WATER QUALITY MODEL FOR BIG SUNFLOWER RIVER

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INTRODUCTION AND PURPOSE

The development of hydrodynamic and water quality models for Big Sunflower was initiated in response to an increasing need for a comprehensive water quality model that will facilitate decision-making in the overall management activities of the river system, including assessment of existing water quality, estimation of waste assimilative capacity under various conditions and seasonal variations, and analysis of the effect of waste discharge into the Big Sunflower River. The Water Quality Analysis Simulation Program-5 (WASP5) was chosen for application to Big Sunflower River (Ambrose et al. 1993). This model is capable of interpreting and predicting water quality responses to natural phenomena and man-made pollution. WASP5 system consists of three stand-alone computer programs, DYNHYD5, EUTRO5, and TOXI5 that can be run in conjunction or separately. The hydrodynamics program, DYNHYD5 simulates the movement of water, while the water quality program, EUTRO5, simulates the movement and interaction of pollutants within the water.

The study area includes the Big Sunflower River, its northern and southern ends, and tributaries flowing into this river. The Big Sunflower River lies almost entirely within Sharkey, Sunflower, Washington, Humphreys, Bolivar, and Coahoma counties (Figure 1). The major metropolitan areas in this study are comprised of Clarksdale, Sunflower, and Indianola.

The initial model calibration was accomplished utilizing historical data collected during the period of July 30-August 1, 1974 (Shindala et al. 1997). Final model calibration was performed utilizing a set of field data acquired on the Big Sunflower River during October 19-23, 1997. This paper presents the details of the implementation of the hydrodynamic and water quality modeling framework together with results of the hydrodynamic and water quality calibration efforts.

HYDRODYNAMIC MODEL COMPUTATIONAL METHODOLOGY

The computational procedure developed in DYNHYD5 program is based on the solution of one-dimensional equations describing the propagation of a long wave through a shallow water system while conserving both momentum (energy) and volume (mass). It is also based on the conventional Saint-Venant equations that describe one-dimensional unsteady flow in an open channel. Prediction of water velocities and flow can be made based on the conservation of momentum by using the equation of motion.

Expressing the principle of conservation of mass applied to an elemental reach of a prismatic channel with rectangular cross-section, the equation of continuity has the following form:

$$\frac{\partial H}{\partial t} + D\frac{\partial U}{\partial x} = 0 \qquad (1)$$

where H is the water surface elevation (head) (m), D is the water depth (m), U is the longitudinal velocity (m/sec), t is the time (sec), and x is the longitudinal distance (m).

Based on the conservation of volume, prediction of water heights (heads) and volume of every segment in the model network can be made using the equation of continuity. The equation of motion can be derived from the principle of conservation of energy, or momentum. The equations of motion and continuity used in DYNHYD5 are presented below (Ambrose et al. 1993):

$$\frac{\partial U}{\partial t} = -U\frac{\partial U}{\partial x} + a_{g\lambda} + a_f + a_{w\lambda} \qquad (2)$$

$$\frac{\partial A}{\partial t} = -\frac{\partial Q}{\partial x} \quad OR \quad \frac{\partial H}{\partial t} = -\frac{1}{B}\frac{\partial Q}{\partial x} \qquad (3)$$

where the first term on the left side of equation (2) is the local inertia term, or the velocity rate of change with respect to time (m/sec^2); the first term of the right side of equation (2) is the Bernoulli acceleration, or the rate of momentum change by mass transfer; also defined as the convective inertia term from Newton's second law, (m/sec^2); $a_{g,\lambda}$ is gravitational acceleration along the axis of the channel (m/sec^2); a_f is frictional acceleration (m/sec^2); $a_{w,\lambda}$ is wind stress acceleration along axis of channel (m/sec^2); x is distance along axis of channel (m); t is time (sec); U is velocity along that axis of channel (m/sec); λ is longitudinal axis; g is acceleration gravity (m/sec^2); A is cross-sectional area of a segment (m^2); Q is flow (m^3/sec); B is width (m); H is water surface elevation (m); $\partial H/\partial t$ is rate of water surface elevational change with respect to time (m/sec); $\partial Q/B\,\partial x$ is rate of water volume change with respect to distance per unit width (m/sec).

Equations (2) and (3) form a basis for the hydrodynamic model, and their solutions give the velocities and heads throughout the water body over the duration of model simulation. The "link-node" network is used in this model to solve the equations of motion and continuity at alternating points. At each time step, the equation of motion is solved at the links, giving velocities for mass transport calculations, and the equation of continuity is solved at the nodes, giving heads for pollutant concentration calculations.

The equations of motion and continuity have to be written in a finite difference form, as shown below, in order to apply them to a link-node computational network (Ambrose et al. 1993).

$$\frac{U_i^t - U_i}{\Delta t} = -U_i \frac{\Delta U_i}{\Delta x_i} - g\frac{\Delta H_i}{\Delta x_i} - \frac{g n_i^2}{R_i^{4/3}} U_i |U_i| + \frac{C_d}{R_i}\frac{\rho_a}{\rho_w} W_i^2 \cos\Psi_i \qquad (4)$$

$$\frac{H_j^t - H_j}{\Delta t} = -\frac{\Delta Q_j}{B_j \Delta x_j} \qquad (5)$$

where U_i^t is the velocity in channel i at time t (m/sec); Δx_i is the channel length (m); Δt is the time (sec); i is channel or link number; $\Delta U_i/\Delta x_i$ is velocity gradient in channel i with respect to distance (sec^{-1}); $\Delta H_i/\Delta x_i$ is water surface gradient in channel i with respect to distance (m/m); j is junction or node number; C_d is the drag coefficient (assumed to retain constant value of 0.0026) (dimensionless); n_i is Manning's roughness coefficient (sec/$m^{1/3}$); R_i is hydraulic radius; ρ_a and ρ_w are the density of air and water respectively (kg/m^3); W_i is the wind speed (relative to the moving water surface) measured at a height of 10 meters (m/sec); Ψ_i is the angle between the channel direction and the wind direction (relative to the moving water surface).

After preparing all input parameters in the network such as initial values for channel velocities and junction heads, boundary conditions for downstream heads, and forcing functions for freshwater inflow and wind stress, equations (4) and (5) in explicit finite difference form are solved using a modified Runge-Kutta procedure.

WATER QUALITY MODEL COMPUTATIONAL METHODOLOGY

The WASP5 modeling framework consists of several components, one of which (EUTRO5) was specifically designed for the assessment of processes impacting eutrophication and dissolved oxygen dynamics. EUTRO5 is a dynamic compartment modeling program 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, and boundary exchange are represented in the basic program. The hydrodynamic model that supplies dynamic or tidally averaged circulation information to the EUTRO5 water quality model is DYNHYD5. The hydrodynamic model is a pseudo two-dimensional model that simulates water movement due to tides, winds, and tributary inflows.

