEC-RAS model performed the hydraulic modeling. MSU researchers, utilizing the WASP model, performed the water quality modeling.

The present study differed from the previous modeling study (Martin et al., 2003) in that the present study included assessment of the impact of phytoplankton productivity as well as organic carbon and nutrient loads on dissolved oxygen conditions within the system under the existing and design conditions. Data were available from the Vicksburg District to aid in model calibration. The water quality model was calibrated to summer low flow conditions and then applied to the conditions identified in Table 1. In the previous study, phytoplankton were not simulated and no data were available to allow for model calibration. The modeling approach is described in greater detail in the following sections.

2 ANALYSIS OF POINT AND NON-POINT SOURCE FLOWS AND LOADINGS

Point source loads to the Big Sunflower system were identified and assessed as part of the previous TMDL modeling study (Martin et al., 2003). No point source loads were identified to the sections of the river modeled in this study. In addition, since this study concentrated on low flow conditions and there were no major tributaries to the sections modeled, non-point source loads were not considered in the present study. Therefore the only flows and loads considered were those entering at the upstream boundary of the model. The upper boundary of the present study was the inactive Lock and Dam (weir) near Highway 12 Bridge.

3 HYDRAULIC ANALYSIS

3.1 Model Description

The hydraulic model used in this study was the Corps of Engineers Hydrologic Engineering Center's River Analysis System (HEC-RAS, Version 3.1.3; HEC, 2002). This is an updated version of the HEC-RAS model used in the previous modeling study (Martin et al., 2003). However, none of the updates directly impacted the results of this modeling study.

HEC-RAS, analyzes networks of natural and man-made channels and computes water surface profiles based on steady one dimensional flow. HEC-RAS operates under the MS-Windows environment and provides state-of-the-art GUI graphics for both input and output. The basic computational procedure is based on the solution of the one-dimensional energy equation. The basic equation in algebraic form is:

Equation 1

$$WS_1 + \alpha_1 \frac{V_1^2}{2g} = WS_2 + \alpha_2 \frac{V_2^2}{2g} + h_e$$

where: WS = water surface elevation at node, m; α = velocity coefficient; V = average velocity at node, m/s; g = gravitational constant, m/s^2; h_e = average friction loss in channel reach between nodes, m; 1 = upstream conditions; and, 2 = downstream conditions.

Energy losses are evaluated by friction (Manning's equation) and contraction/expansion (coefficient multiplied by the change in velocity head). The momentum equation is utilized in situations where the water surface profile is rapidly varied. These situations include mixed flow regime calculations (i.e., hydraulic jumps), hydraulics of bridges, and evaluating profiles at river confluences (stream junctions).

The HEC-RAS uses the standard step method for solution of the one-dimensional energy equation, with energy losses evaluated by averaging over a reach, using the Manning equation. Solution of Equation 1 is performed by the standard step method, the details of which are contained in any standard text

(Hoggan, 1997). While HEC-RAS has the capability of performing unsteady flow analyses, only the steady flow component was used in the present study.

The basic input to HEC-RAS includes geometric data and steady flow data. The geometric data consists of establishing the connectivity of the system (the river system schematic), cross-sectional data, reach lengths, energy loss coefficients (friction losses, contraction and expansion losses), and stream junction information. A river may consist of a single reach (length of river) or may be subdivided into two or more reaches with specified connectivity. Junctions are defined at locations where two reaches come together or split apart. Each reach is further subdivided into stations and cross-sectional data provided at each section. The cross-sectional data may be further subdivided into a main channel and left/right overbank areas. Roughness coefficients (Manning's n values) may be specified for the main channel and left/right overbank areas or allowed to vary as a function of channel width and/or depth.

Steady flow data include downstream boundary conditions (for subcritical flows) and discharge information. For subcritical flows, a downstream boundary is specified either as: a known water surface elevation, a critical depth, a normal depth or a rating curve. Discharge information is provided at the head of each reach, and assumed to remain constant unless a discharge change is specified. Inflows from tributaries and point sources not included in the hydraulic model set-up are specified at flow change locations. That is, to specify an incremental flow, a specific section (cross-section) receiving the inflow would be specified and the total flow (upstream plus the incremental flow) specified at that flow change location. The flow would again be assumed constant until another flow change location is specified. At junctions, the flow at the head of each downstream (receiving) reach is specified. For junctions, it is up to the user to ensure that flow continuity and energy are balanced at the junction, although tabulated junction information is provided by HEC-RAS to aid in the analysis.

3.2 Model set-up

3.2.1 Geometry

The section of the river modeled for this study extended from the Lock and Dam near the Highway 12 Bridge (River Mile 61.39) to the lowest end of the diversion channel near the Steele Bayou structure (RM 0). Note that some caution needs to be exercised in interpreting the locations of the reaches. Several river mile conventions have been used and those used in the present study differ somewhat from previous studies.

The HEC-RAS model was applied by the Vicksburg District to the Big Sunflower system to compute changes in hydraulic conditions under existing and proposed conditions. The Vicksburg District then modified the model input to meet the needs of the water quality modeling study. Those modifications included eliminating cross-sections upstream of the inactive Lock and Dam (weir) near Highway 12 Bridge, which was the upper boundary for the present study. In addition, several branches in which no flow occurred for the low flow conditions of interest in this study were eliminated from the model grid. These included Dowling Bayou and a small section of the Big Sunflower (reach 8) below the six-mile cutoff, which typically do not receive inflows under low flow conditions.

The section of the Big Sunflower River modeled in the present study consisted of seven reaches (Figure 1):

- Big Sunflower River Reach 3: consisting of 48 cross-sections extending from river mile 61.39 (the location of the Lock and Dam near Highway 12 bridge) to river mile 33.6.
- Big Sunflower River Reach 5: consisting of 46 cross-sections extending from river mile 26.03 to 19.42 and representing the Holly Bluff Cutoff.
- Big Sunflower River Reach 6: consisting of 14 cross-sections extending from river mile 19.3, below the Holly Bluff Cutoff to 6.9 and including sections of six-mile cutoff connecting the Big Sunflower and Little Sunflower Rivers extending from river mile 2.23 to 0.01.
- Old Sunflower Bendway Reach 1: consisting of 5 cross-sections extending from river mile 33.2 to 28.4.
- Old Sunflower Bendway Reach 2: consisting of 8 cross-sections extending from river mile 28.2 to 19.5.
- Little Sunflower River Reach 1: consisting of 59 cross-sections extending from river mile 28.1 to river mile 7.2.
- Little Sunflower River Reach 2: consisting of 4 cross-sections extending from river mile 6.9 to 1.4 (the Little Sunflower control structure).
- Lsun Reach 1: consisting of two cross-sections extending from river mile 0.2 to 0.1.
- Little Sun to Steele Reach 1: consisting of 16 cross-sections extending from river mile 16.5 to 0.

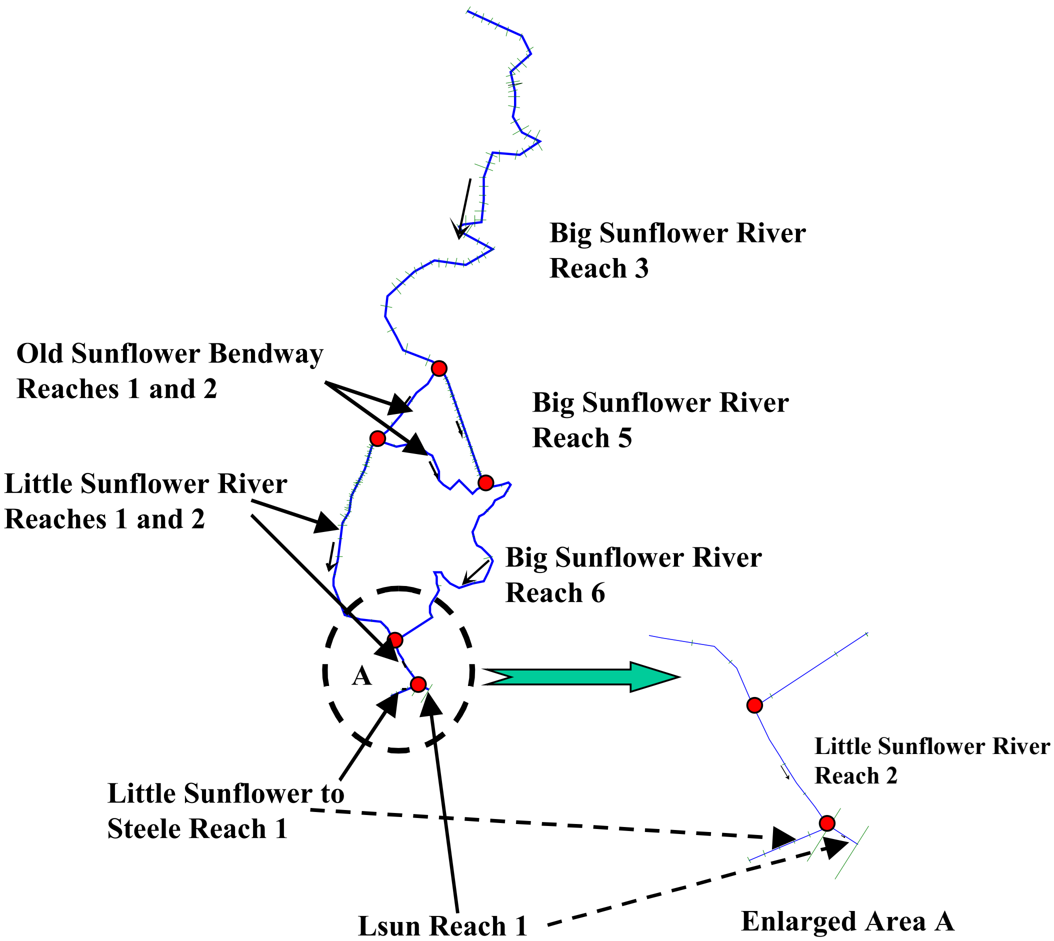


Figure 1. Modeled sections of the Big Sunflower River basin

The later two reaches (Lsun and Little Sun to Steele) were not included in the previous TMDL modeling study (Martin et al., 2003) but were added by the Vicksburg District for the purposes of this study. River mile 0 of the Little Sun to Steele (diversion channel) was the lower boundary of the modeled river and the point at which the boundary condition was specified. The HEC-RAS geometric data used in this study were obtained from the Vicksburg District (in November 2005 from Malcolm Dove, pers. communication).

Two sets of geometry were developed by the Vicksburg District and compared in the present study: existing and recommended conditions. The recommended conditions reflected proposed maintenance dredging in the Old Sun Bendway and portions of the Little Sunflower Reach 1 and Big Sunflower River Reaches 3 and 6. The proposed maintenance dredging would lower the bottom elevation by 2-4 feet, depending upon the location.

3.2.2 Flows and Boundaries

Water surface elevations were specified at the downstream boundary (RM 0, Little Sun to Steele diversion channel, Figure 1). The downstream boundary elevations simulated were 68.5, 70 and 73 feet NGVD at the Steele Bayou Structure (Table 1). Three flow conditions were analyzed in this study, based upon input provided by the Vicksburg District: 200 cfs, 250 cfs and 300 cfs. No tributaries or point sources with significant flows occurred in the section of river modeled.

For branching reaches (Old Sun Bendway and Big Sunflower Reach 5) the flows in the individual branches were computed by the Vicksburg District based upon continuity and an energy balance. The distribution of flows between the Old Sun Bendway and Big Sunflower Reach 5 (Holly Bluff Cutoff) varied with the flow magnitude and downstream water surface elevation (above 70 ft) as indicated in the table below. The difference in the flow in the Bendway and the boundary flows (200, 250 or 200 cfs) represents the flow in Reach 5 (Holly Bluff cutoff). In general the Old Sun Bendway received the majority of the flow, and the percentage of the total flow in the Bendway was predicted to increase following recommended maintenance dredging.

Table 2. Flow distribution to the Old Sunflower Bendway under differing hydraulic conditions.

	FLOW IN OLD SUN BENDWAY (cfs)					
	200 cfs		250 cfs		300 cfs	
ELEVATION (ft)	EXIST	REC.	EXIST	REC.	EXIST	REC.
68.5	180.00	198.00	192.50	247.50	210.00	297.00
70	180.00	198.00	192.50	247.50	210.00	297.00
73	108.00	174.00	120.00	205.00	135.00	234.00
	FLOW FRACTION					
	200 cfs		250 cfs		300 cfs	
ELEVATION (ft)	EXIST	REC.	EXIST	REC.	EXIST	REC.
68.5	0.90	0.99	0.77	0.99	0.70	0.99
70	0.90	0.99	0.77	0.99	0.70	0.99
73	0.54	0.87	0.48	0.82	0.45	0.78

Two reaches included in the geometry, Little Sunflower Reach 1 and LSun, received no flow for the conditions simulated. A token flow of 1 cfs was included in the Vicksburg District's HEC RAS simulations of these two reaches in order to allow the model to run.

4 WATER QUALITY ANALYSIS

4.1 Model Description

The water quality model selected for this application was the Water Analysis Simulation Program Version 7.1, an updated version of the WASP model used in the previous TMDL modeling study (WASP 6; Ambrose et al., 1993, Wool et al., 2001). The updated version contains a number of features, such as additional state variables, not used in the present study. The only updated capability used in this study (and not available in the previous version) was the explicit prediction of structural reaeration. This feature was used in the present study to estimate changes in hydraulic conditions on reaeration over the weir in the Big Sunflower River Reach 5 (Holly Bluff Cutoff, Figure 1).

WASP is a dynamic compartment model that can be used to analyze a variety of water quality problems for aquatic systems, including both the water column and the underlying benthos. The time-varying processes of advection, dispersion, point and non-point mass loading, boundary exchange are represented in the basic program (Ambrose et al., 1993). WASP is considered the Environmental Protection Agency (EPA) standard for dynamic analysis. Technical support through the EPA is available and the model has an extensive record of testing and application.

The underlying framework of the analysis, used in water quality modeling, is based on the principle of conservation of mass. The mass balance equation around an infinitesimally small fluid volume is (Ambrose et al., 1993):

Equation 2

$$\frac{\partial C}{\partial t} = -\frac{\partial}{\partial x}(U_x C) - \frac{\partial}{\partial y}(U_y C) - \frac{\partial}{\partial z}(U_z C) + S_L + S_B + S_K$$
$$+ \frac{\partial}{\partial x}(E_x \frac{\partial C}{\partial x}) + \frac{\partial}{\partial y}(E_y \frac{\partial C}{\partial y}) + \frac{\partial}{\partial z}(E_z \frac{\partial C}{\partial z})$$

where: C = concentration of the water quality constituent, mg/l or g/m^3 ; t = time, days; U_x , U_y , U_z = longitudinal, lateral, and vertical advective velocities, m/day; E_x , E_y , E_z = longitudinal, lateral, and vertical advective diffusion coefficients, m^2/day; S_L = direct and diffuse loading rate, g/m^3-day; S_B = boundary loading rate (including upstream, downstream, benthic, and atmospheric), g/m^3-day; and, S_K = total kinetic transformation rate where positive is source and negative is sink, g/m^3-day.

Equation 2 is the general WASP mass balance equation, and represents three major classes of water quality processes, namely, transport, loading, and transformation.

The mass balance equation is solved for each state variable. The number of state variables and the interaction between them depends upon the particular kinetic module used. There are two primary modules, or submodels. One submodel deals specifically with eutrophication (EUTRO) and the other organic contaminants (TOXI). Submodels are also available for metals, mercury, and water temperature.

In EUTRO (Version 7.1) up to sixteen state variables may be simulated by the model. Of these, only eight were simulated in the present study. Table 3 presents the eight state variables and kinetic processes. The water quality parameters can be considered as four interacting systems: phytoplankton kinetics, the phosphorus cycle, the nitrogen cycle, and the dissolved oxygen balance.

WASP provides considerable flexibility in specifying the variable inputs, such as flows, loads, boundary conditions, and exogenous variables, such as extinction coefficient, temperature, etc., required to run the model. An additional advantage of WASP is that the hydraulic transport can be specified or derived by linking WASP with a hydrodynamic model. For example, the WASP model has been linked with a variety of one, two, and three-dimensional hydrodynamic models. WASP can also be linked with non-point source models such as the Storm Water Management Model (SWMM; Ambrose et al., 1993).

Table 3. Eight State Variables and Kinetic Process Simulated in the Study (of the 16 model state variables)

KINETIC PROCESSES	
1. Ammonia (NH_3) Mineralization of Organic Nitrogen Phytoplankton Death Algal Uptake (Growth) Nitrification Benthic Flux	5. CBOD Phytoplankton Death Oxidation CBOD Denitrification Settling
2. Nitrate Nitrogen (NO_3) Nitrification Algal Uptake Denitrification	6. Dissolved Oxygen (DO) Reaeration Phytoplankton Growth Nitrification CBOD Oxidation Sediment Oxygen Demand
3. Orthophosphorus (PO_4) Mineralization of Organic Phosphorus Phytoplankton Death Algal Uptake Benthic Flux	7. Organic Nitrogen (ON) Phytoplankton Respiration Phytoplankton Death Mineralization
4. Phytoplankton (CHL) Growth Respiration Settling	8. Organic Phosphorus (OP) Phytoplankton Respiration Phytoplankton Death Mineralization

Although WASP is a dynamic model, it can be used to obtain steady-state predictions by specifying constant flows, boundary conditions, loads, and other time varying input and then running the model until steady-state predictions are obtained, as was the strategy for this study. However, the ability to link WASP to a hydrodynamic model and with a time-variable hydrologic model is a distinct advantage should dynamic (continuous) simulations be needed in future studies.

