FINAL

TMDLs for Dissolved Oxygen and Nutrients in Selected Subsegments in the Lower Terrebonne Basin, Louisiana

(120401, 120404, 120405, 120406)

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EXECUTIVE SUMMARY

Section 303(d) of the Clean Water Act and the U.S. Environmental Protection Agency's (EPA's) Water Quality Planning and Management Regulations (at Title 40 of the *Code of Federal Regulations* [CFR] Part 130) require states to develop Total Maximum Daily Loads (TMDLs) for impaired waterbodies. A TMDL establishes the amount of a pollutant that a waterbody can assimilate while still meeting the water quality standard for that pollutant. TMDLs provide the scientific basis for a state to establish water quality-based controls to reduce pollution from both point and nonpoint sources to restore and maintain the quality of the state's water resources (USEPA 1991).

A TMDL for a given pollutant and waterbody is composed of the sum of individual wasteload allocations (WLAs) for point sources and load allocations (LAs) for nonpoint sources and natural background levels. In addition, the TMDL must include an implicit or explicit margin of safety (MOS) to account for the uncertainty in the relationship between pollutant loads and the quality of the receiving waterbody, and it may include a future growth (FG) component. The TMDL components are illustrated using the following equation:

$$TMDL = \Sigma\ WLAs + \Sigma\ LAs + MOS + FG$$

The study area for this TMDL includes four lower Terrebonne Basin subsegments. The lower Terrebonne Basin is in Terrebonne Parish. Land use in the lower Terrebonne Basin is dominated by wetlands. Heavy rainfall events typically occur in March and April as frontal weather systems pass through.

The Louisiana Department of Environmental Quality (LDEQ) has included four lower Terrebonne Basin subsegments on the state's 2004 section 303(d) list of impaired waterbodies. The subsegments are listed for dissolved oxygen and nutrient impairments. The impaired designated uses for the subsegments (Table ES-1) are primary and secondary contact recreation (PCR and SCR), fish and wildlife propagation (FWP), outstanding natural resource (ONR), and shellfish propagation (SFP). The subsegments are either fully supporting (F) or not supporting (N).

Table ES-1. Section 303(d) listing for subsegments included in this report

Subsegment	Subsegment name	Subsegment description	Designated use				
			PCR	SCR	FWP	ONR	SFP
120401	Bayou Penchant	Bayou Chene to Lake Penchant	F	F	N	N	
120404	Lake Penchant	Lake Penchant	F	F	N		
120405	Lake Hatch and Lake Theriot	Lake Hatch and Lake Theriot	F	F	N		
120406	Lake de Cade	Lake de Cade	F	F	F		F

A water quality model (LA-QUAL) was set up to simulate dissolved oxygen, 25-day carbonaceous biochemical oxygen demand (CBOD), ammonia nitrogen, and nitrate+nitrite. The model was calibrated using data from fieldwork conducted in July 2006. The projection simulation was run at critical flows and temperatures to address seasonality, as the Clean Water

Act requires. Reductions of existing nonpoint source loads were required for the projection simulation to show maintenance of the dissolved oxygen standard, 5 milligrams per liter (mg/L). There were no reductions to point sources. In general, the modeling in this study was consistent with guidance in the Louisiana TMDL technical procedures manual (LDEQ 2005). TMDLs for oxygen-demanding substances ($CBOD_u$, ammonia, and sediment oxygen demand [SOD]) were calculated using the projection simulation.

In TMDL development, allowable loads from all pollutant sources that cumulatively amount to no more than the TMDL must be established, thereby providing the basis for establishing water quality-based controls. WLAs were assigned to permitted point source discharges. The LAs include background loadings and human-induced nonpoint sources. An explicit MOS of 10 percent and an FG component of 10 percent were also included.

The dissolved oxygen 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 dissolved oxygen criterion is supported, nutrients are also controlled and limited. Implementing the dissolved oxygen TMDL through future wastewater discharge permits, if required, and implementing best management practices to control and reduce runoff of soil and oxygen-demanding pollutants from nonpoint sources in the watershed will also control and reduce the nutrient loading from those sources.

Table ES-2 presents a summary of the dissolved oxygen TMDLs for the subsegments addressed in this report. The numeric water quality criterion that applies to the impaired subsegments and used to calculate the total allowable dissolved oxygen pollutant loads is 5 mg/L.

Table ES-3 presents a summary of the reduction percentages for LAs. Reduction percentages from baseline conditions for total oxygen demand ranged from less than 1 to 21 percent. There were no reductions for WLAs.

Table ES-2. Summary of dissolved oxygen TMDLs, WLAs, LAs, MOSs, and FGs for the lower Terrebonne Basin

Subsegment	Oxygen demand (lb/d)				
120401	SOD	$CBOD_u$	Ammonia	Organic N	Total
WLA	0.00	0.00	0.00	0.00	0.00
MOS for WLA	0.00	0.00	0.00	0.00	0.00
FG for WLA	0.00	0.00	0.00	0.00	0.00
LA	35,121.04	95,353.91	1,889.29	42,639.13	175,003.37
MOS for LA	4,390.13	11,919.24	236.16	5,329.89	21,875.42
FG for LA	4,390.13	11,919.24	236.16	5,329.89	21,875.42
TMDL	43,901.30	119,192.39	2,361.61	53,298.91	218,754.22

Table ES-2. (continued)

Subsegment	Oxygen demand (lb/d)				
120404	**SOD**	**$CBOD_u$**	**Ammonia**	**Organic N**	**Total**
WLA	0.00	0.00	0.00	0.00	0.00
MOS for WLA	0.00	0.00	0.00	0.00	0.00
FG for WLA	0.00	0.00	0.00	0.00	0.00
LA	12,674.81	8,045.13	373.67	8,398.65	29,492.25
MOS for LA	1,584.35	1,005.64	46.71	1,049.83	3,686.53
FG for LA	1,584.35	1,005.64	46.71	1,049.83	3,686.53
TMDL	15,843.51	10,056.41	467.08	10,498.31	36,865.32
Subsegment	**Oxygen demand (lb/d)**				
120405	**SOD**	**$CBOD_u$**	**Ammonia**	**Organic N**	**Total**
WLA	0.00	0.00	0.00	0.00	0.00
MOS for WLA	0.00	0.00	0.00	0.00	0.00
FG for WLA	0.00	0.00	0.00	0.00	0.00
LA	50,867.98	5,509.87	671.26	3,031.74	60,080.84
MOS for LA	6,358.50	688.73	83.91	378.97	7,510.11
FG for LA	6,358.50	688.73	83.91	378.97	7,510.11
TMDL	63,584.98	6,887.33	839.07	3,789.67	75,101.06
Subsegment	**Oxygen demand (lb/d)**				
120406	**SOD**	**$CBOD_u$**	**Ammonia**	**Organic N**	**Total**
WLA	0.00	1.54	0.96	0.48	2.98
MOS for WLA	0.00	0.19	0.12	0.06	0.37
FG for WLA	0.00	0.19	0.12	0.06	0.37
LA	46,618.22	38,758.46	4,754.46	14,269.76	104,400.90
MOS for LA	5,827.28	4,844.81	594.31	1,783.72	13,050.11
FG for LA	5,827.28	4,844.81	594.31	1,783.72	13,050.11
TMDL	58,272.78	48,450.00	5,944.28	17,837.80	130,504.86

Table ES-3. Summary of reduction percentages for LAs in the lower Terrebonne Basin

Subsegment	Oxygen demanding				
	SOD	**$CBOD_u$**	**Ammonia**	**Organic N**	**Total**
120401	0.00	0.00	0.00	0.00	0.00
120404	0.22	0.00	0.00	0.00	0.09
120405	0.00	60.21	39.69	70.75	21.15
120406	0.00	0.00	0.00	0.00	0.00

Table ES-4 presents a summary of the nutrient TMDLs for the subsegments addressed in this report. The state’s nutrient criteria are narrative and include the following language (LDEQ 2007):

> 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.

Table ES-4. Summary of nutrient TMDLs, WLAs, LAs, MOSs, and FGs for the lower Terrebonne Basin

Subsegment	∑ WLA (lb/d)	∑ LA (lb/d)	MOS	FG (10%) (lb/d)	Total allowable loading (lb/d)	Percent reduction
Total phosphorus						
120405	0.000	0.096	Implicit	0.011	0.106	0.000
120406	0.000	0.158	Implicit	0.018	0.176	0.000
Total nitrogen						
120405	0.000	0.868	Implicit	0.10	0.96	0.000
120406	0.000	1.403	Implicit	0.16	1.56	0.000

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 percent 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.

The proposed TMDLs in this report were developed on the basis of pre- and post-hurricane water quality conditions. Some point sources in this TMDL have been updated with post-hurricane information, where available. Post-hurricane water quality conditions and other factors could delay the implementation of these proposed TMDLs, render some proposed TMDLs obsolete, or require modifications of the TMDLs. Although hurricane effects might be valid for some TMDLs, any deviation from the TMDLs should be justified using site-specific data or information.