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):

$$\frac{\partial C}{\partial t} = -\frac{\partial}{\partial x}(U_x C) - \frac{\partial}{\partial y}(U_y C) - \frac{\partial}{\partial z}(U_z C) + \frac{\partial}{\partial x}\left(E_x \frac{\partial C}{\partial x}\right) + \frac{\partial}{\partial y}\left(E_y \frac{\partial C}{\partial y}\right) + \frac{\partial}{\partial z}\left(E_z \frac{\partial C}{\partial z}\right) + S_L + S_B + S_K \qquad (6)$$

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

Equation (6) can also be written as a general mass-balance equation of a non-conservative substance, dissolved or suspended in flowing fluids, and may be expressed as (Park et al. 1996):

$$\frac{\partial C}{\partial t} = (\textit{physical transport}) + (\textit{kinetic processes}) \qquad (7)$$

where C = concentration and t = time. The time scale in equation (7) can be intra- or inter-tidal. The term (physical transport) is presumed to be identical for all water quality state variables. The physical transport moves materials spatially and can be in zero-, one-, two- or three-dimensional spatial scale. The term (kinetic processes) is different for different water quality state variables and may involve interactions among state variables. The complexity arising from the kinetic processes is largely dependent on one's objectives: the number of model state variables and kinetic processes that are represented in the model. EUTRO5 can be operated at various levels of complexity to simulate some or all of the related variables and interactions. Due to the nutrient enrichment and eutrophication problems in the Big Sunflower River, intermediate eutrophication kinetics, which is complexity level 5 in EUTRO5 is used.

A great deal of complexity and difficulty may be avoided if the physical transport and the kinetic processes in equations (6) and (7) are decoupled. The decoupling method has been employed in WASP5. The solution scheme involved two-step computation, in which substances are physically transported and then followed by the application of kinetic processes.

Equation (6) is the general WASP5 mass balance equation and represents three major classes of water quality processes, namely, transport, loading, and transformation. It is solved for each state variable. To this general equation, the EUTRO5 subroutines add specific transformation processes to customize the general mass balance for the eight state variables in the water column and benthos. The water quality parameters can be considered as four interacting systems: phytoplankton kinetics, the phosphorus cycle, the nitrogen cycle, and the dissolved oxygen balance.

Five state variables modeled in EUTRO5 for dissolved oxygen balance are: phytoplankton carbon, ammonia, nitrate, carbonaceous biochemical oxygen demand, and dissolved oxygen. In the application of the model to the Big Sunflower River, sediment layers are not incorporated. In EUTRO5, flow-induced reaeration is based on the Covar (1976) method and wind-induced reaeration is determined by O' Connor (1983).

Three phosphorus variables modeled in EUTRO5 are: phytoplankton phosphorus, organic phosphorus, and inorganic (orthophosphate) phosphorus. Four nitrogen variables modeled in EUTRO5 are: phytoplankton nitrogen, organic nitrogen, ammonia nitrogen, and nitrate nitrogen.

SEGMENTATION OF BIG SUNFLOWER RIVER

One-dimensional segmentation in the Big Sunflower River was selected to represent the spatial heterogeneity of the water bodies in longitudinal and lateral directions. By using approximately equal surface areas, this type of segmentation is capable of representing the physical shape of the water system.

Segmentation into approximately one-mile lengths for the hydrodynamic model of Reaches 1, 2, and 3 of the Big Sunflower River is illustrated in Figure 2. The model simulation report here is for both the Big Sunflower River and tributaries. The present model segmentation scheme, however, does not require vertical resolution because of the well-mixed nature of the river system.

The hydrodynamic model DYNHYD5 for Reach 1 on the Big Sunflower River consists of 27 segments. The downstream segment at the bridge culverts near Roundaway (Johnson Crossing) (RM: 164.15). The upstream boundary segment is located above Clarksdale (RM: 190.00).

The hydrodynamic model DYNHYD5 model for Reach 2 consists of 127 segments. The downstream boundary segment is located at low head dam (RM: 54.01) approximately one half mile south of Highway 12 bridge, midway between Belzoni and Hollandale. Tributary boundary segments in Reach 2 are provided for Hushpuckena River, Black Bayou, Dougherty Bayou, Lead Bayou, Jones Bayou, Quiver River, and Bogue Phalia. The upstream boundary segment for Reach 2 adjoins the downstream segment for Reach 1 at the bridge culverts near Roundaway (Johnson Crossing) (R.M: 164.15).

The hydrodynamic model DYNHYD5 for Reach 3 consists of 28 segments. The upstream boundary segment adjoins the downstream segment of Reach 2 located at the low head dam (R.M: 54.01) approximately one half mile south of Highway 12 bridge, midway between Belzoni and Hollandale. The downstream boundary segment in Reach 3 is located at the upper end of Holly-Bluff cut-off (R.M: 26.00). No major tributaries into Reach 3.

HYDRODYNAMIC MODEL INPUT PARAMETERS

The initial input parameters of the hydrodynamic model DYNHYD5 include data for junctions (nodes) or segments, channels (links), freshwater inflows, downstream boundaries, wind and precipitation/ evaporation. All of the parameters incorporated in the model were either temporal or spatial variables, or both. Since available data were not sufficient to define many of the variables mentioned above on an hourly basis, they were approximated by a series of piecewise linear functions.

The initial flow conditions in Reaches 1, 2, and 3 of the Big Sunflower River were computed using the steady state HEC-2 computer model. In Reaches 1 and 2, the HEC-2 model was calibrated using October 1993 low flow data. Reach 3, flow measurements in October 19-23, 1997, were used to calibrate the HEC-2 model. If the flow and geometric parameters are assumed correct, calibration consists of adjusted Manning's n until stream stage computations reasonably reproduce measured water surface elevations.

Junction Parameters

The input parameters associated with junctions in DYNHYD5 are initial surface elevation (head), surface area, and bottom elevations. Segment volumes and mean depths are calculated internally using the above parameters. Computed results of HEC-2 hydrodynamic model were used to supply information into DYNHYD5 which include bottom elevations, surface area, and initial water surface elevations. In Reaches 1 and 2, flow conditions in October 1993 were considered as base flow and initial conditions for the October 19-23, 1997, data calibration.

