DEVELOPMENT OF A TOTAL MAXIMUM DAILY LOAD (TMDL) FOR TOTAL BIOCHEMICAL OXYGEN DEMAND ($TBOD_U$) FOR INDIAN CREEK NEAR IUKA. MS

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INTRODUCTION

The identification of waterbodies not meeting their designated use and the development of total maximum daily loads (TMDLs) for those waterbodies are required by Section 303(d) of the Clean Water Act and the Environmental Protection Agency's Water Quality Planning and Management Regulations. The Mississippi Department of Environmental Quality (MDEQ) has identified a segment of Indian Creek as being impaired for a total length of 3 miles as reported in the Mississippi 1998 Section 303(d) List of Waterbodies. This segment is located in northeastern Mississippi within the Tennessee River Basin: beginning at the luka POTW outfall and ending at the confluence of Pickens Branch, Figure 1. The pollutant of concern in Indian Creek is enrichment of organic matter, which causes low instream levels of dissolved oxygen (DO). Oxidizable organic matter is measured in terms of total ultimate biochemical oxygen demand ($TBOD_U$). $TBOD_U$ is the oxygen consumed by microorganisms while stabilizing carbonaceous and nitrogenous compounds under aerobic conditions over an extended time period. $TBOD_U$ is equal to the sum of carbonaceous biochemical oxygen demand ($CBOD_U$) and nitrogenous biochemical oxygen demand ($NBOD_U$).

The TMDL process is designed to restore and maintain the quality of impaired waterbodies through the establishment of pollutant specific allowable loads. The TMDL for Indian Creek is the maximum allowable load of $TBOD_U$ that can be placed in the waterbody, while allowing the waterbody to maintain state water quality standards. The allowable load of $TBOD_U$ for Indian Creek was developed based on the state standard for DO as defined in the State *of* Mississippi Water Quality Criteria for Intrastate, Interstate, and Coastal Wafers (MDEQ 1995b). The state standard specifies that for waters designated for use as fish and wildlife support, the DO concentration shall be maintained at a daily average of not less than 5.0 mgll with an instantaneous minimum of not less than **4.0** mg/l. In order to adequately protect the designated use of Indian Creek, these standards must be attained under low-flow, critical conditions. MDEQ Regulations define "low-flow, critical conditions" as the 7Q10 flow and temperatures of 26°C in the summer (May – October) and 20°C in the winter (November – April). The 7Q10 flow is the minimum flow expected for seven consecutive days during a time period of ten years. A water quality model, QUAL2E, was selected to determine the assimilative capacity of the creek for the pollutant of concern under critical conditions.

The QUAL2E model includes both point and nonpoint sources of $TBOD_U$. One point source of $TBOD_U$ is located within the modeled segment of Indian Creek, the luka POTW facility, a two-cell conventional lagoon with a chlorine contact chamber. Discharge monitoring reports (DMRs) and effluent samples collected in September 1998, during a study of Indian Creek, were used to characterize the facility's effluent. DMRs indicate that this facility is currently operating within the limits for 5-day biochemical oxygen demand (BOD_5) loading set within its NPDES permit. Nonpoint sources of $TBOD_U$ were quantified by measuring the background concentration in the headwaters of the creek.

MODEL CALIBRATION STUDY

The QUAL2E model was developed to simulate the existing, instream conditions documented during an intensive study of Indian Creek performed by MDEQ. In order to investigate the impact of organic enrichment in Indian Creek during critical conditions, this study was performed during a low-flow, high-temperature period in September 1998. Seven monitoring stations were established upstream and within the impaired segment of Indian Creek. The locations of the monitoring stations, labeled IC-1 through IC-7, are shown in Figure 1.

Data collected at each monitoring station consisted of analysis of the habitat and benthic macroinvertebrate community, measurement of hydraulic and meteorological parameters, in-situ data, and water chemistry parameters. The in-situ parameters; DO, pH, temperature, and specific conductivity, were monitored with datasondes in 30-minuite intervals for at least 24-hours at each of the monitoring stations. Water chemistry parameters included total organic carbon, total phosphorous, total Kjeldahl nitrogen, ammonia nitrogen, nitrite nitrogen, nitrate nitrogen, total suspended solids, and chlorophyll-a. Additional water chemistry samples were collected at several of the monitoring stations for analysis of $CBOD_U$ and $NBOD_U$. Effluent samples from the luka POTW were also analyzed for these in-situ and water chemistry parameters.