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1 INTRODUCTION

Section 303(d) of the Clean Water Act and the U.S. Environmental Protection Agency's (EPA's) Water Quality Planning and Management Regulations (at Title 40 of the *Code of Federal Regulations* [CFR] Part 130) require states to develop Total Maximum Daily Loads (TMDLs) for waterbodies that are not supporting their designated uses, even if pollutant sources have implemented technology-based controls. A TMDL establishes the maximum allowable load (in mass per unit time) of a pollutant that a waterbody is able to assimilate while still supporting its designated uses. The maximum allowable load is determined on the basis of the relationship between pollutant sources and in-stream water quality. A TMDL provides the scientific basis for a state to establish water quality-based controls to reduce pollution from both point and nonpoint sources to restore and maintain the quality of the state's water resources (USEPA 1991).

Monitoring data collected by the Louisiana Department of Environmental Quality (LDEQ) indicate that observed dissolved oxygen levels sometimes do not meet the state's water quality criteria for four subsegments in the lower Terrebonne Basin. The impaired designated uses for the subsegments are primary and secondary contact recreation, fish and wildlife propagation, outstanding natural resource water, and shellfish propagation. The subsegments are either fully supporting (F) or not supporting (N) the designated uses. Table 1-1 presents information from Louisiana's 2004 section 303(d) list for the four subsegments. For example, prolonged hot weather decreases oxygen concentrations and can cause fish kills even in clean waters because warm water cannot hold as much oxygen as cold water (Scorecard 2005).

Table 1-1. Subsegments and impairments addressed in this report

Subsegment	Subsegment name	Subsegment description	Designated use				
			PCR	SCR	FWP	ONR	SFP
120401	Bayou Penchant	Bayou Chene to Lake Penchant	F	F	N	N	
120404	Lake Penchant	Lake Penchant	F	F	N		
120405	Lake Hatch and Lake Theriot	Lake Hatch and Lake Theriot	F	F	N		
120406	Lake de Cade	Lake de Cade	F	F	F		F

Oxygen concentrations in the water column fluctuate under natural conditions, but severe depletion usually results from human activities that introduce large quantities of biodegradable organic materials into surface waters. In polluted waters, bacterial degradation of organic materials can result in a net decline in oxygen concentrations in the water. Oxygen depletion can also result from chemical reactions that place a chemical oxygen demand on receiving waters. Other factors, such as temperature and salinity, influence the amount of oxygen dissolved in water. Prolonged hot weather decreases oxygen concentrations and can cause fish kills even in clean waters because warm water cannot hold as much oxygen as cold water (Scorecard 2005).

Other factors that affect dissolved oxygen concentrations include the following (Murphy 2005):

- Volume and velocity of water flowing in the waterbody
- Climate and season
- The type and number of organisms in the waterbody

- Altitude
- Dissolved or suspended solids
- Amount of nutrients in the water
- Organic waste
- Riparian vegetation
- Ground water inflow

Low dissolved oxygen concentrations in streams can be linked to both natural conditions and human activities. In Louisiana natural stream conditions like low flow, high temperature, and high organic content often result in dissolved oxygen levels already below current water quality criteria, making it difficult to develop standards for best management practices, or BMPs (Mason et al. 2007). Additional data for these 303(d)-listed areas are needed to determine whether the low dissolved oxygen occurs naturally or is related to human activity (i.e., is anthropogenic).

2 BACKGROUND INFORMATION

2.1 General Description

The study region consisted of four subsegments in the lower portion of the Terrebonne Basin. They include Bayou Penchant (subsegment 120401), Lake Penchant (subsegment 120404), Lake Hatch and Lake Theriot (subsegment 120405), and Lake de Cade (subsegment 120406). In Louisiana, the lower Terrebonne Basin includes portions of Terrebonne Parish. Table 2-1 lists the parish and approximate drainage area of each subsegment and Figure 2-1 shows the locations of the subsegments. The watershed's U.S. Geological Survey (USGS) hydrologic unit code is 08090302.

Table 2-1. Drainage area and parish of each subsegment

Subsegment name	Subsegment	Parish	Area (mi^2)	Area (km^2)
Bayou Penchant	120401	Terrebonne	181	470
Lake Penchant	120404	Terrebonne	29	76
Lake Hatch and Lake Theriot	120405	Terrebonne	32	83
Lake de Cade	120406	Terrebonne	53	137

2.2 Land Use

Land use data were obtained from the 2001 USGS National Land Cover Dataset (NLCD; Table 2-2 and Figure 2-2). The predominant land use in the impaired subsegments is wetland. The percentage of wetlands in the watersheds ranges from 69 percent to 82.1 percent followed by open water. There is very little, if none, barren, developed, scrub/shrub, or forest in any subsegments. Subsegments 120405 and 120406 have larger areas of pasture/hay. Subsegment 120401 is almost entirely wetland and open water.

Table 2-2. Land uses percentages for each listed subsegment in the lower Terrebonne Basin

Land use	Percent of total area			
	Bayou Penchant (120401)	Lake Penchant (120404)	Lake Hatch and Lake Theriot (120405)	Lake de Cade (1201406)
Water	9.89	7.95	7.17	28.61
Developed	0.00	0.00	0.16	0.18
Barren	0.35	0.00	0.00	0.02
Forest	0.00	0.00	0.00	0.01
Grassland/shrub	0.00	0.00	0.00	0.00
Pasture/hay	0.00	0.00	3.22	2.16
Cultivated crops	0.00	0.00	0.01	0.10
Wetlands	89.76	92.05	89.44	68.93
TOTAL	100.00	100.00	100.00	100.00

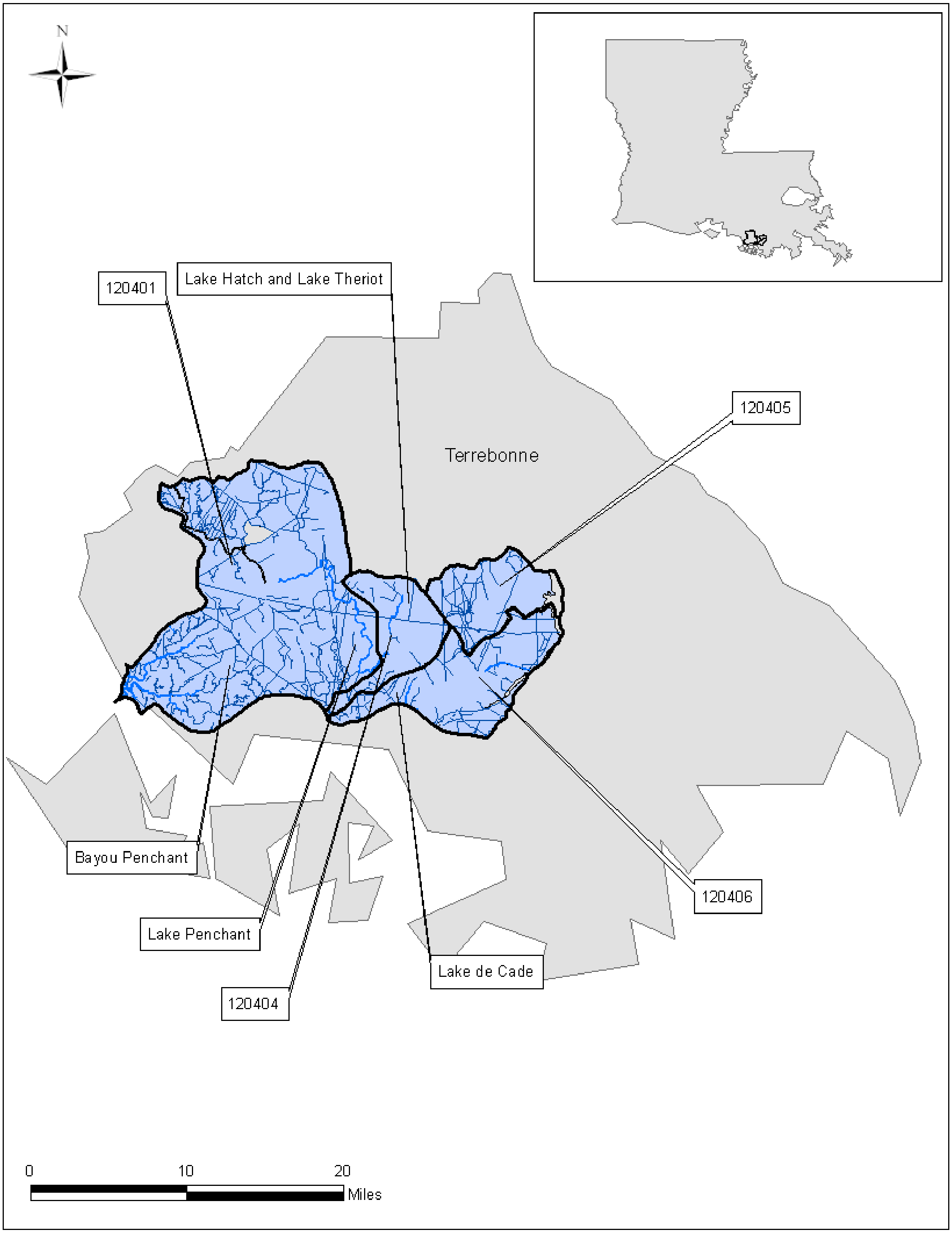

Figure 2-1. Locations of lower Terrebonne Basin subsegments.