4.2 Model set-up

The EUTRO model was applied to the Big Sunflower River, extending from the Lock and Dam near Highway 12 to the Steele Bayou control structure. Steady-flow hydraulic information was obtained from the HEC-RAS hydraulic model described in the preceding section. Using the hydraulic information from HEC-RAS, the WASP model was run with constant water quality boundary conditions over a sufficient period to obtain steady-state predictions.

4.3 Model Implementation

4.3.1 Model Geometry

For the present study, for each river section depicted in Figure 1, the geometric information were obtained from the HEC-RAS model and varied with the conditions simulated (Table 1). The geometric data obtained from HEC-RAS included:

- Segment Volumes (obtained by differences from cumulative volumes output by HEC-RAS)
- Segment Depths
- Segment Velocities
- Cross-sectional areas and reach lengths
- Surface areas (obtained by differences from cumulative surface areas output by HEC-RAS)

These data were obtained from summary output tables generated by HEC-RAS which were copied to spreadsheets developed for this study to convert the HEC-RAS output to WASP input. Information from the spreadsheets was then inserted into WASP input files resulting in separate input files for each flow condition simulated (Table 1).

The HEC-RAS model predicts hydraulic characteristics at channel cross-sections, while WASP segments represent the volumetric element between cross-sections. In the HEC-RAS model for the Big Sunflower River, the distance between cross-sections, or spacing, varied widely as is common in models whose primary purpose is to compute variations in hydraulic characteristics (such as velocities and depths) as a function of flow. Where cross-sections were closely spaced in the HEC-RAS simulation, an overlay grid was used in the WASP simulation. That is, individual WASP segments may have included more than 2 cross-sections. For that case, the volumes and surface areas specified to WASP represented total values, while the depths and velocities specified to WASP were average values.

The water quality model EUTRO for the Big Sunflower River was divided into 81 segments as illustrated below (Table 4, Figure 1). Note that the Little Sunflower reach 1 and LSun were included in the mode grid only to allow for simulations in the future under high flow conditions, if that should be necessary. For the present study these two reaches received no flows and were not included in water quality simulations.

Table 4. WASP model segmentation

Reach	From Segment	To Segment
Big Sunflower Reach 3	1	20
Old Sun Bendway Reach 1	21	24
Old Sun Bendway Reach 2	25	31
Big Sunflower Reach 6	32	42
Little Sunflower Reach 2	43	45
Little Sun to Steele	46	55
Big Sunflower Reach 5	56	64
Little Sunflower Reach 1	65	80
LSun Reach 1	81	81

4.3.2 Flows and Boundaries

The flows specified to WASP were obtained from the hydraulic simulation (see Section 3). Boundary flows simulated were 200, 250 and 300 cfs. The flow spilt between the Big Sunflower reach 5 (Holly Bluff Cutoff) and the Old Sun Bendway varied as a function of flows and bottom boundary elevations and between the existing and recommended conditions, as discussed previously (Table 2).

No point or non-point sources flows were included in simulations. Since there were no flow reversals at the downstream boundary, the specified downstream water quality boundary conditions had no impact on simulations. Therefore only an upstream boundary condition (at the upstream boundary for Big Sunflower Reach 3, Figure 1) was required. The water quality boundary conditions were based in part on data collected by the Vicksburg District at station BS-11 (Big

Sunflower River @ Little Calleo). A boundary condition for each water quality constituent simulated was specified and held constant for all inflows as tabulated below.

Table 5. Boundary conditions

Parameter	Boundary condition	Units
DO	7.0	mg/L
CBODU	4.8	mg/L
NO3	0.42	mg/L
NH3	0.29	mg/L
Org-N	2.06	mg/L
Org-P	0.19	mg/L
Ortho-P	0.29	mg/L

4.3.3 Environmental Parameters

Environmental parameters in EUTRO allow specification of spatially varying coefficients or processes that have an impact on model predictions, but are not themselves included in simulations. For this application, the environmental parameters included water temperature, the coefficient of light extinction, and the rates of sediment nutrient release and oxygen demand. The water temperature was assumed a constant 26 ^oC, averaged from field measurements. The specified rate of sediment oxygen demand was based on previous modeling studies and was a constant 2.0 g m^{-2} day^{-1}. Sediment release rates for ammonia and phosphates were 100 and 1 g m^{-2} day^{-1}. A constant light extinction coefficient of 5.2 m^{-1} was specified, based upon field photometric measurements by the Vicksburg District.

An additional feature in the WASP Version 7 model not included in previous model versions was the capability of predicting the impacts of structural reaeration. Structural reaeration is estimated from the Butts and Evans (1983) formulation

Equation 3

$$r = 1 + 0.38abH\ (1 - 0.11H)\ (1 + 0.046T)$$

where r is the ratio of the dissolved oxygen deficit above and below the dam; H the difference in water surface elevation; and, the coefficients *a* and *b* correct for water quality and dam type. Based upon Chapra (1997) the water quality coefficient (a) for this study was taken to be equal to 1.0 while the dam coefficient was taken to be equal to 0.7. The difference in water surface elevation (H) was taken from results of the hydraulic (HEC-RAS) simulations and is tabulated below. As indicated, increasing the downstream elevation (pool elevation at Steele Bayou) decreased the elevation difference, as did the recommended dredging over the existing conditions.

Table 6 Computed difference in water surface elevation over the Holly Bluff Cutoff weir (Big Sunflower reach 5).

	CHANGE IN DEPTH (m) OVER WEIR					
	200 cfs		250 cfs		300 cfs	
ELEVATION (ft)	EXIST	REC.	EXIST	REC.	EXIST	REC.
68.5	1.24	1.21	1.21	1.14	1.17	1.07
70	0.89	0.86	0.90	0.83	0.89	0.79
73	0.11	0.04	0.13	0.05	0.14	0.06

4.3.4 Kinetic Constants

The kinetic rate constants used in the present study differed from those used in the previous (Martin et al., 2003) modeling study for two reasons. In the previous study there were no data available in this portion of the river for model calibration. Data were available for this study and were used to estimate site-specific values for model coefficients. Secondly, available data allowed simulation of phytoplankton on dissolved oxygen and nutrient cycling. Phytoplankton was not simulated in the previous study. Kinetic coefficients used in model simulations are tabulated below.

4.3.5 Time series

Certain environmental parameters are specified to WASP as time series, such as wind speed. The wind speed for the present simulation was assumed a constant 2 m sec^{-1}, which was the average wind speed for the region as reported by Shindala et al. (1998).

Table 7. Kinetic coefficients used in simulations

Ammonia	
Nitrification Rate Constant @20 °C (per day)	0.1
Nitrification Temperature Coefficient	1.08
Half Saturation Constant for Nitrification Oxygen Limit (mg O/L)	0.5
Nitrate	
Denitrification Rate Constant @20 °C (per day)	0.1
Denitrification Temperature Coefficient	1.045
Half Saturation Constant for Denitrification Oxygen Limit (mg O/L)	10
Organic N	
Dissolved Organic Nitrogen Mineralization Rate Constant @20 °C (per day)	0.01
Dissolved Organic Nitrogen Mineralization Temperature Coefficient	1.08
Fraction of Phytoplankton Death Recycled to Organic Nitrogen	0.5
Organic P	
Mineralization Rate Constant for Dissolved Organic P @20 °C (per day)	0.22
Dissolved Organic Phosphorus Mineralization Temperature Coefficient	1.08
Fraction of Phytoplankton Death Recycled to Organic Phosphorus	0.5
CBOD	
BOD (1) Decay Rate Constant @20 °C (per day)	0.05
BOD (1) Decay Rate Temperature Correction Coefficient	1.047
BOD (1) Half Saturation Oxygen Limit (mg O/L)	0.5
Phytoplankton	
Phytoplankton Maximum Growth Rate Constant @20 °C (per day)	2
Phytoplankton Growth Temperature Coefficient	1.068
Phytoplankton Carbon to Chlorophyll Ratio	50
Phytoplankton Half-Saturation Constant for Nitrogen Uptake (mg N/L)	0.025
Phytoplankton Half-Saturation Constant for Phosphorus Uptake (mg P/L)	0.001
Phytoplankton Endogenous Respiration Rate Constant @20 °C (per day)	0.1
Phytoplankton Respiration Temperature Coefficient	1.045
Phytoplankton Death Rate Constant (Non-Zooplankton Predation) (per day)	0.05
Phytoplankton Phosphorus to Carbon Ratio	0.025
Phytoplankton Nitrogen to Carbon Ratio	0.25
Phytoplankton Half-Sat. for Recycle of Nitrogen and Phosphorus (mg Phyt C/L)	1

4.3.6 Dispersion: Transport Parameters

In addition to advective transport (as a result of flows), transport of water quality constituents in WASP can also occur as a function of dispersion. In the present study, only advective transport was considered and rates of dispersion were set to zero.

4.3.7 Calibration Data

Data were collected by the Vicksburg District and used to develop boundary conditions for the model and for model calibration. Water quality profile data collected included water temperatures, conductivity, DO, pH, turbidity, TOC, TSS, TS, BOD, chlorophyll-a and OPO4. Monthly grab samples collected at depths from the surface to 1.5 feet of depth were analyzed for water temperature, conductivity, DO, pH, turbidity, TKN, TP, NO2/NO3, TOC, TSS, NH3, TDS, SO4, and chlorophyll-a. The locations and dates of collection are tabulated below. For the purposes of model calibration, only data collected during the months of July to October were used. Profile data collected were depth averaged for comparison to model predictions.

Table 8. Locations and dates of data collected

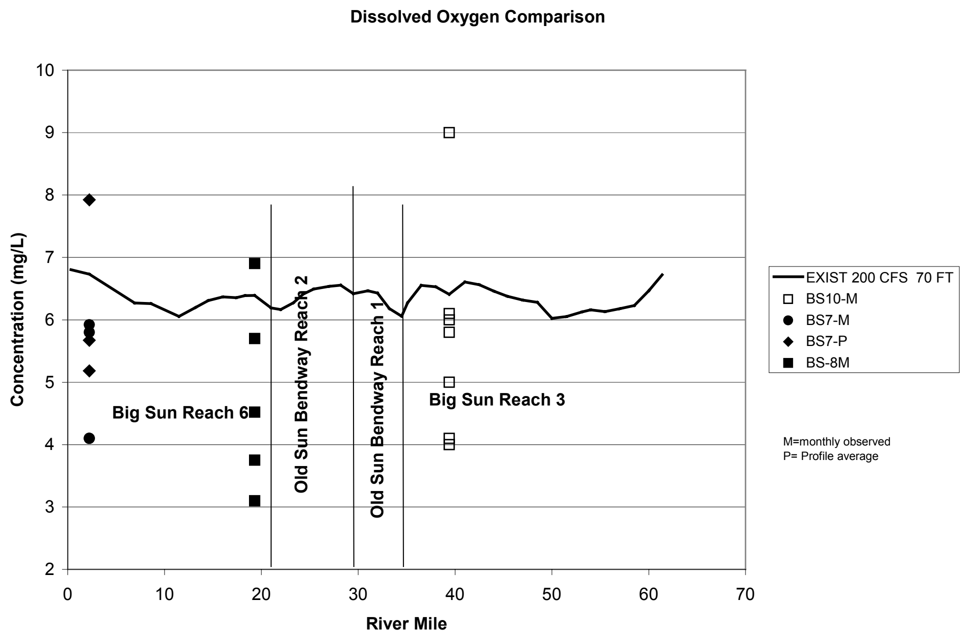
Locations				Monthly Data		Profiles
WASP Segment	River Section	River Mile	Station	Dates	No. Dates	Dates
16	Big Sun Reach 3	39.4	BS-10	4/04 to 7/05	32	
32	Big Sun Reach 6	19.3	BS-8	5/03 to 7/05	32	
41	Big Sun Reach 6	2.23	BS-7	6/04 to 3/05	13	6/05, 7/05. 8/05
52	Little Sun to Steele	5.2	BS-6			7/05
53	Little Sun to Steele	4.68	BS-5			7/05
54	Little Sun to Steele	3	BS-4			7/05
55	Little Sun to Steele	1.5	BS-3			7/05
55	Little Sun to Steele	1.5	BS-2			7/05
55	Little Sun to Steele	1.5	BS-1			7/05
63	Big Sun Reach 5	19.89	BS-9	6/04 to 3/05	13	6/05, 7/05. 8/05
65	Little Sun Reach 1	28.1	LS-3	4/03 to 3/05	27	
66	Little Sun Reach 1	27.17	LS-2	6/04 to 3/05	11	
71	Little Sun Reach 1	22.2	LS-1	2/03 to 7/05	41	6/05, 7/05. 8/05

4.4 Model Results

4.4.1 Calibration

The WASP model was initially calibrated using hydraulic data for existing conditions, a flow of 200 cfs and a downstream elevation of 70 ft. Model predictions were compared to available field data collected by the Vicksburg District. The data included monthly samples, taken at surface-1.5 ft depth, during the months of July-October. Predictions were also compared to the depth-average of profile data collected during that period. Comparisons of model predictions and observed data are provided in Figure 2-Figure 6 for dissolved oxygen, chlorophyll-a, ammonia, nitrate-nitrogen, and phosphates, respectively. Model predictions fell within the range of field data. However, considerable variability in the field data were observed. An exception was phosphates which were consistently over-predicted even using a relatively low sediment release rate. The only loss mechanism for phosphorus included in the model was uptake by phytoplankton. However, other loss mechanisms, such as possibly sorption and settling, may be important in this system.

Graphical comparisons between predicted and observed concentrations, similarly to those illustrated by Figure 2-Figure 6, were made for all of the 18 conditions simulated and are included in Appendices A and B. The comparisons were not for the purpose of model calibration but rather were intended to provide a qualitative check of the model's performance. Similar trends to those illustrated were predicted for all conditions simulated and none of predictions were considered unreasonable.



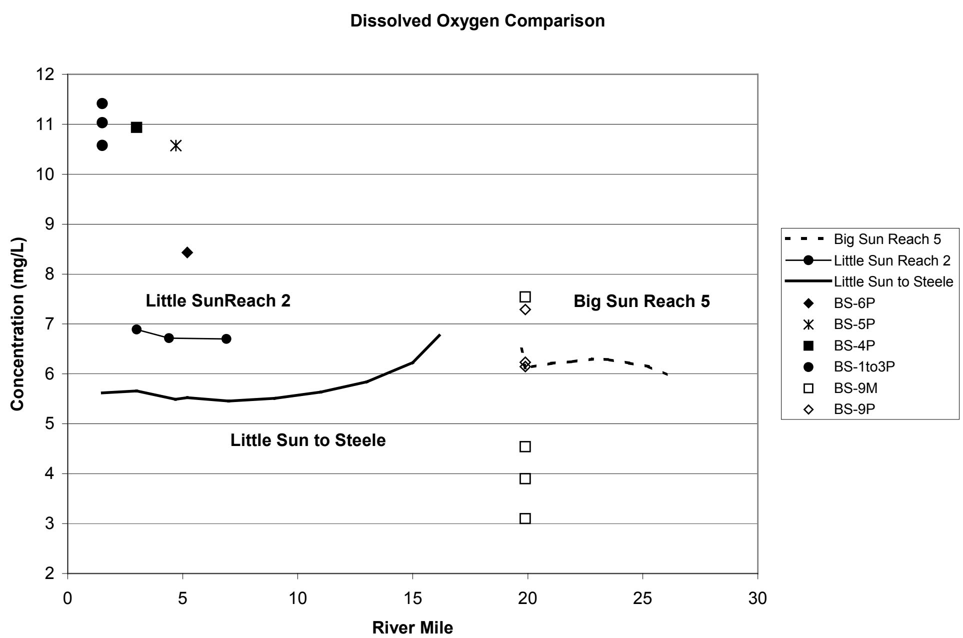
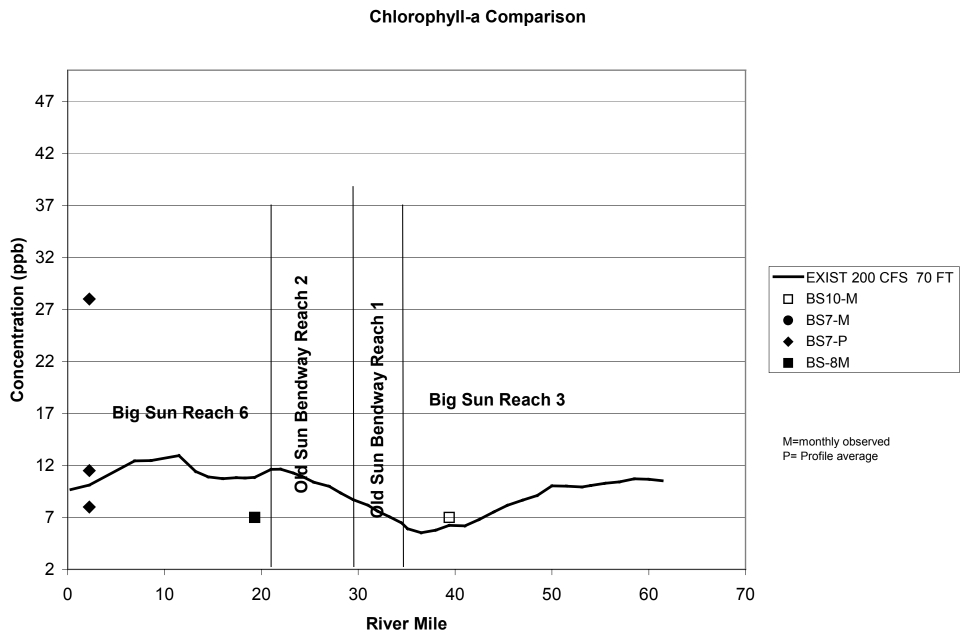


Figure 2. Predicted dissolved oxygen concentrations for existing conditions with a flow of 200 cfs and downstream elevation of 70 ft.