Collection of the water chemistry samples was coordinated with a time-of-travel study. The time-of-travel study was conducted by releasing 350 ml of Rhodamine WT Dye into Indian Creek at monitoring station IC-1. The downstream movement of the dye cloud was monitored by recording the instream dye concentration using a Model 10 Series Flourometer, Turner Instruments, Inc. The average water velocity in each reach was calculated, based on the results of the dye study, by dividing the reach distances by the travel time of the dye peak through each reach. Water chemistry samples were collected as the dye cloud passed and 12 hours following at each monitoring station. Assuming approximate plug-flow conditions, this sampling strategy allows the use of water chemistry data for estimating the rates at which chemical processes occur under natural conditions in the creek. Two composite water samples, each collected over a 24-hour period, were collected at the luka POTW lagoon. These samples were collected from the second cell of the lagoon near the outfall pipe using an ISCO sampler. All water chemistry samples were analyzed by the MDEQ Laboratory in Pearl, MS according to protocols outlined in Standard Methods *for* the Examination *of* Water and Wastewater , *20th* Edition (Clescon, Greenburg, Eaton, eds. 1998).

An analysis of the chemical data collected during the intensive study showed a decrease in the levels of DO and an increase in the specific conductivity below the luka POTW outfall. The mean DO decreased from 6.36 mg/l at monitoring station IC-2 (river mile 10.2), which is upstream of the POTW outfall, to 2.98 mgll at monitoring station IC-4 (river mile 8.8), which is downstream of the POTW outfall. The mean instream DO increased to 6.21 mg/l at monitoring station IC-7 (river mile 7.0), indicating recovery from the effects of organic enrichment at this point. The diurnal variation of instream DO also increased significantly at the monitoring stations below the POTW outfall (river mile 9.3). Diurnal DO variations of up to 2.5 mgll were recorded at monitoring station IC-3 (river mile 9.4). The specific conductivity increased from a mean of 57.6 µS/cm at monitoring station IC-2 to 102.1 µS/cm at monitoring station IC-4. In addition, levels of total organic carbon, total Kjeldahl nitrogen, total suspended solids, and chlorophyll-a also showed notable increases below the POTW outfall.

Analysis of the instream biology and habitat was performed at four of the monitoring stations on Indian Creek and at Pickens Branch, a tributary of Indian Creek. Biological data collected at Pickens Branch were used to establish reference conditions in a non-impaired stream for comparison purposes. The biological evaluations consisted of a habitat assessment and an analysis of the benthic macroinvertabrates found in the stream. The use of benthic macroinvertabrates in bioassessments provides an indication of the long-term water quality of a stream. Certain types of these organisms are extremely sensitive to pollution, thus the presence or absence of sensitive organisms in an area provides a long-term indication of the quality of the water to which they have been exposed (MDEQ 1998b).

Benthic macroinvertabrates were collected according to a specific protocol referred to as a rapid biological assessment or RBA. The RBAs were performed at stations IC-2, IC-3, IC-5, and IC-7. The RBAs performed at the station above the luka POTW discharge, IC-2, and furthest downstream from the POTW outfall. IC-7, indicated the best water quality conditions when compared to the reference condition. However, notable differences from the reference site, indicating poorer water quality, were found at stations IC-3 and IC-5. Habitat assessments performed at all of the monitoring sites indicated that all stations had relatively good habitat. The results of the RBAs and habitat evaluations are described in further detail in Indian Creek TMDL Development: *Macroinvertabrate* Assessment (MDEQ 1998b).

