INDIAN BAYOU WATERSHED TMDL
FOR OXYGEN-DEMAND SUBSTANCES OR POLLUTANTS

SUBSEGMENT 030805

TMDL Report

Engineering Section 2
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Originated: January 4, 2001
Revised: March 13, 2001

EXECUTIVE SUMMARY

A TMDL for oxygen-demand pollutants has been developed for the Indian Bayou Watershed based on hydrologic and water quality data available as of December 2000. Indian Bayou was not listed on any 303(d) list; however, Indian Bayou was part of the 1999 ambient sampling program and was found to not be meeting its designated use of Fish and Wildlife Propagation. It is, however, meeting its designated uses of Primary and Secondary Contact Recreation. The suspected causes of impairment are organic enrichment/low DO. Hydromodification, agriculture, and natural sources are the suspected sources of impairment.

The ambient monitoring samples for Indian Bayou were obtained in 1999 during a period of extreme drought conditions with many dissolved oxygen samples falling below the dissolved oxygen criteria for this waterbody. Also, the water quality survey conducted in June 2000, again during a period of extreme drought conditions revealed dissolved oxygen levels well below criteria. Indian Bayou was ranked as high priority (priority 1) on the list for development of a total maximum daily load (TMDL).

Indian Bayou was modeled from its headwaters to its confluence with the West Fork Calcasieu River. The Indian Bayou watershed is subsegment 030805 of the Calcasieu River Basin (Basin 3). Subsegment 030805 is comprised of Indian Bayou and all tributaries, including Hickory Branch Canal and Little Indian Bayou.

Indian Bayou land use is 54% agriculture. Indian Bayou also has almost 32% forestry and rangeland. Only 3.74% of the land is urban with little population growth in the last 10 years.

A UAA has been approved for Indian Bayou making the DO standard for Indian Bayou 3.0 mg/L March through November and 5.0 mg/L December through February. Therefore, model projections were performed at those particular seasons and DO criteria. Projections show that compliance with the current dissolved oxygen criteria will require a 60% reduction of man-made nonpoint loading.

Several point sources fall within the subsegment. These facilities were deemed either intermittent stormwater or minor discharges on unnamed tributaries and were represented in the nonpoint loading via benthic loads. Limits for these small facilities are generally set by state policy.

A survey was conducted (June 28, 2000) during a period of severe drought conditions. The Indian Bayou watershed was in a condition of low flow. There were no tributaries that had a velocity that could be measured with typical survey equipment. The nonpoint source loads included nonpoint loading not associated with flow.

The various spreadsheets that were used in conjunction with the modeling program may be found in the appendices in the order in which they were used. Water quality calibration was also based on measurements taken during the survey. Projections were adjusted to meet the dissolved oxygen criteria by reducing man-made nonpoint source loads.

Land use in the Indian Bayou watershed is fairly homogeneous. It is primarily agriculture. TMDLs have been calculated for Indian Bayou and are presented in the following tables. Due to the many assumptions made while developing the model, the inherent error within the model algorithms, and the scale of a watershed-based model, the results of the model should be used only as an aid in making water quality based decisions.

Current Standard:	Summer season (Mar - Nov)		Winter season (Dec - Feb)	
	BOD Loading (lbs/day)	% of TMDL	BOD Loading (lbs/day)	% of TMDL
Headwater/Tributary Loads	18	0.22	65	0.74
Benthic Loads	5,604	79.78	5,604	79.26
Point Source Loads	0	0	0	0
Margin Of Safety	1,401	20.00	1,401	20.00
Reduction of man-made nonpoint	60%		60%	
Total maximum daily load (TMDL)	7,024	100	7,070	100

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1.0 Introduction

Indian Bayou, Segment 030805 of the Calcasieu Basin, was part of the 1999 ambient sampling program and was found to be impaired due to organic enrichment/low DO and requiring the development of a total maximum daily load (TMDL) for dissolved oxygen. The 1999 ambient water quality sampling of Indian Bayou was done during a period of extreme drought conditions that significantly contributed to the low-flow, low-dissolved oxygen conditions found. A calibrated water quality model for the Indian Bayou watershed was developed and projections were run to quantify the nonpoint source load allocations (LAs) required to meet established dissolved oxygen criteria. This report presents the model development and results.

2.0 Study Area Description

2.1 Calcasieu Basin

The Calcasieu River Basin is located in southwestern Louisiana and is positioned in a north-south direction. The drainage area of the Calcasieu Basin comprises approximately 3,910 square miles. Headwaters of the Calcasieu River are in the hills west of Alexandria. The river flows south for about 160 miles to the Gulf of Mexico. The mouth of the river is about 30 miles east of the Texas-Louisiana state line. The landscape in this basin varies from pine forested hills in the upper end to brackish and salt marshes in the lower reach around Calcasieu Lake. (LA DEQ, 1996).

2.2 Indian Bayou Watershed, Subsegment 030805

This area is typical of the basin and is primarily used for agriculture as documented in Table 1 (LADEQ, 2000). Segment 030805 is comprised of Indian Bayou as the main stem to its confluence with the West Fork Calcasieu River. The modeled portion of Indian Bayou receives intermittent flow from the following tributaries: Hickory Branch Canal, Little Indian Bayou, and several unnamed tributaries.