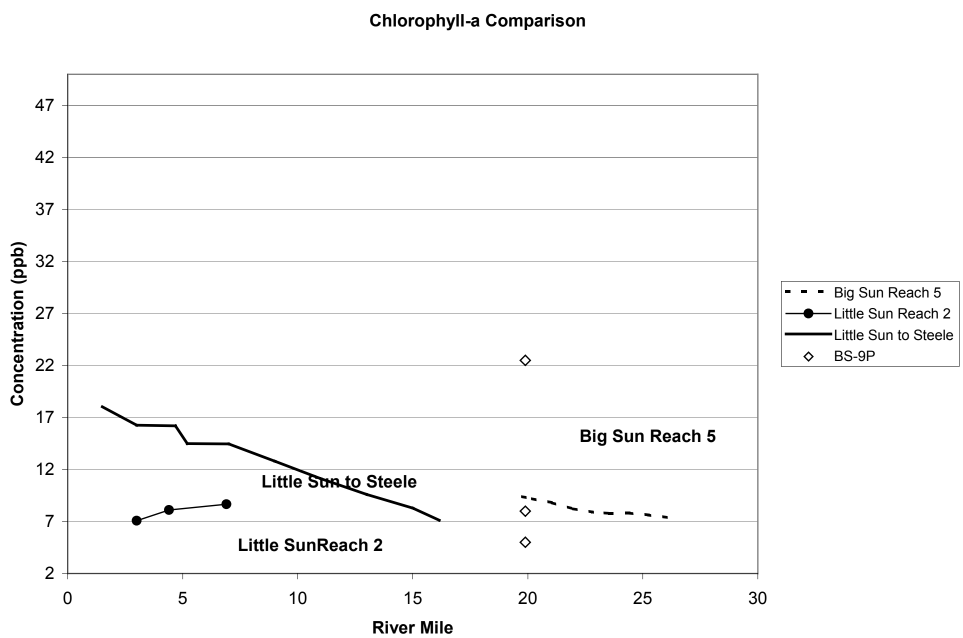


Figure 3. Predicted chlorophyll-a concentrations for existing conditions with a flow of 200 cfs and downstream elevation of 70 ft.

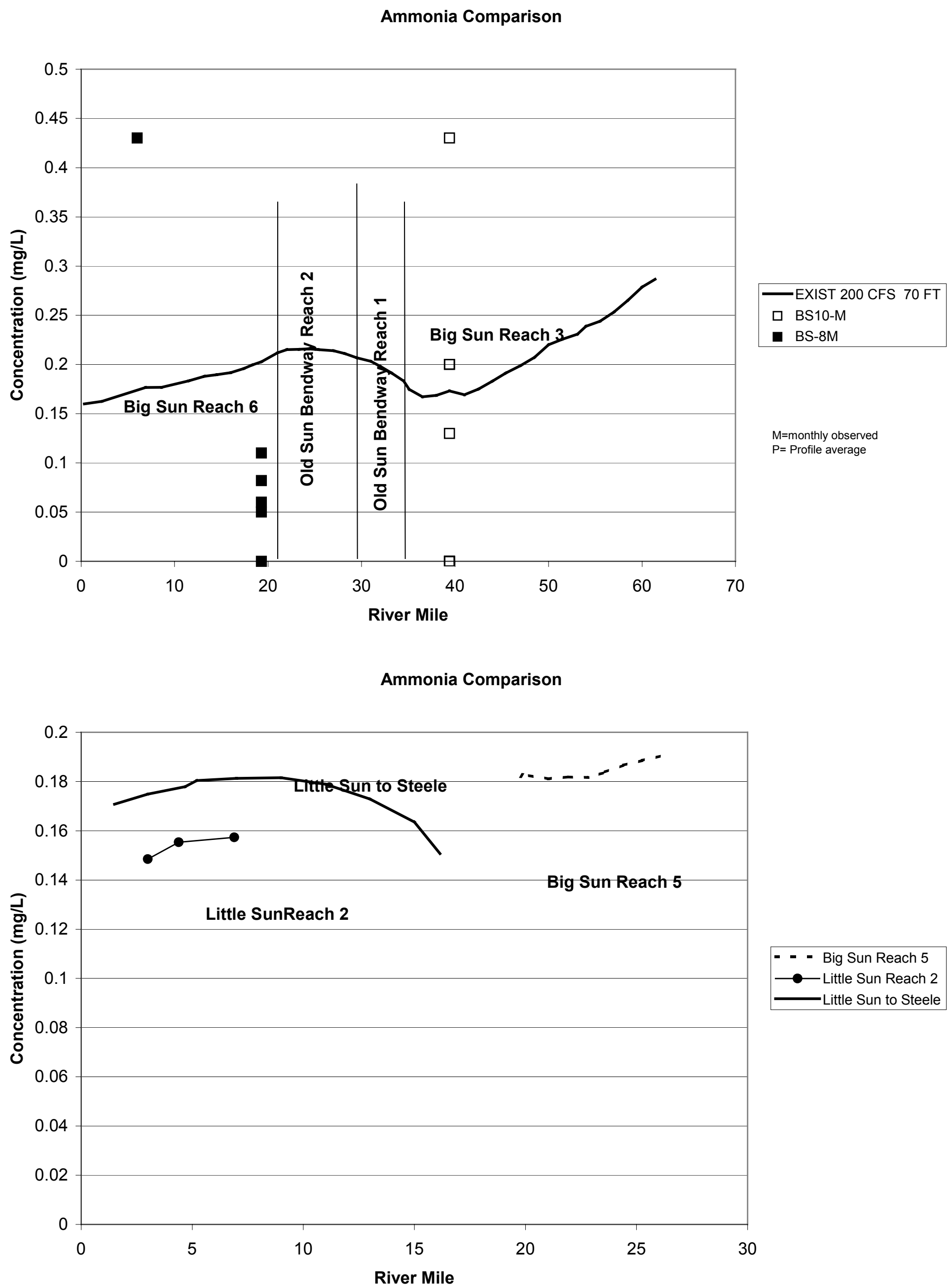


Figure 4. Predicted ammonia concentrations for existing conditions with a flow of 200 cfs and downstream elevation of 70 ft.

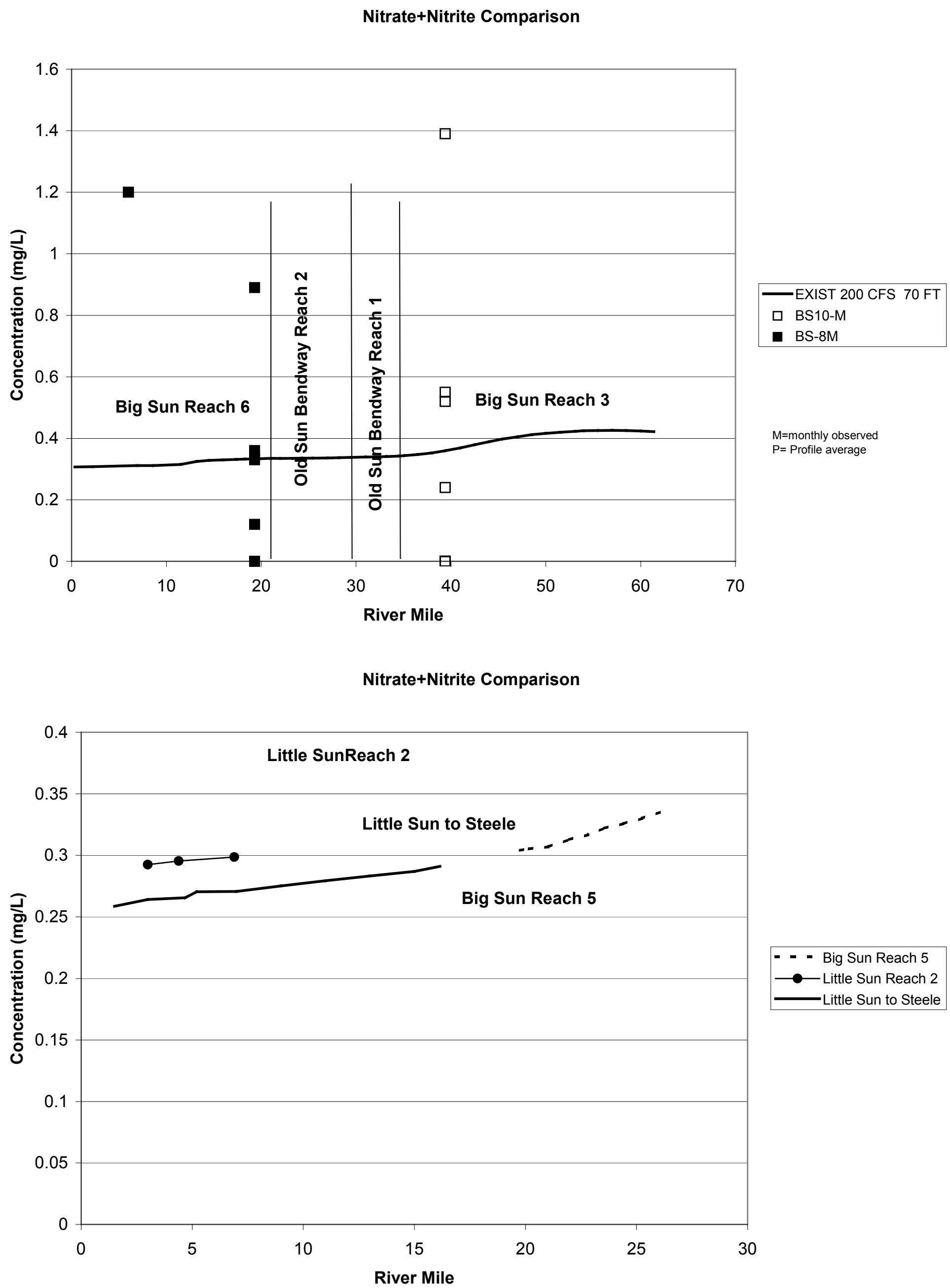
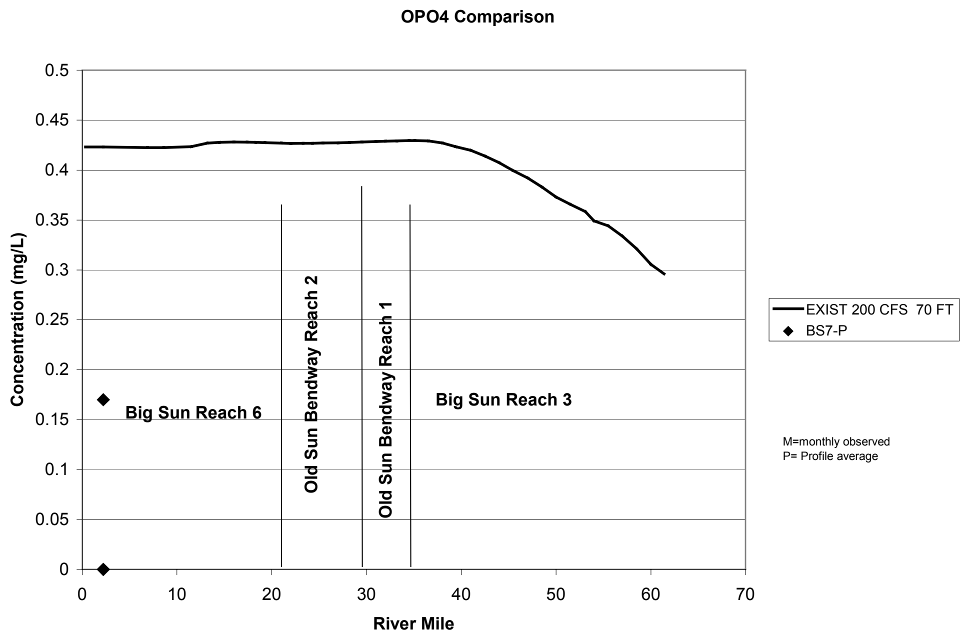


Figure 5. Predicted nitrate concentrations for existing conditions with a flow of 200 cfs and downstream elevation of 70 ft.



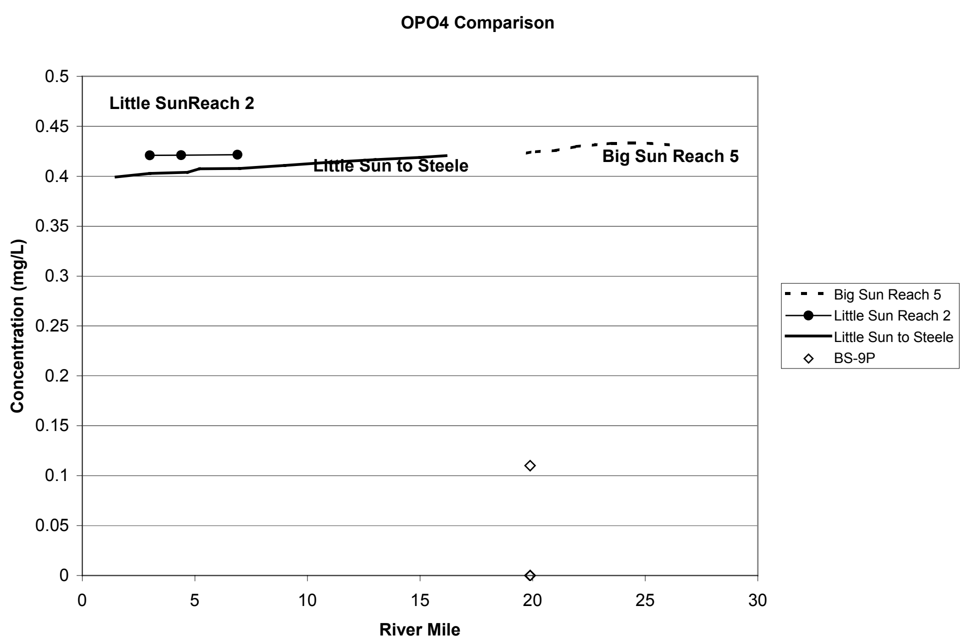


Figure 6. Predicted phosphate concentrations for existing conditions with a flow of 200 cfs and downstream elevation of 70 ft.

4.4.2 Model Projections

Model predicted dissolved oxygen concentrations for each of the 18 conditions simulated (Table 1) are illustrated in Appendices A and B. Reach average, maximum, and minimum variations in dissolved oxygen are summarized in Table 9-Table 11.

Over the entire reach of river simulated there was relatively little variation (<0.05 mg/l) in the average dissolved oxygen concentrations between any of the conditions simulated. Individual reach average, maximum, and minimum computed concentrations did vary between conditions simulated as a function of changing hydraulic conditions, as illustrated by the changes in travel times through individual river reaches (Table 12)

Table 9. Comparison of average, maximum and minimum predicted dissolved oxygen concentrations for existing and recommended conditions as a function of flow for a downstream pool elevation of 68.5 ft.

		AVERAGE DISSOLVED OXYGEN CONCENTRATIONS (mg/L)					
		200 cfs		250 cfs		300 cfs	
		EXIST	REC.	EXIST	REC.	EXIST	REC.
Big Sunflower R	Reach 3	6.33	6.46	6.33	6.44	6.34	6.42
Old Sun Bend	Reach 1,2	6.47	6.13	6.47	6.15	6.44	6.15
Big Sun	Reach 6	6.31	6.33	6.33	6.33	6.33	6.32
Little Sunflower	Reach 2	6.70	6.65	6.68	6.65	6.66	6.64
LSUN to STEELE	Reach 1	6.30	6.11	6.33	6.20	6.36	6.27
Big Sunflower R	Reach 5	6.18	6.30	6.22	6.31	6.21	6.31
		MAXIMUM DISSOLVED OXYGEN CONCENTRATIONS **(mg/L)**					
		200 cfs		250 cfs		300 cfs	
		EXIST	REC.	EXIST	REC.	EXIST	REC.
Big Sunflower R	Reach 3	6.72	6.68	6.77	6.69	6.80	6.73
Old Sun Bend	Reach 1,2	6.64	6.31	6.62	6.29	6.57	6.25
Big Sun	Reach 6	6.70	6.59	6.65	6.56	6.60	6.54
Little Sunflower	Reach 2	6.81	6.79	6.79	6.77	6.77	6.76
LSUN to STEELE	Reach 1	6.68	6.65	6.69	6.66	6.69	6.67
Big Sunflower R	Reach 5	6.30	6.39	6.76	6.39	6.78	6.41
		MINIMUM DISSOLVED OXYGEN CONCENTRATIONS **(mg/L)**					
		200 cfs		250 cfs		300 cfs	
		EXIST	REC.	EXIST	REC.	EXIST	REC.
Big Sunflower R	Reach 3	6.02	6.05	6.04	6.08	6.07	6.09
Old Sun Bendway	Reach 1,2	6.18	5.88	6.23	5.96	6.23	5.99
Big Sunflower R	Reach 6	5.94	6.03	5.97	6.07	5.99	6.09
Little Sunflower	Reach 2	6.63	6.56	6.62	6.56	6.60	6.56
LSUN to STEELE	Reach 1	6.16	5.98	6.22	6.06	6.27	6.16
Big Sunflower R	Reach 5	5.99	6.15	6.04	6.14	6.08	6.13

Table 10. Comparison of average, maximum and minimum predicted dissolved oxygen concentrations for existing and recommended conditions as a function of flow for a downstream pool elevation of 70 ft.

