TMDLS FOR DISSOLVED OXYGEN AND NUTRIENTS FOR BAYOU PETIT CAILLOU (SUBSEGMENT 120709)

MARCH 24, 2008

TMDLS FOR DISSOLVED OXYGEN AND NUTRIENTS FOR BAYOU PETIT CAILLOU (SUBSEGMENT 120709)

Prepared for

USEPA Region 6
Water Quality Protection Division
Watershed Management Section
1445 Ross Avenue, Suite 1200
Dallas, TX 75202-2733

Contract No. 68-C-02-108
Task Order: #95

Prepared by

FTN Associates, Ltd.
3 Innwood Circle, Suite 220
Little Rock, AR 72211

FTN No. 2110-616

March 24, 2008

EXECUTIVE SUMMARY

Section 303(d) of the Federal Clean Water Act requires states to identify waterbodies that are not meeting water quality standards and to develop total maximum daily pollutant loads for those waterbodies. A total maximum daily load (TMDL) is the amount of pollutant that a waterbody can assimilate without exceeding the established water quality standard for that pollutant. Through a TMDL, pollutant loads can be distributed or allocated to point sources and nonpoint sources discharging to the waterbody. This report presents TMDLs that have been developed for dissolved oxygen (DO) and nutrients for Bayou Petit Caillou (Subsegment 120709) in the Terrebonne basin in southern Louisiana.

Subsegment 120709 (Bayou Petit Caillou) is located south of Houma in southern Louisiana near the Gulf of Mexico. This subsegment covers 28.4 square miles and the predominant land uses are open water (64.7%) and wetlands (33.1%). There are only two point source discharges in this subsegment, both of which are facilities involved in oil and gas exploration, production, and/or development.

Subsegment 120709 was cited as being impaired on the final 2004 303(d) list for Louisiana as not fully supporting the designated use of propagation of fish and wildlife. It was ranked as priority #2 for TMDL development. The cause for impairment cited in the 303(d) list was low DO. The DO criterion specified in the Louisiana water quality standards for this subsegment is 5 mg/L year-round. There are no numeric criteria for nutrients in Louisiana.

A water quality model (LA-QUAL) was set up to simulate DO, carbonaceous biochemical oxygen demand (CBOD), ammonia nitrogen, and organic nitrogen in Bayou Petit Caillou. The model was set up and calibrated using Louisiana Department of Environmental Quality routine monitoring data and various other information for widths, depths, flows, decay rates, etc.

The summer and winter projection simulations were run at critical temperatures to address seasonality as required by the Clean Water Act. A 57% reduction of existing nonpoint source loads was required for the summer projection simulation to show the DO criterion of 5 mg/L being maintained. No nonpoint source load reductions were necessary for the winter

projection. In general, the modeling in this study was consistent with guidance in the Louisiana TMDL Technical Procedures Manual.

A TMDL for oxygen-demanding substances (CBOD, ammonia nitrogen, organic nitrogen, and sediment oxygen demand) was calculated using the results of the summer and winter projection simulations. An implicit margin of safety (MOS) was established for the DO TMDL through the use of conservative assumptions in the water quality modeling. Additionally, 10% of the allowable loading was set aside as an explicit MOS and another 10% of the allowable loading was set aside for future growth (FG). Results of the DO TMDL calculations are summarized in Tables ES.1 and ES.2. The point source flows and concentrations used in the DO TMDL calculations are listed in Table ES.3.

A nutrient TMDL was developed for this subsegment using allowable nitrogen loads from the DO modeling and a naturally occurring ratio of total nitrogen to total phosphorus from reference waterbodies. No reductions of existing nutrient loads are needed because average concentrations of total nitrogen and total phosphorus were lower in Bayou Petit Caillou than in the reference waterbodies. Because no reductions are needed, the total allowable loading in Bayou Petit Caillou was included in the load allocation (LA). The nutrient TMDL included an explicit MOS equal to 10% of the TMDL and an explicit FG allowance equal to 10% of the TMDL. The nutrient TMDL is summarized in Table ES.4.

The DO TMDL establishes load limitations for oxygen-demanding substances and goals for reducing those pollutants. When oxygen-demanding substances are controlled and limited to ensure that the DO criterion is supported, nutrients are also controlled and limited. Implementing the DO TMDL through future wastewater discharge permits, if required, and implementing best management practices to control and reduce oxygen-demanding pollutants from nonpoint sources in the watershed will also control and reduce the nutrient loading from those sources.

Table ES.1. Summer DO TMDL for Subsegment 120709.

	Oxygen Demand (kg/day) from:					Oxygen Demand (lbs/day) from:					Percent Reduction Needed
	SOD	CBODu	Organic Nitrogen	Ammonia Nitrogen	Total	SOD	CBODu	Organic Nitrogen	Ammonia Nitrogen	Total	
Point Sources											
WLA	NA	0.05	0	0	0.05	NA	0.11	0	0	0.11	0%
MOS	NA	0.005	0	0	0.005	NA	0.011	0	0	0.011	NA
FG	NA	0.005	0	0	0.005	NA	0.011	0	0	0.011	NA
Nonpoint Sources											
LA	2559.19	12040.00	0.73	0.11	14600	5642.0	26543.6	1.61	0.24	32187.5	57%
MOS	319.90	1505.00	0.09	0.01	1825	705.3	3318.0	0.20	0.02	4023.5	NA
FG	319.90	1505.00	0.09	0.01	1825	705.3	3318.0	0.20	0.02	4023.5	NA
TMDL	3198.99	15050.00	0.91	0.13	18250	7052.6	33179.6	2.01	0.28	40234.5	NA

Table ES.2. Winter DO TMDL for Subsegment 120709.

	Oxygen Demand (kg/day) from:					Oxygen Demand (lbs/day) from:					Percent Reduction Needed
	SOD	CBODu	Organic Nitrogen	Ammonia Nitrogen	Total	SOD	CBODu	Organic Nitrogen	Ammonia Nitrogen	Total	
Point Sources											
WLA	NA	0.04	0	0	0.04	NA	0.11	0	0	0.09	0%
MOS	NA	0.005	0	0	0.005	NA	0.011	0	0	0.011	NA
FG	NA	0.005	0	0	0.005	NA	0.011	0	0	0.011	NA
Nonpoint Sources											
LA	3644.9	28000.00	0.73	0.11	31645.7	8035.6	61729.4	1.61	0.24	69766.9	0%
MOS	455.6	3500.00	0.09	0.01	3,955.7	1004.5	7716.2	0.20	0.02	8720.9	NA
FG	455.6	3500.00	0.09	0.01	3955.7	1004.5	7716.2	0.20	0.02	8720.9	NA
TMDL	4556.1	35000.05	0.91	0.13	39557.2	10044.5	77161.9	2.01	0.28	87208.7	NA

Table ES.3. Flow, concentrations, and loads for point source included in DO TMDL.