Average annual precipitation in the segment, based on the nearest Louisiana Climatic Station, is 62 inches based on a 30-year record (LSU, 2000). Land use in the Calcasieu Basin is largely forestry. Land uses in Segment 030805 are shown in Table 1 below (LA DEQ, 2000).

Table 1. Land uses in Subsegment 030805 of the Calcasieu Basin

Land use	Acres	%
Agricultural	17,716	54.39
Forest Land	6,140	18.85
Rangeland	4,273	13.12
Wetland	2,761	8.48
Urban	1,217	3.74
Water	467	1.43

2.3 Water Quality Standards

Water quality standards for the State of Louisiana have been defined (LA DEQ, 2000). The standards are defined according to designated uses of the waterbodies. Both general narrative standards and numerical criteria have been defined. General standards include prevention of objectionable color, taste and odor, solids, toxics, oil and grease, foam, and nutrient conditions as well as aesthetic degradation. The numerical criteria are shown in Table 2.

Designated uses for Indian Bayou from its headwaters to the Calcasieu River (waterbody subsegment 030805) include primary contact recreation, secondary contact recreation, propagation of fish and wildlife, and agriculture.

Indian Bayou was assessed in 2000 as a waterbody not meeting the dissolved oxygen criteria. Section 303(d) of the Clean Water Act requires the identification, listing, ranking and development of TMDLs for waters that do not meet applicable water quality standards after implementation of technology-based controls. Current dissolved oxygen criteria are shown in Table 3. Waterbodies are placed on the 303(d) list based on the comparison of data from ambient monthly samples and the criteria. Due to diurnal variations in dissolved oxygen, the time in which the assessment samples were taken was an important factor. Algae and macrophytes that produce dissolved oxygen in the water column in the presence of sunlight (photosynthesis) and utilize dissolved oxygen in the absence of sunlight (respiration) cause diurnal variations in dissolved oxygen. This process can cause the dissolved oxygen levels of the water to be depressed during the morning hours and elevated during the evening hours. Either extreme is not representative of the stream. It is uncertain if the samples that were used to assess Indian Bayou during the 1999 ambient sampling program were representative of the stream or the diurnal effects of algae and macrophytes. Also, the 1999 ambient water quality sampling period was a drought year, contributing or exacerbating low-flow, low-dissolved oxygen conditions.

Table 2. Current Numerical Criteria for Indian Bayou (LA DEQ, 2000)

Parameter	Criteria
Cl, mg/L	250
SO_4, mg/L	75
pH	6.0-8.5
BAC	1
Temperature, deg Celsius	34
TDS, mg/L	500

Table 3. Dissolved Oxygen Criteria for Indian Bayou, (mg/L)

March - November	3.0
December - February	5.0

2.4 Discharger Inventory

All of the dischargers located in this watershed are small and need not be included in a model of this scale. It is unlikely that they will have an impact on the targeted waterbody due to the small load and/or the distance from the waterbody named in the 303(d) lists. These dischargers are accounted for as nonpoint loading through the process of calibration. They fall within one of several state or regional policies that govern permit limitations. These dischargers will be given effluent limitations according to the state policy. Current permit information and discharge monitoring reports were reviewed for all of these facilities.

2.5 Previous Studies and Other Data

The majority of the data used for this project was obtained during a watershed survey conducted on June 28, 2000. Discharge data, cross-section data, field data, and lab water quality data from the watershed survey are presented in Appendix C. The Ultimate BOD plots are also in Appendix C.

3.0 Documentation of Calibration Model

3.1 Model Description and Input Data Documention

3.1.1 Program Description

The model used for this TMDL was LA-QUAL, a steady-state one-dimensional water quality model. Its history dates back to the QUAL-I model developed by the Texas Water Development Board with Frank D. Masch & Associates in 1970 and 1971. William A. White wrote the original code.

In June, 1972, the United States Environmental Protection Agency awarded Water Resources Engineers, Inc. (now Camp Dresser & McKee) a contract to modify QUAL-I for application to the Chattahoochee-Flint River, the Upper Mississippi River, the Iowa-Cedar River, and the Santee River. The modified version of QUAL-I was known as QUAL-II.

Over the next three years, several versions of the model evolved in response to specific client needs. In March, 1976, the Southeast Michigan Council of Governments (SEMCOG) contracted with Water Resources Engineers, Inc. to make further modifications and to combine the best features of the existing versions of QUAL-II into a single model. That became known as the QUAL-II/SEMCOG version.

Between 1978 and 1984, Bruce L. Wiland with the Texas Department of Water Resources modified QUAL-II for application to the Houston Ship Channel estuarine system. Numerous modifications were made to enable modeling this very large and complex system including the addition of tidal dispersion, lower boundary conditions, nitrification inhibition, sensitivity analysis capability, branching tributaries, and various input/output changes. This model became known as QUAL-TX and was subsequently applied to streams thoughout the State of Texas.