		AVERAGE DISSOLVED OXYGEN CONCENTRATIONS (mg/L)					
		200 cfs		250 cfs		300 cfs	
		EXIST	REC.	EXIST	REC.	EXIST	REC.
Big Sunflower R	Reach 3	6.33	6.46	6.33	6.45	6.34	6.42
Old Sun Bend	Reach 1,2	6.37	5.94	6.38	5.77	6.36	6.04
Big Sun	Reach 6	6.38	6.41	6.37	6.59	6.36	6.36
Little Sunflower	Reach 2	6.77	6.73	6.75	6.88	6.73	6.70
LSUN to STEELE	Reach 1	5.77	5.61	5.93	6.11	6.04	5.95
Big Sunflower R	Reach 5	6.23	6.32	6.21	6.18	6.20	6.31
		MAXIMUM DISSOLVED OXYGEN CONCENTRATIONS **(mg/L)**					
		200 cfs		250 cfs		300 cfs	
		EXIST	REC.	EXIST	REC.	EXIST	REC.
Big Sunflower R	Reach 3	6.72	6.68	6.77	6.69	6.80	6.73
Old Sun Bend	Reach 1,2	6.56	6.18	6.55	6.16	6.51	6.17
Big Sun	Reach 6	6.80	6.69	6.75	6.85	6.69	6.62
Little Sunflower	Reach 2	6.89	6.88	6.86	7.02	6.83	6.82
LSUN to STEELE	Reach 1	6.77	6.75	6.77	6.96	6.76	6.75
Big Sunflower R	Reach 5	6.56	6.44	6.68	6.30	6.70	6.47
		MINIMUM DISSOLVED OXYGEN CONCENTRATIONS **(mg/L)**					
		200 cfs		250 cfs		300 cfs	
		EXIST	REC.	EXIST	REC.	EXIST	REC.
Big Sunflower R	Reach 3	6.02	6.05	6.04	6.10	6.07	6.09
Old Sun Bendway	Reach 1,2	6.16	5.75	6.18	5.62	6.17	5.89
Big Sunflower R	Reach 6	6.05	6.14	6.07	6.34	6.07	6.17
Little Sunflower	Reach 2	6.70	6.64	6.68	6.79	6.66	6.63
LSUN to STEELE	Reach 1	5.45	5.24	5.65	5.80	5.79	5.68
Big Sunflower R	Reach 5	5.99	6.15	6.04	6.04	6.08	6.13

Table 11. Comparison of average, maximum and minimum predicted dissolved oxygen concentrations for existing and recommended conditions as a function of flow for a downstream pool elevation of 73.

		AVERAGE DISSOLVED OXYGEN CONCENTRATIONS (mg/L)					
		200 cfs		250 cfs		300 cfs	
		EXIST	REC.	EXIST	REC.	EXIST	REC.
Big Sunflower	Reach 3	6.34	6.47	6.34	6.45	6.35	6.44
Old Sun Bendway	Reach 1,2	5.79	5.71	5.78	5.77	5.85	5.80
Big Sunflower	Reach 6	6.54	6.62	6.51	6.59	6.47	6.55
Little Sunflower	Reach 2	6.92	6.90	6.90	6.88	6.88	6.86
LSUN to STEELE	Reach 1	6.11	6.05	6.16	6.11	6.20	6.16
Big Sunflower	Reach 5	6.17	6.17	6.16	6.18	6.16	6.16
		MAXIMUM DISSOLVED OXYGEN CONCENTRATIONS **(mg/L)**					
		200 cfs		250 cfs		300 cfs	
		EXIST	REC.	EXIST	REC.	EXIST	REC.
Big Sunflower R	Reach 3	6.69	6.69	6.73	6.69	6.79	6.74
Old Sun Bend	Reach 1,2	6.12	6.20	6.12	6.16	6.18	6.12
Big Sun	Reach 6	7.01	6.90	6.95	6.85	6.89	6.82
Little Sunflower	Reach 2	7.05	7.05	7.02	7.02	6.99	6.99
LSUN to STEELE	Reach 1	6.97	6.97	6.96	6.96	6.94	6.94
Big Sunflower R	Reach 5	6.34	6.32	6.32	6.30	6.31	6.29
		MINIMUM DISSOLVED OXYGEN CONCENTRATIONS **(mg/L)**					
		200 cfs		250 cfs		300 cfs	
		EXIST	REC.	EXIST	REC.	EXIST	REC.
Big Sunflower R	Reach 3	6.05	6.06	6.06	6.10	6.09	6.12
Old Sun Bendway	Reach 1,2	5.53	5.54	5.52	5.62	5.60	5.66
Big Sunflower R	Reach 6	6.24	6.32	6.25	6.34	6.24	6.35
Little Sunflower	Reach 2	6.84	6.80	6.83	6.79	6.81	6.78
LSUN to STEELE	Reach 1	5.79	5.71	5.87	5.80	5.93	5.87
Big Sunflower R	Reach 5	6.03	6.00	6.06	6.04	6.11	6.06

Table 12. Estimated travel time (hours) within river reaches for the conditions simulated

			Elev. 68.5 ft		Elev. 70 ft		Elev. 73 ft	
River	**Reach**	**Profile**	**Exist**	**Rec**	**Exist**	**Rec**	**Exist**	**Rec**
Old Sun Bend	Reach 1	200	13.51	15.57	14.32	18.93	32.28	34.65
Old Sun Bend	Reach 1	250	13.32	13.97	14.06	16.21	29.61	29.73
Old Sun Bend	Reach 1	300	13.06	12.86	13.71	14.44	26.95	26.37
Old Sun Bend	Reach 2	200	30.86	45.43	37.24	53.88	96.51	87.78
Old Sun Bend	Reach 2	250	30.31	38.1	35.72	44.09	87.14	74.71
Old Sun Bend	Reach 2	300	29.31	33.26	33.79	37.67	77.88	65.7
LSUN TO STEELE	Reach 1	200	93.69	93.69	127.57	127.57	205.91	205.91
LSUN TO STEELE	Reach 1	250	77.58	77.58	103.17	103.17	165	165
LSUN TO STEELE	Reach 1	300	67	67	87.05	87.05	137.77	137.77
Little Sunflower	Reach 2	200	118.63	118.63	132.08	132.08	168.26	168.26
Little Sunflower	Reach 2	250	96.95	96.95	106.64	106.64	134.87	134.87
Little Sunflower	Reach 2	300	82.55	82.55	89.81	89.81	112.65	112.65
Big Sunflower R	Reach 3	200	613.66	732.32	613.66	732.34	628.49	740.74
Big Sunflower R	Reach 3	250	499.53	587.58	499.53	587.59	509.41	597.47
Big Sunflower R	Reach 3	300	421.77	490.7	421.77	490.71	429.49	501.74
Big Sunflower R	Reach 5	200	538.42	5331.52	541.67	5361.81	124.67	428.66
Big Sunflower R	Reach 5	250	191.56	4275.13	192.66	4296.89	89.38	250.51
Big Sunflower R	Reach 5	300	124.21	3566.6	124.86	3582.82	71.17	172.52
Big Sunflower R	Reach 6	200	223.69	250.83	250.57	277.83	321.45	347.39
Big Sunflower R	Reach 6	250	183.16	204.85	202.47	224.26	257.45	278.16
Big Sunflower R	Reach 6	300	156.26	174.31	170.65	188.78	214.94	232.18

5 SUMMARY AND DISCUSSION

The objective of this work was to estimate potential dissolved oxygen and organic enrichment impacts on the Sunflower River Basin due to project induced changes in the hydraulic regime. Changes in the hydraulic regime included increased depths and decreased velocities due to increases in the downstream pool elevation and/or channel maintenance dredging.

The Vicksburg District estimated changes in the hydraulic regime by an application of the HEC-RAS model to available flow and existing/projected geometric data. The predicted hydraulic conditions were used, along with available water quality data obtained by the Vicksburg District, in the application of a water quality model (WASP) to evaluate the impact of changes in those conditions on water quality of the Big Sunflower River basin. The portion of the river modeled in this study extended from the weir near Highway 12 to the Steele Bayou control structure (Figure 1). There were no significant point sources or tributaries to this reach of the river. Therefore the predicted water quality of this section of the river was impacted only by: flows and loads from the uppermost boundary, nutrient loads and oxygen demands by the sediments, atmospheric reaeration (wind and stream driven), algal growth and death, and internal cycling.

The overall predicted average dissolved oxygen concentrations changed little (< 0.05 mg/L) between the conditions simulated, existing and recommended (Table 1). Predicted dissolved oxygen concentrations did vary between individual reaches. The greatest decrease in the reach-averaged concentrations between existing and recommended conditions, 0.6 mg/L, occurred in the Old Sunflower Bendway (Figure 1) for a flow of 250 cfs and downstream pool elevation of 70 feet. However, reach-average dissolved oxygen concentrations in Big Sunflower

Reaches 3 and 6 generally increased under recommended conditions (Table 10-Table 12).

An advantage of the WASP model is the number of output variables provided for review and the efficient post-processing system that facilitates the evaluation of causal factors for predicted variations in concentrations. These predictions have been preserved in model output files but are not included in this report for the sake of brevity. However, an analysis of the model output demonstrates that there is not a clear relationship between changes in hydraulic conditions and corresponding changes in dissolved oxygen concentrations.

An increase in the pool elevation at Steele Bayou and/or the recommended maintenance dredging of the river was predicted, in general, to result in greater river depths and decreased river velocities. As a result, travel times through individual reaches increased (Table 12). The deepening and/or dredging would also result in an alteration in the distribution of flows down the Old Sunflower Bendway and those down the Big Sunflower Reach 5 (Holly Bluff Cutoff). A greater proportion of the total flow would go to the Old Sunflower Bendway (

Table 2) with increased downstream elevation and/or maintenance dredging, resulting in dramatically increased travel times in Reach 5 (Table 12). In addition, water surface elevations in the Big Sunflower Reach 5 increased with deepening and/or dredging resulting in lesser elevation differences over the weir in the Big Sunflower Reach 5 (Holly Bluff Cutoff) thereby reducing the degree of structural reaeration (Table 6, Equation 3). Steam reaeration is also directly proportional to velocities and inversely proportional to depth, so that a decrease in velocities and increase in depth would result in decreased stream reaeration.

It may be expected that the greater depths, increased travel time and reduced reaeration would result in decreased dissolved oxygen concentrations in the Big Sunflower Reach 5. However, model predictions suggested that the concentrations would, on average, increase. Evaluations of model predictions indicated that the increase in averaged dissolved oxygen concentrations in this reach resulted from an increase in phytoplankton productivity, which benefited from the increased retention time. Additionally, with the impact of wind, the total rate of reaeration did not appreciably change from that under existing conditions.

Conversely, it could be surmised that dissolved oxygen concentrations in the Old Sunflower Bendway would change little following an increase in pool elevation or maintenance dredging (recommended conditions, Table 1). Although depth increased in this section, the flows increased, resulting in only a moderate increase in travel times (Table 12). However, predicted dissolved oxygen concentrations were reduced more in this reach that any other. Evaluation of model results suggested that with comparable travel times and increased depth, reaeration was reduced as well as total light, resulting in a decrease in phytoplankton productivity following deepening.

The results of this modeling study suggest that there is no clear relationship between the proposed increase of the pool elevation at Steele Bayou and/or maintenance dredging (recommended conditions) and variations in dissolved oxygen concentrations. External (modeled) loads to the system only occurred at the upstream boundary, and their effect on oxygen demands was generally limited to the upper river reach (Big Sunflower River Reach 5). In downstream reaches, the relative importance of sediments as a source of nutrients, internal cycling and algal productivity would increase. Data collected by the Vicksburg District clearly indicate that algal productivity is an important process impacting dissolved oxygen concentrations. Additionally, in downstream reaches, increased depths and decreased velocities would result in decreased stream reaeration and increased impacts of sediment demands. However, as stream reaeration decreases, the relative importance of wind reaeration would increase.

This study would suggest that with deepening, the relative importance of internal cycling and algal productivity would increase. However, the quantitative estimates of the impact of those changes provided by the model application have considerable uncertainty associated with them. This is due in part to limitations in the available data. Data on nutrients and chlorophyll concentrations in the water column are limited, impacting model calibration. No measurements are available for the rates of sediment oxygen demand and nutrient release, which have a direct impact on predicted internal cycling. Additional data, if collected in the future, may be used to further support and reduce the uncertainty associated with model projections.

6 REFERENCES

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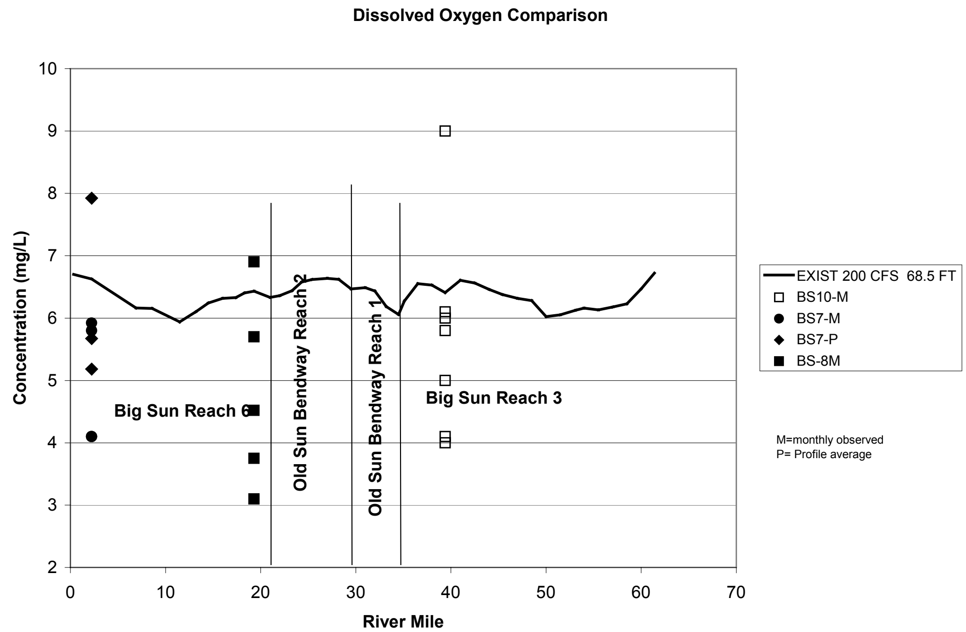
APPENDIX A: MODEL PREDICTIONS FOR EXISTING CONDITIONS



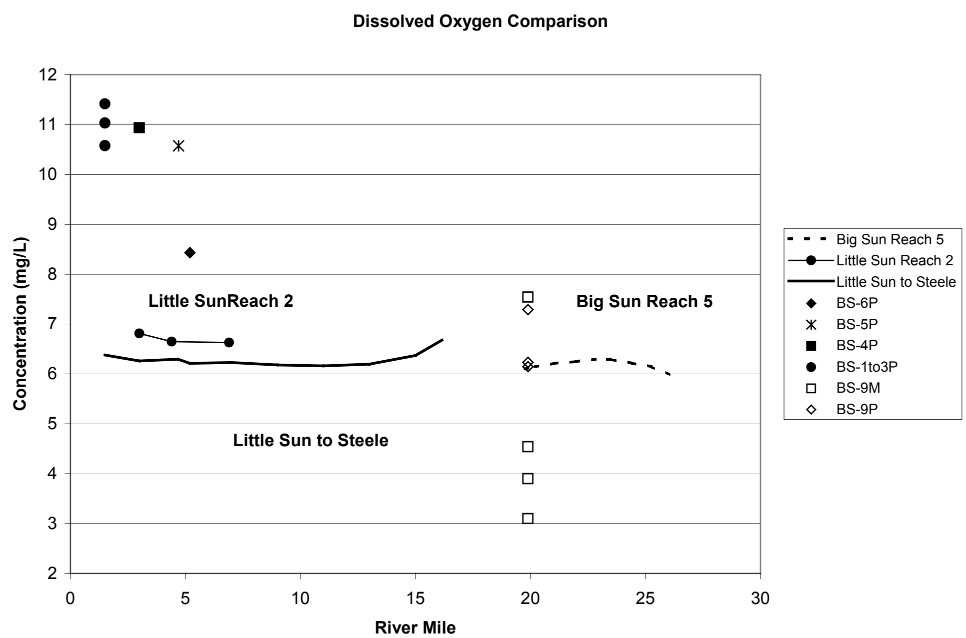
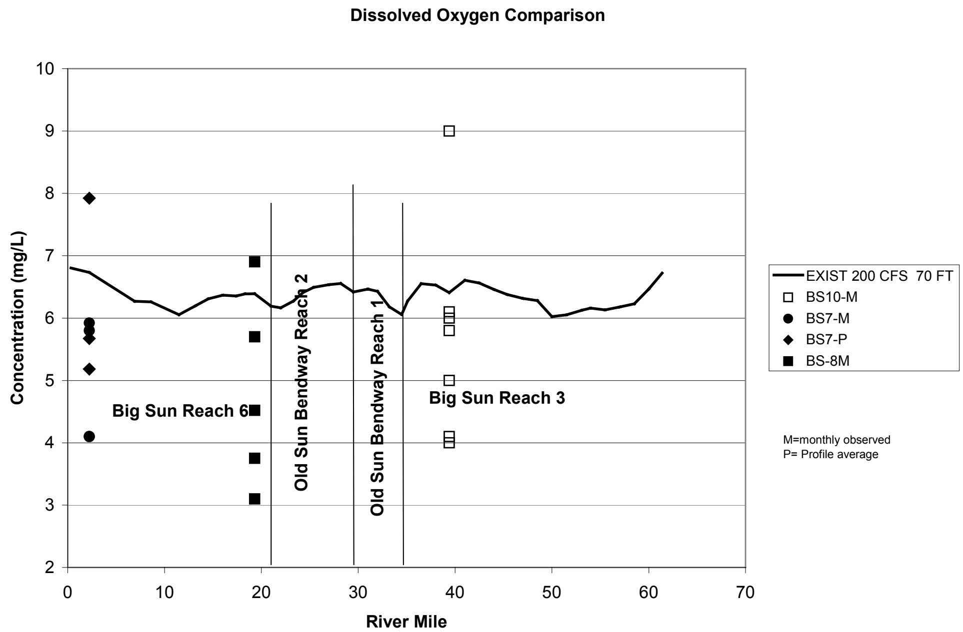


Figure A- 1. Predicted dissolved oxygen concentrations for existing conditions with a flow of 200 cfs and downstream elevation of 68.5 ft.