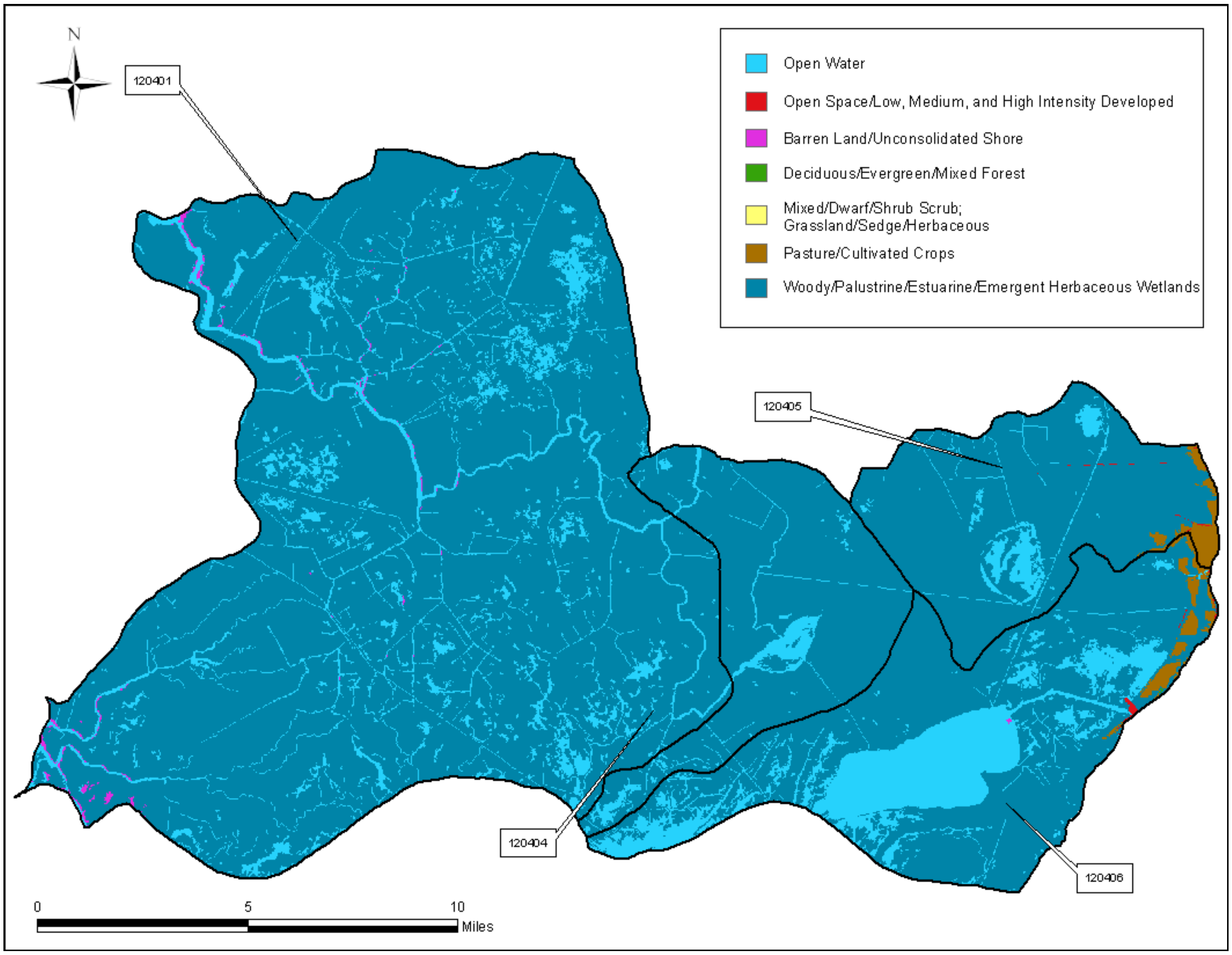

Figure 2-2. Land use in the lower Terrebonne Basin subsegments.

2.3 Hydrologic Setting

Because reversing flows occur at times throughout the Terrebonne Basin, there are very few USGS flow gages in the Terrebonne Basin. The USGS online hydrology database (NWISWeb) contains three stations with flow data for the listed subsegments that are impaired for dissolved oxygen and nutrients. Two stations—Carrion Crow Bayou (USGS station 0738165033; subsegment 120401) and Bayou Penchant near Theriot (USGS station 0738165055; subsegment 120401)—had only one peak discharge value, so these were not used. The remaining station is on Bayou Penchant south of Morgan City (USGS 073816503; subsegment 120401). Not using negative flows, the average flow on this station is 2,833 cubic feet per second (cfs) with a minimum of 25 cfs and a maximum of 10,900 cfs.

2.4 Designated Uses and Water Quality Criteria

Louisiana's 2004 section 303(d) list indicates that the four listed subsegments—all assigned a use of primary or secondary contact recreation, fish and wildlife propagation, outstanding natural resource, or shellfish propagation—do not meet applicable water quality standards because of unknown sources. Primary contact recreation includes any recreational or other water contact involving full-body exposure to water and a considerable probability of ingesting water.

Examples of the use are swimming and water skiing. Secondary contact recreation involves activities like fishing, wading, or boating, where water contact is accidental or incidental, and there is a minimal chance of ingesting appreciable amounts of water. Fish and wildlife propagation includes the use of water for aquatic habitat, food, resting, reproduction, cover, or travel corridors for any indigenous wildlife and aquatic life species associated with the aquatic environment. Outstanding Natural Resource Waters are waterbodies designated for preservation, protection, reclamation, or enhancement of wilderness, aesthetic qualities, and ecological regimes, such as those designated under the Louisiana Natural and Scenic Rivers System or those designated by the department as waters of ecological significance. Characteristics of outstanding natural resource waters include highly diverse or unique in-stream or riparian habitat, high species diversity, balanced trophic structure, unique species, or similar qualities. Shellfish propagation involves the use of water to maintain biological systems that support economically important species of shellfish so that their productivity is preserved and the health of human consumers of these species is protected.

The assessment methodology presented in LDEQ's 305(b) report (LDEQ 2004) specifies that primary contact recreation, secondary contact recreation, and fish and wildlife propagation uses are to be fully supported. The state minimum dissolved oxygen criterion for the subsegments in this TMDL is 5 milligrams per liter (mg/L) year-round.

Louisiana does not have numeric water quality standards for nutrients, but its narrative standard for nutrients states the following:

- The naturally occurring range of nitrogen-phosphorus ratios shall be maintained (except for intermittent streams), and
- 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 antidegradation policy (*Louisiana Administrative Code* [LAC] Title 33, Part IX, Section 1109.A), which states that state waters exhibiting high water quality should be maintained at that high level of water quality. If that is not possible, water quality of a level that supports the designated uses of the waterbody should be maintained. The designated uses of a waterbody may be changed to allow a lower level of water quality only through a use attainability study.

2.5 Identification of Sources

2.5.1 Point Sources

LDEQ stores permit information using internal databases. LDEQ generated a list of point source discharges in the study area by using the TEMPO and PTS databases. Information on point source discharges to the listed subsegments was obtained from the Electronic Document Management System (EDMS) database at LDEQ. Data were pulled from EDMS and analyzed for the TMDLs. Each facility was evaluated on the basis of its discharges and permit limits to determine whether the facility would be used in developing the TMDLs. The evaluation yielded a permitted point source discharges in subsegment 120406 (Table 2-3).

Table 2-3. Point source in the lower Terrebonne Basin

NPDES permit number	Outfall	Facility name	Location	Receiving water	Flow (gpd)	Weekly ave BOD_5 (mg/L)
LAG480431	001	The Offshore Drilling Company	Lake Decade NE bank, near Theriot	Lake Decade	1,780	45

2.5.2 Nonpoint Sources

Louisiana's section 303(d) list does not identify the suspected cause of the dissolved oxygen impairment in the subsegments of the Upper Terrebonne Basin. The source is listed as *unknown*.

3 CHARACTERIZATION OF EXISTING WATER QUALITY

3.1 Water Quality Data

Water quality data were obtained from LDEQ's routine ambient water quality monitoring program (Figure 3-1). Appendix A includes summaries of the data for the 303(d)-listed constituents, along with additional constituents used in the TMDL development process. Dissolved oxygen data were available for each of the four listed subsegments (see Table 3-1).