In 1999, the Louisiana Department of Environmental Quality and Wiland Consulting, Inc. developed LA-QUAL based on QUAL-TX Version 3.4. The program was converted from a DOS-based program to a Windows-based program with a graphical interface and enhanced graphic output. Other program modifications specific to the needs of Louisiana and the Louisiana DEQ were also made. LA-QUAL is a user-oriented model and is intended to provide the basis for evaluating total maximum daily loads in the State of Louisiana.

3.1.2 Model Schematic or Vector Diagram

A vector diagram of the modeled area is presented in Appendix A. The vector diagram shows the reach/element design and the locations of major tributaries. The modeled segment consists of 4 reaches numbered in ascending order from headwater to confluence with West Fork Calcasieu. The modeled area is characterized by the 5 sample sites starting from the West Fork Calcasieu and working up to the headwater of Indian Bayou. A digitized map of the stream showing river kilometers, locations of cross-sections and June 28, 2000 survey sampling sites is included in Appendix F.

3.1.3 Hydrology and Stream Geometry and Sources

LADEQ had a monthly water quality sampling station on Indian Bayou for a period of one year, 1999. Data collected during an Eularian survey conducted June 28, 2000, was used to establish the input for the model calibration and is presented in Appendix C.

The stream geometry at the headwater is shallow and narrow with no flow at site 5. The stream in general continues to widen and deepen until it reaches its confluence with West Fork Calcasieu. There was inflow noted at sites 3 and 4.

The reach and element design for the Indian Bayou model was made using a 0.20 km element length. The total number of reaches and elements was within the limitations of the model. "The current version is dimensioned for a maximum of 200 reaches, 100 headwaters, 300 wasteloads and 3000 elements" (LA-QUAL User's Manual). The final design incorporated 4 reaches, 1 headwater, and 130 elements. A simple spreadsheet was used to calculate the reach length, element length, and cumulative number of elements at the bottom of each reach. This spreadsheet is presented in Appendix A.

Rather than directly inputting the widths and depths of the stream, the model requires that the advective hydraulic characteristics (a modification of the Leopold Coefficients and Exponents) be entered. Since the measured widths and depths from the hydrologic survey were taken during zero flow conditions, they were input as the modified Leopold equation constants. The exponent and coefficient values were obtained from calibration.

3.1.4 Headwater

Since the survey was conducted during drought conditions, no measureable headwater flow was obtainable with the current instrumentation. Therefore, a minimum flow of 0.0001 cms or 0.00353 cfs was used for headwater.

3.1.5 Water Quality Input Data and Their Sources

Water quality data collected during the June 28, 2000 survey on Indian Bayou and its tributaries was entered in a spreadsheet for ease of analysis. Overall, water quality was good with all the current numerical criteria being met for this modeled area except DO at two sites.

Diurnal DO variation was noted and attributed to two causes: temperature induced and possible algal production and respiration. Nutrients and suspended solids were low. Dissolved solids were relatively high.

The ultimate BOD, CBOD, NBOD, and corresponding decay rates were computed for each sample taken. A complete listing is presented in Appendix C. This data was the primary source for the model calibration input data for initial conditions, decay rates, headwater temperature, and headwater DO.

3.1.5.1 Temperature Correction of Kinetics, Data Type 4

The temperature values computed are used to correct the rate coefficients in the source/sink terms for the other water quality variables. These coefficients are input at 20 ^{o}C and are then corrected to temperature using the following equation:

$$X_T = X_{20} * Theta^{(T-20)}$$

Where:

X_T = the value of the coefficient at the local temperature T in degrees Celsius
X_{20} = the value of the coefficient at the standard temperature at 20 degrees Celsius
Theta = an empirical constant for each reaction coefficient
(QUAL2E Documentation and User Model, 1987)

In absence of specified values for data type 4, the model uses default values. A complete listing of these values can be found in the LA-QUAL for Windows User's Manual (LDEQ, 2000).

3.1.5.2 Initial Conditions, Data Type 11

The initial conditions are used to reduce the number of iterations required by the model. The values required for this model were temperature and DO by reach. The initial condition input values were determined from the June 28, 2000 survey stations located on Indian Bayou. See Appendix C for a composite of the survey water quality data.

3.1.5.3 Reaeration Rates, Data Type 12

The 0.7/ Depth was used as the Reaeration equation for reaches 1-3 due to the extremely small velocity. 0.7/Depth is the metric equivalent to 2.3/Depth in english units. O'Connor – Dobbins was used for Reach 4 because of the greater depth and width, and an increase in velocity.

3.1.5.4 Sediment Oxygen Demand, Data Type 12

Values of SOD from the Louisiana Technical Procedures Manual (LTP), were used in several preliminary calibration runs. These values have been established for wasteload allocation modeling of short stream reaches directly below treatment plant outfalls and were not suitable for a watershed level model. SOD values were therefore achieved through calibration.

3.1.5.5 Carbonaceous BOD Decay and Settling Rates, Data Type 12

These rates are labeled Aerobic BOD Decay and BOD Settling in LA-Qual. The CBOD bottle rates were used for decay rates in the model. The settling rates were achieved through calibration. The decay and settling rates used for each reach are shown in Appendix A.