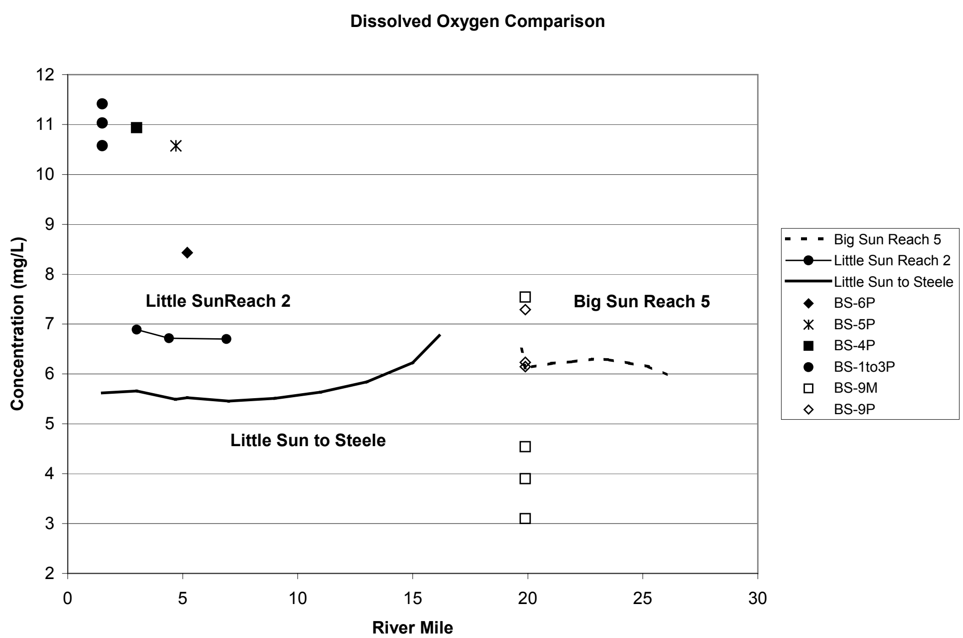
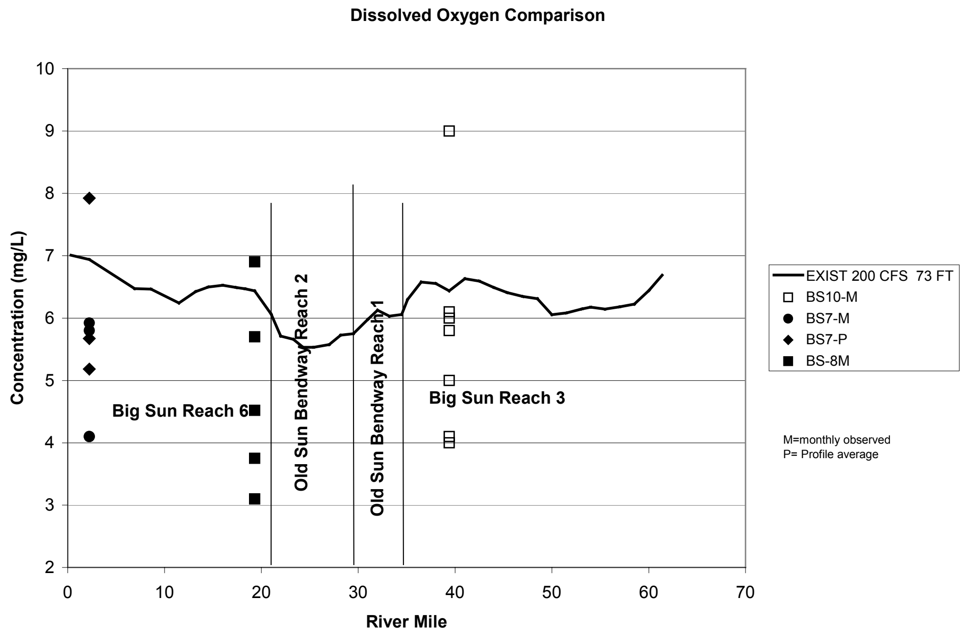


Figure A- 2. Predicted dissolved oxygen concentrations for existing conditions with a flow of 200 cfs and downstream elevation of 70 ft.



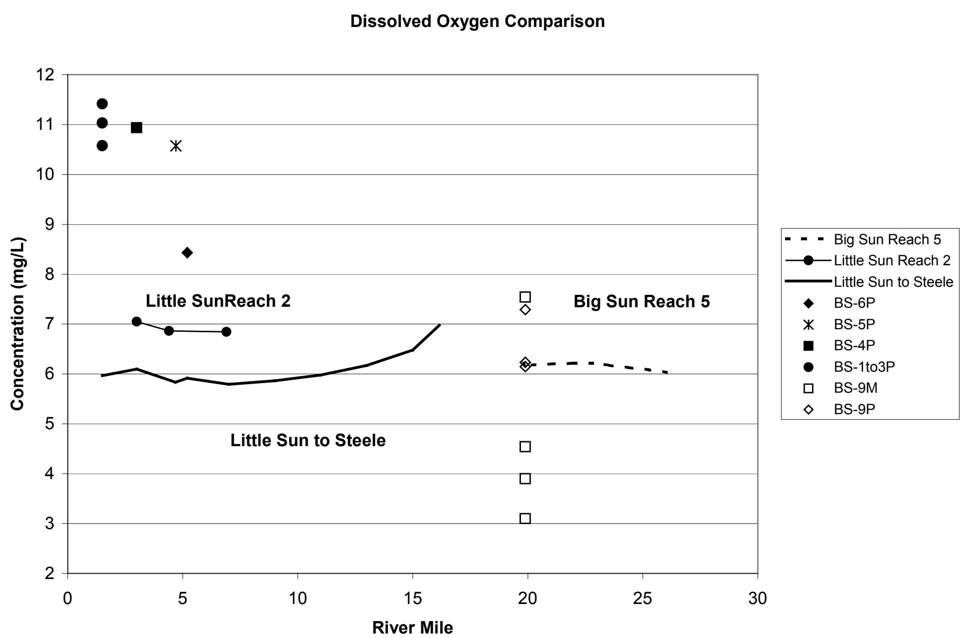
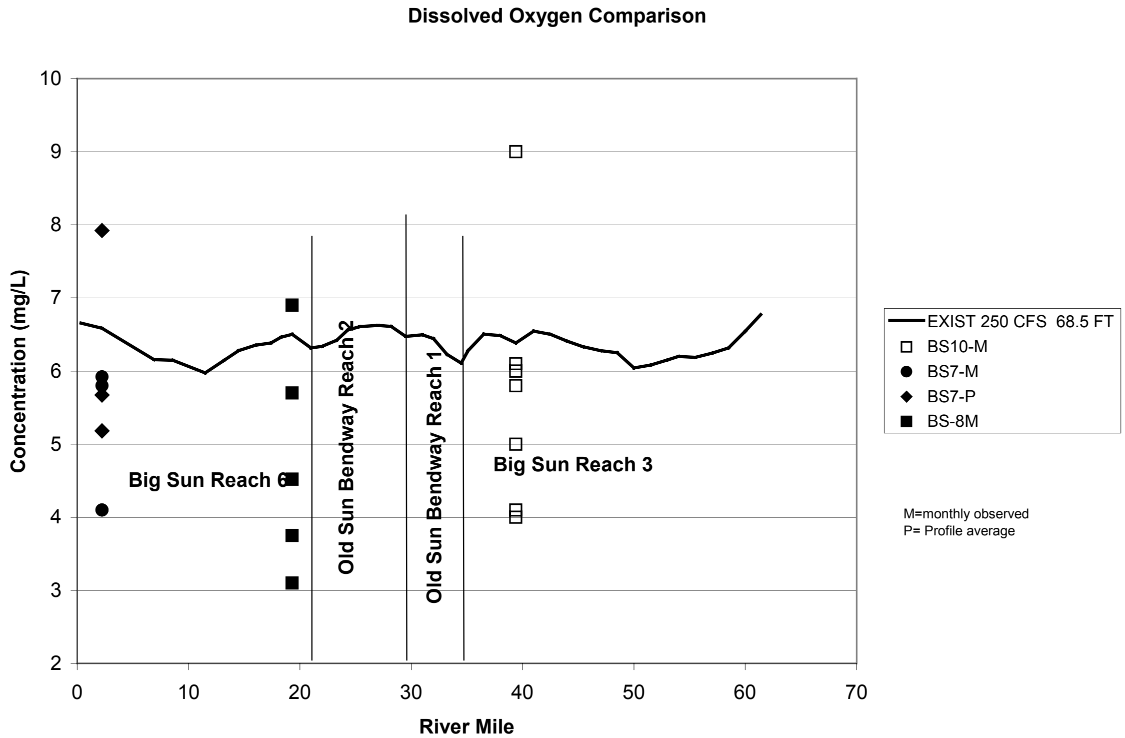


Figure A- 3. Predicted dissolved oxygen concentrations for existing conditions with a flow of 200 cfs and downstream elevation of 73 ft.



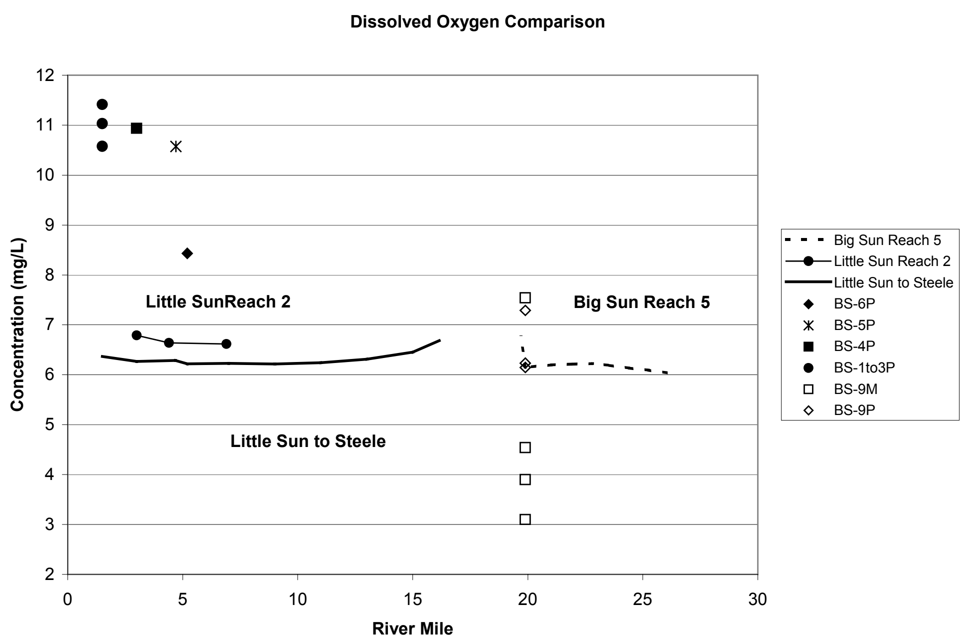
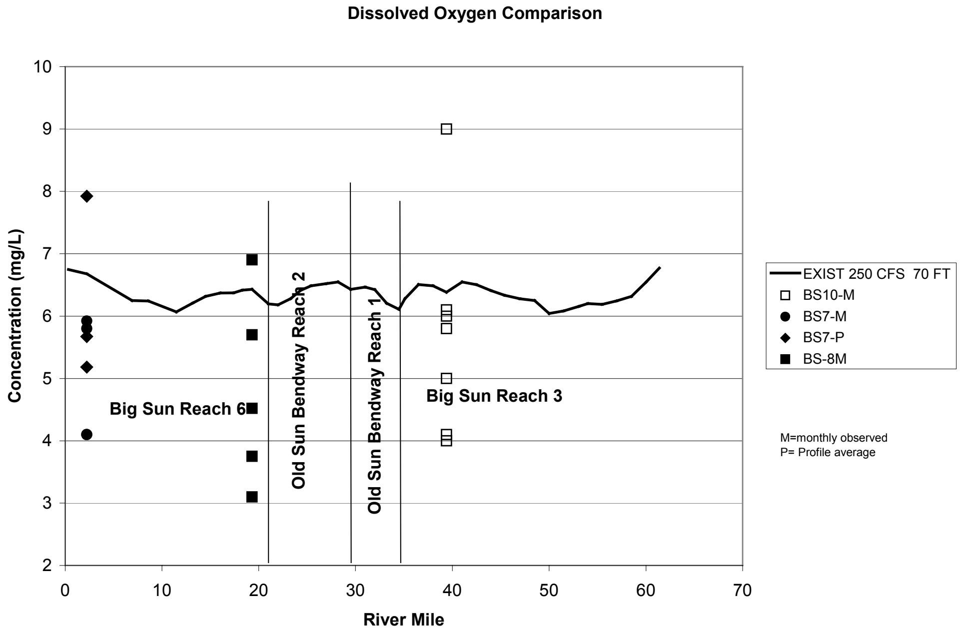


Figure A- 4. Predicted dissolved oxygen concentrations for existing conditions with a flow of 250 cfs and downstream elevation of 68.5 ft.



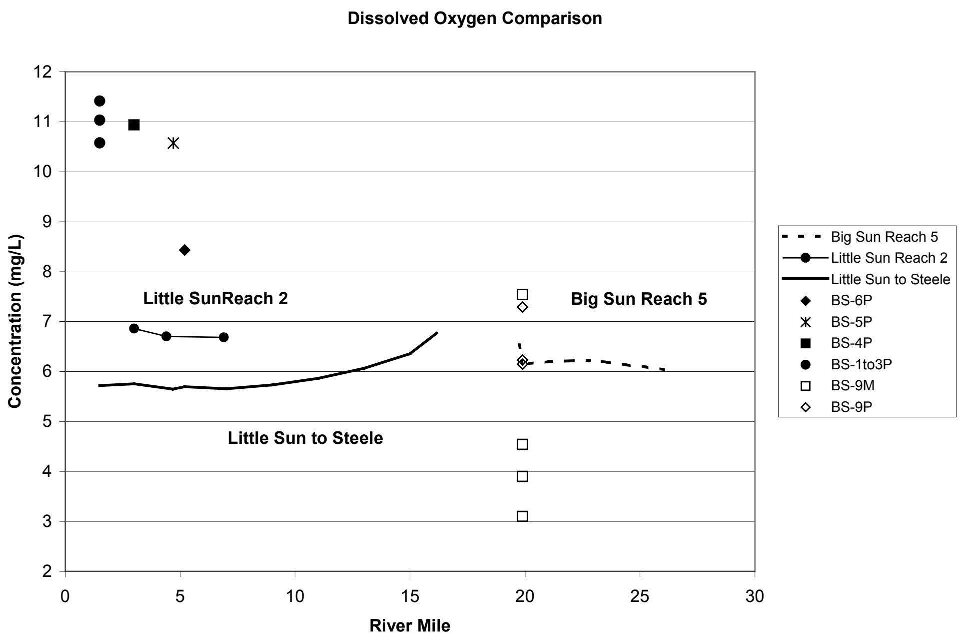
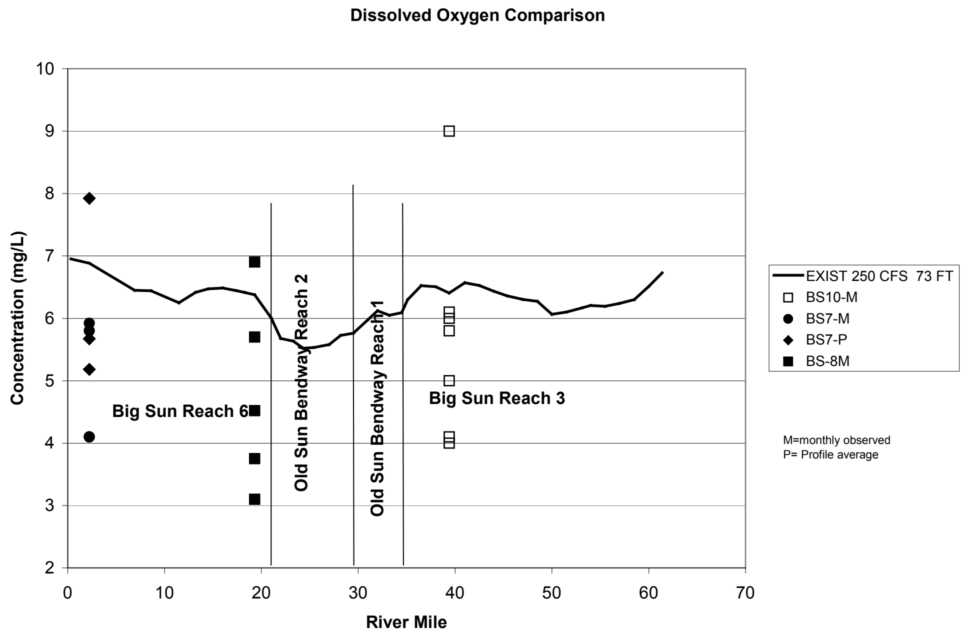


Figure A- 5. Predicted dissolved oxygen concentrations for existing conditions with a flow of 250 cfs and downstream elevation of 70 ft.