MODEL DEVELOPEMNT

The water quality model selected for TMDL development is a one-dimensional mathematical model for DO distribution in freshwater streams. QUAL2E, the Enhanced Stream Water Quality Model, is the most recent in a series of models originally developed by the Texas Water Development Board in the 1960's. It has been extensively reviewed and tested and is presently supported by EPA's Center for Water Quality Modeling in Athens, GA. QUAL2E can simulate up to 15 water quality consistuents in well-mixed, dendritic systems (USEPA 1987). All of the major consistuents that impact the instream DO are included among the model's capabilities. The QUAL2E model simulates water quality consistuents using a mass transport reaction equation that includes the processes of advection and dispersion. Advection refers to the movement of the modeled consistuents with water flowing downstream. Dispersion relates to the spreading of modeled consistuents primarily due to sheer forces (Chapra 1997). The program simulates changes in water quality conditions with time by computing the conditions in a series of reaches, with water passing from one reach to the next. A hydraulic balance in terms of discharge and a materials balance in terms of concentration are calculated within each modeled reach (Maidment 1992).

The QUAL2E model treats a waterbody as a collection of reaches. Each reach is divided into a series of equal-length computational elements. Uniform hydraulic and water chemistry characteristics are assumed within each computational element (Chapra 1997). Indian Creek was divided into five such reaches in the QUAL2E model. Each reach was further subdivided into computational elements of 0.1 mile. Reach divisions were based on several factors including the location of the NPDES permitted point source, hydraulic characteristics of the channel, and accessibility of the creek. The modeled segment of Indian Creek begins at monitoring station IC-3 (river mile 9.4), just below the Iuka POTW and continues to the confluence of Pickens Branch with Indian Creek, below monitoring station IC-7 (river mile *6.6).*

Hydraulic Processes

The first step in developing a water quality model is establishing the hydraulic characteristics of the steam system. These characteristics determine the rate and magnitude of many of the physical and chemical processes including setting and resuspension of particulate organic matter, decay of $CBOD_U$, and atmospheric reaeration. The hydraulic data collected during the intensive study of Indian Creek, which were designed to characterize these processes, included instantaneous stream flow measurements, surveys of channel geometry, and a time-of-travel study. The flows measured during the study ranged from 1.03 cfs at monitoring station IC-1 to 3.01 cfs at monitoring station IC-7. Average reach velocities ranged from 0.05 feetlsecond between stations IC-2 and IC-3 to 0.27 feetlsecond between stations IC-3 and IC-4. Differences in the average reach velocity were attributed to variations in the channel geomorphology, channel slope, and obstructions in the channel such as fallen trees.

The hydraulic processes were simulated in the QUAL2E model using a steady, nonuniform representation in which the flow, velocity, and channel width and depth are constant with time at any given point in the modeled system. However, these parameters change in the longitudinal direction within the modeled reaches. Flow at the upstream boundary and incremental inflow from groundwater infiltration and ungaged tributaries were defined in the model input, based on data that were collected during the intensive study. Water movement within the creek was simulated in the model by using stage discharge relationships described in the *QUAL2E* Documentation and User Manual (USEPA 1987). In order to ensure accuracy of the simulated water velocity and channel geometry, the simulated travel times and channel geometry were compared to the travel times and geometry measured during the study.

Water Quality Processes

The QUAL2E model simulates the effect of interacting water quality processes that affect the instream DO concentration. These processes are reaeration, $CBOD_U$ decay and settling, nitrification, algal photosynthesis and respiration, and sediment oxygen demand (SOD).

Reaeration. The QUAL2E model includes eight options for calculating or specifying the reaeration coefficient. The accuracy and applicability of these options have been the subject of a great deal of study and comparison, resulting in recommendations for conditions under which each of the options should be used. The method developed by Tsivoglou and Wallace, is recommended for use in small streams in Mississippi with flows less than 10 cfs (MDEQ 1995a). The Tsivoglou and Wallace method, which was selected for use in the Indian Creek model, calculates the reaeration coefficient according to Equation 1:

$$k_a = CSu \qquad (1)$$

where k_a = reaeration coefficient (day^{-1}), S = stream slope (ft/mile), u = stream velocity (mile/day). The value of C is specified as 0.11 for streams in which the flow is less then 10 cfs according to *Empirical Stream Model Assumptions for Conventional Pollutants and Conventional Water Quality Models* (MDEQ 1995a). Stream velocity was determined from the time-of-travel study. The stream slopes in each reach were calculated from measurements of the water surface elevation made with a Trimble 4800 GPS System.