3.1.5.6 Nitrogenous Decay and Settling Rates, Data Type 13

These rates are labeled NCM decay and NCM Settling in LA-QUAL. The Org-N decay and settling rates were used to simulate NBOD rates because the Org-N decay rate is the limiting rate in the nitrogen cycle and is the part of NBOD that is settleable. The NBOD bottle rates were used for decay rates in the model. The settling rates were achieved through calibration. The decay and settling rates used for each reach are shown in Appendix A.

3.1.5.7 Incremental Conditions, Data Types 16, 17, and 18

The incremental conditions are used in the calibration to represent nonpoint source loads associated with flows. Incremental inflow was determined in reaches 2 and 3.

General indicators of groundwater inflow are low DO, an increase in conductivity and phosphorus. All of these indicators are present at site 3.

General indicators of bank inflow are increases in TOC, CBOD, and color with a decrease in conductivity. Also the increase in DO indicates a disturbance in the water column. All of these indicators are present at site 2.

3.1.5.8 Nonpoint Sources, Data Type 19

Nonpoint source loads, which are not associated with a flow, are input into this part of the model. These loads are used to simulate loads from the stream bed that have been resuspended into the water column. The values used in the model were determined by calibration. The data and sources are presented in Appendix A.

3.1.5.9 Headwaters, Data Types 20, 21, and 22

A minimal flow of 0.0001 cms or 0.00353 cfs was used for the headwater flow. The survey was conducted during severe drought conditions and could not determine any measureable headwater flow.

3.1.5.10 Wasteloads, Data Types 24, 25, and 26

The model uses wasteloads to represent treatment plant effluent or unmodeled tributaries. None of the tributaries were found to have measurable flow and therefore, not modeled. There are no treatment plant discharges directly into Indian Bayou.

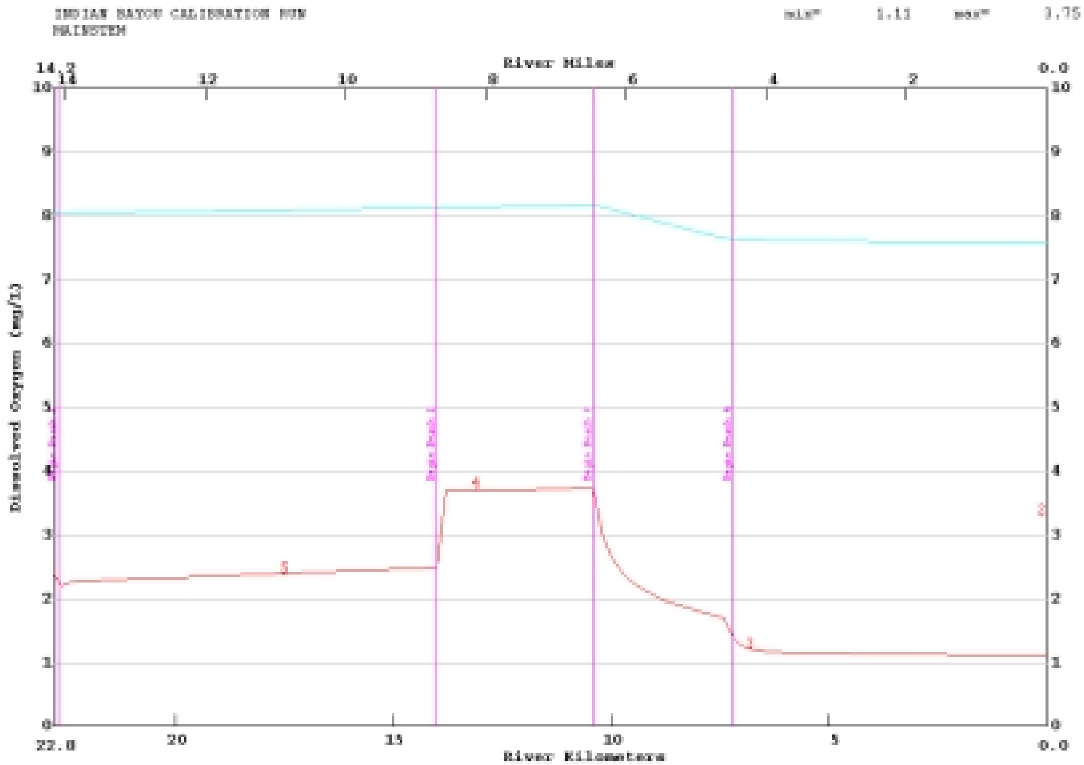
3.1.5.11 Boundary Conditions, Data Type 27

This waterbody was not tidally influenced, however, with the significant flow of the West Fork Calcasieu meeting the minimal flow of Indian Bayou at their confluence, dispersion was added to reach 4. Reach 4 is the bottom of the modeled segment and characterized by site 2.

3.2 Model Discussion and Results

The calibration model input and output is presented in Appendix A. The overlay plotting option was used to determine if calibration had been achieved. A plot of the dissolved oxygen concentration versus river kilometer is presented in Figure 1.