Channel Parameters

The input parameters associated with channels in DYNHYD5 are characteristic length, width, hydraulic radius or depth, channel orientation (from true north), initial velocity (vary spatially), and Manning's roughness coefficient (vary spatially). The computed velocity, top-width, and water depth and Manning's n values determined from HEC-2 runs were used to supply information into DYNHYD5.

Inflow Parameters

The major freshwater inflows to Reach 1 of Big Sunflower River enter at upper-end of Sunflower River near Clarksdale, from the Clarksdale POTW and Power Plant, and from Harris and Clark Bayous. Variable fresh water inflows were specified from the generated hydrographs at upper-end of Big Sunflower River near Clarksdale, from measured POTW flow, from the measured well flows, and from generated hydrographs from Harris and Clark Bayous.

In Reach 2, the freshwater inflows enter the Big Sunflower River at the culverts (Johnson Crossing), Hushpuckena River, Black Bayou, Mound Bayou, Lead Bayou, Dougherty Bayou, Jones Bayou, Quiver River, and Bogue Phalia. Measured fresh water inflows into Reach 2 of Big Sunflower River from Mound Bayou, Jones Bayou, and Bogue Phalia were 1.0 cfs (0.0283 cms), 0.09 cfs (0.0025 cms), and 30.2 cfs (0.8552 cms), respectively. Variable fresh water inflows were generated at Johnson Crossing, Hushpuckena River, Black Bayou, Lead Bayou, and Quiver River. In this study, a unit hydrograph at Merigold was first constructed and a synthetic unit hydrograph calibrated based on Snyder theory (Zitta et al. 1996). This calibrated unit hydrograph at Merigold was used to construct synthetic unit hydrographs at other model boundaries. The amount of precipitation excess (Pe) for constructing the freshwater hydrograph from each river was based upon the form of the measured flow at Merigold and the point measurements taken on the other streams. In the construction of inflow hydrographs at Black Bayou, Hushpuckena River, Quiver River, Lead Bayou, and Big Sunflower at Johnson Crossing, rainfall measurements made at Arkabutla Dam, Cleveland, Sunflower, Enid Dam, Stoneville, Indianola, Greenwood, and Yazoo City were used in model calibration and application.

Wastewater treatment discharge into Reach 2 of the Big Sunflower River from Doddsville POTW, Sunflower POTW, South Fresh Farms, Delta Pride Catfish North Facility (Indianola), and Indianola POTW was 0.030 cfs (0.0194 MGD), 0.156 (MGD), 0.1 cfs (0.068 MGD), 0.77 cfs (0.5 MGD), 2.336 cfs (1.51 MGD), respectively.

In Reach 3, the freshwater inflow enters the Big Sunflower River at Lock & Dam. Variable inflow was specified based on USCOE and USGS measurements.

Downstream Boundary Parameters

Variable outflows were specified for the downstream boundaries in Reaches 1, 2, and 3 of the Big Sunflower River.

Wind Parameters

The input parameters associated with wind acceleration are wind speed, wind direction, and channel. In the study, wind effects were considered negligible. Therefore, the wind velocity of zero, m/sec, was assumed. As mentioned in Bowie et al. (1985), this approach is reasonable for stream and river reaeration modeling.

Other Parameters

Only mild and short precipitation was reported during the study. Stream channel and precipitation effects were not considered significant.

WATER QUALITY MODEL INPUT PARAMETERS

Input parameters to the water quality model EUTRO5 include environmental, transport, boundaries, and transformations. All of the parameters incorporated in the model were either temporal or spatial variables or both. Since available data were not sufficient to define many of the variables mentioned above on an hourly basis, they were approximated by a series of piecewise linear functions. The piecewise linear functions or approximations used in this model consist of a series of variables and break points usually at high slack, low slack time interval, or daily interval dependent on the type of the variable and availability of data.

Environmental Parameters

Environmental parameters in EUTRO5 define the basic identity, including the segmentation and the simulation control. In particular, the environmental input parameters include type of simulation, number of segments, number of systems, time step option, advection factor, and segment volumes. In the model network, eight state variables of Ammonia Nitrogen (NH3), Nitrate Nitrogen (NO3), Inorganic Phosphorus (PO4), Phytoplankton Carbon (CHL), Carbonaceous Biochemical Oxygen Demand (CBOD), Dissolved Oxygen (DO), Organic Nitrogen (ON), and Organic Phosphorus (OP) are simulated in the 25 segments of Reach 1, 117 segments of Reach 2, and 26 segments of Reach 3. In the water quality model advection factor $v = 0$ is specified to modify the finite difference approximation of $\partial c/\partial x$ used in the advection term by EUTRO5. This will result in the most stable solution (Ambrose et al. 1993). Initial volumes for each segment are specified by using the segment surface area and depth. However, the volumes and time step specified in these environmental parameters will be reset by the hydrodynamic file.

Transport Parameters

This group of parameters defines the advective and dispersive transport of simulated model variables. Input parameters include advective flows, dispersion coefficients, cross-sectional areas, and characteristic lengths. The hydrodynamic results file (*.HYD) contains averaged hydrodynamic variables for use in EUTRO5 simulations. This includes basic network and inflow information, junction volumes (m^3), flows (m^3/sec), depths (m), and velocities (m/sec), and channel flows (m^3/sec). Flow continuity is automatically maintained.

The number of exchange fields between segments is 24 for Reach 1, 116 for Reach 2, and 25 for Reach 3. The cross-sectional areas are specified for each dispersion coefficient, reflecting the area through which mixing occurs. The characteristic mixing lengths are also specified for each dispersion coefficient, reflecting the characteristic length over which mixing occurs.

Boundary Conditions

This group of parameters includes: a) boundary concentrations, b) waste loads, and c) initial conditions.

a) Boundary Concentrations. Boundary concentrations in Reach 1 were specified for two (2) model boundary segments at one upstream boundary (the upper end of the Big Sunflower River) and one downstream boundary at culverts bridge (Johnson Crossing). Constant and variable concentrations were specified for each water quality constituent at each boundary dependent on the availability of data.

Boundary concentrations in Reach 2 were specified for ten (10) model boundary segments at nine upstream boundaries and one downstream boundary at low head dam. The nine model boundary segments are at culverts bridge (Johnson Crossing) near Roundaway, Hushpuckena River, Black Bayou, Mound Bayou, Dougherty Bayou, Lead Bayou, Jones Bayou, Quiver River, and Bogue Phalia.) Constant and variable concentrations were specified for each water quality constituent at each boundary dependent on the availability of data.