$CBOD_U$ Decay and Settling. Decomposition of carbonaceous organic matter coupled with reaeration will result in a decrease in the dissolved oxygen levels downstream of a point source until a critical minimum is reached. This phenomenon is commonly referred to as a "DO sag." The instream concentration of $CBOD_U$, which is critical for determining the magnitude of the DO sag, depends on two processes; the oxidation of $CBOD_U$ and the setting of $CBOD_U$. The oxidation rate of $CBOD_U$ was calculated from data collected during the study, while the $CBOD_U$ settling rate was estimated through model literature values and model calibration. The oxidation of carbonaceous matter can be described mathematically using first order kinetics according to Equation 2:

$$L = L_o e^{(-k^*t)} \qquad (2)$$

where L = amount of $CBOD_U$ remaining at time t (lbs/day), L_o = $CBOD_U$, or the total oxygen depletion due to oxidation of carbonaceous material present at time t_0 (lbs/day), k = first-order $CBOD_U$ decay rate (day^{-1}), t = time (days). The value of k depends on both the characteristics of the organic matter and the instream conditions after the release of the effluent. Based on Equation 2, the value of k was determined graphically by developing a semi-log plot of the $CBOD_U$ load versus downstream travel time. The $CBOD_U$ loads were calculated at monitoring stations IC-3, IC-5, IC-6, and IC-7. Downstream travel times were measured with the time-of-travel study. Assuming that the $CBOD_U$ decay is first order, the semi-log plot will produce a straight line with a slope equal to k (USEPA 1985). The slope, -1.27, indicates that the $CBOD_U$ decay rate in base e is 1.27 day^{-1} at a temperature of 20°C. The R^2 value, 0.97, reflects a strong correlation between the variables.

Nitrification. In addition to $CBOD_U$ decay, oxidation of nitrogenous compounds has a significant effect on the level of DO in a waterbody. The total amount of oxidizable nitrogen in a system is present as organic nitrogen and ammonia nitrogen. The QUAL2E model simulates the conversion of organic nitrogen to ammonia nitrogen using a hydrolysis rate coefficient. Subsequently, nitrification, the conversion of ammonia nitrogen to nitrite nitrogen followed by the conversion of nitrite nitrogen to nitrate nitrogen, is simulated as a two–step process in the model. In order to more accurately reflect actual instream conditions, the modeled nitrification process is inhibited by the model when DO levels are depressed.

The theoretical amount of oxygen used during nitrification is 4.57 grams of oxygen per gram of oxidizable nitrogen (Chapra 1997). However, not all of the organic nitrogen and ammonia nitrogen in the waterbody is oxidized to nitrate. Because nitrogen is an essential nutrient for plant growth, these forms of nitrogen are taken up by algae for growth. Settling of nitrogen dissolved in the water column and the release of nitrogen from sediments and from algae during respiration are also included in the modeled mass-balance of the nitrogen species (USEPA 1987).

The QUAL2E model simulates the nitrogen cycle using four nitrogen species; organic nitrogen, ammonia nitrogen, nitrite nitrogen, and nitrate nitrogen. The rate coefficients involved in organic nitrogen hydrolysis, nitrification, algal uptake of ammonia, and settling were based on literature values suggested for use in the *QUAL2E Documentation and User Manual* (USEPA 1987). These rates were not measured during the intensive study

Algal Photosynthesis and Respiration. In the QUAL2E model, the concentration of phytoplanktonic algal biomass is considered to be directly proportional to the concentration of chlorophyll-*a*. The model has several options for simulating the growth rate of algae and the effect of light and nutrient concentrations on the growth rate. As described in the *QUAL2E Documentation and User Manual*, the local specific growth rate of algae is known to be coupled to the availability of light and required nutrients. There are a variety of mathematical expressions for describing these interactions. QUAL2E has the capability to model the interaction among these limiting factors in three different ways; multiplicative, limiting nutrient, and harmonic mean. For the Indian Creek model, the limiting nutrient option was used. This option represents the local algal growth rate as limited by light and either nitrogen or phosphorous, but not both. Thus, the algal growth is controlled by the nutrient with the smaller growth limitation factor (USEPA 1987).