Subseg. Number	NPDES Number	Name of Discharger	Flow rate (gpd)	Concentrations			Loads*		
				BOD_5 or $CBOD_5$ (mg/L)	Ammonia Nitrogen (mg/L)	Organic Nitrogen (mg/L)	BOD_5 or $CBOD_5$ (lbs/day)	Ammonia Nitrogen (lbs/day)	Organic Nitrogen (lbs/day)
120709	LAG33A340	Burlington Resources	100	45	0	0	0.038	0	0
120709 Total Loads:							0.038	0	0

*Loads of organic nitrogen and ammonia nitrogen in this table represent loads of nitrogen, not oxygen demand.

Table ES.4. Nutrient TMDL for Subsegment 120709.

Component	Loads (kg/day)		Loads (lbs/day)	
	Total Nitrogen	Total Phosphorus	Total Nitrogen	Total Phosphorus
LA	0.279	0.025	0.615	0.054
WLA	0.000	0.000	0.000	0.000
MOS	0.035	0.003	0.077	0.007
FG	0.035	0.003	0.077	0.007
TMDL	0.349	0.031	0.769	0.068

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

TABLE OF CONTENTS (CONTINUED)

LIST OF APPENDICES

LIST OF TABLES

1.0 INTRODUCTION

This report presents total maximum daily loads (TMDLs) for dissolved oxygen (DO) and nutrients for the southern end of Bayou Petit Caillou, which is in Subsegment 120709. This subsegment was included on the final 2004 303(d) list for Louisiana (Louisiana Department of Environmental Quality (LDEQ) 2005) as not fully supporting the designated use of propagation of fish and wildlife. The priority ranking and the suspected sources and suspected causes for impairment from the 303(d) list are presented in Table 1.1. The TMDLs in this report were developed in accordance with Section 303(d) of the Federal Clean Water Act and United States Environmental Protection Agency (USEPA) regulations at 40 CFR 130.7.

The purpose of a TMDL is to determine the pollutant loading that a waterbody can assimilate without exceeding the water quality standard for that pollutant and to establish the load reduction that is necessary to meet the standard in a waterbody. The TMDL is the sum of the wasteload allocation (WLA), the load allocation (LA), and a margin of safety (MOS). The WLA is the load allocated to point sources of the pollutant of concern, and the LA is the load allocated to nonpoint sources (NPS). The MOS is a percentage of the TMDL that accounts for the uncertainty associated with the model assumptions, data inadequacies, and future growth.

Table 1.1. Summary of 303(d) listing for Subsegment 120709.

Subsegment Number	**Waterbody Description**	**Suspected Causes**	**Suspected Sources**	**Priority Ranking (1 = highest)**
120709	Bayou Petit Caillou – from Houma Navigation Canal to Terrebonne Bay	Low DO	Unknown source	2

2.0 STUDY AREA DESCRIPTION

2.1 General Information

Bayou Petit Caillou (Subsegment 120709) is located in southern Louisiana in the lower Terrebonne basin (see Figure A.1 in Appendix A). The confluence of Bayou Petit Caillou and the Houma Navigation Canal is located in the northeastern corner of the subsegment, and Bayou Petit Caillou flows south through the eastern side of the subsegment.

Bayou Petit Caillou is a distributary of Bayou Terrebonne, branching off 4 miles southeast of Houma and flowing 35 miles south to the Gulf of Mexico. Subsegment 120709 is located towards the southern end of Bayou Petit Caillou and covers 28.4 square miles in southeastern Terrebonne Parish.

2.2 Land Use

Land use characteristics for Subsegment 120709 were compiled from the United States Geological Survey (USGS) 2001 National Land Cover Database (USGS 2006). These data are the most recent land use data that are currently available for this area. The spatial distribution of these land uses is shown on Figure A.2 (located in Appendix A) and land use percentages are shown in Table 2.1. Almost all the subsegment is either water or wetlands.

Table 2.1. Land uses percentages for Subsegment 120709.

Land Use Type	Percent of Total Area
Water	64.7%
Urban/Transportation	0.0%
Barren	2.2%
Forest	0.0%
Shrubland/Grassland	0.0%
Pasture/Hay	0.0%
Row Crops	0.0%
Small Grains	0.0%
Wetlands	33.1%
TOTAL	100.0%

2.3 Water Quality Standards

Water quality standards for Louisiana are included in the Title 33 Environmental Regulatory Code (LDEQ 2007). The designated uses for Subsegment 120709 are primary contact recreation, secondary contact recreation, propagation of fish and wildlife, and oyster propagation. The primary numeric criteria for the TMDLs presented in this report are the DO criterion of 5 mg/L (year-round) and the temperature criterion of 32°C.

The Title 33 Environmental Regulatory Code does not include numeric criteria for nutrients, but it does include the following narrative criteria for nutrients (LAC 33: IX.1113.B.8):

> “The naturally occurring range of nitrogen-phosphorous ratios shall be maintained. This range shall not apply to designated intermittent streams. To establish the appropriate range of ratios and compensate for natural seasonal fluctuations, the administrative authority will use site-specific studies to establish limits for nutrients. Nutrient concentrations that produce aquatic growth to the extent that it creates a public nuisance or interferes with designated water uses shall not be added to any surface waters.”

The Louisiana water quality standards also include an anti-degradation policy (LAC 33:IX.1109.A). This policy states that waters exhibiting high water quality should be maintained at that high level of water quality. If this is not possible, water quality of a level that supports designated uses of the waterbody should be maintained. Changing the designated uses of a waterbody to allow a lower level of water quality can only be achieved through a use attainability study.

2.4 Point Sources

A list of point sources in selected portions of the Terrebonne basin was developed using data from LDEQ's internal point source databases with additional information obtained from LDEQ’s Electronic Document Management System (EDMS). Using this information, two point sources were identified within Subsegment 120709 (see Table 2.2). Both of these point sources are facilities involved in oil and gas exploration, production, and/or development. A review of permits, applications, and discharge monitoring reports (DMRs) indicated that only the Burlington Resources facility is actually discharging sanitary wastewater. The Burlington Resources discharge was therefore included in the TMDLs, but it was not included in the water quality model due to its very small flow rate (estimated to be 100 gallons per day (gpd)). The Rapiere Resources discharge was not included in the water quality model or in the TMDLs because it does not appear to be discharging effluent with an oxygen demand.