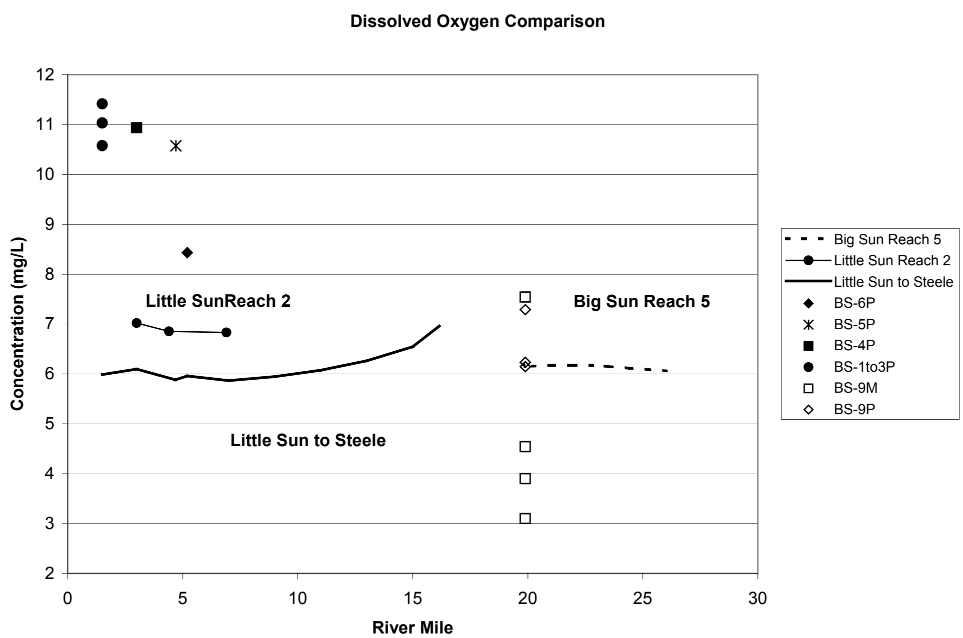
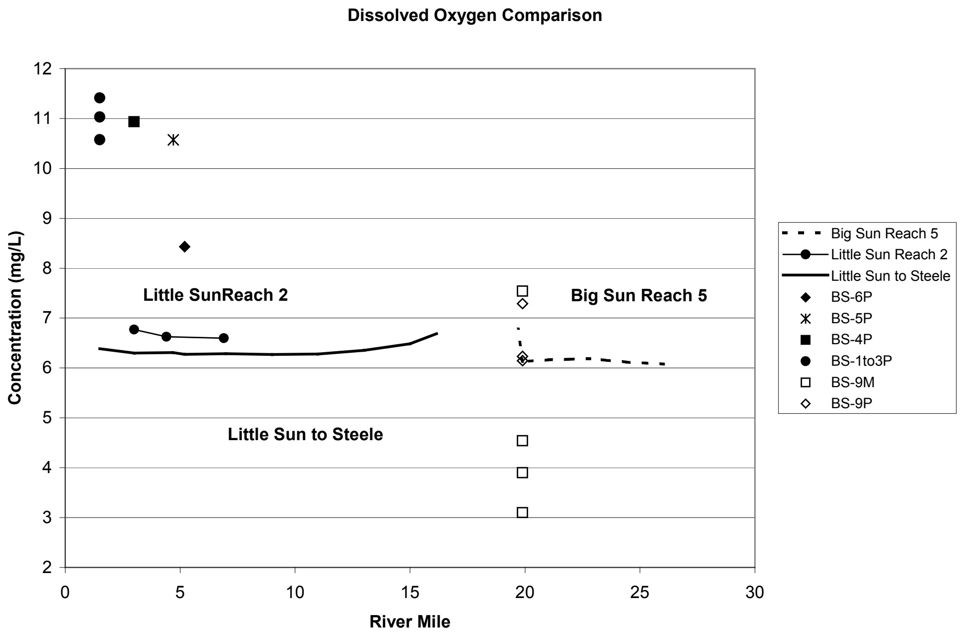


Figure A- 6. Predicted dissolved oxygen concentrations for existing conditions with a flow of 250 cfs and downstream elevation of 73 ft.



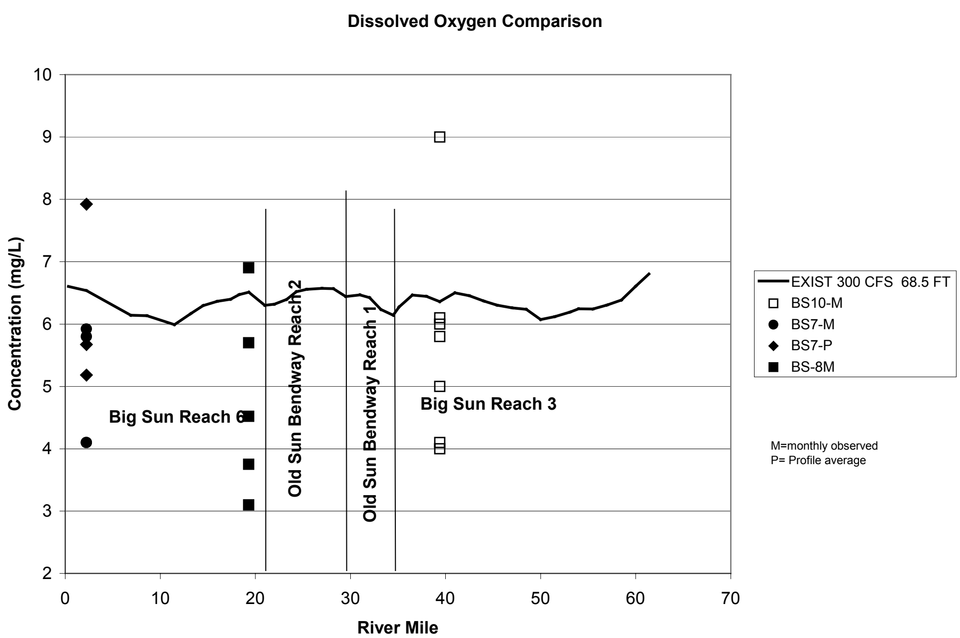
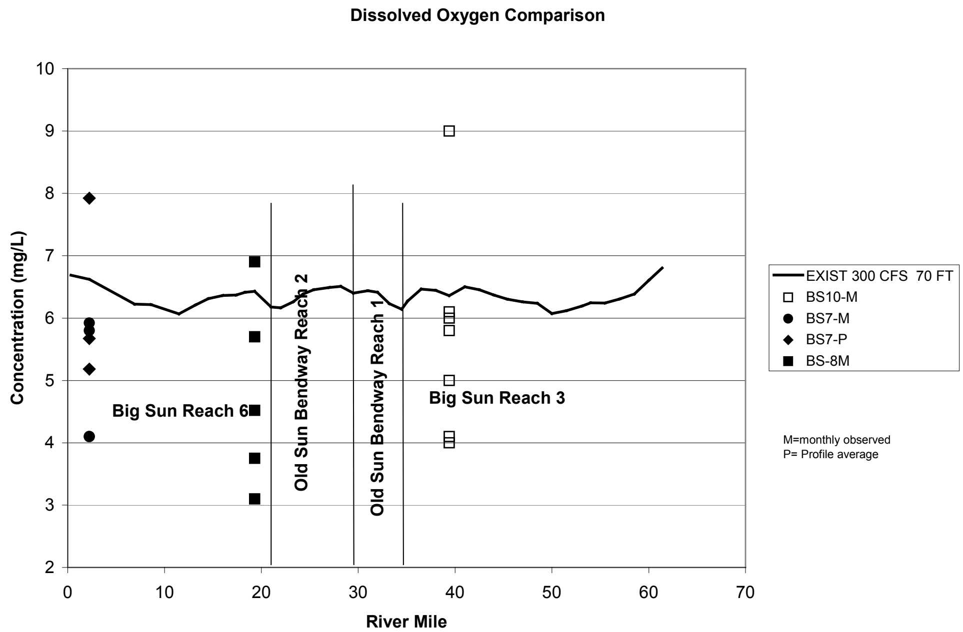


Figure A- 7. Predicted dissolved oxygen concentrations for existing conditions with a flow of 300 cfs and downstream elevation of 68.5 ft.



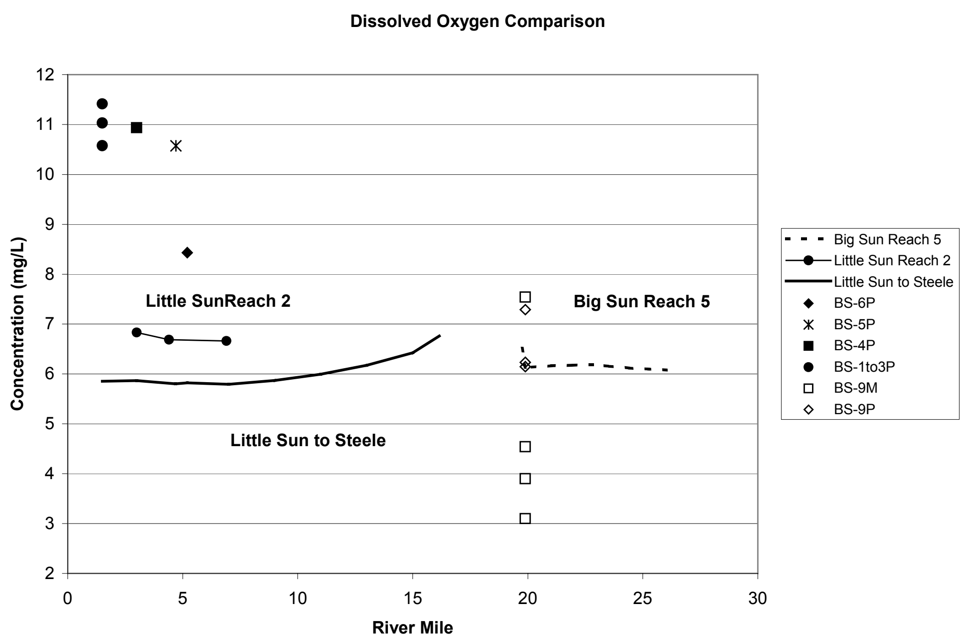
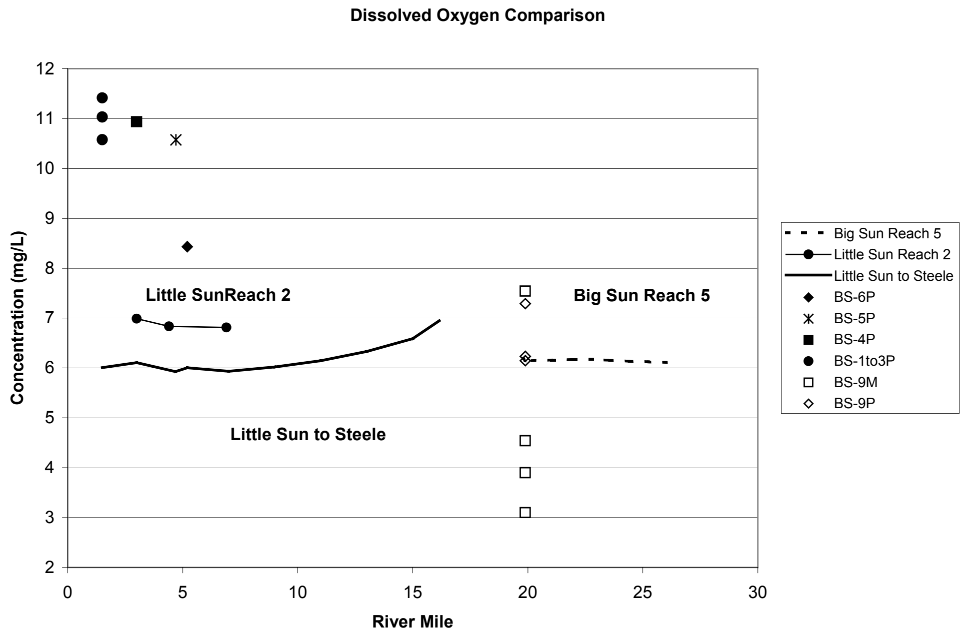


Figure A- 8. Predicted dissolved oxygen concentrations for existing conditions with a flow of 300 cfs and downstream elevation of 70 ft.



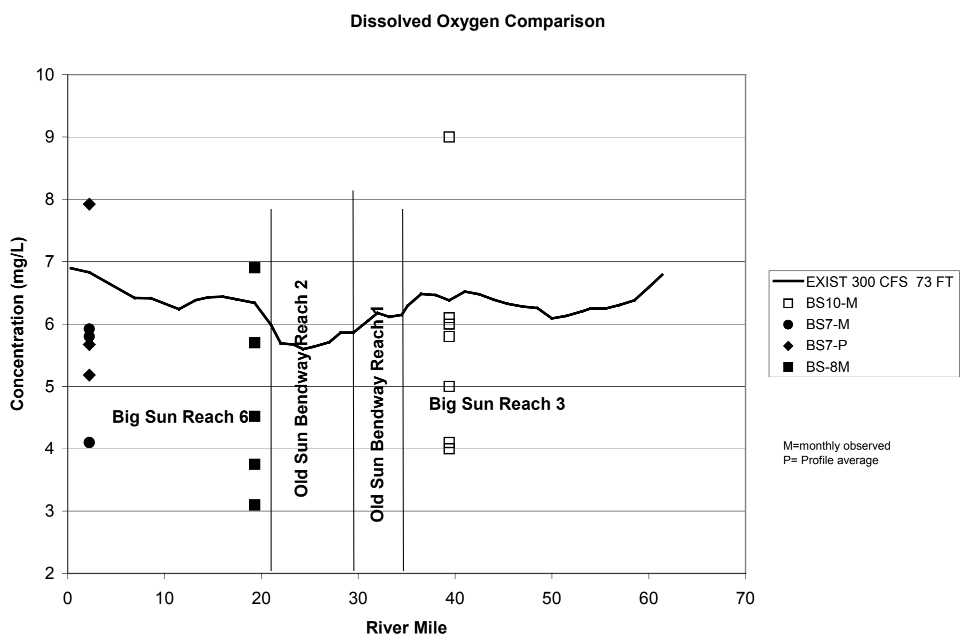
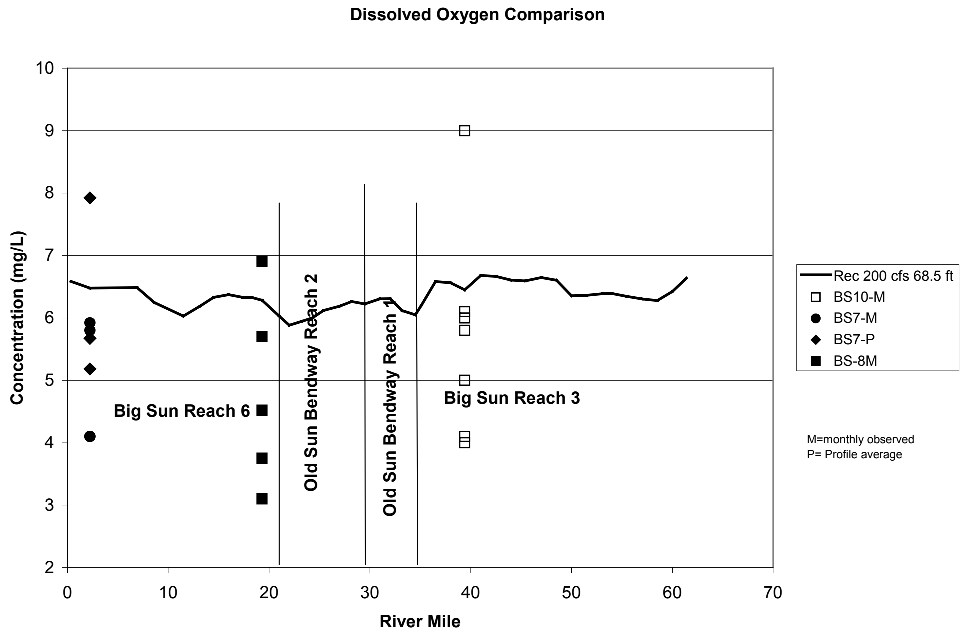


Figure A- 9. Predicted dissolved oxygen concentrations for existing conditions with a flow of 300 cfs and downstream elevation of 73 ft.