Figure 1. Calibration Model--Dissolved Oxygen versus River Kilometer



Indian Bayou main stem extends from its headwaters to the confluence with the West Fork Calcasieu River and is represented by Reaches 1 - 4. The model simulates the measured values of DO adequately at the one meter depth. The survey data shows that in June 2000, the current DO standard of 3.0 mg/L was not being met on the modeled portion of Indian Bayou. The calibration model went through the measured survey data values using reasonable model input values and was determined to be a reasonable calibration.

4.0 Water Quality Projections

The traditional summer and winter projections loading scenarios were performed for both the current DO standards. These scenarios were:

a. Summer Projection Scenario – Reduced man-made nonpoint loads at summer season critical conditions.
b. Winter Projection Scenario – No Reduction of man-made nonpoint loads at winter season critical conditions.

4.1 Critical Conditions

4.1.1 Seasonality and Margin of Safety

The Clean Water Act requires the consideration of seasonal variation of conditions affecting the constituent of concern, and the inclusion of a margin of safety (MOS) in the development of a TMDL. For the Indian Bayou TMDL, an analysis of LDEQ ambient data has been employed to determine critical seasonal conditions and an appropriate margin of safety has been used.

Critical conditions for dissolved oxygen were determined for Indian Bayou using water quality data from the station on the LDEQ Ambient Monitoring Network. The critical conditions for dissolved oxygen concentrations were those of nonpoint run-off and low stream flow combined with high temperature.

When the rainfall runoff (and nonpoint loading) and stream flow are high, turbulence is higher due to the higher flow and the temperature is lowered by the runoff. In addition, runoff coefficients are higher in cooler weather due to reduced evaporation and evapotranspiration, so that the high flow periods of the year tend to be the cooler periods. DO saturation rates are, of course, much higher when water temperatures are cooler, but BOD decay rates are much lower. For these reasons, periods of high loading are periods of higher reaeration and dissolved oxygen but not necessarily periods of high BOD decay.

This phenomenon was interpreted in TMDL modeling by assuming that the annual nonpoint loading, rather than loading for any particular day, is responsible for the accumulated benthic blanket of the bayou, which is, in turn, expressed as SOD and/or resuspended BOD in the model. This accumulated loading has its greatest impact on the bayou during periods of higher temperature and lower flow. The manmade portion of the NPS loading is the difference between the calibration load and the reference stream load where the calibration load is higher.

Critical summer conditions were simulated in the Indian Bayou oxygen demand TMDL projection modeling by using an estimated 0.1 cfs for all headwaters as stated in the Louisiana Technical Procedures Manual and temperature of 27.4ºC for the summer season. Incremental flow was assumed to be present due to its presence during severe drought conditions; model loading was from sediment oxygen demand. Critical winter conditions were simulated by using an estimated 1.0 cfs as stated in the Louisiana Technical Procedures Manual and temperature of 12.2ºC. Again, incremental flow was assumed to be present due to its presence during severe drought conditions; model loading was from sediment oxygen demand.

In reality, the highest temperatures occur in July-August, the lowest stream flows occur in October-November, and the maximum point source discharges often occur following a significant rainfall, i.e., high-flow conditions. The model is established as if all these conditions happened at the same time. Other conservative assumptions regarding rates and loadings are also made during the modeling process. In addition to these conservative measures, an explicit MOS of 20% was used for both point and nonpoint loads to account for future growth, safety, model uncertainty and data inadequacies.

4.1.2 Hydrology and Stream Geometry and Sources

The headwater flows used in all the projection scenarios were based on the summer and winter defaults listed in the Louisiana Technical Procedures Manual (LTP). All incremental flows were assumed to be present during critical flow periods since they were present during drought conditions. This assumption was based on the survey data taken at drought conditions.

Rather than directly inputting the widths and depths of the stream, the model requires that the advective hydraulic characteristics (a modification of the Leopold Coefficients and Exponents) be entered. Since the velocity was zero for the 2000 survey, the measured widths and depths from the hydrologic survey were input as the modified Leopold equation constants. The coefficients and exponents used were the same as calibration.

4.1.3 Water Quality Input Data and Their Sources

The initial condition temperatures were set to the 90th percentile critical season temperature in accordance with the LTP. Critical temperatures for each season were determined from the temperature data collected by LADEQ as part of its current ambient monitoring strategy. The 90th percentile temperature for each season was computed for LADEQ water quality ambient station #0845 on Indian Bayou from January to December 1999. This represents one year of record which is all that was available. The temperature analysis spreadsheet is shown in Appendix B. The dissolved oxygen values for the initial conditions were set at 90% of the DO saturation at the 90th percentile temperature for the season.

The CBOD decay and settling rates as well as the NBOD decay and settling rates, were held constant at the calibration rates. The reaeration rates determined from calibration were used in the projections. The data and calculations are shown in Appendix B.

The incremental conditions are normally used in the calibration to represent nonpoint source loads associated with flows. For the projection and scenario runs, the incremental flows were also assumed to be present because of their presence during the severe drought conditions. Any small flows, such as individual sewage package plants are assumed to be susceptible to evaporation or groundwater recharge.