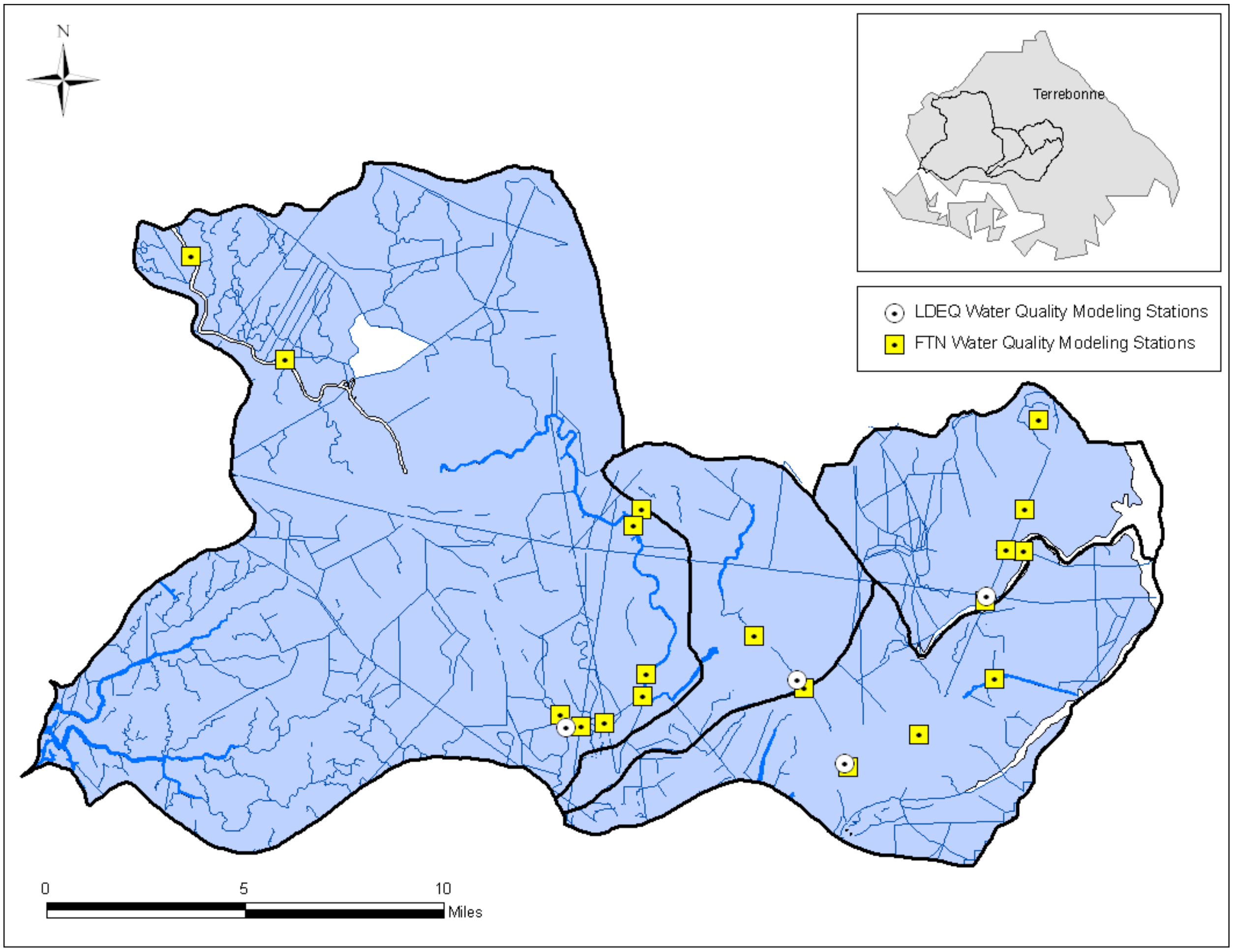

Figure 3-1. Locations of monitoring stations in the lower Terrebonne Basin.

Table 3-1. LDEQ water quality monitoring stations and dissolved oxygen data summaries

Subsegment	LDEQ station	Station name	Period of record	No. of obs.	DO min (mg/L)	DO max (mg/L)	DO ave. (mg/L)
120401	932	Bayou Carencro at Brady Canal, LA	1/26/00–10/18/00	10	3.6	9.4	5.72
120404	935	Peoples Canal north of Bayou Mauvais Bois Ridge, LA	1/26/00–12/20/00	12	2.7	8.2	5.54
120405	936	Minors Canal north of Marmande Ridge, LA	1/26/00–12/20/00	12	3.3	9.5	6.16
120406	937	Lake de Cade, LA	1/12/00–4/20/04	16	4.64	10.6	7.35

Note: DO = dissolved oxygen

A field survey of the four model subsegments was conducted in the Terrebonne Basin during July 2006. The hydrologic conditions during the field survey were typical for the Terrebonne Basin during summer (high temperatures and generally low flows). A list of the field survey sites and the types of data collected at each site is presented in Table 3-2. The water quality samples were analyzed for 20-day carbonaceous biochemical oxygen demand (CBOD) time series, total Kjeldahl nitrogen (TKN), ammonia nitrogen (NH_3-N), nitrate+nitrite nitrogen, total phosphorus, chlorophyll *a*, total organic carbon (TOC), and total suspended solids (TSS). The in situ measurements and water quality sampling results are summarized in Appendix A. Appendix A also contains summaries of the depth, widths, and flows measured with the acoustic Doppler current profiler (ADCP) instrument. Plots of the continuous monitoring data are presented in Appendix A. Copies of the field notes from the field survey are included in Appendix B.

Table 3-2. Data types from July 2006 monitoring

Subsegment	Site ID	Site name	Data types collected
120401	120401-A	Bayou Penchant southeast of Bayou Chene	In situ, sample
120401	120401-B	Bayou Penchant near Bayou Copasaw	In situ, flow
120401	120401-C	Bayou Copasaw near Bayou Penchant	In situ, sample, flow
120401	120401-D	Bayou Penchant near Brady Canal	In situ, sample
120401	120401-E	Little Carencro Bayou	In situ, flow
120401	120401-F	Carencro Bayou (Bayou Carrion Crow)	In situ, flow
120401	120401-G	Bayou Penchant near Kent Bayou Oil and Gas Field	In situ, sample
120404	120404-A	Lake Penchant	In situ, sample, depth
120404	935	Peoples Canal north of Bayou Mauvais, Bois Ridge, LA	In situ, sample, cross section, flow
120405	120405-A	Lake Hatch	In situ, sample, depth
120405	120405-C	Marmande Canal between Minors Canal and Lake Theriot	Flow
120405	120405-D	Marmande Canal east of Minors Canal	In situ, sample, level logger
120405	120405-E	Minors Canal north of Lake Theriot	in situ, cross section
120405	936	Minors Canal north of Marmande Ridge, LA	In situ, sample
120406	120406-A	Falgout Canal Bayou	In situ, sample, level logger
120406	120406-B	Lake DeCade (eastern part)	In situ, depth, contin. in situ
120406	937	Lake DeCade (western part)	In situ, sample, depth

3.2 Comparison of Observed Data to Criteria

Water quality monitoring data were obtained from LDEQ and during the July 2006 sampling event. Table 3-3 provides a summary of the LDEQ dissolved oxygen data available for stations in the model subsegments. Each station has between 10 and 16 data points. All four stations had dissolved oxygen observations below the water quality criterion of 5 mg/L.

Table 3-3. Summary of LDEQ dissolved oxygen data for the lower Terrebonne Basin

LDEQ station	Subsegment	Period of record	No. of samples	DO min. (mg/L)	DO max. (mg/L)	DO ave. (mg/L)	Percent samples < 5 mg/L
932	120401	1/26/00–10/18/00	10	3.6	9.4	5.72	30
935	120404	1/26/00–12/20/00	12	2.7	8.2	5.54	25
936	120405	1/26/00–12/20/00	12	3.3	9.5	6.16	33
937	120406	1/12/00–4/20/04	16	4.6	10.6	7.35	13

Note: DO = dissolved oxygen

Table 3-4 provides a summary of the July 2006 dissolved oxygen data for stations in the model subsegments. Each station has between 2 and 18 data points. All four stations had dissolved oxygen observations below the water quality criterion of 5 mg/L, except for subsegment 120406.