APPENDIX B: MODEL PREDICTIONS FOR RECOMMENDED CONDITIONS



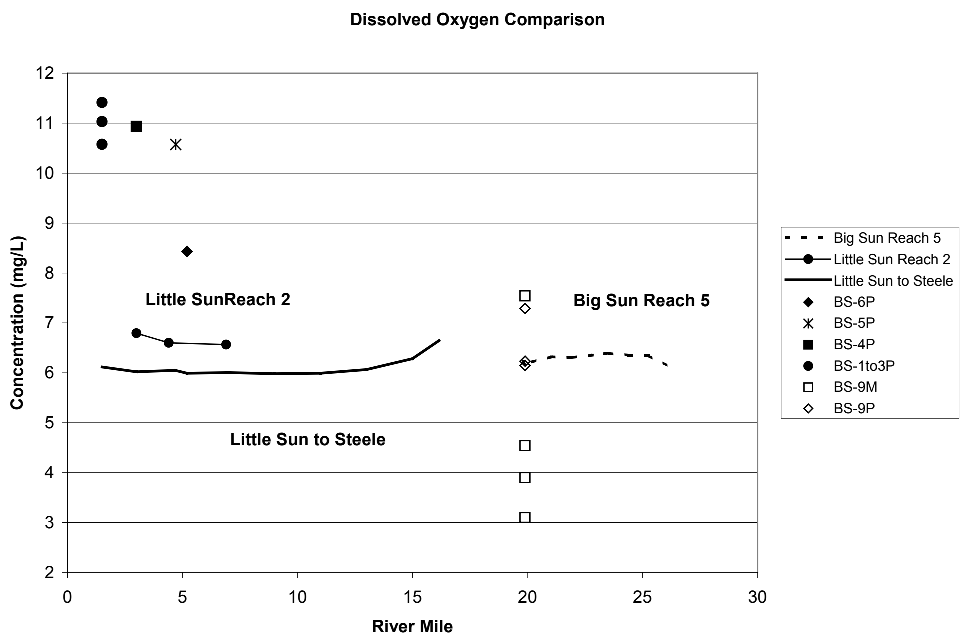
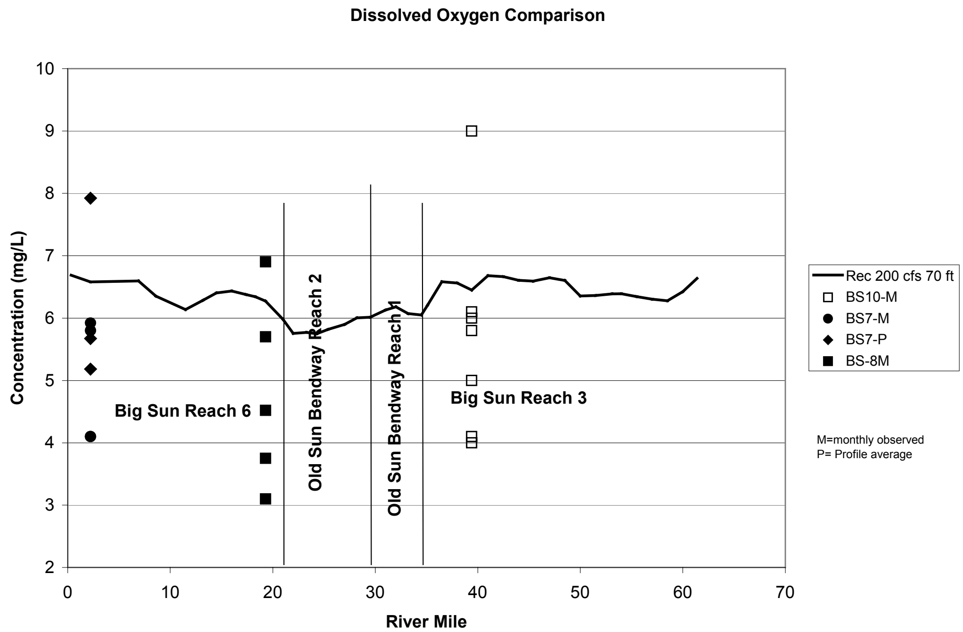


Figure A- 1. Predicted dissolved oxygen concentrations for recommended conditions with a flow of 200 cfs and downstream elevation of 68.5 ft.



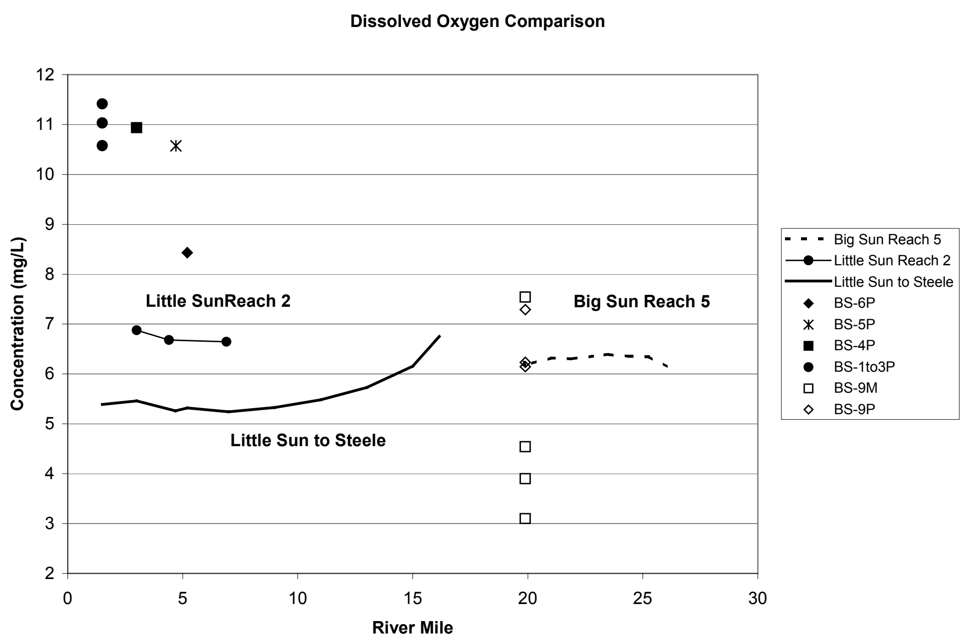
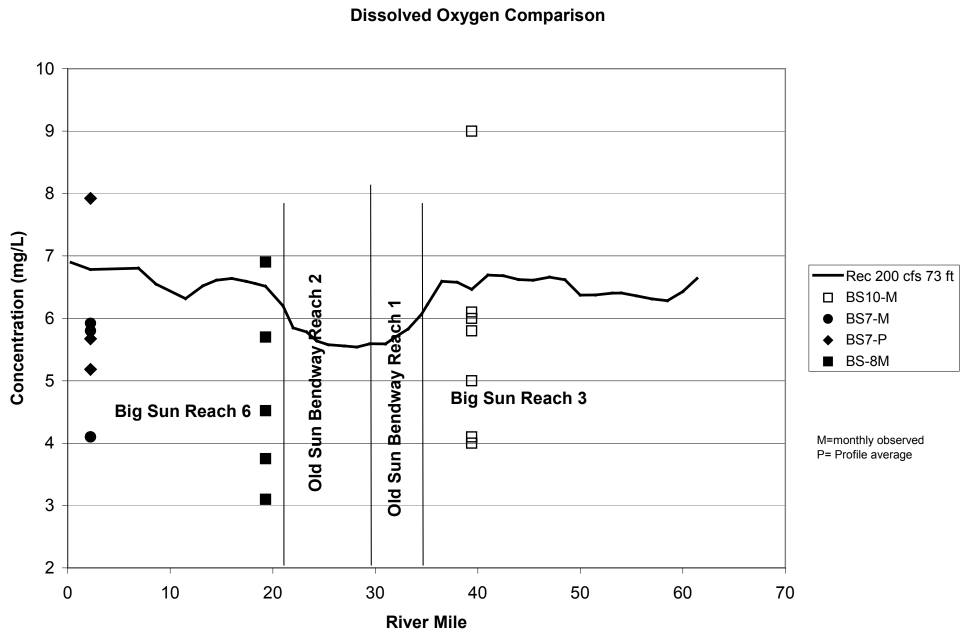


Figure A- 2. Predicted dissolved oxygen concentrations for recommended conditions with a flow of 200 cfs and downstream elevation of 70 ft.



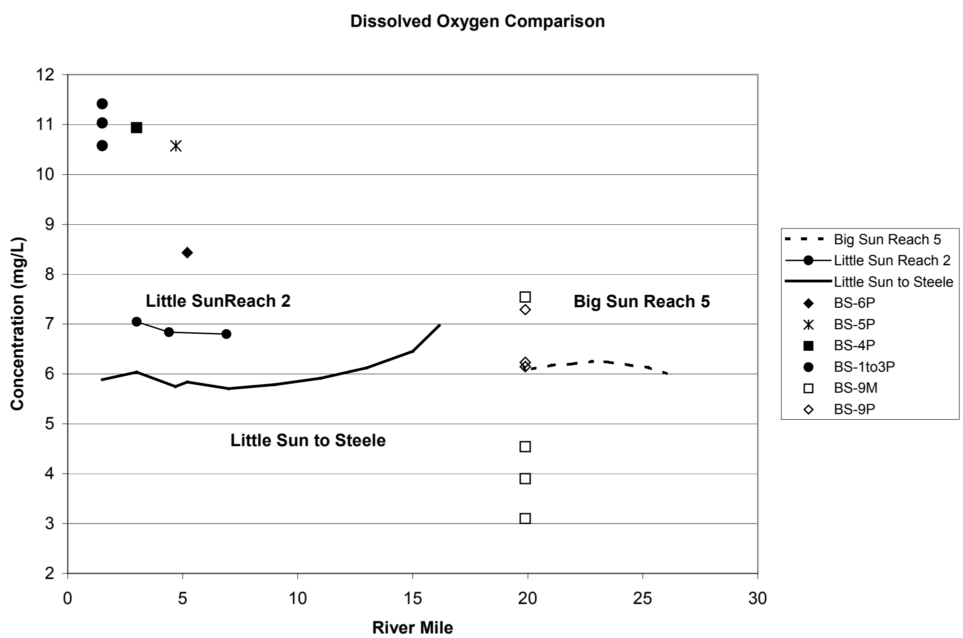
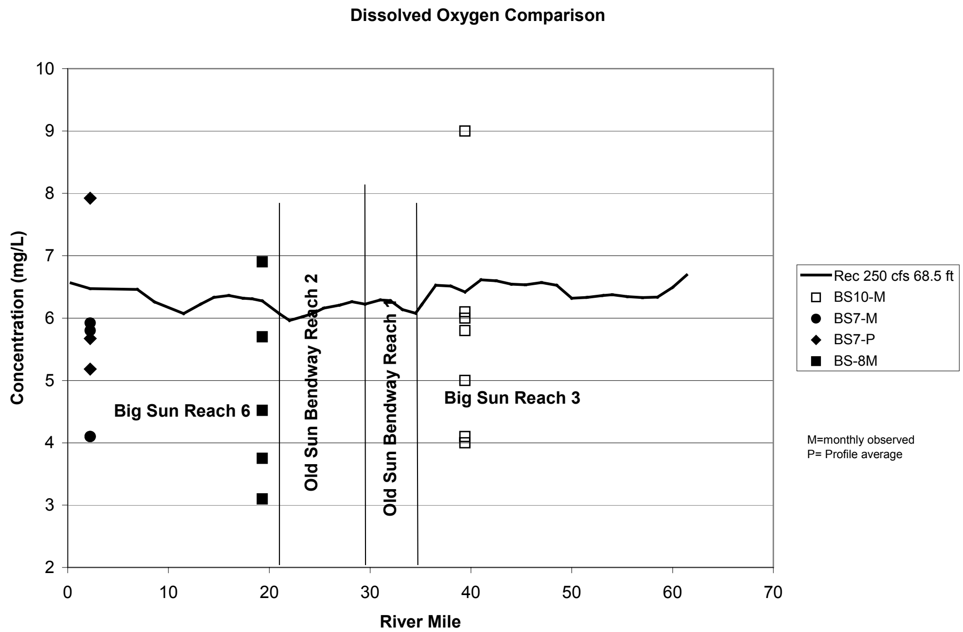


Figure A- 3. Predicted dissolved oxygen concentrations for recommended conditions with a flow of 200 cfs and downstream elevation of 73 ft.



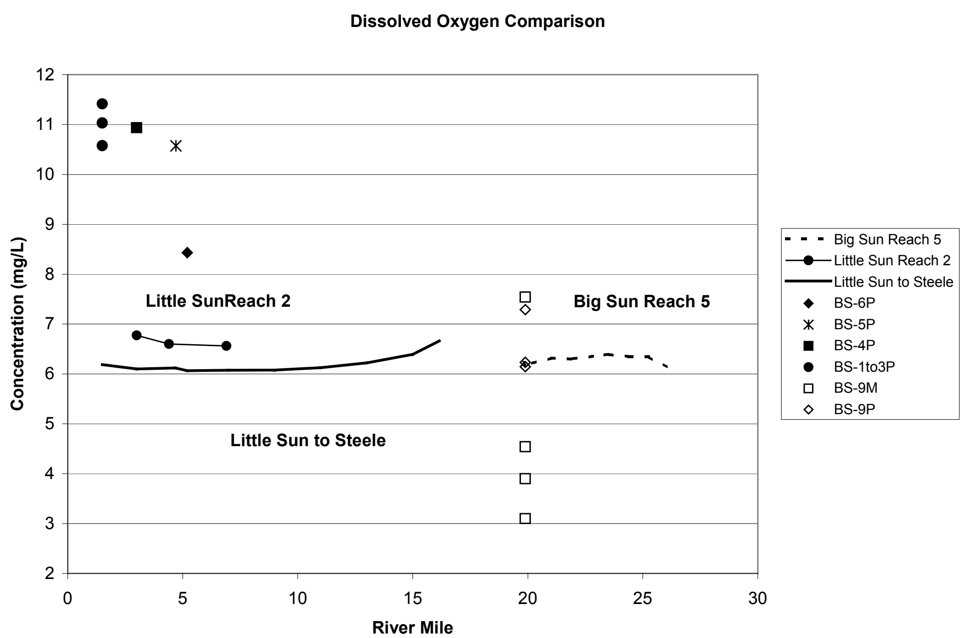
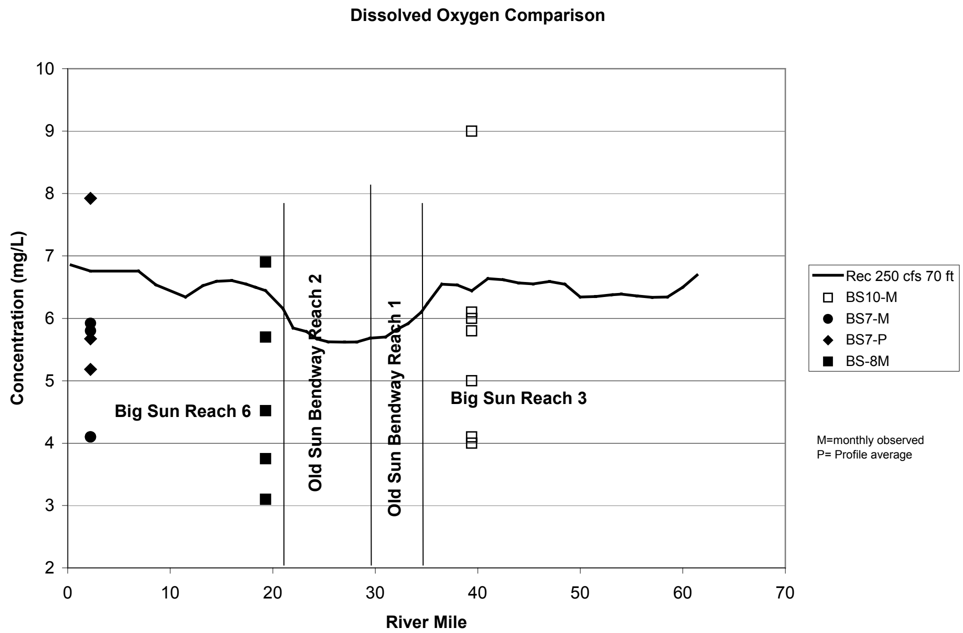


Figure A- 4. Predicted dissolved oxygen concentrations for recommended conditions with a flow of 250 cfs and downstream elevation of 68.5 ft.