Table 2.2. Point sources for Subsegment 120709.

Permit	Facility	Facility Type	Discharge Type	Included in Model?	Included in TMDL?
LAG33A433 (AI = 91773)	Rapiere Resources Company – Bay St. Elaine Field Production Facility	Oil/Gas Exploration, Production, & Development	Rainwater	No	No
LAG33A340 (AI = 33002)	Burlington Resources – Bay St. Elaine Field Production Facility	Oil/Gas Exploration, Production, & Development	Sanitary Wastewater	No	Yes

2.5 Nonpoint Sources

The 303(d) list did not cite any specific nonpoint sources as suspected sources of the DO impairment for Subsegment 120709 (Table 1.1).

Individual nonpoint sources are not identified and quantified here because this TMDL focuses on total nonpoint source loading. Individual sources should be identified and quantified by state or local agencies if they develop an implementation plan.

2.6 Historical Data Summary

The only LDEQ routine water quality monitoring station in Subsegment 120709 is Station 956 (Bayou Petit Caillou at Tambour Bay, Louisiana). Data from this station are summarized for selected parameters in Table 2.3. Data from three other LDEQ stations were also used for boundary conditions in the model; these stations are Station 949 (Bayou Petit Caillou near Cocodrie), Station 952 (Houma Navigation Canal north of Bayou Petit Caillou), and Station 961 (Lake Pelto south of Cocodrie). A tabular listing of the data for all four of these LDEQ stations is shown in Tables B.1 through B.4 in Appendix B. Their locations are shown in Figure A.1 in Appendix A. All four stations have only 2 years of data (2000 and 2005).

Table 2.3 Water quality data for LDEQ Station 956.

Parameter	No. of Values	Min. (mg/L)	Median (mg/L)	Average (mg/L)	Max. (mg/L)	Number of Exceedances	Percent of Exceedances
DO	23	3.66	6.05	6.41	10.35	5	21.7%
TOC	23	3.4	7.4	7.86	12.8	NA	NA
Total Phosphorus	23	0.08	0.13	0.13	0.23	NA	NA
TKN	23	0.33	0.85	0.95	2.92	NA	NA
NH_3-N	20	<0.10	0.12	0.12	0.17	NA	NA
NO_2+NO_3-N	19	0.04	0.09	0.11	0.26	NA	NA

2.7 Previous Studies

No previous studies were identified for Subsegment 120709.

3.0 CALIBRATION OF WATER QUALITY MODEL

3.1 Model Setup

In order to evaluate the linkage between pollutant sources and water quality, a computer simulation model was used. The model used for these TMDLs was version 8.11 of LA-QUAL (Wiland and LeBlanc 2007), which was selected because it includes the relevant physical, chemical, and biological processes and it has been used successfully in the past for other TMDLs in Louisiana. The LA-QUAL model was set up to simulate organic nitrogen, ammonia nitrogen, ultimate carbonaceous biochemical oxygen demand (CBODu), DO, salinity, and specific conductivity. The reason for simulating salinity and specific conductivity was to calibrate the dispersion and to allow the model to adjust DO saturation concentrations based on salinity.

Bayou Petit Caillou was divided into three reaches to represent varying depths and widths along the length of the subsegment. All three reaches were divided into smaller elements to take into account variations in water quality along their length. A diagram of the model layout is shown in Appendix C.

3.2 Calibration Period and Calibration Targets

The two conditions that usually characterize critical periods for DO are high temperatures and low flows. High temperatures decrease DO saturation values and increase rates for oxygen demanding processes (BOD decay, nitrification, and sediment oxygen demand (SOD)). In most systems, low flows cause reaeration rates to be lower. The purpose of selecting a critical period for calibration is so that the model will be calibrated as accurately as possible for making projection simulations for critical conditions.

Routine water quality monitoring data have been conducted at one LDEQ sampling station in this subsegment (Station 956) in 2000 and 2005 (summarized in Table B.3). Several consecutive low DO values occurred between July 11, 2000, to September 5, 2000. This period was chosen as the calibration period. The calibration target (i.e., the concentration to which the model was calibrated) for each parameter was set equal to an average of concentrations measured by LDEQ during this time period. Organic nitrogen was estimated as the TKN concentration minus the ammonia nitrogen concentration. CBODu was estimated from total organic carbon (TOC) by multiplying the TOC by a CBODu to TOC ratio. The data used to compute this ratio are shown in Appendix D.

3.3 Temperature Correction of Kinetics (Data Type 4)

The temperature correction factors used in the model were consistent with the Louisiana Technical Procedures Manual (LTP; LDEQ 2006). These correction factors were:

Correction for BOD decay:	1.047 (value in LTP is same as model default)
Correction for SOD:	1.065 (value in LTP is same as model default)
Correction for ammonia N decay:	1.070 (specified in Data Group 4)
Correction for organic N decay:	1.020 (not specified in LTP; model default used)
Correction for reaeration:	automatically calculated by the model

3.4 Hydraulics and Dispersion (Data Types 9 and 10)

The hydraulics were specified in the input for the LA-QUAL model using the power functions (width = $a * Q^b + c$ and depth = $d * Q^e + f$). The average width for each reach was estimated by setting “boundaries” to form the east and west sides of the simulated waterbody and then calculating the surface area of each reach and dividing by the length of each reach. These boundaries are shown on the LA-QUAL vector diagram in Appendix C. Depths were estimated from bathymetric contours for surrounding areas on 1:100,000 topographic maps. Widths and depths were entered as constants (i.e., independent of flow) because water levels in this subsegment are controlled by tides rather than by flow rates.

A dispersion coefficient of 18 m^2/sec was input for all three reaches. This value was adjusted during calibration to provide an acceptable match between predicted and observed values of salinity and specific conductivity at LDEQ Station 956. The hydraulics input data and sources are shown in Tables E.1 and E.2 in Appendix E.

3.5 Initial Conditions (Data Type 11)

Because temperature is not being simulated in the model, the temperature for the reach was specified in the initial conditions for LA-QUAL. The temperature for all reaches was set to

30.8°C, which was the average of temperatures measured at the LDEQ Station 956 during the calibration period. The same method was used to determine the initial DO and ammonia concentrations. The input data and sources for the initial conditions are shown in Table E.3 in Appendix E.