The availability of light in a stream is one of the most significant factors effecting algal photosynthesis (Chapra 1997). QUAL2E has three options available for simulating the amount of light available for algae growth; half saturation, Smith's function, and Steel's equation. Although the three options differ in mathematical form, the relationships exhibit similar characteristics, showing an increasing rate of photosynthesis with increasing light intensity up to a maximum value. At high light intensities, some of the expressions exhibit photoinhibition, while others show photosynthetic activity remaining at the maximum rate. For the Indian Creek model the first option, half saturation, was used. This option requires the input of a light intensity and a half saturation coefficient in BTU/ft^2/hour. The default values given in the *QUAL2E Documentation and User Manual* for the half saturation coefficient, 0.11 BTU/ft^2/min, and light intensity, 1,300 BTU/ft^2/day, were used as estimates (USEPA 1987).

QUAL2E simulates the respiration rate of algae with a single, user-input respiration rate parameter. The respiration rate is used to approximate the endogenous respiration of algae, the conversion of algal nitrogen to organic nitrogen, and the conversion of algal phosphorous to organic phosphorous. The respiration rate of algae in Indian Creek was measured with the use of light and dark bottle tests. These tests were conducted by deploying light and dark bottles in the creek at all of the monitoring stations. The method consisted of placing a sample of creek water in two plastic bottles of equal volume and measuring the initial DO. The bottles were secured in the creek within the photic zone. The light bottle is a clear bottle that will allow light penetration. Thus, both photosynthesis and respiration can occur in the light bottle. The dark bottle does not allow light penetration, so that only respiration can occur in the bottle. The bottles were left in the creek for a period of approximately six hours. The final concentration of DO in each bottle was then determined. The results of the light and dark bottle tests were used to calculate the rates of water column respiration along with net photosynthesis, and gross primary productivity.

It should be noted that there are some differences in the values of photosynthesis and respiration measured with the light and dark bottles and the actual values of these parameters. Because the water samples in the light and dark bottle tests are enclosed in a bottle, they are not subject to the natural currents of water movement in the waterbody. Also, the light and dark bottle tests do not include the effects of oxygen demand due to sediments, attached periphyton, and other irregular substances.

Because the QUAL2E model requires a constant respiration rate throughout all the modeled reaches, an average respiration rate was calculated from the rates measured at stations IC-3 through IC-7. An average algal respiration rate of 1.60 mg-oxygen/mg-algae was used. This rate is within the recommended range of respiration values included in the *QUAL2E Documentation and User Manual* (USEPA 1987).

Sediment Oxygen Demand. SOD is a representation of the oxygen demanding processes of the bottom substances, attached periphyton, and other irregular substances. It can account for a large portion of the total oxygen demand in a waterbody, especially where the settling rate of organic matter is high, allowing the formation of sludge beds. The major factors effecting SOD are temperature, available oxygen at the sediment-water interface, makeup of the biological community, organic and physical characteristics of the sediment, and the velocity of the currents flowing over the sediments (UESPA 1985).

The QUAL2E model represents SOD as an oxygen demand with the units of gm-oxygen/ft^2/day. One limitation to the QUAL2E simulation of SOD is that it is not linked to other components of the water quality simulation such as $CBOD_U$ settling and the algae and nutrient cycles (USEPA 1987). Thus, SOD must be assessed individually and input into the model as an independent variable in each reach. The values of SOD for each reach were estimated using data collected during the intensive study.