Table 3-4. Summary of dissolved oxygen data from July 2006 monitoring event

Subsegment	Number of locations	Range of sample depths	Number of samples	DO min. (mg/L)	DO max. (mg/L)	DO ave. (mg/L)	Percent samples < 5 mg/L
120401	7	3–11	18	3.0	8.9	5.1	38.9
120404	2	2.25	2	3.7	6.0	4.8	50.0
120405	4	1–15	7	3.1	10.4	6.9	14.3
120406	3	2.5–3	3	6.5	7.3	6.9	0.0

Note: DO = dissolved oxygen

4 WATER QUALITY MODEL SETUP AND CALIBRATION

4.1 Model Setup

LA-QUAL (Version 8.11) was chosen to simulate dissolved oxygen in the TMDL subsegments. LA-QUAL is a steady-state model that LDEQ developed based on the QUAL-TX (Version 3.4) model. Several modifications were made to the QUAL-TX model, including the addition of new aeration equations that better represent conditions in Louisiana.

LA-QUAL evaluates the relationships between pollutant sources and water quality. Model configuration involved setting up the model segments and setting initial conditions, boundary conditions, and hydraulic and kinetic parameters. This section describes the configuration and key components of the model.

Two models were used for the lower Terrebonne Basin: Bayou Penchant (120401)/Lake Penchant (120404); and Bayou Black (120202)/Intracoastal Waterways (120304 and 120403). Only the main stems of the systems were explicitly simulated and thus segmented for modeling purposes. Segmentation refers to separating a waterbody into smaller computational units. Segmentation occurred around major hydrological features, such as tributaries. Tributaries were represented through boundary condition designation. Appendix C contains diagrams of the model segmentations and stream kilometers.

4.2 Calibration Period

The calibration period was selected to coincide with the intensive field monitoring that had occurred in July 2006. The data used for calibration are the averages of the samples taken during the measurement period from July 10 through July 13, 2006. These dates were selected for calibration because they were the only dates for which data were available. This period is considered the critical period because high temperatures decrease dissolved oxygen saturation values and increase rates for oxygen-demanding processes, such as biochemical oxygen demand (BOD) decay, nitrification, and sediment oxygen demand (SOD). In addition, lower flow rates do not cause strong reaeration, so the exchange of oxygen between air and water is low.

4.3 Model Options (Data Type 2)

Data type 2 is used to identify the constituents being modeled to achieve calibration—for this TMDL, dissolved oxygen, BOD, and a nitrogen series (ammonia nitrogen, and nitrate+nitrite).

4.4 Program Constants (Data Type 3)

LA-QUAL is programmed with certain default program parameters. Data type 3 is used to override the default parameters and is optional; that is, values need to be entered only if values other than the default values are desired. Default values were used for all program parameters except for the hydraulic calculation method. This parameter was changed from method 1 to method 2. For descriptions of the parameters and their default values, see the LA-QUAL user manual (Wiland Consulting, Inc. 2005).

4.5 Temperature Correction of Kinetics (Data Type 4)

Data type 4 contains factors used for temperature correction in rate equations. The temperature correction factors used in the model were consistent with the *Standard Operating Procedure for Louisiana TMDL Technical Procedures* (LTP) when these factors were available (LDEQ 2005). The correction factors were as follows:

- Correction for BOD decay: 1.047 (LTP and model default)
- Correction for SOD: 1.065 (LTP and model default)
- Correction for ammonia N decay: 1.083 (model default)
- Correction for organic N decay: 1.020 (model default)
- Correction for reaeration: 1.024 (LTP and model default)

4.6 Hydraulics (Data Type 9)

These data types describe the hydraulic characteristics of the model reaches. The stream hydraulics were specified in the input file for the model using the following power functions:

$$width = a \times Q^b + c$$
$$depth = d \times Q^e + f$$

where:

a =	width coefficient	=	0.0
b =	width exponent	=	0.0
c =	width constant	=	average width of segment
d =	depth coefficient	=	0.0
e =	depth exponent	=	0.0
f =	depth constant	=	average depth of segment

The average width and depth for each segment were based on observed measurements in July 2006; they are shown in Table 4-1. Slight adjustments in some reaches to better simulate observed hydrology and water quality.

Table 4-1. Average channel widths and depths for each model segment

Model reach	120401/120404		120405/120406	
	Width (m)	Depth (m)	Width (m)	Depth (m)
1	135	1.00	1,527	1.55
2	110	1.00	1,029	1.55
3	90	1.77	25	1.55
4	155	1.77	10	1.55
5	90	1.77	2,428	0.80
6	110	1.77	20	1.90
7	35	1.77	46	1.55
8	2,131	1.77	110	1.55
9	983	1.77	30	1.55
10	148	1.77	970	0.75
11	61	1.77	50	1.55
12	72	1.40	20	1.55
13	72	1.40	--	--
14	70	1.40	--	--
15	65	1.40	--	--
16	65	1.40	--	--
17	88	1.40	--	--

4.7 Dispersion (Data Types 10 and 27)

Dispersion was specified in the model because subsegments in these models are tidally influenced. The tidal influence creates diurnal flow reversals that provide mixing and dispersive transport. Lower boundary conditions were added to the model using results from monitoring locations near the end of the reaches from the intensive study in July 2006.

4.8 Initial Conditions (Data Type 11)

Initial conditions were set for temperature, dissolved oxygen, nitrate+nitrite, and chlorophyll *a* using observed water quality data, while ammonia data were set to a constant. Because LA-QUAL is a steady-state model, the initial conditions affect only the number of iterations needed to reach steady-state conditions. Setting initial conditions on the basis of observed data reduces the amount of iterations the model must perform to reach steady-state.

Salinity, nitrate+nitrite, phosphorus, phytoplankton, and macrophytes were the parameters not simulated in the model. Their initial conditions were set to zero so that the model would not assume a fixed concentration and include their effects.

4.9 Water Quality Kinetics (Data Types 12 and 13)

Several kinetic rates, including reaeration, SOD, CBOD decay, nitrification, and mineralization (organic nitrogen decay) rates, were used in the model. Data types 12 and 13 focus on different rates used by the model. Data type 12 is needed only if BOD or dissolved oxygen is being simulated, and data type 13 is needed only if nitrogen or phosphorus is being simulated. For this TMDL, both data types were included.

The model calculates the reaeration rate by using one of a standard set of equations. For this TMDL, the O'Conner-Dobbins equation was used. This equation is applicable to moderately deep to deep channels (1 ft to 30 ft with flow between 0.5 ft/s and 12.2 ft/d). The equation is

$$K_2 = \frac{3.932 \times V^{0.969}}{D^{1.5}}$$

where:

V = stream velocity (meters per second)
D = stream depth (meters)

For the portion of the models that simulates lakes, a different method was used. This equation is

$$K_2 = \frac{a}{D}$$

where:

a = oxygen transfer coefficient (meters per day)
D = stream depth (meters)

The input files that list these values are provided in Appendix D. Table 4-2 summarizes these rates. The CBOD decay rate varied per subsegment and was based on the measured $CBOD_3$,

$CBOD_5$, $CBOD_{12}$, $CBOD_{20}$, and $CBOD_{25}$ data. Slight adjustments were made in some reaches to better simulate observed water quality. The SOD was calibrated in the model and varied per subsegment reach. SOD was calibrated after the CBOD levels were finalized. The SOD rates changed iteratively until modeled dissolved oxygen concentrations agreed well with measured water column dissolved oxygen concentrations.

Table 4-2. Water quality kinetics rates

Program constant	120401/120404	120405/120406
Background SOD ($g/m^2/d$)	0.6–2.8	1.2–2.5
BOD #1 decay rate (aerobic) (1/d)	0.05–0.12	0.01–0.31
Organic nitrogen settling rate (m/d)	0.02	0.003–0.01
Ammonia nitrogen oxidation rate (1/d)	0.1–0.15	0.2
Oxygen transfer coefficient "*a*" (m/d)	0.93	0.93

4.10 Incremental Data (Data Types 16, 17, and 18)

These data types include information on inflows and outflows from the model reaches. For this TMDL, incremental information for flow, temperature, dissolved oxygen, CBOD, organic nitrogen, ammonia, and nitrate+nitrite was included. Appendix D contains the input files with these values. Incremental flow was determined from flow measurements obtained during the July 2006 monitoring.

4.11 Nonpoint Source Loads (Data Type 19)

This data type accounts for nonpoint source loads not associated with incremental and tributary flows. The nonpoint source loads that are specified in the model can be most easily understood as resuspended load from the bottom sediments and are modeled as SOD, CBOD loads, and organic nitrogen loads. The SOD (from data type 12) and the mass loads of organic nitrogen and CBOD (data type 19) were all treated as calibration parameters; their values were adjusted until the model output was similar to the calibration target values.

Typically, these three calibration parameters were adjusted in a specific order based on the interactions between state variables in the model. First, the organic nitrogen loads were adjusted until the predicted organic nitrogen concentrations were similar to the observed concentrations. Organic nitrogen was calibrated first because none of the other state variables will affect the organic nitrogen concentrations. Next, the $CBOD_u$ loads were adjusted until the predicted $CBOD_u$ concentrations were similar to the observed concentrations. Finally, the SOD rates were adjusted until the predicted dissolved oxygen concentrations were similar to the observed concentrations. The SOD rate was not adjusted below 0.5 grams per square meter per day ($g/m^2/day$). The dissolved oxygen was calibrated last because all the other state variables affect dissolved oxygen.