For constituents not being simulated, the initial concentrations were set to zero. Otherwise the model would have assumed a fixed concentration of those constituents and the model would have included effects of the unmodeled constituents on the modeled constituents.

3.6 Water Quality Kinetics (Data Types 12 and 13)

Kinetic rates used in LA-QUAL include reaeration rates, CBOD decay rates, nitrification rates, and mineralization rates (organic nitrogen decay). The kinetic rates used in the model input are shown in Table E.4 in Appendix E.

For reaeration, the Louisiana Equation (option 15) was specified in the model because it was developed specifically for waterbodies in Louisiana and it has been used successfully in the past for other TMDLs in Louisiana. Although the advective velocity in this subsegment is lower than streams for which the Louisiana Equation was developed, this equation will still maintain a minimum reaeration that is equivalent to using a surface transfer coefficient of 0.664 m/day.

The CBOD decay and nitrification rates were set equal to the medians of 144 laboratory decay rates for various subsegments in the lower Terrebonne basin. These decay rates were from field surveys completed by LDEQ and are shown in Table D.1 in Appendix D.

The mineralization rate (organic nitrogen decay) in the model was set equal to 0.02/day for all reaches. This value was similar to the values shown in Table 5.3 of the “Rates, Constants, and Kinetics” publication (USEPA 1985) for dissolved organic nitrogen being transformed to ammonia nitrogen. The literature values for mineralization rates are shown in Appendix F.

3.7 Nonpoint Source Loads (Data Type 19)

The nonpoint source loads that are specified in the model can be most easily understood as resuspended loads from the bottom sediments, and are modeled as SOD, benthic ammonia source rates, CBOD loads, and organic nitrogen loads. The SOD (specified in Data Type 12), the benthic ammonia source rates (specified in Data Type 13), and the mass loads of organic nitrogen and CBODu (specified in Data Type 19) were all treated as calibration parameters; their values were adjusted until the model output was similar to the calibration target values. The nonpoint source load values used as model input are shown in Table E.5 in Appendix E.

3.8 Headwater Flow Rate (Data Type 20)

A headwater flow rate was specified for the model. Inflow to Subsegment 120709 was estimated from flows reported at USGS Gage 07381328 (Houma Navigation Canal at Dulac, Louisiana). Flow data was not available for this gage during the calibration period. The minimum flow reported for the period July through September was used based on the fact that estimated runoff for the Terrebonne basin during July through September 2000 was significantly lower than the estimated runoff during July through September 2003. This flow was split at the junction between Houma Navigation Canal and Bayou Grand Caillou and at the junction between Houma Navigation Canal and Bayou Petit Caillou. At the junction with Grand Caillou, half the flow was assumed to stay in the Houma Navigation Canal. The flow entering Subsegment 120709 at the junction between Houma Navigation Canal and Bayou Petit Caillou was assumed to be equivalent to one-third of the remaining Houma Navigation Canal flow. These calculations are included at the end of Appendix E.

3.9 Headwater Water Quality (Data Types 20, 21, and 22)

Concentrations of conductivity, salinity, DO, CBODu, organic nitrogen, nitrate+nitrite nitrogen, and ammonia nitrogen were specified in the model for the headwater flow. Water quality for the headwater was set to the average of the concentrations measured between July 11 and September 5, 2000, at LDEQ Station 952 (Houma Navigation Canal north of Bayou Petit Caillou). This station was chosen since some (if not most) of the inflow into Bayou Petit Caillou just north of Subsegment 120709 comes from the Houma Navigation Canal. In addition, this station is relatively close to Bayou Petit Caillou, and the data at this station are similar to the data for Bayou Petit Caillou at Station 949 (upstream, or northeast, of Subsegment 120709).

Since LDEQ does not measure CBOD for its routine surveys, CBODu had to be estimated. CBODu was estimated from the TOC by multiplying the TOC by a TOC to CBODu ratio. The ratio chosen was the median ratio for 144 values in the southern Terrebonne basin (the same way the decay rates were chosen). The values used as model input are shown in Table E.6 in Appendix E and the CBODu and TOC data are shown in Table D.1 in Appendix D.

3.10 Lower Boundary Conditions

Because Subsegment 120709 is tidally influenced and dispersion was specified in the model, lower boundary conditions had to be included in the model. Data from LDEQ Station 961 (Lake Pelto south of Cocodrie) were used to provide the inputs for lower boundary conditions. Station 961 was the closest LDEQ station to the downstream end of Subsegment 120709. Each input was the average of the three values measured at the station during the calibration period (July 11 to September 5, 2000). The CBODu was estimated from the TOC using the same method used for the headwater CBODu (see Section 3.9). The lower boundary inputs are shown in Table E.7 in Appendix E.

3.11 Model Results for Calibration

Plots of predicted and observed water quality for the calibration are presented in Appendix G and a printout of the LA-QUAL output file is included as Appendix H. The calibration was considered to be acceptable based on the amount of data that were available.

4.0 WATER QUALITY MODEL PROJECTION

USEPA's regulations at 40 CFR 130.7 require the determination of TMDLs to take into account critical conditions for stream flow, loading, and water quality parameters. Therefore, the calibrated model was used to project water quality for critical conditions. The identification of critical conditions and the model input data used for critical conditions are discussed below.

4.1 Identification of Critical Conditions

Section 303(d) of the Federal Clean Water Act and USEPA's regulations at 40 CFR 130.7 both require the consideration of seasonal variation of conditions affecting the constituent of concern and the inclusion of an MOS in the development of a TMDL. For the TMDL in this report, analyses of LDEQ long-term ambient data were used to determine critical seasonal conditions. Both an implicit MOS and an explicit MOS were used in developing the projection simulations.

Critical conditions for DO have been determined for Louisiana waterbodies in previous TMDL studies. The analyses concluded that the critical conditions for stream DO concentrations occur during periods with negligible nonpoint runoff, low stream flow, and high water temperature. For coastal waterbodies, though, critical conditions for DO tend to be correlated more closely to high water temperature than to flow rates during the critical periods. High temperatures cause DO saturation values to be lower and SOD, CBOD decay, and nitrification to be higher. High flow rates usually generate more reaeration in streams (due to increased velocity and turbulence), but changes in flow rates for coastal waters normally have little or no effect on reaeration because the advective velocities are very small. Periods of high nonpoint loading to Louisiana waterbodies tend to be cooler periods of the year because rainfall during summer usually creates less runoff due to evapotranspiration in the watershed. Therefore, periods of high nonpoint loading do not necessarily coincide with critical periods for DO.