The headwater UCBOD and UNBOD used in all the projection scenarios were taken from the June 2000 survey data. The temperature used was the 90th percentile critical season temperature determined from the LADEQ ambient monitoring station on Indian Bayou (Site # 0845). The DO was 90% of the DO saturation at the 90^{th} percentile temperature for the season determined from the same site. The period of record used was January to December 1999.

4.1.3.1 Sediment Oxygen Demand, Data Type 12

In the summer and winter projections, the man-made SOD was reduced based on the dissolved oxygen criteria set for the projection.

4.1.3.2 Nonpoint Sources, Data Type 19

The resuspended man-made CBOD and NBOD loading was reduced by 60% in the summer projection scenario to meet the summer water quality criterion for dissolved oxygen. The stream is projected to meet criteria during the winter season. These reductions were determined using the calibrated values for Nonpoint CBOD & NBOD and the total benthic natural loading of 2.0 gm O2/m2/day. A percentage of each loading component was calculated by comparison to the total calibration benthic value. The natural benthic value was subtracted from the total calibration benthic load to determine the man-made benthic loading value. These percentages were then applied to the 60% of man-made loading value, and the CBOD and NBOD loading portions of the reduced man-made benthic loading were determined by adding the CBOD and NBOD portions of the man-made benthic loading to the CBOD and NBOD portions, respectfully, of the background benthic loading. These calculations are shown in Appendix B. The value and sources of CBOD and NBOD for each projection run are presented in Appendix B.

4.1.3.3 Wasteloads, Data Types 24, 25, and 26

There were no significant dischargers to the mainstem. The Hickory Branch and Little Indian Bayou tributaries were added as wasteloads to the mainstem.

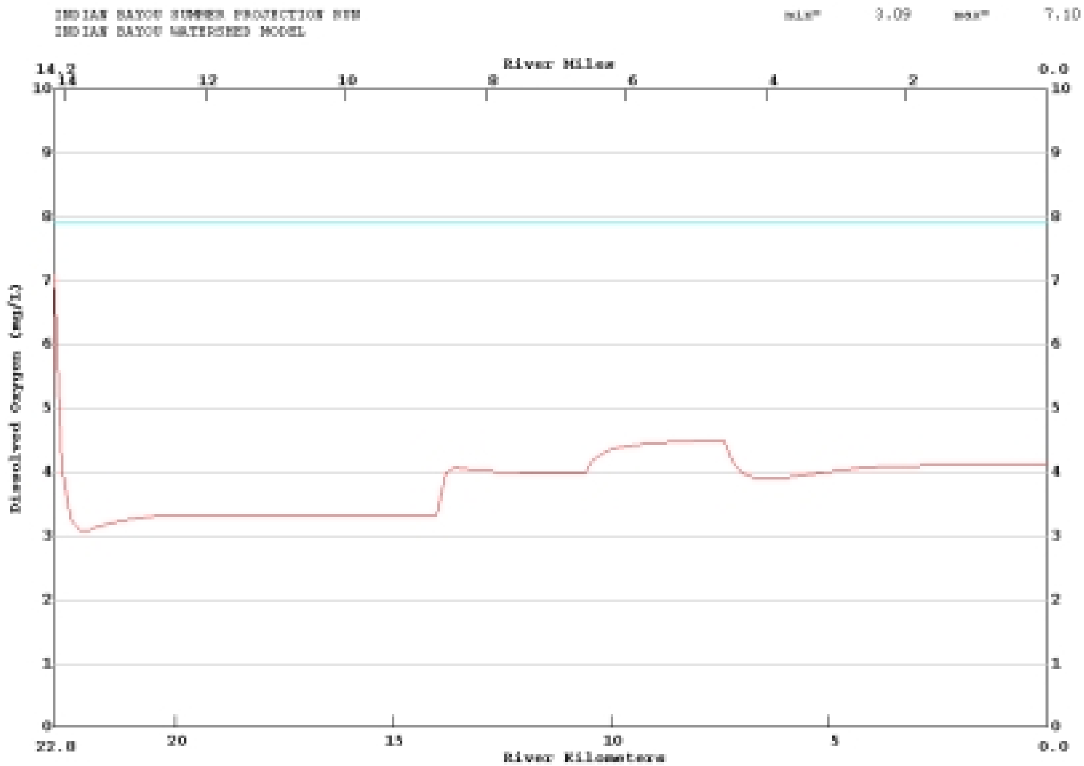
4.2 Projection Model Discussion and Results

The projection model inputs and output data sets are presented in Appendix B.

4.2.1 Summer Projections

Summer projections were run for the current standard of 3.0 mg/L March – November. In order to meet the 3.0 mg/L standard, a 60% reduction of man-made nonpoint sources is necessary. As shown in the output graph, the bayou meets the dissolved oxygen criterion. The minimum DO on the main stem is 3.09 mg/L. A graph of the dissolved oxygen concentration versus river kilometer for the summer projection is presented in Figure 2.