Boundary concentrations in Reach 3 were specified for two (2) model boundary segments at one upstream boundary (low head dam) and one downstream boundary at the upper end of Holly-Bluff cut off. Constant and variable concentrations were specified for each water quality constituent at each boundary dependent on the availability of data.

b) Waste Loads. The waste source survey conducted by MSDEQ during the period October 19-23, 1997, was used in this calibration phase. Four municipal and two industrial waste sources were considered. However, non-point source loads from urban and agricultural runoff, precipitation, and atmospheric deposition of pollutants were not incorporated into the model. One waste load was considered in Reach 1; it was from Clarksdale POTW. Five waste loads from Doddsville POTW, Sunflower POTW, South Fresh Farms, Delta Pride Catfish-North Facility (Indianola), and Indianola POTW were considered in Reach 2. No waste load was considered in Reach 3. A constant waste load with time is inputted at the nearest segment.

c) Initial Conditions. Initial conditions include initial concentrations, as well as solids transport field for each solid and the dissolved fraction in each segment. For dynamic simulations where the transient concentration response is desired, initial concentrations are inputted closely reflecting the measured values at the beginning of the simulation. Longitudinal linear interpolation was made between available sampling stations (Figure 2) for determining the initial concentrations throughout the water quality segments.

Transformation Parameters

This group of parameters includes spatially variable parameters, constants, and kinetic time functions for the eight water quality state variables being simulated herein. Spatially variable parameters such as water temperature, sediment oxygen demand, salinity, extinction coefficient, specific temperature correction coefficient for sediment oxygen demand, and segment specific reaeration rate are inputted for each segment. Constant extinction coefficient (4.0/m) value used in the study was based on the modeling study of the Upper Tennessee-Tombigbee Waterway (Shindala et al. 1991). Sediment oxygen demand of 1.5 g/m^2-day for Reaches 1 and 2 and sediment oxygen demand of 1.0 g/m^2-day for Reach 3 were based on the Water Quality results study conducted by USEPA (October 19-23, 1997).

Calibration of water quality model using model calculated reaeration rates and a user inputted constant reaeration rate were made. After adjustments, the model calculated reaeration rates for Reaches 1 and 2 were selected for use in the study. For Reach 3, user inputted spatially varied reaeration rates equal to 3/d were selected for use in the study. The symbol d is the average segment depth, feet. This is because during low flow conditions the average velocities in Reach 3 for Big Sunflower River were extremely low (below 0.1 fps). Furthermore, several segments of Reach 3 have average depths in excess of 10 feet. These conditions are outside of the application range for the O'Connor-Dobbins model.

Specified values of constants as shown in Table 1 apply over the entire network throughout the simulation.

HYDRODYNAMIC MODEL CALIBRATION

Initial calibration of the hydrodynamic model (DYNHYD5) for the Big Sunflower River was accomplished utilizing historical data (USGS 1974). Results of this initial calibration effort are discussed in the Supplement to Completion Report (Shindala et al. 1997). The results of simulation utilizing the October 19-23, 1997, intensive survey data were considered as the final calibration effort.

When the DYNHYD5 model is fully equipped with the proper bathymetry geometry and boundary conditions, only one parameter remains to be specified (e.g. Manning's n bottom roughness). For this reason, it is prudent that the input conditions of the model do not diverge greatly from reality.

The first parameter to calibrate is the Manning's n bottom roughness which is adjusted first globally and then, if necessary, locally. After the value of bottom roughness is roughly calibrated, the dispersion coefficient is the next parameter to be determined. This can be accomplished by comparing salinity time series data and spatial distributions, using DYNHYD5 with EUTRO5.

In the hydrodynamic calibration and using DYNHYD5, water level and velocity were collected and used for model calibration.

Database

General field data jointly collected by the Mississippi Department of Environmental Quality (MSDEQ), United States Geological Services (USGS), National Oceanic Atmospheric Administration (NOAA), and Clarksdale Public Utilities during the study period (October 19-23, 1997) were used to calibrate the hydrodynamic model. The locations and type of hydrodynamic sampling stations for the October 19-23, 1997, survey are shown in Figure 2. As shown in Figure 2, water level and flow measurements were conducted by USGS and the Office of Land and Water Resources (L&W), MSDEQ, and U.S Corps of Engineers (USCOE) at several flow stations. Cross-section measurements in Reaches 1, 2, and 3 were conducted by USGS, MSDEQ, and USCOE. Thalwegs profiles of the Big Sunflower for Reaches 2 and 3 were measured and prepared by MSDEQ. Low flow studies conducted on the Big Sunflower River in October 1987, October 1992, and October 1993 by MSDEQ and USGS were used in this study for calibration of the hydrodynamic model under low flow (base flow) conditions.

Precipitation data were recorded hourly and daily by NOAA at several meteorological stations in the area (NOAA 1997). Rainfall data were also taken at Indianola POTW by USEPA during the October 1997 survey. Other rainfall data were taken by USCOE at the gage on the Big Sunflower River at Sunflower. Distribution and amount of precipitation (radar weather observations) in the study were also obtained from National Climatic Data Center (NCDC).

The pumping rates from the well production near the City of Clarksdale were provided by the City of Clarksdale Public Utilities (Clark 1997). The effluent flow rates from the City of Clarksdale Publicly Owned Treatment Works (POTW) were measured by MSDEQ.

Calibration Results of Hydrodynamic Model

The determination of Manning's n and the accuracy of cross-sections are the most important items to consider for hydrodynamic model calibration. The HEC-2 hydrodynamic model was initially run to provide information for calibration of initial conditions for DYNHYD5. Flow conditions in Reaches 1, 2, and 3 of the Big Sunflower River were computed separately. Several Manning's n were adjusted slightly in each of three reaches until the computed results reasonably matched the observed data. In Reach 1, flow conditions in October 1993, July 28-August 1, 1974, and October 19-23, 1997, were computed. After adjustments, several Manning's n were selected for use in Reach 1. The values of Manning's n were in the range of 0.04-0.10. Calibration water surface and flow profiles for October 1993 and October 19-23, 1997, utilizing DYNHYD5, are presented in Figure 3. As shown, the computed water surface and flow results fell within the range of observed data taken during the period October 20-22, 1997.

In Reach 2, flow conditions in October 1993 and October 19-23, 1997, were computed. After adjustments, Manning's n of 0.02 and 0.04 were selected for use in this reach. Calibration water surface and flow profiles for October 1993 and October 19-23, 1997, utilizing DYNHYD5, are presented in Figure 3. As shown, the computed water surface and flow results fell within the range of observed data taken during the period October 21-23, 1997.

In Reach 3, flow conditions in October 19-23, 1997, were computed. After adjustments, Manning's n of 0.04 was selected for use in this reach. Calibration water surface and flow profiles for October 1993 and October 19-23, 1997, utilizing DYNHYD5, are presented in Figure 3. As shown, the computed water surface and flow results fell within the range of observed data taken during the period October 21-23, 1997.