LDEQ interprets this phenomenon in its 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 waterbody, which is, in turn, expressed as SOD and/or re-suspended BOD in the model. This accumulated loading has its greatest impact on the waterbody during periods of higher temperature.

The projection simulations were run with the headwater flow rates set to the LTP default flows of 0.1 cfs (0.003 m^3/sec) for summer and 1.0 cfs (0.03 m^3/sec) for winter. These default values were used because DO values in coastal waterbodies typically are not correlated to flow rates, and because no data were available to calculate a critical flow. Temperatures in the projection simulations were set to 90th percentile seasonal temperatures in order to be conservative and to be consistent with the LTP.

The impact of various conservative assumptions regarding rates and loadings yields an implicit MOS that is not quantified. Over and above this implicit MOS, an explicit MOS of 10% was incorporated into the DO TMDL in this report to account for model uncertainty.

4.2 Temperature Inputs

The LTP (LDEQ 2006) specified that the critical temperature should be determined by calculating the 90th percentile seasonal temperature for the waterbody being modeled. The LDEQ water quality monitoring station on Bayou Petit Caillou is not a long-term station, so there was not enough data to estimate 90th percentile seasonal temperatures. There is an LDEQ station on nearby Lake Palourde with a long term temperature record (Station 0338). Therefore, data from Lake Palourde were used to estimate 90th percentile temperatures for Bayou Petit Caillou. The long-term water temperature data collected by LDEQ at Station 0338 on Lake Palourde are summarized in Table I.2 in Appendix I. Calculations for 90th percentile temperatures were developed for this station for each season (summer and winter). These calculations are shown in Table I.2. These calculations resulted in 90th percentile temperatures of 30.7°C for summer and 22.6°C for winter (see Table I.2). These temperatures were adjusted based on differences between seasonal average temperatures taken at Bayou Petit Caillou (Station 0956) and Lake Palourde (Station 0338) during their overlapping periods of record (2000 and 2005). These calculations are shown in Table I.1 in Appendix I. The 90th percentile temperatures used as model inputs for the projection simulations were 30.6°C for summer and 22.8°C for winter. These values were specified in Data Type 11.

4.3 Headwater Inputs

The inputs for the headwater for the projection simulation were based on guidance in the LTP. As specified in the LTP, the DO concentrations for the headwater inflows were set to 90% saturation at the seasonal critical temperatures. Headwater concentrations for other parameters were set to calibration values. The headwater inflows were set to the default values specified in the LTP: 0.1 cfs for the summer projection, and 1.0 cfs for the winter projection.

4.4 Point Source Inputs

As mentioned in Section 2.4, no point source discharges were included in the model.

4.5 Nonpoint Source Loads

Because the initial projection simulations were showing DO values below the 5.0 mg/L criterion, the nonpoint source loadings were reduced until all of the predicted DO values were equal to or greater than the water quality criterion of 5.0 mg/L. The same percent reduction was applied to the SOD and nonpoint mass loads of CBODu and organic nitrogen.

4.6 Other Inputs

The only model inputs that were changed from the calibration to the projection simulation were the inputs discussed above in Sections 4.2 through 4.5. Other model inputs (e.g., hydraulic coefficients, decay rates, reaeration equations, etc.) were unchanged from the calibration simulation.

4.7 Model Results for Projections

Plots of predicted water quality for the projections are presented in Appendix J and printouts of the LA-QUAL output files are included as Appendix K.

Oxygen demanding load reductions were required to meet the DO standard. A nonpoint source load reduction of approximately 57% was required to bring the predicted DO values up to at least 5.0 mg/L for the summer projection. No load reductions were necessary for the winter projection.

These percent reductions for nonpoint source loads represent percentages of the entire nonpoint source loading, not percentages of the manmade nonpoint source loading. The nonpoint source loads in this report were not divided between natural and manmade because it would be difficult to estimate natural nonpoint source loads for the study area.

5.0 DO TMDL DEVELOPMENT

5.1 TMDL Calculations

A TMDL for DO was calculated for Subsegment 120709 using the results of the summer and winter projection simulations. The DO TMDL is presented as oxygen demand from CBODu, organic nitrogen, ammonia nitrogen, and SOD. Summaries of the TMDL are presented in Tables 5.1 and 5.2.

The TMDL calculations were performed using a FORTRAN program that was written by FTN personnel. This program reads two files; one is the LA-QUAL output file from the projection simulation and the other is a small input file with miscellaneous information needed for the TMDL calculations (shown in Appendix L). The output files from the program are also shown in Appendix L for the summer and winter projections. The source code for the program is shown in Appendix M. A one-page summary of the methodology for the TMDL calculations is included at the beginning of Appendix M.

The oxygen demand from organic nitrogen and ammonia nitrogen was calculated as 4.33 times the nitrogen loads (assuming that all organic nitrogen is eventually converted to ammonia). The value of 4.33 is the same ratio of oxygen demand to nitrogen that is used by the LA-QUAL model. For the SOD loads, a temperature correction factor was included in the calculations (in order to be consistent with LDEQ procedures).

5.2 Point Source Loads

The WLA for point sources for each season was calculated as the load from the Burlington Resources facility. The estimated flow from this facility was multiplied by 1.25 before the loads were calculated so that 20% of the resulting loads could be reserved for the MOS and FG. These loads were calculated using the FORTRAN program described above. Table 5.3 lists the flow, concentrations, and loads for the point source discharge that was included in the DO TMDL.

Table 5.1. Summer DO TMDL for Subsegment 120709.

	Oxygen Demand (kg/day) from:					Oxygen Demand (lbs/day) from:					Percent Reduction Needed
	SOD	CBODu	Organic Nitrogen	Ammonia Nitrogen	Total	SOD	CBODu	Organic Nitrogen	Ammonia Nitrogen	Total	
Point Sources											
WLA	NA	0.05	0	0	0.05	NA	0.11	0	0	0.11	0%
MOS	NA	0.005	0	0	0.005	NA	0.011	0	0	0.011	NA
FG	NA	0.005	0	0	0.005	NA	0.011	0	0	0.011	NA
Nonpoint Sources											
LA	2559.19	12040.00	0.73	0.11	14600	5642.0	26543.6	1.61	0.24	32187.5	57%
MOS	319.90	1505.00	0.09	0.01	1825	705.3	3318.0	0.20	0.02	4023.5	NA
FG	319.90	1505.00	0.09	0.01	1825	705.3	3318.0	0.20	0.02	4023.5	NA
TMDL	3198.99	15050.00	0.91	0.13	18250	7052.6	33179.6	2.01	0.28	40234.5	NA

Table 5.2. Winter DO TMDL for Subsegment 120709.