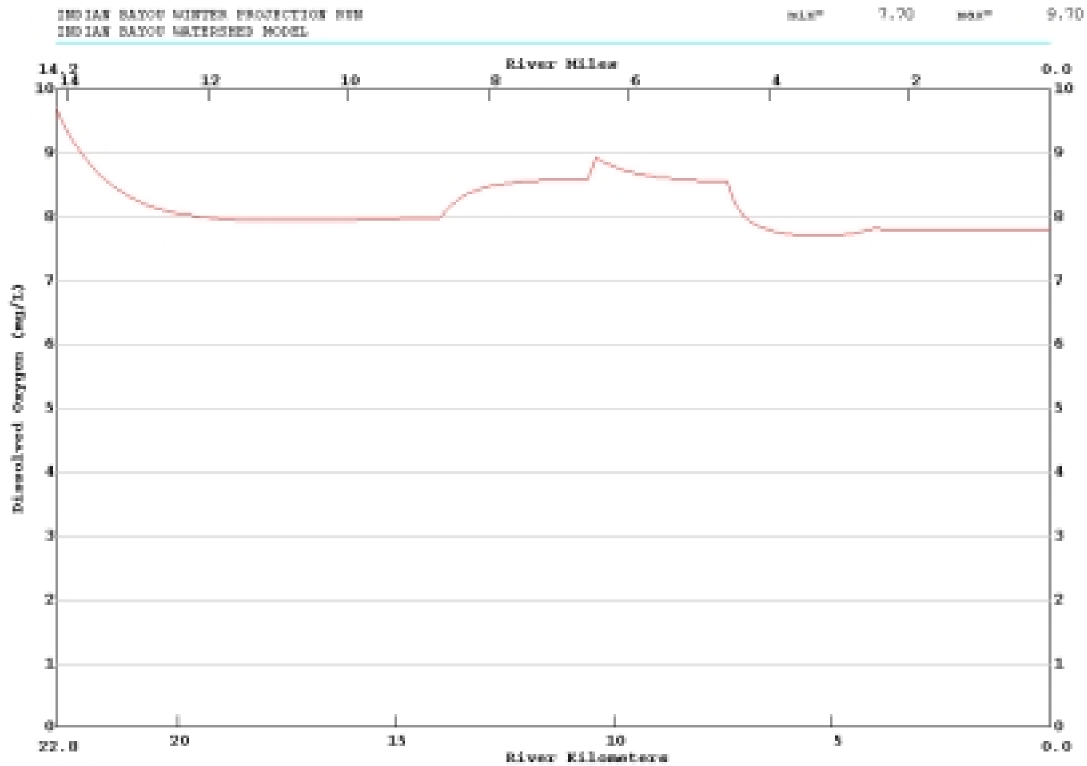
Figure 2. Summer Projection Model--Dissolved Oxygen versus River Kilometer



4.2.2 Winter Projection

Winter projections were run at the current standard. The current standard is 5.0 mg/L December - February. In order to meet the current standard, no reduction of man-made nonpoint sources is required. As shown in the output graph, the bayou meets the DO criterion. The minimum DO on the main stem is 7.70 mg/L. A graph of the projected winter dissolved oxygen concentration versus river kilometer is presented in Figure 3.

Figure 3. Winter Projection Model--Dissolved Oxygen versus River Kilometer



4.3 Calculated TMDLs, WLAs and LAs

TMDLs have been calculated for the summer and winter projection runs. They are presented in Appendix E. A summary of the loads is presented in Table 4.

Table 4. Seasonal Total Maximum Daily Load Summaries—Current Criteria

ALLOCATION	SUMMER (MAR-NOV) DO criterion=3.0 mg/L (lbs/day)	WINTER (DEC-FEB) DO criterion=5.0 mg/L (lbs/day)
Point Source WLA	0	0
Headwater/Tributary Loads	18	65
Benthic Loads	5,604	5,604
Margin of Safety	1,401	1,401
TMDL = WLA + LA + MOS	7,024	7,070

4.3.1 Outline of TMDL calculations

An outline of the TMDL calculations is provided to assist in understanding the calculations in the Appendices. Slight variances may occur based on individual cases.

- The natural background benthic loading was estimated from reference stream NBOD, CBOD, and SOD data.
- The calibration anthropogenic (man-made) benthic loading was determined as follows:
  - Calibration nonpoint CBOD and NBOD (resuspension), and SOD were summed for each reach as gm O_2/m^2-day to get the total calibration benthic loading.
  - The natural background benthic loading was subtracted from the total calibration benthic loading to get the total anthropogenic (man-made) calibration benthic loading.
- Projection runs were made with:
  - Point sources represented at 125% of design flow (based on Department of Health design criteria) to provide an explicit 20% margin of safety for point source loading.
  - Headwater flows at seasonal 7Q10 or 0.1(summer)/1.0(winter) cfs, whichever was greater.
  - Headwater concentrations of CBOD, NBOD, and DO at calibration levels.
- For each reach, the nonpoint CBOD and NBOD (resuspension) were adjusted to bring the projected in-stream dissolved oxygen into compliance with criteria. No additional explicit margin of safety was employed for nonpoint loading. The loading capacity and percent reduction of nonpoint were calculated as follows:
  - The total projection benthic loading at 20^{o}C was calculated as the sum of projection NBOD, CBOD, and SOD expressed as gm O_2/m^2-day.
  - The natural background benthic loading was subtracted from the total projection benthic loading to get the total anthropogenic (man-made) projection benthic loading.
  - The total anthropogenic projection benthic loading was subtracted from the total calibration anthropogenic benthic loading and that number divided by the total calibration anthropogenic benthic loading to obtain the percent reduction of nonpoint loading needed to achieve the in-stream dissolved oxygen criteria.
- The total projection benthic loading for each reach was calculated as follows:
  - The projection SOD at 20^{o}C was adjusted to stream critical temperature.
  - The projection CBOD, NBOD, and SOD were summed to get the total benthic loading at critical stream temperature in lb/d for each reach.
- The total stream loading capacity at critical stream temperature was calculated as the sum of:
  - Headwater CBOD and NBOD loading in lb/d.
  - Projection benthic loading for all reaches of the stream in lb/d.
  - Total point source CBOD and NBOD loading in lb/d.
  - The facility margin of safety.