WATER QUALITY MODEL CALIBRATION

Initial calibration of the water quality model (EUTRO5) for the Big Sunflower River was accomplished utilizing historical data (USGS 1974). Results are discussed in the Supplement to Completion Report (Shindala et al. 1997). The results of simulation utilizing the October 19-23, 1997, intensive survey data were considered as the final calibration efforts.

The final calibration is a set of consistent model coefficients (Table 1) that are reasonable and are capable of reproducing the observed data for all state variables with the exception of exogenous variables such as flow, temperature, solar radiation, and extinction coefficients. The method employed in determining the values for the model coefficients was essentially one of trial and error. The starting point was a set of rate constants and parameter values that were used in the initial calibration (Shindala et al. 1997). Model constants that were used in previous modeling studies were also consulted (Ambrose et al. 1993; Bowie et al. 1985).

Database

General field data jointly collected by USEPA and MSDEQ during October 19-23, 1997, were used to calibrate the water quality model.

The locations of the water quality sampling stations in Reaches 1, 2, and 3 of the Big Sunflower River for the October 19-23, 1997, survey are shown in Figure 2. In the survey, a large number of physical, chemical, and bacteriological parameters were collected from thirty-four (34) selected sampling stations as shown in the figure. Six waste sources (municipal and industrial) were surveyed during the October 19-23, 1997, study.

Calibration Results of Water Quality Model

The values of constants as shown in Table 1 were used throughout the simulation which apply over the entire network. A sample of spatial and/or temporal profiles of observed versus model computed water quality parameters for calibration phase is presented in Figures 4 and 5. For dissolved oxygen, the computed values generally fell close to or within the range of observed data in Reaches 1, 2, and 3. For CBOD5, nitrogen and phosphorus compounds in Reaches 1, 2, and 3, the computed values generally reproduces the observed data within its ranges very well. Examination of the profiles clearly shows that EUTRO5, in general, reproduces most of the observed water quality data but does not compute every data point.

CONCLUSION

A one-dimensionally vertically well-mixed system and real-time model consisting of linked hydrodynamic and water quality models was developed for the Big Sunflower River in Mississippi. The computed water surface reasonably matched the observed water surface at sampling stations in the calibration phase. The magnitude of flow data was found to be in the range of observed data at each sampling station. Comparisons of the computed and observed data were made qualitatively by using spatial and temporal comparisons. The response of model prediction calculations is consistent with trends of the observed data ranges, but not with absolute values in all cases. The model, in general, can accurately predict the concentration of water quality constituents in the range of observed data taken.

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Table 1: EUTRO5 Model Constants for Big Sunflower River

Description	ISC	Name	Units	Typical Value/Range	Big Sunflower River
Nitrification Rate @ 20 °C	11	K12C	Day^{-1}	0.09[1] 0.02-0.2[2]	0.05
Temperature Coefficient for Nitrification	12	K12T	-	1.08[1] 1.02-1.08[2]	1.08
Half - saturation Constant for Nitrification-Oxygen Limitation	13	KNIT	Mg O_2/L	2.0[1]	0.5
Denitrification Rate @ 20 °C	21	K20C	Day^{-1}	0.09[1] 0.0-1.0[2]	0.1
Temperature Coefficient for Denitrification	22	K20T	-	1.045[1] 1.02-1.09[2]	1.045
Half - Saturation Constant for Denitrification-Oxygen Limitation	23	KNO3	Mg O_2/L	0.1[1]	0.1
CBOD Deoxygenation rate @ 20° C	71	KDC	Day^{-1}	0.21,0.16[1] 0.02-5.6[2]	0.05
Temperature Coefficient for Carbonaceous Deoxygenation	72	KDT	-	1.047[1] 1.02-1.15[2]	1.047
Half - Saturation Constant for Deoxygenation	75	KBOD	Mg O_2/L	0.5[1]	0.5
Mineralization rate of Dissolved Organic Nitrogen	91	K71C	Day^{-1}	0.075[1] 0.02-0.075[2]	0.1
Temperature Coefficient for ON Mineralization	92	K71T	-	1.08[2]	1.08
Mineralization Rate of Dissolved Organic Phosphorus	100	K83C	Day^{-1}	0.22[1] 0.22[2]	0.22
Temperature Coefficient for OP Mineralization	101	K83T	-	1.08[1,2]	1.08
Half Saturation Constant for Phytoplankton Limitation of Phosphorus	59	KMPHY	-	1.0	1.0
Saturation Growth Rate @ 20°C	41	K1C	Day^{-1}	2.0[1] 0.2-8[2]	1.5
Temperature Coefficient for Growth	42	K1T	-	1.068[1]	1.068
Fraction of Dead and Respired (FON) Phytoplankton Nitrogen Recycled to Organic Nitrogen	95	FON	-	0.5[1]	0.5
Fraction of Dead and Respired (FOP) Phytoplankton Phosphorus Recycled to Organic Phosphorus	104	FOP	-	1.0[1]	0.5
Carbon/Chlorophyll Ratio	46	CCHL	mg C/mg Chla	21-45[1] 10-112[2]	50.0
Saturation Light Intensity	47	IS1	Ly/day	200-350[2]	300
Nitrogen Half – Saturation Constant for Growth	48	KMNG1	Mg N/L	25[1] 1.5 - 400[2]	25
Phosphorus Half - Saturation Constant for Growth	49	KMPG1	μg PO_4-P/L	1[1] 0.5-30[2]	1
Endogeneous Respiration rate @ 20°C	50	K1RC	Day^{-1}	0.125[1] 0.02-0.6[2]	0.15
Temperature Coefficient for Respiration	51	K1RT	-	1.045[1]	1.045
Non - Predatory Death Rate	52	K1D	Day^{-1}	0.02[1] 0.005-0.172[2]	0.05
Grazing Rate on Phytoplankton Per Unit Zooplankton Population	53	K1G	L/cell-day	0.0[1]	0.0
Phosphorus to Carbon ratio	57	PCRB	mg PO_4-P/mg C	0.025[1] 0.025-0.05[2]	0.025
Nitrogen to Carbon ratio	58	NCRB	mg N/mg C	0.25[1] 0.05-0.43[2]	0.25
Oxygen to Carbon Ratio	81	OCRB	mg O_2/mg C	2.67[1]	2.67

[1] Ambrose et al (1993), [2] Bowie et al (1985)