	Oxygen Demand (kg/day) from:					Oxygen Demand (lbs/day) from:					Percent Reduction Needed
	SOD	CBODu	Organic Nitrogen	Ammonia Nitrogen	Total	SOD	CBODu	Organic Nitrogen	Ammonia Nitrogen	Total	
Point Sources											
WLA	NA	0.04	0	0	0.04	NA	0.11	0	0	0.09	0%
MOS	NA	0.005	0	0	0.005	NA	0.011	0	0	0.011	NA
FG	NA	0.005	0	0	0.005	NA	0.011	0	0	0.011	NA
Nonpoint Sources											
LA	3644.9	28000.00	0.73	0.11	31645.7	8035.6	61729.4	1.61	0.24	69766.9	0%
MOS	455.6	3500.00	0.09	0.01	3,955.7	1004.5	7716.2	0.20	0.02	8720.9	NA
FG	455.6	3500.00	0.09	0.01	3955.7	1004.5	7716.2	0.20	0.02	8720.9	NA
TMDL	4556.1	35000.05	0.91	0.13	39557.2	10044.5	77161.9	2.01	0.28	87208.7	NA

Table 5.3. Flow, concentrations, and loads for point source included in DO TMDL.

Subseg. Number	NPDES Number	Name of Discharger	Flow rate (gpd)	Concentrations			Loads*		
				BOD_5 or $CBOD_5$ (mg/L)	Ammonia Nitrogen (mg/L)	Organic Nitrogen (mg/L)	BOD_5 or $CBOD_5$ (lbs/day)	Ammonia Nitrogen (lbs/day)	Organic Nitrogen (lbs/day)
120709	LAG33A340	Burlington Resources	100	45	0	0	0.038	0	0
120709 Total Loads:							0.038	0	0

*Loads of organic nitrogen and ammonia nitrogen in this table represent loads of nitrogen, not oxygen demand.

The non-conservative behavior of DO allows many small, remote point source discharges to be assimilated by the receiving waterbodies before they reach the modeled waterbody. These discharges are said to have little to no impact on the modeled waterbody. Therefore, they are not included in the model and are not subject to any reductions based on this TMDL. These facilities are permitted in accordance with state regulations and policies that provide adequate protective controls. New, similarly insignificant point sources will continue to be issued permits in this manner. Significant existing point source discharges are either included in the model or are determined to be insignificant by other modeling. New significant point source discharges would have to be evaluated individually to determine what impact they have on the impaired waterbody and the appropriate controls.

5.3 MOS and FG

The MOS accounts for any lack of knowledge or uncertainty concerning the relationship between pollutant loading and water quality. The model projections were run with the 90th percentile seasonal water temperatures (conservative values), and the calibration targets were set to the lowest DO values from the routine monitoring. These modeling procedures yield an implicit MOS, which is not quantified. In addition to the implicit MOS, the DO TMDL in this report includes an explicit MOS equal to 10% of the TMDL and an explicit allowance for FG that is also equal to 10% of the TMDL.

5.4 Seasonal Variation

As discussed in Section 4.1, critical conditions for DO in Louisiana waterbodies have been determined to be when there is negligible nonpoint runoff and low stream flow combined with high water temperatures. In addition, the model accounts for loadings that occur at higher flows by modeling SOD. Oxygen-demanding pollutants that enter the waterbodies during higher flows settle to the bottom and then exert the greatest oxygen demand during the high temperature seasons.

5.5 Ammonia Toxicity Calculations

Although Subsegment 120709 is not on a 303(d) list for ammonia, the ammonia concentrations predicted in the projection simulations were checked to make sure that they did not exceed USEPA criteria for ammonia toxicity (USEPA 1999). The USEPA criteria are dependent on temperature and pH. The water temperatures used to calculate the ammonia toxicity criteria for summer and winter for Subsegment 120709 were the same as the critical temperatures used in the projection simulations. Average pH values for each season were calculated from routine monitoring data at LDEQ Station 956. The resulting criteria for ammonia nitrogen were 1.68 mg/L for summer and 3.07 mg/L for winter. The ammonia nitrogen concentrations predicted by the LA-QUAL model were well below these criteria. This indicates that the ammonia nitrogen loadings that will maintain the DO standard are low enough that the USEPA ammonia toxicity criteria will not be exceeded under critical conditions. The ammonia toxicity calculations are shown in Appendix N.

6.0 NUTRIENT TMDL DEVELOPMENT

6.1 Seasonality and Critical Conditions

USEPA's regulations at 40 CFR 130.7 require the determination of TMDLs to take into account critical conditions for stream flow, loading, and water quality parameters. Also, both Section 303(d) of the Clean Water Act and regulations at 40 CFR 130.7 require TMDLs to consider seasonal variations for meeting water quality standards. Aquatic life impairments typically occur as a result of long term exposure to elevated nutrient concentrations rather than short-term fluctuations in nutrient concentrations. This nutrient TMDL was developed for average annual conditions. The most obvious result of nutrients is algal blooms. When the algae die, the resultant biological oxygen demand consumes oxygen, which adversely affects aquatic life. The effect occurs in a short time but the build-up of nutrients and the conditions to start the algal bloom may occur over an extended time.

6.2 Comparison with Reference Stream Data

Since there are no numeric nutrient criteria for Louisiana, the need for nutrient reductions in Bayou Petit Caillou was evaluated by comparing total nitrogen (TKN+NO_2+NO_3) and total phosphorus concentrations in Bayou Petit Caillou with values from least disturbed reference sites. Five references sites in the lower Terrebonne basin were identified and sampled as part of study conducted under contract to USEPA Region 6 by the Cadmus Group, Inc., and ARCADIS U.S., Inc., along with other team members (Cadmus Group 2007). Each site was sampled four times during 2005 through 2006. These data are shown in Appendix O. Overall average concentrations of total nitrogen (TKN plus nitrate+nitrite) and total phosphorus for the reference sites were calculated to be 0.15 mg/L total phosphorus and 1.70 mg/L total nitrogen. Using LDEQ routine monitoring data at station 956 (Bayou Petit Caillou at Tambour Bay), the average concentrations in Bayou Petit Caillou were calculated to be 0.13 mg/L of total phosphorus (see Table 2.3) and 1.06 mg/L of total nitrogen (0.95 mg/L TKN + 0.11 mg/L NO_2+NO_3; see Table 2.3). Because the Bayou Petit Caillou average nutrient concentrations are lower than the reference site average concentrations, no nutrient reductions are needed for Bayou Petit Caillou.