4.12 Headwater Flow, Water Quality, and Junction Data (Data Types 20, 21, 22, and 23)

These data types account for flow and water quality from upstream of the modeled subsegment. Headwater flow and water quality data were derived from monitoring data. In general, the flow measured at the most upstream station was taken as the headwater flow. Water quality data (mainly CBOD and dissolved oxygen) were estimated from the monitoring data at the most upstream stations.

4.13 Wasteload Flow and Water Quality Data (Data Types 24, 25, and 26)

These data types account for flow and water quality from point sources discharging into the listed waterbodies. The model included one permitted outflows. There were also 6 tributaries or outflows that were included as input in these data types. The input file that lists inputs and their associated flows and concentrations are provided in Table 4-3. Data from tributaries was developed from observed data. Permit design flows were used as the flows from permits. Dissolved oxygen was set to 5.0 mg/L for the permitted facility. Permitted BOD_5 discharge limits were converted to ultimate CBOD using a conversion factor of 2.3. Organic nitrogen and nitrate+nitrite were assumed from surrounding waters for the point source and ammonia was assumed. Data for tributaries was obtained from observed data, assumption, and calibration.

Table 4-3. Summary of point sources and tributaries used in LA-QUAL

Subsegment	Point source/ tributary name	Flow (mgd)	DO (mg/L)	$CBOD_u$ (mg/L)	Org N (mg/L)	Ammonia (mg/L)	NO_3+NO_2 (mg/L)	Comment
120401	Trib 1 outflow	-166.775	3.70	3.42	0.95	0.05	0.02	Flow to another waterbody
120401	Trib 2 inflow	51.713	3.70	3.42	2.00	0.05	0.02	Tributary
120401	Trib 3 outflow	-441.501	3.70	3.42	0.95	0.05	0.02	Flow to another waterbody
120401	Trib 5 inflow	69.166	3.70	10.00	4.00	0.05	0.02	Tributary
120401	Trib 6 outflow	-73.045	3.70	3.42	0.95	0.05	0.02	Flow to another waterbody
120404	Trib 4 outflow	0.000	3.70	3.42	0.95	0.05	0.02	Flow to another waterbody
120406	LAG480431	0.003	5.00	103.50	0.80	0.10	0.04	Point source

4.14 Calibration and Model Results

Model calibration was a multistep process using ammonia, $CBOD_u$, and SOD concentrations for each reach, starting with the most upstream reach and working down to the outflow reach. Organic nitrogen was first adjusted so that predicted concentrations matched observed data. The ammonia and nitrate loads were then adjusted so that the predicted nitrogen concentrations would match the observed concentrations. After ammonia was calibrated, the $CBOD_u$ loads were adjusted until the predicted $CBOD_u$ concentrations were similar to the observed concentrations. Finally, SOD was adjusted until the predicted dissolved oxygen concentrations were similar to the observed concentrations.

Table 4-4 lists the oxygen demand loadings for calibration conditions, which were based on existing conditions. Overall, the model did well in predicting the observed values for temperature, ammonia, BOD, and dissolved oxygen, and the model was considered adequately calibrated on the basis of the data available. Plots of observed and calibration water quality are presented in Appendix E. Figure 4-1 is an example calibration plot.

Table 4-4. Existing oxygen demand

Subsegment	Oxygen demand (lb/d)				
	SOD	$CBOD_u$	Ammonia	Organic N	Total
120401	43,901	159,751	3,470	70,918	278,040
120404	15,878	10,106	473	10,554	37,011
120405	63,585	8,731	803	5,835	78,954
120406	58,273	48,323	5,923	17,675	130,194

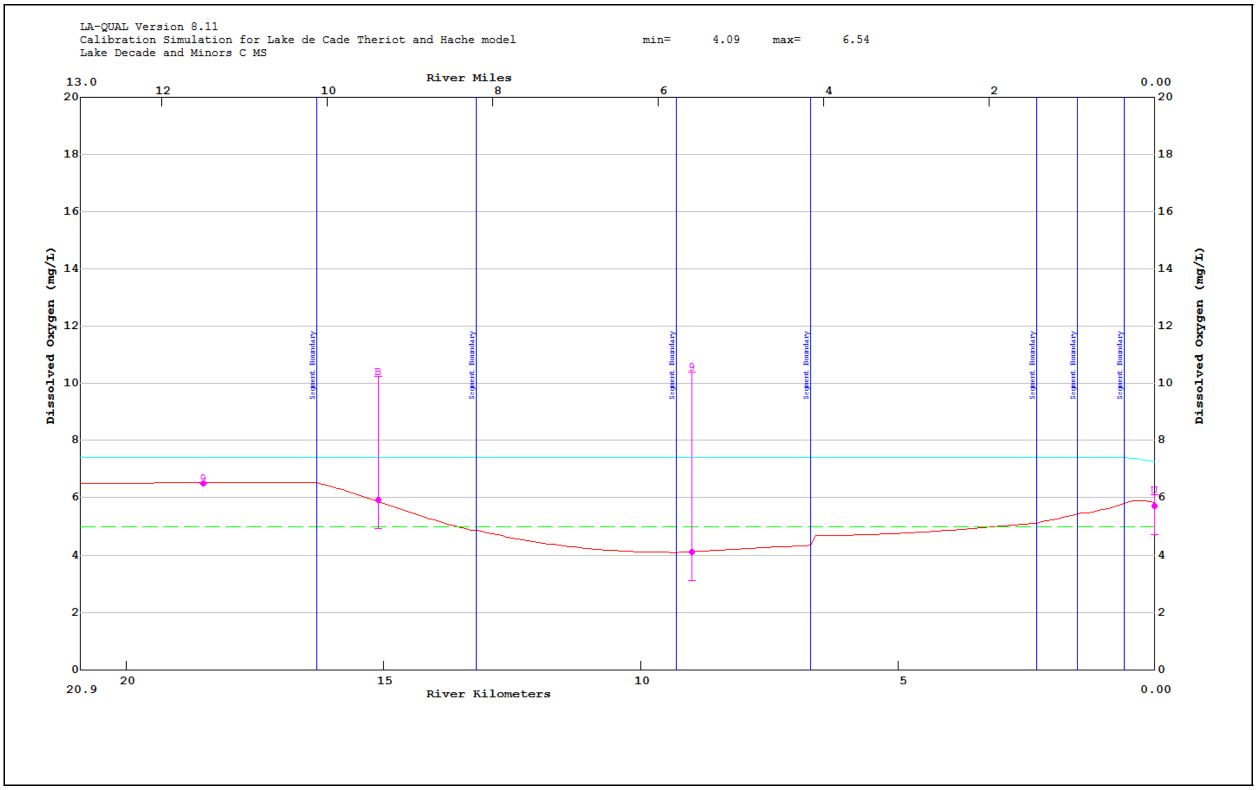

Figure 4-1. Calibration plot for dissolved oxygen in subsegment 120406.

5 WATER QUALITY MODEL PROJECTION

EPA's regulations at 40 CFR 130.7 require that parties determining TMDLs take into account critical conditions for stream flow, loading, and water quality parameters. The calibrated model was used to project water quality for critical conditions. Two scenarios were run for the critical conditions: baseline and TMDL. The model was run for baseline conditions, which used the same water quality and model parameters as the calibration model; however, the flow and temperature were changed to critical conditions and effluent water quality from permitted dischargers were changed to permit limits. The TMDL model run was the same as the baseline run; however, pollutant loadings were reduced so that dissolved oxygen met criteria at all locations. Identifying critical conditions and the model input data used for critical conditions are discussed in this section. Appendix F contains the baseline output files and Appendix G contains the TMDL output files. The output files include the input parameters.

5.1 Identification of Critical Conditions

The LDEQ LTP defines critical conditions in terms of flow and temperature. Critical flow conditions for tidally influenced regions are simulated using one-third the average or typical flow averaged over one tidal cycle, irrespective of flow. In addition, all point sources are assumed to be discharging at design capacity and at their permit limits. The LTP specifies that the critical temperature should be determined by calculating the 90^{th} percentile seasonal temperature for the waterbody being modeled, if data are available. Otherwise, 30 degrees Celsius (ºC) was used.

5.2 Temperature Inputs

The critical temperatures for the headwaters were based on the 90^{th} percentile temperature of LDEQ ambient monitoring in the representative subsegment. A critical temperature of 30 °C was used for incremental and wasteload inputs. Because these subsegments have a year-round standard for dissolved oxygen, a winter projection simulation was not performed. The most critical time of year for meeting a constant dissolved oxygen standard is the period of high temperatures and low flows.