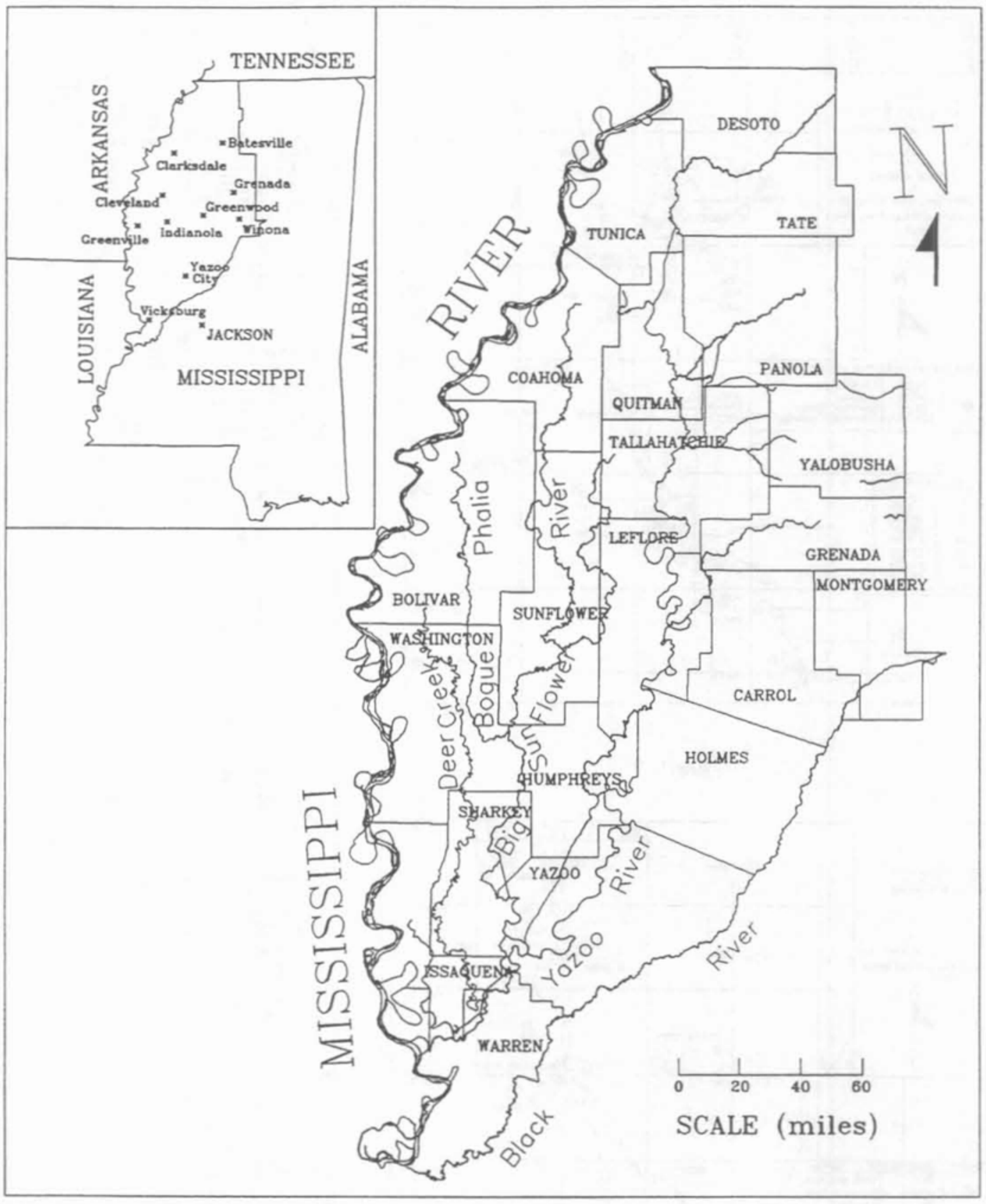

Figure 1: Location of the Study Area

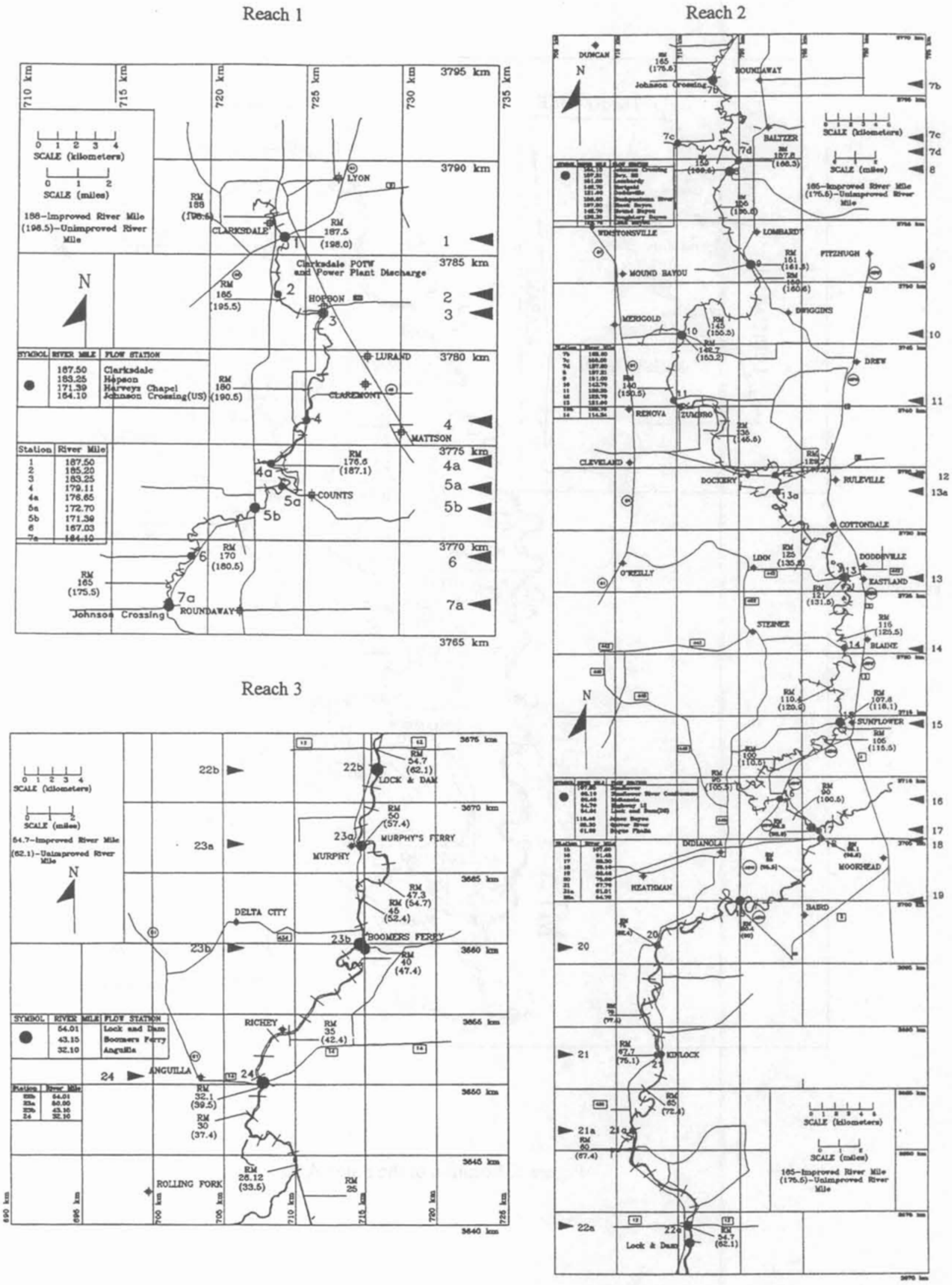

Figure 2: Segmentation Map and Location of Sampling