6.3 Calculations for TMDL Components

The TMDL for total phosphorus and total nitrogen for Subsegment 120709 was calculated based on allowable loads of nitrogen from the DO modeling and a naturally occurring ratio of total nitrogen to total phosphorus. The naturally occurring ratio of total nitrogen to total phosphorus was used because the Louisiana Water Quality Standards require that ratio to be maintained in streams and lakes (see Section 2.3). The naturally occurring ratio of total nitrogen to total phosphorus was calculated to be 11.3 using the mean values of total nitrogen and total phosphorus from the reference streams in Appendix O (1.70 mg/L and 0.15 mg/L). The allowable loads of total nitrogen were calculated as the simulated loads of organic nitrogen and ammonia nitrogen in the projection simulations plus assumed values of nitrate+nitrite nitrogen. The allowable loads of total phosphorus were then calculated as simply the allowable loads of total nitrogen divided by 11.3 (the naturally occurring ratio of total nitrogen to total phosphorus). The MOS and FG components for this nutrient TMDL were calculated as 10% each (or 20% combined) of the total loading after including the MOS and FG. The details of these calculations are shown in Appendix O and the results are summarized in Table 6.1.

Because no reductions to nutrients were required, the WLA was set to zero and all of the loading was included in the LA. It is assumed that the point sources may continue to discharge at their current concentration level of nutrients and not make any deleterious effect on water quality. Any increase in effluent concentrations could require additional monitoring and modeling and a revision to this TMDL.

Table 6.1. Nutrient TMDL for Subsegment 120709.

Component	Loads (kg/day)		Loads (lbs/day)	
	Total Nitrogen	Total Phosphorus	Total Nitrogen	Total Phosphorus
LA	0.279	0.025	0.615	0.054
WLA	0.000	0.000	0.000	0.000
MOS	0.035	0.003	0.077	0.007
FG	0.035	0.003	0.077	0.007
TMDL	0.349	0.031	0.769	0.068

6.4 Summary of Load Reductions

The analysis outlined in Section 6.2 above indicated that no reduction of nutrient loads is necessary.

The DO TMDL (see Section 5) establishes load limitations for oxygen-demanding substances and goals for reducing those pollutants. When oxygen-demanding substances are controlled and limited to ensure that the DO criterion is supported, nutrients are also controlled and limited. Implementing the DO TMDL through future wastewater permits, if required, and implementing best management practices to control and reduce oxygen-demanding pollutants from nonpoint sources in the watershed will also control and reduce the nutrient loading from those sources.

7.0 SENSITIVITY ANALYSES

All modeling studies necessarily involve uncertainty and some degree of approximation. 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 sensitivity analyses were performed by allowing the LA-QUAL model to vary one input parameter at a time while holding all other parameters to their original value. The calibration simulation was used as the baseline for the sensitivity analysis. The percent change of the model’s minimum DO projections to each parameter is presented in Table 7.1. Each parameter was varied by ±30%, except for temperature, which were varied ±2ºC.

Values reported in Table 7.1 are sorted by percentage variation of minimum DO from smallest percentage variation to largest. Reaeration, depth, and SOD (benthal demand) were the parameters to which DO was most sensitive.

Table 7.1. Summary of results of sensitivity analyses.

Input Parameter	Parameter Change	Predicted Minimum DO (mg/L)	Percent Change in Predicted DO (%)
Baseline	--	3.59	N/A
Reaeration	-30%	1.95	-45.6
SOD	+30%	2.46	-31.4
Velocity	-30%	2.56	-28.6
Reaeration	+30%	4.54	+26.6
Depth	+30%	2.73	-23.9
Depth	-30%	4.40	+22.5
Headwater flow	-30%	2.95	-17.7
Initial temperature	+2EC	2.96	-17.5
Initial temperature	-2EC	4.20	+17.0
SOD	-30%	4.14	+15.5
Headwater flow	+30%	3.92	+9.1
Velocity	+30%	3.69	+2.7
Wasteload flow	-30%	3.50	-2.5
Wasteload flow	+30%	3.67	+2.3
BOD decay rate	-30%	3.65	+1.7
BOD decay rate	+30%	3.54	-1.4
Wasteload BOD	+30%	3.58	-0.3
Wasteload BOD	-30%	3.60	+0.3
NH3 decay rate	-30%	3.59	0
Organic N decay rate	+30%	3.59	0
Organic N decay rate	-30%	3.59	0
Wasteload NH3	+30%	3.59	0
Wasteload NH3	-30%	3.59	0
NH3 decay rate	+30%	3.59	0
Wasteload DO	+30%	3.59	0
Wasteload DO	-30%	3.59	0
Wasteload Organic N	+30%	3.59	0
Wasteload Organic N	-30%	3.59	0

8.0 OTHER RELEVANT INFORMATION

This TMDL has been developed to be consistent with the state anti-degradation policy (LAC 33:IX.1109.A).

This TMDL report does not include an implementation plan. Implementation plans are not required for TMDLs under current federal regulations. Implementation plans can be developed most effectively and efficiently on the state and local level.

LDEQ will work with other agencies such as local Soil Conservation Districts to implement nonpoint source best management practices in the watershed through the Section 319 programs. LDEQ will also continue to monitor the waters to determine whether standards are being attained.

In accordance with Section 106 of the Federal Clean Water Act, and under the authority of the Louisiana Environmental Quality Act, LDEQ has established a comprehensive program for monitoring the quality of the state's surface waters. The LDEQ Surveillance Section collects surface water samples at various locations, utilizing appropriate sampling methods and procedures for ensuring the quality of the data collected. The objectives of the surface water monitoring program are to determine the quality of the state's surface waters, to develop a long-term data base for water quality trend analysis, and to monitor the effectiveness of pollution controls. The data obtained through the surface water monitoring program is used to develop the state's biennial 305(b) report (Water Quality Inventory) and the 303(d) list of impaired waters. This information is also utilized in establishing priorities for the LDEQ nonpoint source program.