The TMDL for the Indian Bayou watershed was set equal to the total stream loading capacity.

5.0 Sensitivity Analyses

All modeling studies necessarily involve uncertainty and some degree of approximation. It is therefore of value to consider the sensitivity of the model output to changes in model coefficients, and in the hypothesized relationships among the parameters of the model. The LA-QUAL model allows multiple parameters to be varied with a single run. The model adjusts each parameter up or down by the percentage given in the input set. The rest of the parameters listed in the sensitivity section are held at their original value. Thus the sensitivity of each parameter is reviewed separately. A sensitivity analysis was performed on the calibration. The sensitivity of the model's minimum DO to these parameters is presented in Table 6. Parameters were varied by +/- 30%, except temperature, which was adjusted +/- 2 degrees Centigrade. The calibration minimum DO was 1.11 mg/L.

Table 5 Summary of Calibration Model Sensitivity Analysis

	Positive Changes in parameter			**Negative Changes in parameter**		
Parameter	% change	Minimum DO (mg/l)	Percentage Difference	% change	Minimum DO (mg/l)	Percentage Difference
Stream Reaeration	-30.0	0.18	-83.6	30.0	1.91	72
Benthal Demand	-30.0	1.72	55.3	30.0	0.58	-47.4
Initial Temperature	-2 deg C	1.39	25.8	2 deg C	0.83	-25.3
BOD Decay Rate	-30.0	1.34	21.1	30.0	0.95	-14.6
BOD Settling Rate	-30.0	0.92	-16.9	30.0	1.25	12.9
Nonconservative Settling	-30.0	1.07	-3.2	30.0	1.13	2.1
Nonconservative Decay	-30.0	1.11	0	30.0	1.11	-0.1

As shown in the summary table, reaeration is the parameter to which DO is most sensitive (72.0% to -83.6%). The other parameters creating major variations in the minimum DO values are Benthal Demand (-47.4% to 55.3%), and Initial Temperature (-25.3% to 25.8%). BOD Decay and BOD Settling are moderately sensitive with variations ranging from –16.9% to 21.1%.

6.0 Conclusions

The results of the summer projections show that the water quality standard for dissolved oxygen for Indian Bayou (WQ Subsegment 030805) of the current 3.0 mg/L can be maintained during the summer critical season, (March – November). This can be accomplished with the imposition of a 60% reduction of man-made nonpoint sources.

The results of the winter projection model show that the water quality criterion for dissolved oxygen for Indian Bayou of 5.0 mg/L can be maintained during the winter critical season, (December – February). To achieve the current summer standard, a 60% reduction of man-made nonpoint sources is required.

Continued monitoring is recommended to see how well the nonpoint reductions improve the dissolved oxygen values. Additional modeling may be required if the improvements do not meet expectations.

The LDEQ has implemented a watershed approach to surface water quality monitoring. Through this approach, the entire state is sampled over a five-year cycle with two targeted basins sampled each year. Long-term trend monitoring sites at various locations on the larger rivers and Lake Pontchartrain are sampled throughout the five-year cycle. Sampling is conducted on a monthly basis or more frequently if necessary to yield at least 12 samples per site each year. Sampling sites are located where they are considered to be representative of the waterbody. Under the current monitoring schedule, targeted basins follow the TMDL priorities. In this manner, the first TMDLs will have been implemented by the time the first priority basins will be monitored again in the second five-year cycle. This will allow the LDEQ to determine whether there has been any improvement in water quality following implementation of the TMDLs. As the monitoring results are evaluated at the end of each year, waterbodies may be added to or removed from the 303(d) list. The sampling schedule for the first five-year cycle is shown below.

1998 - Mermentau and Vermilion-Teche River Basins
1999 - Calcasieu and Ouachita River Basins
2000 - Barataria and Terrebonne Basins
2001 - Lake Pontchartrain Basin and Pearl River Basin
2002 - Red and Sabine River Basins

(Atchafalaya and Mississippi Rivers will be sampled continuously.)
Ouachita and Calcasieu Basins will be sampled again in 2004.

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Appendix A

Calibration Model Development

Appendix B

Projection Model Development

Appendix C

Survey Data Measurements and Analysis Results

Appendix D

Historical and Ambient Data

Appendix E

Recommended TMDL

Appendix F

Maps and Diagrams