5.3 Headwater and Tributary (Wasteload) Inputs

The inputs for the headwater and tributaries for the projection simulation were based on guidance in the LTP. According to the LTP, the critical flow rates for tidal systems for summer should be set to one-third the average or typical flow averaged over one tidal cycle, irrespective of flow. These flows were calculated for headwater and tributary model flows and used in the baseline and TMDL model predictions.

Dissolved oxygen from headwaters and tributaries were set to the water quality criterion of 5 mg/L or the observed concentration, whichever was greater. $CBOD_u$ levels from headwaters and tributaries were reduced until modeled dissolved oxygen met the criteria. The ammonia levels were low from both the headwaters and tributaries; therefore, the ammonia inputs were not changed from the calibration values.

5.4 Point Source Inputs

Ammonia and organic nitrogen levels were changed from observed or assumed concentrations to proposed concentrations. The nitrogen concentrations were assumed to be half the amount of the oxygen demand, with two-thirds assumed to be ammonia loading and one-third as organic nitrogen loading. These assumptions are consistent with information presented in the LTP. If necessary, input concentrations were reduced to keep the dissolved oxygen concentration above 5 mg/L.

5.5 Downstream Values

Modeling parameters for downstream boundary conditions were the same as the calibration parameters except for temperature and dissolved oxygen. The temperature was set to the critical condition. The dissolved oxygen value, if below criteria, was set to the water quality standard of 5.0 mg/L.

5.6 Baseline Model Results

Baseline line conditions were run under critical conditions for calibrated parameters and water quality values. Plots of baseline water quality are presented in Appendix H. Baseline oxygen demand is presented in Table 5-1.

Table 5-1. Baseline oxygen demand

Subsegment	Oxygen demand (lb/d)				
	SOD	$CBOD_u$	Ammonia	Organic N	Total
120401	43,901	119,192	2,362	53,299	218,754
120404	15,878	10,056	467	10,498	36,900
120405	63,585	17,311	1,391	12,957	95,243
120406	58,273	48,450	5,944	17,838	130,505

5.7 Model Results for Projection

Several steps were used to develop the reduction percentages for oxygen demand. The TMDL was calculated by first iteratively reducing SOD. After meeting the dissolved oxygen criterion by reducing SOD, the CBOD reduction rate was calculated by the SOD/CBOD relationship ($SOD = a \times \sqrt{CBOD}$). Slight adjustments were made to the SOD reduction rate, and an updated CBOD reduction rate was calculated. This process was repeated until the optimal reduction rates were determined.

To meet the dissolved oxygen standard, 5.0 mg/L, total oxygen demand must be reduced from less than 1 to 21 percent. This percentage reduction for nonpoint source loads represents a percentage of the entire nonpoint source loading, not a percentage of the man-made nonpoint source loading. The nonpoint source loads in this report were not divided between natural and man-made because it would be difficult to estimate natural nonpoint source loads. Plots of predicted water quality are presented in Appendix I.

6 TMDL DEVELOPMENT

A TMDL is the total amount of a pollutant that a receiving waterbody can assimilate while still achieving water quality standards. In TMDL development, allowable loadings from all pollutant sources that cumulatively amount to no more than the TMDL must be established, thereby providing the basis for establishing water quality-based controls.

A TMDL for a given pollutant and waterbody is composed of the sum of individual wasteload allocations (WLAs) for point sources and load allocations (LAs) for nonpoint sources and natural background levels. In addition, the TMDL must include an implicit or explicit margin of safety (MOS) to account for the uncertainty in the relationship between pollutant loads and the quality of the receiving waterbody, and it may include a future growth (FG) component. The TMDL components are illustrated using the following equation:

$$TMDL = \Sigma WLAs + \Sigma LAs + MOS + FG$$

The LA is the portion of the TMDL assigned to nonpoint sources such as natural background loadings. For this TMDL, the LA was calculated by subtracting the WLA, MOS, and FG from the total TMDL allocation. LAs were not allocated to separate nonpoint sources because of the lack of available source characterization data.

The WLA portion of the TMDL equation is the total loading of a pollutant that is assigned to point sources. The permitted or average (expected or observed) flows were used to calculate the WLAs. If the permitted or average flow was unavailable, the permit maximum flow was used. The permit maximum flow was usually the maximum flow covered by the specific type of general permit. For example, the LPDES Class II Sanitary General Permit covers facilities with flow of up to 25,000 gallons per day. Sometimes the permit maximum flow was significantly greater than the expected flow, and therefore the permit maximum was used only when other flows were not available.

Section 303(d) of the Clean Water Act and the regulations at 40 CFR 130.7 require that TMDLs include an MOS to account for uncertainty in available data or in the actual effect that controls will have on the loading reductions and receiving water quality. The MOS may be expressed explicitly as unallocated assimilative capacity or implicitly using conservative assumptions in establishing the TMDL. In addition to the MOS, an FG component may be added to account specifically for FG in the TMDL area.

There are two ways to incorporate the MOS (USEPA 1991). One way is to implicitly incorporate it by using conservative model assumptions to develop allocations, including the following:

- *Using slightly higher water temperatures than the suggested water temperature.* If dissolved oxygen meets the criterion with higher water temperature, it will meet the criterion with lower water temperature when other factors remain unchanged.
- *Using the dissolved oxygen water quality criterion for model inflows.* Dissolved oxygen from headwaters and tributaries was set to the water quality criterion, which is lower than the 90 percent saturation level of dissolved oxygen at 30 ºC.

The other way is to explicitly specify a portion of the TMDL as the MOS and use the remainder for allocations. For this analysis, the MOS is explicit: 10 percent of each targeted TMDL was reserved as the MOS to account for any uncertainty in the TMDL. Using 10 percent of the TMDL load provides an additional level of protection to the designated uses of the subsegments of concern.

The MOS is an allocation for scientific uncertainly, while the FG is an allocation for growth. Ten percent of the load was allocated for FG in the area covered by the TMDL. This growth includes future urban development, including point sources, MS4 areas, agriculture, and other nonpoint sources. The FG could also be used for sources not accounted for or unknown and therefore not otherwise included in the TMDL.

6.1 Dissolved Oxygen TMDLs

The dissolved oxygen TMDLs are presented as oxygen demand from $CBOD_u$, ammonia, organic nitrogen, and SOD, and they were derived using the LA-QUAL model. A summary of the TMDLs is presented in Table 6-1. The TMDLs were calculated from SOD, $CBOD_u$, ammonia, and organic nitrogen from nonpoint source model inputs, tributary flows, incremental flows, and background. Table 6-2 presents a summary of the reduction percentages for LAs; there were no reductions for WLAs, thus reductions from point sources are not required as a result of this TMDL. The reduction percentages for total oxygen demand ranged from less than 1 to 21 percent.

The WLA is presented in Table 6-3. It was calculated using weekly average permit limit and the expected discharge flow. The nitrogen loading was assumed to be half the amount of the oxygen demand, with two-thirds was assumed to be ammonia loading and one-third as organic nitrogen loading. These assumptions are consistent with information presented in the LTP. Reductions from point source discharges are not required as a result of this TMDL.

Table 6-1. Summary of dissolved oxygen TMDLs, WLAs, LAs, MOSs, and FGs for the lower Terrebonne Basin

Subsegment	Oxygen demand (lb/d)				
120401	SOD	$CBOD_u$	Ammonia	Organic Nitrogen	Total
WLA	0.00	0.00	0.00	0.00	0.00
MOS for WLA	0.00	0.00	0.00	0.00	0.00
FG for WLA	0.00	0.00	0.00	0.00	0.00
LA	35,121.04	95,353.91	1,889.29	42,639.13	175,003.37
MOS for LA	4,390.13	11,919.24	236.16	5,329.89	21,875.42
FG for LA	4,390.13	11,919.24	236.16	5,329.89	21,875.42
TMDL	43,901.30	119,192.39	2,361.61	53,298.91	218,754.22

Table 6-1. (continued)

Subsegment	Oxygen demand (lb/d)				
120404	**SOD**	**$CBOD_u$**	**Ammonia**	**Organic Nitrogen**	**Total**
WLA	0.00	0.00	0.00	0.00	0.00
MOS for WLA	0.00	0.00	0.00	0.00	0.00
FG for WLA	0.00	0.00	0.00	0.00	0.00
LA	12,674.81	8,045.13	373.67	8,398.65	29,492.25
MOS for LA	1,584.35	1,005.64	46.71	1,049.83	3,686.53
FG for LA	1,584.35	1,005.64	46.71	1,049.83	3,686.53
TMDL	15,843.51	10,056.41	467.08	10,498.31	36,865.32
Subsegment	**Oxygen demand (lb/d)**				
120405	**SOD**	**$CBOD_u$**	**Ammonia**	**Organic Nitrogen**	**Total**
WLA	0.00	0.00	0.00	0.00	0.00
MOS for WLA	0.00	0.00	0.00	0.00	0.00
FG for WLA	0.00	0.00	0.00	0.00	0.00
LA	50,867.98	5,509.87	671.26	3,031.74	60,080.84
MOS for LA	6,358.50	688.73	83.91	378.97	7,510.11
FG for LA	6,358.50	688.73	83.91	378.97	7,510.11
TMDL	63,584.98	6,887.33	839.07	3,789.67	75,101.06
Subsegment	**Oxygen demand (lb/d)**				
120406	**SOD**	**$CBOD_u$**	**Ammonia**	**Organic Nitrogen**	**Total**
WLA	0.00	1.54	0.96	0.48	2.98
MOS for WLA	0.00	0.19	0.12	0.06	0.37
FG for WLA	0.00	0.19	0.12	0.06	0.37
LA	46,618.22	38,758.46	4,754.46	14,269.76	104,400.90
MOS for LA	5,827.28	4,844.81	594.31	1,783.72	13,050.11
FG for LA	5,827.28	4,844.81	594.31	1,783.72	13,050.11
TMDL	58,272.78	48,450.00	5,944.28	17,837.80	130,504.86