LDEQ has implemented a watershed approach to surface water quality monitoring. Through this approach, the entire state is sampled over a 4-year cycle. Long-term trend monitoring sites at various locations on the larger rivers and Lake Pontchartrain are sampled throughout the 4-year cycle. Sampling is conducted on a monthly basis to yield approximately 12 samples per site each year the site is monitored. Sampling sites are located where they are considered to be representative of the waterbody. Under the current monitoring schedule, approximately one half of the state's waters are newly assessed for each 305(b) and 303(d) listing biennial cycle, with sampling occurring statewide each year. The 4-year cycle follows an initial 5-year rotation that covered all basins in the state according to the TMDL priorities. This will allow 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.

USEPA Region 6 has funded a use attainability assessment (UAA) study for the development of site-specific DO criteria for Terrebonne basin, Louisiana. On January 31, 2008, the contractor (Tetra Tech, Inc.) submitted a draft report for USEPA's review. In addition, the state is involved in analyzing available data for the Barataria and Terrebonne basin waters to evaluate and possibly revise the existing dissolved oxygen criterion.

Once LDEQ adopts and USEPA approves the revised DO criteria, LDEQ will reassess the 303(d) listed subsegments for DO and nutrients in the Terrebonne basin. If the reassessment of a subsegment indicates a subsegment is not impaired on the basis of revised criteria, if appropriate, the DO and nutrients TMDLs may be withdrawn, and USEPA will publish a public notice. If the reassessment of a subsegment indicates that the subsegment is impaired on the basis of the revised criteria, if appropriate, the DO and nutrients TMDLs may be revised, and USEPA will publish a public notice.

Hurricane Katrina made landfall on Monday, August 29, 2005, as a Category 4 hurricane. The storm brought heavy winds and rain to southeast Louisiana, breaching several levees and flooding up to 80% of New Orleans and large areas of coastal Louisiana. Both Hurricanes Katrina and Rita have caused a significant amount of change in sedimentation and water quality in southern Louisiana. Many wastewater treatment facilities were temporarily or permanently damaged. Some wastewater treatment facilities will be rebuilt; others will be relocated. Several federal and state agencies, including USEPA and LDEQ, are engaged in collecting environmental data and assessing the recovery of the Gulf of Mexico waters.

The TMDLs in this report were developed on the basis of pre- and post-hurricane water quality conditions. Post-hurricane water quality conditions and other factors could delay the implementation of these TMDLs, render some TMDLs obsolete, or require modifications of the

TMDLs. Although hurricane effects may be valid for some TMDLs, any deviation from the TMDLs should be justified using site-specific data or information.

9.0 PUBLIC PARTICIPATION

Federal regulations require USEPA to notify the public and seek comment concerning TMDLs it prepares. The TMDLs in this report were developed under contract to USEPA, and USEPA held a public review period seeking comments, information, and data from the public and any other interested parties. The notice for the public review period was published in the Federal Register on October 30, 2007, and the review period closed on November 29, 2007.

Comments were received from LDEQ. These comments were used to revise this TMDL report. The comments and responses to these TMDLs are included in a separate document that includes comments on similar TMDLs with the same public review period.

USEPA will submit the final version of these TMDLs to LDEQ for implementation and incorporation into LDEQ's current water quality management plan.

10.0 REFERENCES

Cadmus Group. 2007. Assessment of Dissolved Oxygen, Physical Habitat, and Biological Characteristics for Man-Made Canals and Unaltered Streams in Terrebonne Basin, Louisiana. Prepared for USEPA Region 6 by The Cadmus Group, Inc. and ARCADIS U.S., Inc., and other team members. Final Report dated May 30, 2007.

LDEQ. 2005. Louisiana 2004 303(d) List of Impaired Water Bodies: Including EPA's Additions. Retrieved from Louisiana Department of Environmental Quality web site at: www.deq.louisiana.gov/portal/Portals/0/planning/04 IR1-FINAL-Appendix H-Cat 5 303d List with EPA - August 17 2005.xls

LDEQ. 2006. Louisiana Total Maximum Daily Load Technical Procedures. Revision 10. Prepared by Office of Environmental Assessment, Louisiana Department of Environmental Quality. Dated August 10, 2006. Retrieved from Louisiana Department of Environmental Quality web site at: www.deq.louisiana.gov/portal/Portals/0/planning/LTP_sop_1727_r10-081006.pdf

LDEQ. 2007. Title 33 Environmental Quality, Part IX Water Quality, Subpart 1 Water Pollution Control, Chapter 11 Surface Water Quality Standards. Including amendments through 5/20/07. Retrieved from Louisiana Department of Environmental Quality web site at: www.deq.louisiana.gov/portal/Portals/0/planning/regs/title33/33v09.pdf

Tetra Tech. 2007. TMDLs for Fecal Coliform Bacteria, Chlorides, Sulfates, Total Dissolved Solids (TDS), Sediment, Total Suspended Solids (TSS), and Turbidity for Selected Subsegments in the Terrebonne Basin, Louisiana. Report prepared by Tetra Tech, Inc. under contract to U.S. EPA. Dated March 29, 2007. Available at: www.epa.gov/Region6/water/npdes/tmdl/2007/louisiana/final/3terretmdls_f.pdf

USEPA. 1985. Rates, Constants, and Kinetics Formulations in Surface Water Quality Modeling (Second Edition). Written by G.L. Bowie et. al. EPA/600/3-85/040. United States Environmental Protection Agency, Environmental Research Laboratory, Athens, GA.

USEPA. 1997. Technical Guidance Manual For Developing Total Maximum Daily Loads, Book 2: Streams and Rivers, Part 1: Biochemical Oxygen Demand/Dissolved Oxygen and Nutrients/Eutrophication. EPA 823-B-97-002. United States Environmental Protection Agency, Office of Water. March 1997.

USEPA. 1999. 1999 Update of Ambient Water Quality Criteria for Ammonia. EPA-822-R-99-014. United States Environmental Protection Agency, Office of Water. December 1999. Retrieved from USEPA web site at: www.epa.gov/ost/standards/ammonia/99update.pdf

USGS. 2006. National Land Cover Database 2001 (NLCD 2001). Retrieved from United States Geological Survey web site at: www.mrlc.gov/mrlc2k_nlcd.asp

Wiland, B.L., and K. LeBlanc. 2007. LA-QUAL for Windows User's Manual. Prepared by Wiland Consulting, Inc. with revisions by K. LeBlanc, Louisiana Department of Environmental Quality. Model Version 8.11, Manual Revision M. August 22, 2007. Downloaded from Louisiana Department of Environmental Quality web site at: www.deq.louisiana.gov/portal/Portals/0/planning/laqual.zip