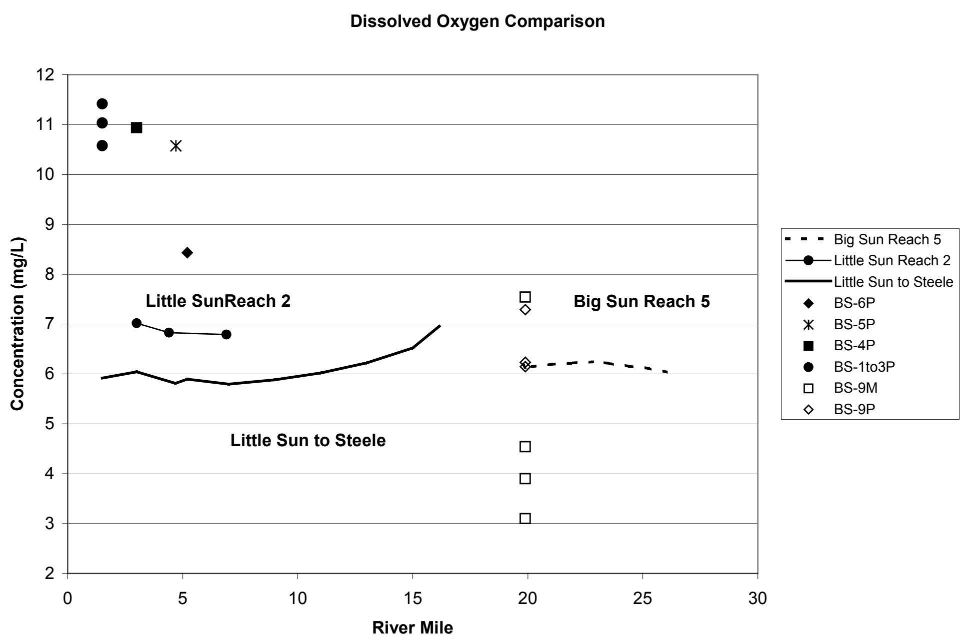
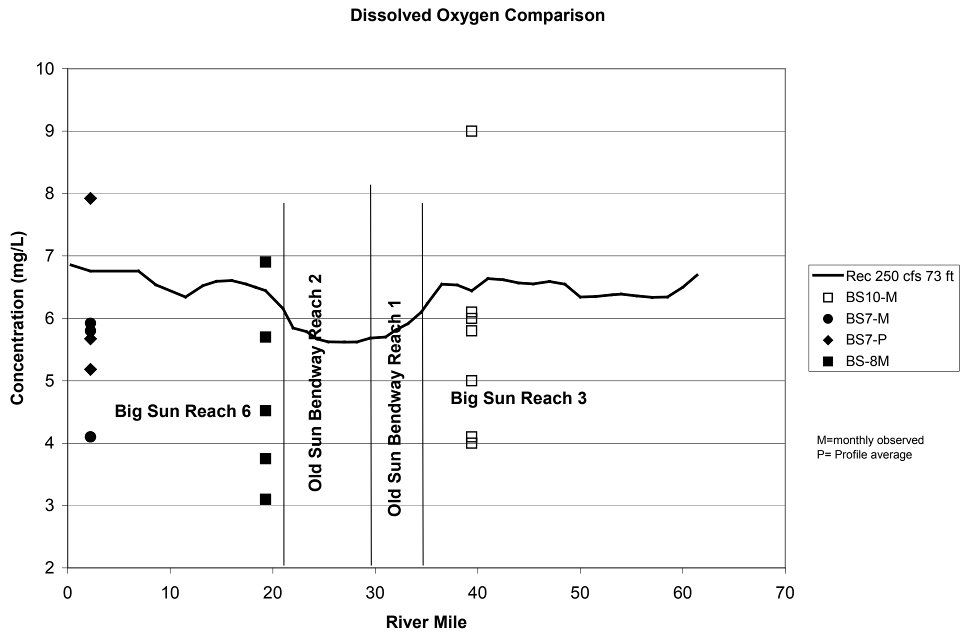


Figure A- 5. Predicted dissolved oxygen concentrations for recommended conditions with a flow of 250 cfs and downstream elevation of 70 ft.



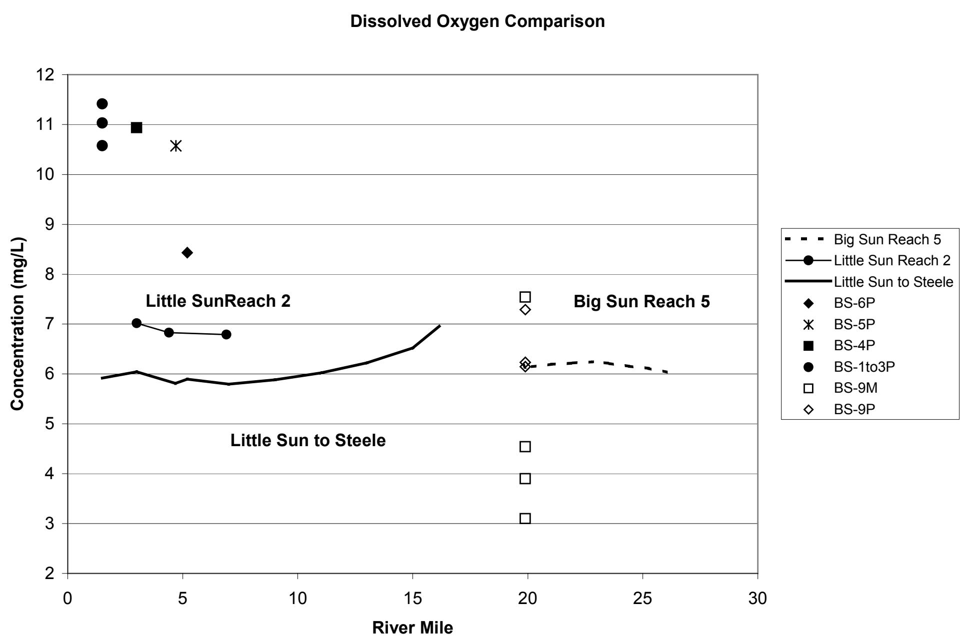
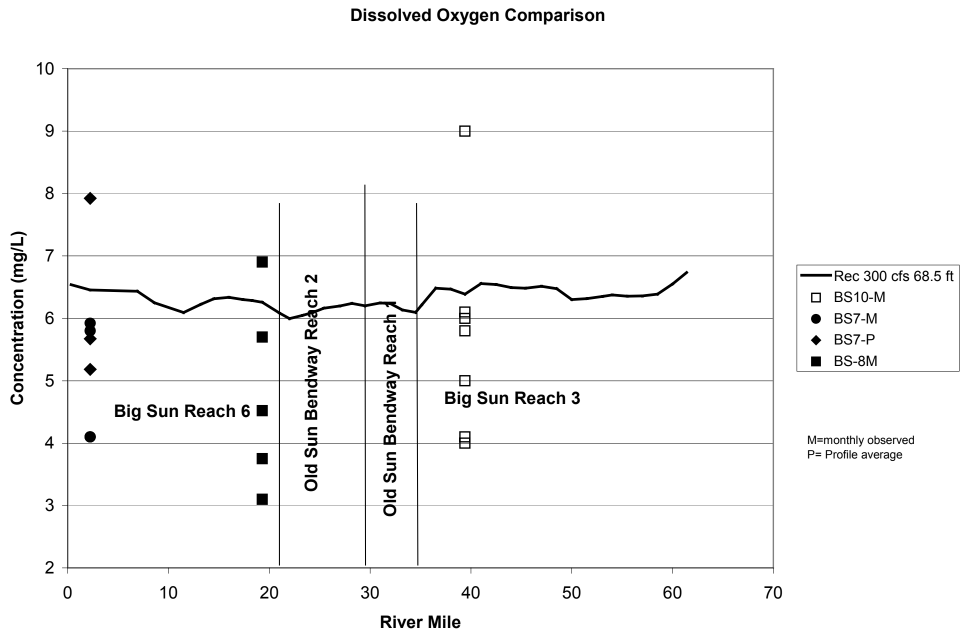


Figure A- 6. Predicted dissolved oxygen concentrations for recommended conditions with a flow of 250 cfs and downstream elevation of 73 ft.



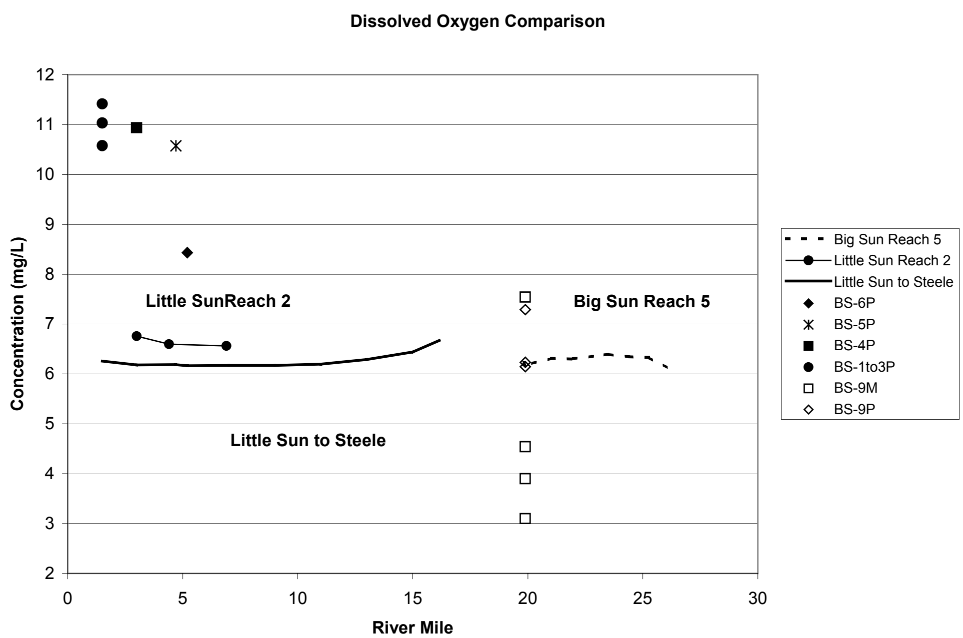
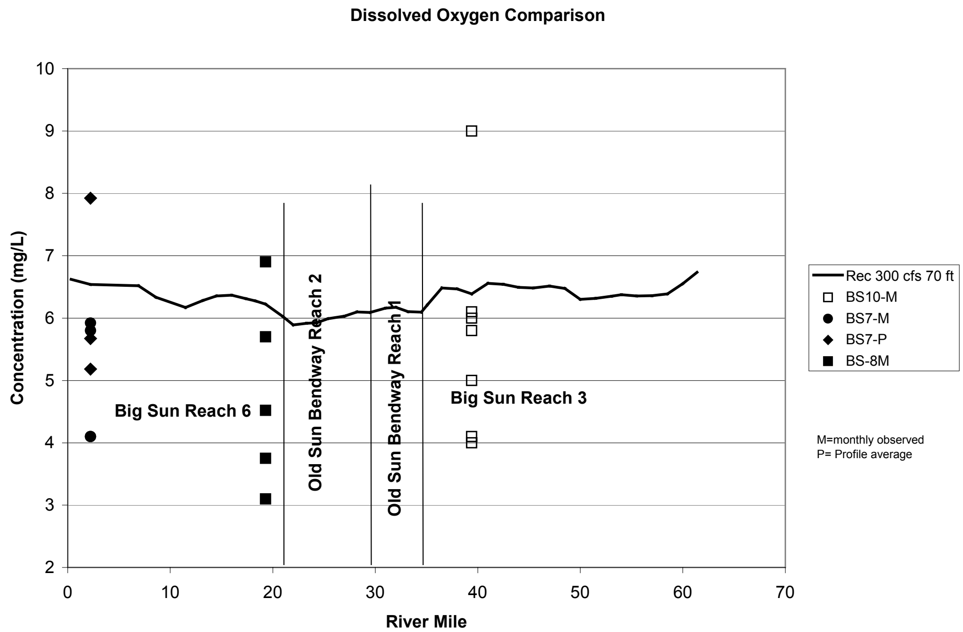


Figure A- 7. Predicted dissolved oxygen concentrations for recommended conditions with a flow of 300 cfs and downstream elevation of 68.5 ft.



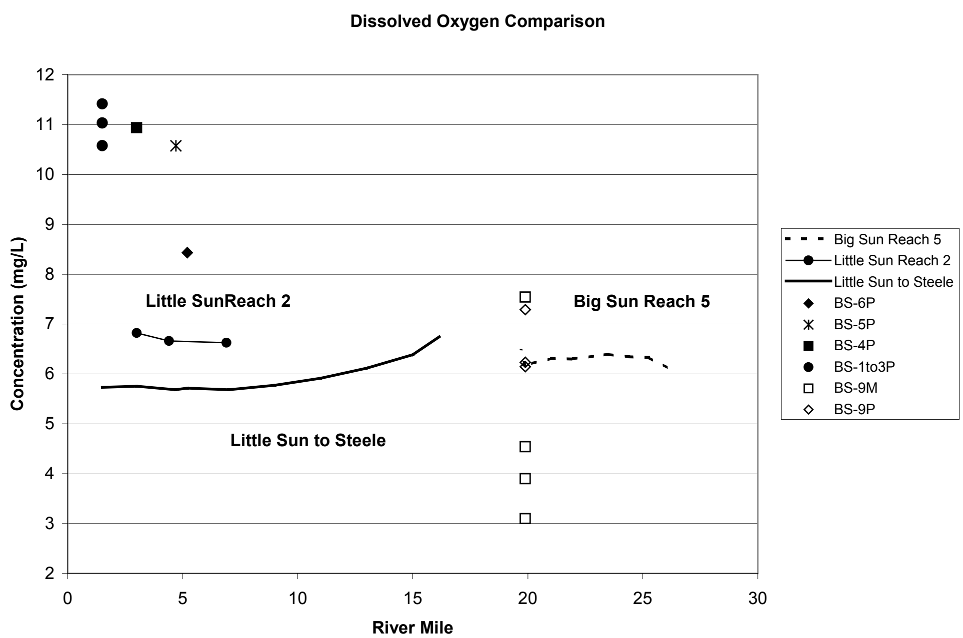
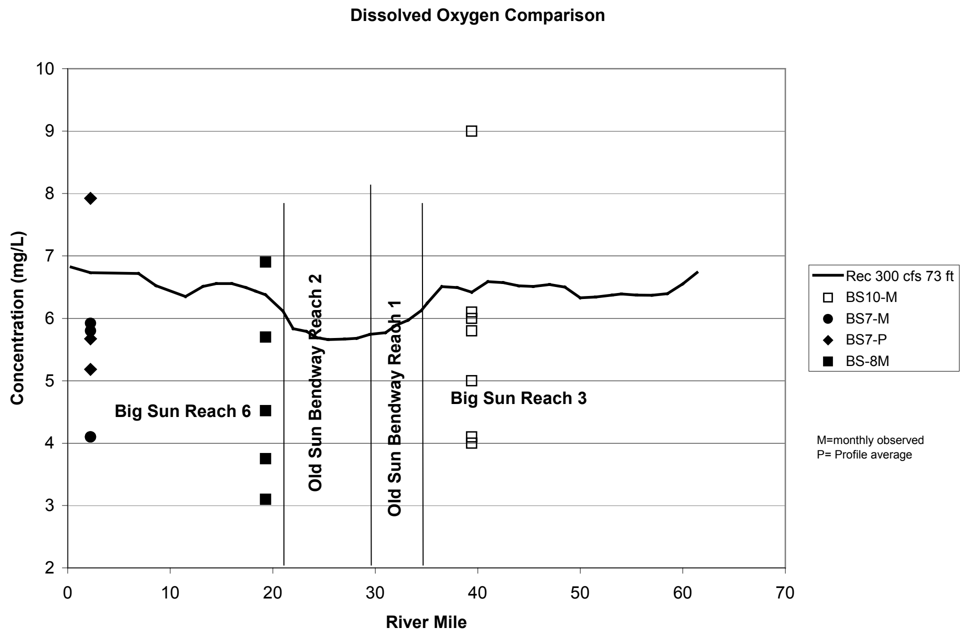


Figure A- 8. Predicted dissolved oxygen concentrations for recommended conditions with a flow of 300 cfs and downstream elevation of 70 ft.



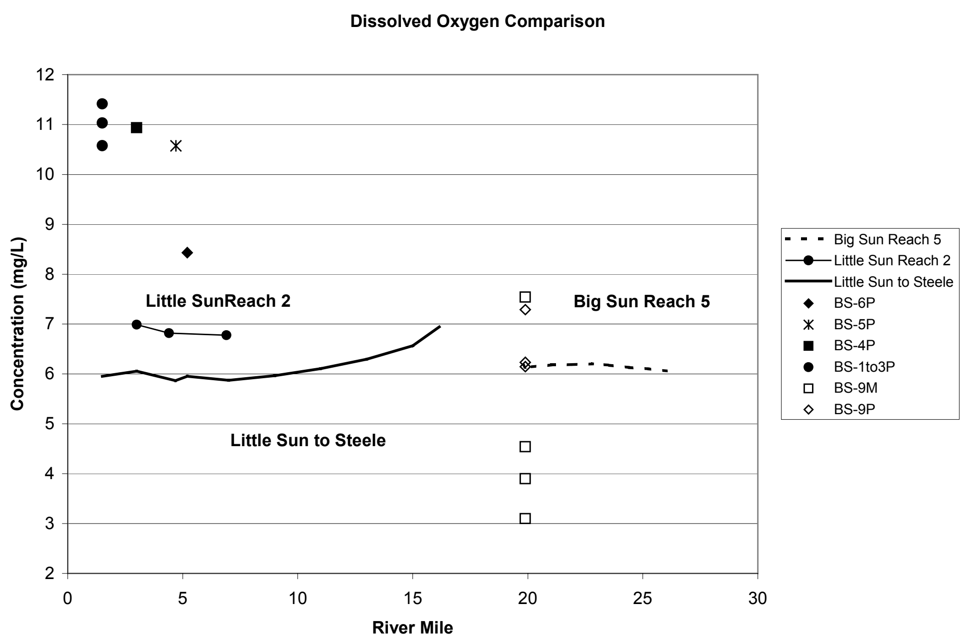


Figure A- 9. Predicted dissolved oxygen concentrations for recommended conditions with a flow of 300 cfs and downstream elevation of 73 ft.