The in-situ data collected at each monitoring station were analyzed to assess the oxygen demanding processes in the sediments of Indian Creek using a modified method, originally developed by Odum and Hoskin (1958) described in *Comparative Studies in the Metabolism of Marine Waters.* This method involved a graphical analysis of DO data collected at each monitoring station. This method assumes that with appropriate corrections, the diurnal DO changes remain proportional to the photosynthesis and respiration of plants and the activities of animals residing in a water body. DO changes occurring in a waterbody are expressed as Equation 3, in which any chemical oxidation occurring in the waterbody is treated as respiration:

$$Q = GPP - R + D \qquad (3)$$

where Q = net rate of change in DO (mg-oxygen/L/day), GPP = rate of change in gross photosynthetic production (mg-oxygen/L/day), R = rate of change in community respiration (mg-oxygen/L/day), D = rate of change in atmospheric reaeration (mg-oxygen/L/day). Graphical analyses of 24-hours of the continuous DO data collected at each monitoring station were used to determine the rates of gross photosynthetic production and respiration. The Tsivoglou and Wallace formulation was used to determine the value of rate of atmospheric reaeration for each monitoring station in Indian Creek.

A 4-hour running interval was used to calculate and produce a graph of the uncorrected DO rate of change. This DO rate of change is uncorrected because it must be adjusted to account for atmospheric reaeration. When the DO concentration is below saturation, as it is in Indian Creek, the waterbody gains oxygen from the atmosphere at a rate equivalent to the atmospheric reaeration rate, adjusted for the dissolved oxygen saturation deficit. Since this oxygen came from the atmosphere and was not actually produced through primary production, the uncorrected DO rate of change was adjusted downward so as not to credit gross photosynthetic production for oxygen production that actually came into the water via atmospheric diffusion (Odum and Hoskin 1958). The corrected DO rate of change was calculated by subtracting the diffusion rate from the uncorrected DO rate of change.

When calculating community respiration, the simplifying assumption must be made that the respiration rate at night is the same as the respiration rate measured during the day. Although this assumption is probably not entirely correct, it introduces only minimal error into the calculations while simplifying the process considerably (Odum and Hoskin 1958). The community respiration rates were calculated by averaging the values of corrected DO rate of change that were measured after sunset. This nighttime value of the corrected DO rate of change was extrapolated as a constant throughout the 24-hour period. The area between the corrected DO rate of change curve and nighttime respiration line that occurs during daylight hours is equal to the gross photosynthetic production. The SOD values were calculated by first determining community respiration according to this method and then subtracting the water column respiration derived from the light and dark bottle tests. The difference between the value of community respiration and water column respiration is attributable to SOD. The value of SOD within each reach was calculated by averaging the values of SOD measured at the monitoring stations on the upstream and downstream ends of each reach.

RESULTS

Calibration of the water quality model used to calculate the TMDL is a critical part of TMDL development. The calibrated QUAL2E model was developed to simulate the conditions measured during the intensive study. The flows, concentrations of nutrients and oxidizable organic matter, and rate coefficients measured during the study were used to set the initial conditions for the model. In order to calibrate the model, parameters affecting the hydraulics and instream water quality were adjusted. The default values were used as starting points for many of the rate coefficients used in the model. Selected default rate coefficients were adjusted within the recommended ranges given in the *QUAL2E Documentation and User Manual* (USEPA 1987), so that the measured flow and water quality conditions matched the modeled flow and water quality conditions as closely as possible. These rate coefficients were adjusted only within the recommended range of the default values given in the *QUAL2E Documentation and User Manual* (USEPA 1987). Figure 2 shows the concentrations of several parameters measured during the intensive study compared to the concentrations predicted by the existing condition model. Although the figure does not show an exact match between the observed and predicted data, most predicted values are reasonably close, indicating that the principal water quality processes are accurately simulated by the model.

DISCUSSION

The TMDL is equal to the sum of the wasteload allocation (WLA), the load allocation (LA), and the margin of safety (MOS). The WLA refers to the load of $TBOD_U$ that is discharged from NPDES permitted point sources. The LA is the $TBOD_U$ load that is attributable to nonpoint and natural background sources of $TBOD_U$. The MOS, which is included in the TMDL to account for any lack of knowledge concerning the relationship between effluent limitations and water quality, can be expressed in several ways. One method is to explicitly specify a portion of the TMDL as the MOS. Another method of expressing the MOS is to implicitly incorporate it into the TMDL by using conservative assumptions when developing the model. For the Indian Creek TMDL, the latter option was used.