Stations in Reaches 1, 2, and 3

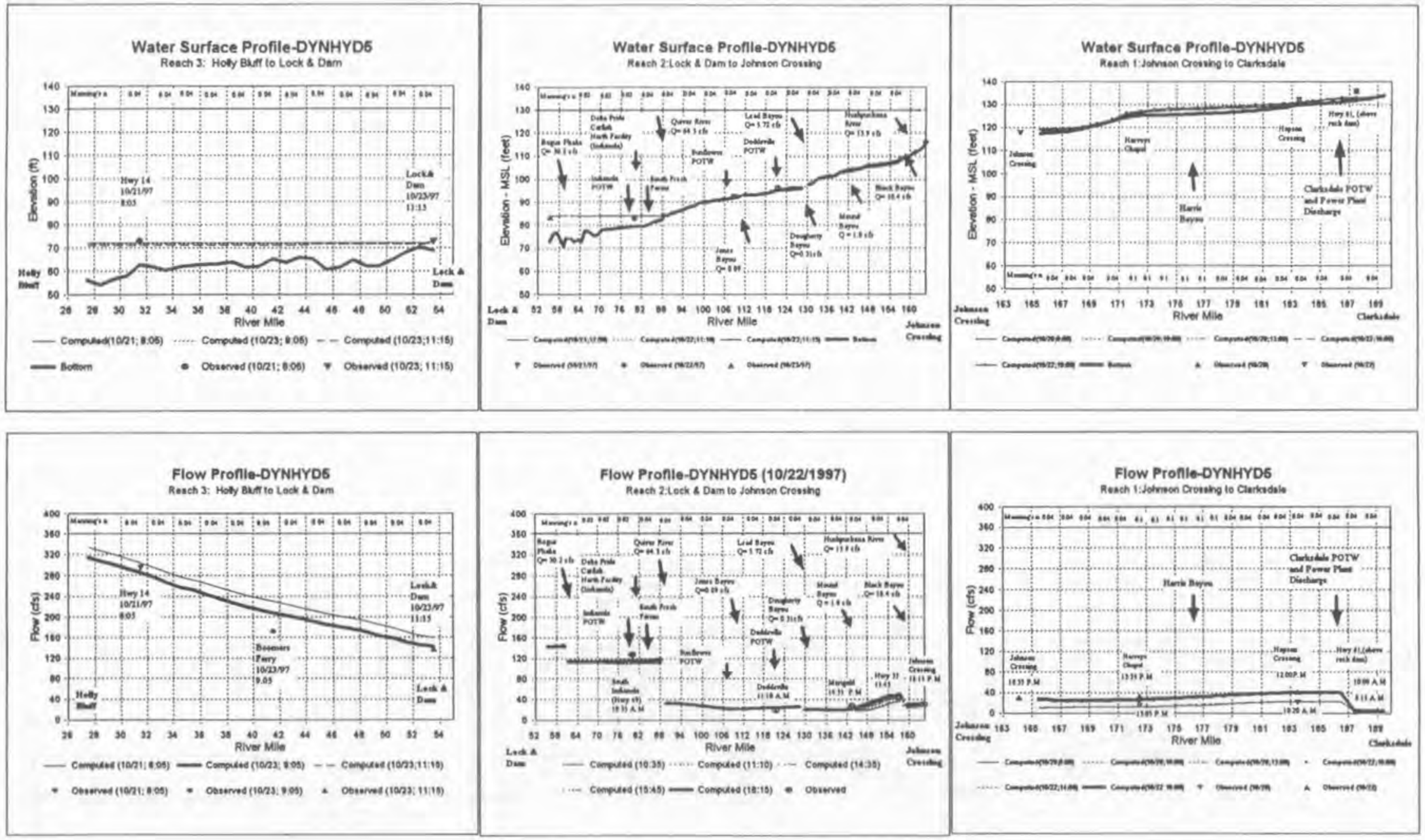

Figure 3: Water Surface Elevation and Flow Spatial Profiles at Big Sunflower River (October 19-23, 1997)