Following development of the calibrated model, predictive models representing critical conditions for winter and summer seasons were developed for calculating the TMDL. The reaction rates, which were determined in the development of the calibrated model, were not changed in the predictive models. The stream flow was adjusted to the 7Q10 flow, and the temperatures were adjusted to seasonal critical temperatures, 26°C in the summer and 20°C in the winter. The 7Q10 flow at the upstream boundary of the model, 0.7 cfs, was calculated according to the method described in *Techniques for Estimating 7-Day, 10-Year Low Flow Characteristics on Ungaged Sites on Streams in MS* (Telis 1992). The flow from the NPDES permitted point source, the Iuka POTW, was also set at its maximum permitted flow in the predictive models.

The predictive models were used to determine the maximum load of $TBOD_U$ that would allow the daily average DO in all reaches of Indian Creek to remain greater than 5.0 mg/l, and thus meet the water quality standard for DO at critical conditions. Initial results from the predictive models indicated that that the DO in Indian Creek was reduced significantly below the water quality standard, to 1.0 mg/l, downstream from the Iuka POTW when the point source was set at its maximum permitted load. In order to determine the TMDL, the point source load was reduced, and the predictive model was run using a trial-and-error process to determine the maximum load that would allow the DO to remain above 5.0 mg/l downstream from the Iuka POTW.

The necessary reductions from the maximum NPDES permitted point source load were 73% in the summer season and 58% in the winter season. The point source load that allows the attainment of water quality standards is equal to the WLA. The LA, which is equal to the nonpoint and background $TBOD_U$ loads measured during the intensive study, was not adjusted. The TMDLs for the summer and winter seasons are given in Table 1. The results of the TMDL indicate that the existing load of $TBOD_U$ exceeds the assimilative capacity of Indian Creek, thus a commensurate reduction in the point source $TBOD_U$ load is recommended by the TMDL report.

CONCLUSION

The QUAL2E model of Indian Creek was developed and calibrated based on an intensive study of the system. This model was used as a predictive tool for calculating a TMDL for $TBOD_U$ in the creek. All of the data collected during this study, as well as additional details about the model setup and calibration are available in the *Draft Total Maximum Daily Load for Organic Enrichment/Low DO for Indian Creek* (MDEQ

2001). Interested persons may obtain a copy of this document by contacting the author.

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Figure 1. Impaired Segment and Monitoring Station Locations

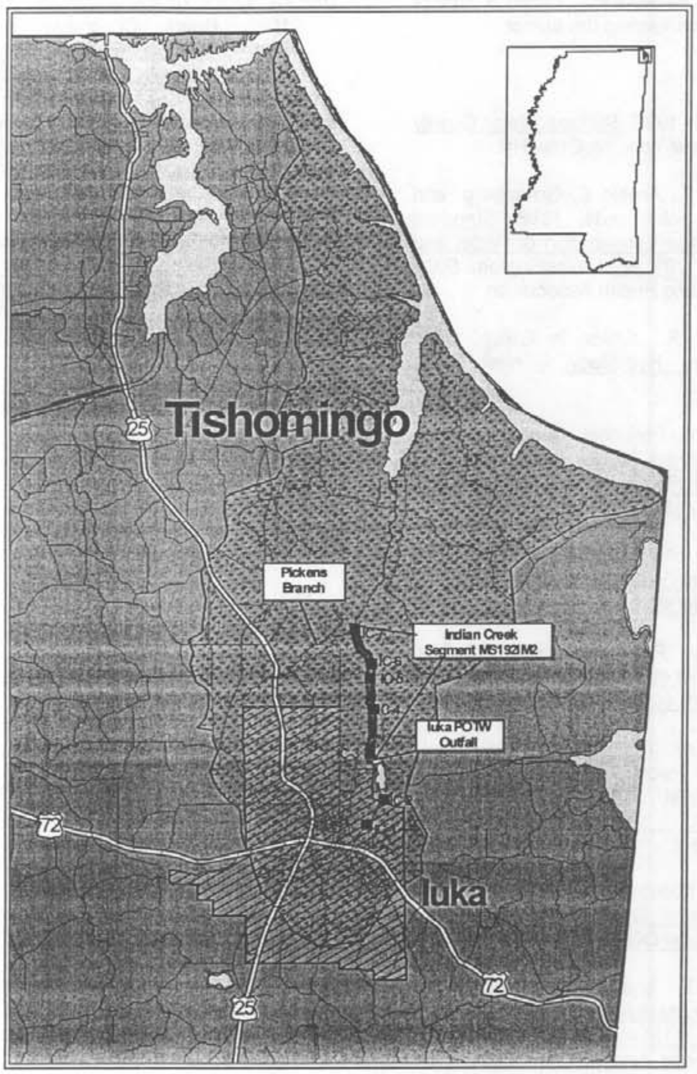

Figure 2. Existing Condition Model Calibration Graphs

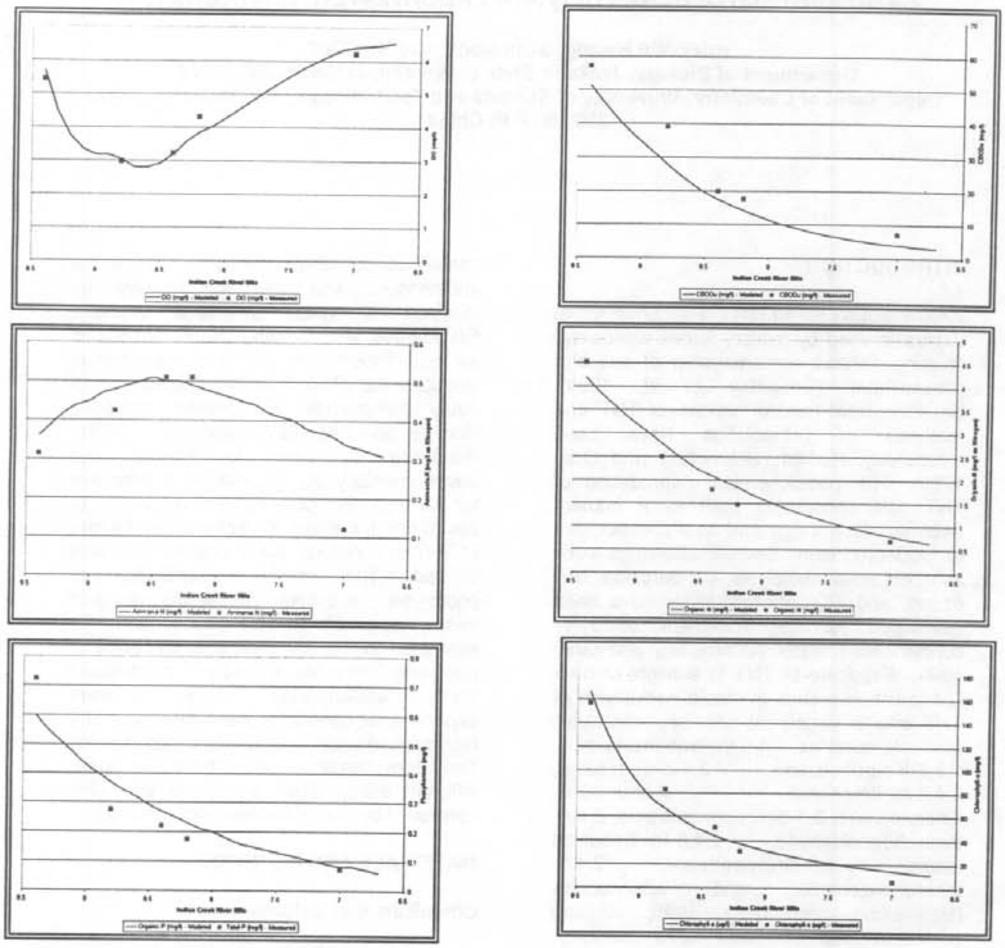

Table 1: TMDL for $TBOD_U$ for Indian Creek Segment MS193IM2

Season	WLA (lbs/day)	LA (lbs/day)	MOS	TMDL (lbs/day)
Summer (May-October)	162.9	33.2	Implicit	**196.1**
Winter (November – April)	238.0	33.2	Implicit	**271.2**