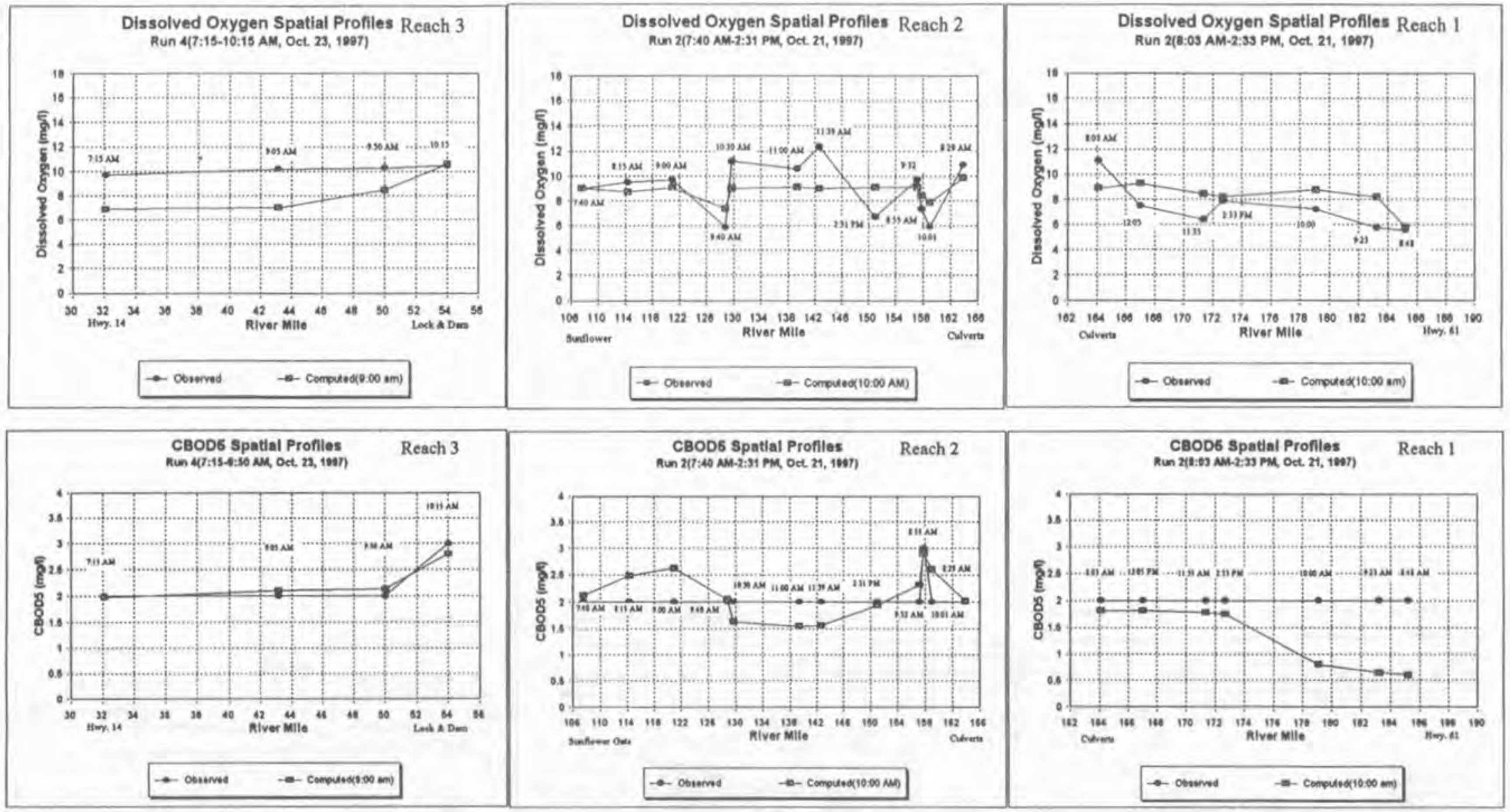

Figure 4: Dissolved Oxygen and CBOD5 Spatial Profiles at Big Sunflower River (October 19-23, 1997)

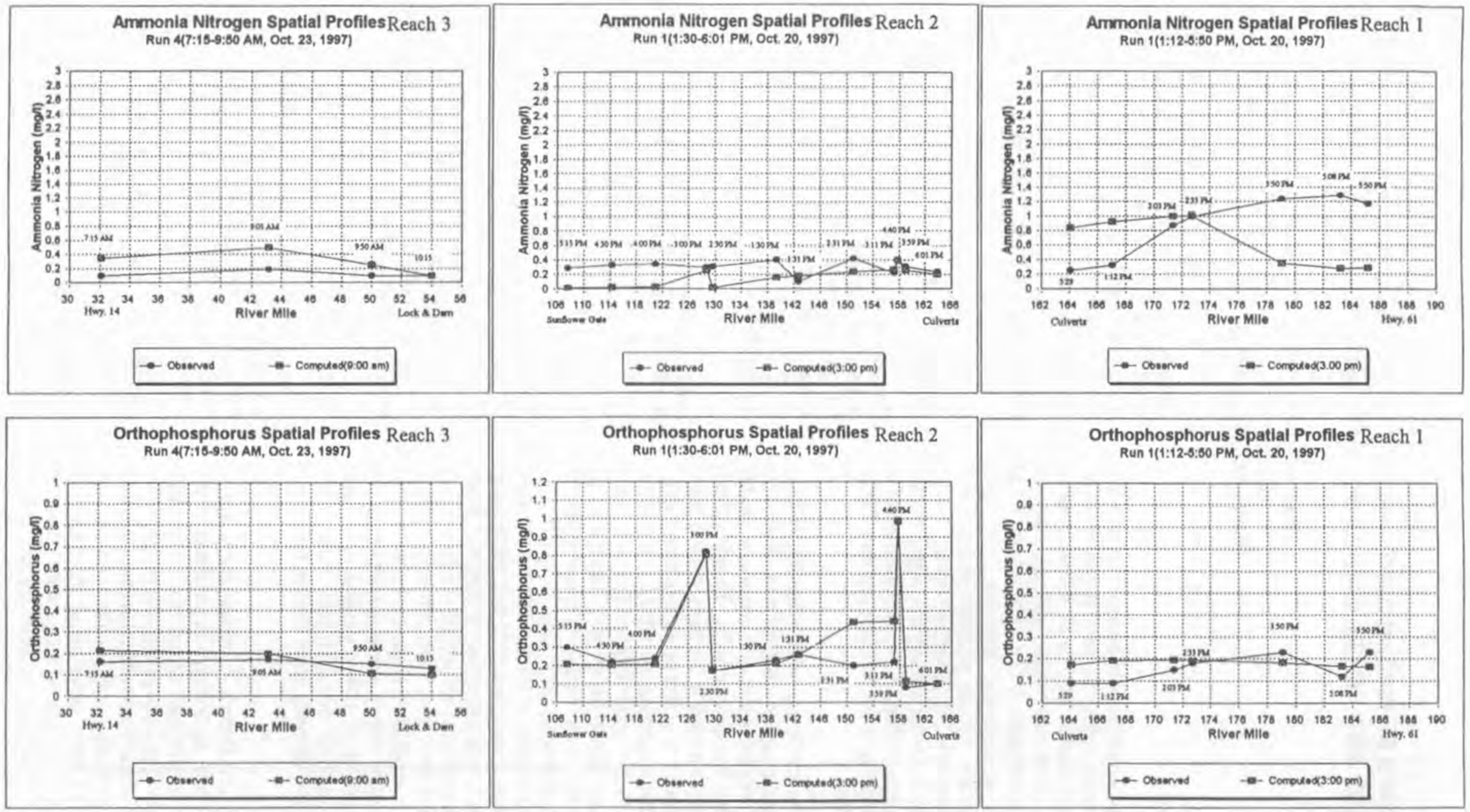

Figure 5: Ammonia Nitrogen and Orthophoshorus Spatial Profiles at Big Sunflower River (October 19-23, 1997)