Table 6-2. Summary of percent reductions for LAs in the lower Terrebonne Basin

Subsegment	Percent reduction				
	SOD	**$CBOD_u$**	**Ammonia**	**Organic Nitrogen**	**Total**
120401	0.00	0.00	0.00	0.00	0.00
120404	0.22	0.00	0.00	0.00	0.09
120405	0.00	60.21	39.69	70.75	21.15
120406	0.00	0.00	0.00	0.00	0.00

Table 6-3. WLAs for lower Terrebonne Basin

NPDES permit number	Outfall	Facility name	Flow (mgd)	Parm.	Conc. (mg/L)	Load (lb/d)
LAG480431	001	The Offshore Drilling Company	0.00178	BOD_5	45.0	0.668
				Ammonia	15.0	0.223
				Org. Nit.	7.5	0.139

6.1.1 Seasonal Variation

Critical conditions for dissolved oxygen in Louisiana waterbodies have been determined to be the following: negligible nonpoint runoff and low stream flow combined with high water temperatures. Oxygen-demanding substances can enter a water system during high flows and settle to the bottom, where they exert a large oxygen demand during the high-temperature/low-flow seasons. Water temperature is one of the leading factors that affect dissolved oxygen in the three segments. High water temperatures lower the dissolved oxygen saturation concentration, decreasing the amount of dissolved oxygen that the stream can contain. In addition, high temperature increases CBOD decay and SOD. Therefore, it is most important to develop a TMDL to address the high-water-temperature conditions.

6.1.2 Sensitivity Analysis

A sensitivity analysis was performed on the model parameters using the sensitivity function built into LA-QUAL. LA-QUAL automatically changed the requested parameters by a set amount while keeping all other parameters constant. The calibration scenario was used as the baseline for the sensitivity analysis. For the analysis, all parameters were varied by ±30 percent. The results for dissolved oxygen and BOD are shown in Table 6-4. Result plots are shown in Appendix J. Changes to the stream reaeration, stream velocity, and background SOD had the largest influence on dissolved oxygen levels. Stream dispersion had no effect on dissolved oxygen.

Table 6-4. Results of sensitivity analysis

		BOD_u (mg/L)						DO (mg/L)					
		BOD aerobic decay rate	BOD settling rate	Stream dispersion	Stream reaeration	Background SOD	Stream velocity	BOD aerobic decay rate	BOD settling rate	Stream dispersion	Stream reaeration	Background SOD	Stream velocity
120401	-30%	6.16	5.44	6.21	5.44	5.44	4.58	5.81	5.62	5.71	5.42	6.17	5.69
	base	5.44	5.44	5.44	5.44	5.44	5.44	5.62	5.62	5.62	5.62	5.62	5.62
	30%	4.82	5.44	4.84	5.44	5.44	5.99	5.46	5.62	5.55	5.75	4.98	5.59
120404	-30%	1.71	1.27	1.24	1.27	1.27	0.85	4.70	4.70	4.70	4.04	4.70	4.70
	base	1.27	1.27	1.27	1.27	1.27	1.27	4.70	4.70	4.70	4.70	4.70	4.70
	30%	0.96	1.27	1.31	1.27	1.27	1.60	4.65	4.70	4.70	4.70	3.97	4.70
120405 (Lake Hatch)	-30%	17.91	14.07	15.21	14.07	14.07	11.03	6.99	6.68	6.47	6.59	7.74	7.56
	base	14.07	14.07	14.07	14.07	14.07	14.07	6.68	6.68	6.68	6.68	6.68	6.68
	30%	11.52	14.07	13.15	14.07	14.07	16.53	6.53	6.68	6.81	6.75	5.61	6.17
120405 (Lake Theriot)	-30%	2.72	2.72	2.72	2.72	2.72	2.72	2.64	5.47	6.00	5.12	6.73	6.36
	base	2.72	2.72	2.72	2.72	2.72	2.72	5.78	5.78	5.78	5.78	5.78	5.78
	30%	2.72	2.72	2.72	2.72	2.72	2.72	2.72	5.66	5.62	6.16	4.83	5.43
120406	-30%	2.72	2.10	2.41	2.10	2.10	1.22	4.41	4.04	4.03	3.07	4.87	4.34
	base	2.10	2.10	2.10	2.10	2.10	2.10	4.04	4.04	4.04	4.04	4.04	4.04
	30%	1.43	2.10	1.86	2.10	2.10	2.72	3.80	4.04	4.05	4.63	3.20	3.86

6.1.3 Ammonia Toxicity Analysis

An analysis was performed on the model input and modeled results to determine whether the modeled ammonia concentrations exceeded EPA criteria for ammonia toxicity (USEPA 1999). The EPA criteria are dependent on temperature and pH. Temperature was taken from the model output. Because pH is not included in the model, it was obtained from levels observed during the July 2006 monitoring event. The resulting criteria and the model-predicted ammonia concentrations are presented in Table 6-5. These concentrations were below the EPA ammonia toxicity criteria and show that the criteria will not be exceeded during critical conditions. These results do not require ammonia or organic nitrogen permit limits for the permits included in this document. If LDEQ determines there is no reasonable potential for a discharger to exceed the ammonia or organic nitrogen WLAs, then a permit may omit these parameters and still comply with this TMDL. The ammonia toxicity calculations are included in Appendix K.

Table 6-5. Predicted ammonia concentration and calculated critical criteria

Subsegment	Predicted ammonia (mg/L)		Calculated critical criteria (mg/L)	
	Minimum	Maximum	Minimum	Maximum
120401	0.09	0.15	0.32	1.70
120404	0.04	0.16	1.98	2.04
120405	0.04	0.11	0.11	1.27
120406	0.06	0.11	0.92	0.92

6.2 Nutrient TMDLs

Nutrients can enter a water system through surface runoff. Once they are in the environment, the most recognizable effect is algae blooms. The buildup of nutrients that leads to the blooms can occur over time even if the effects are not noticed in the short term. When algae die, the result is increased oxygen demand, which is detrimental to aquatic life.

The state's nutrient criteria are narrative and include the following language (LDEQ 2007):

> 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.

To accomplish this, water quality data were collected from non-nutrient impaired subsegments in the Terrebonne Basin. The data included total phosphorus, nitrate+nitrite, and TKN. The nitrate+nitrite and TKN were summed to obtain the total nitrogen concentration. Table 6-6 presents the average concentrations by monitoring location for the non-impaired subsegments. The minimum, mean, and maximum are presented for total phosphorus and total nitrogen.

The data in Table 6-6 were compared with the observed data for the nutrient-impaired subsegments in Table 6-7. The total nitrogen to total phosphorus ratio and mean concentrations in the nutrient listed subsegments are within the ratio and concentration ranges for the non-impaired subsegments. Because of this, no nutrient reductions were necessary for the subsegments listed in Table 6-7.

Table 6-6. Nutrient concentrations in non-impaired subsegments

Subsegment	Subsegment name	Site ID	Total P (mg/L)	NO_2+NO_3 (mg/L)	TKN (mg/L)	Total N (mg/L)	Total N/ total P ratio
120205	Lake Palourde	338	0.15	0.16	1.17	1.33	8.87
120402	Bayou Chene	933	0.15	0.80	0.81	1.60	10.67
120506	Bayou du Large	941	0.15	0.25	0.98	1.23	8.20
120508	Houma Navigation Canal	344	0.13	0.36	0.77	1.13	8.69
120703	Bayou du Large	950	0.14	0.10	0.94	1.04	7.43
		Minimum	0.13	0.10	0.77	1.04	8.00
		Mean	0.14	0.33	0.93	1.27	9.07
		Maximum	0.15	0.80	1.17	1.60	10.67

Table 6-7. Nutrient concentrations in the impaired subsegments in the lower Terrebonne Basin

Subsegment	Subsegment name	Total P (mg/L)	NO_2+NO_3 (mg/L)	TKN (mg/L)	Total N (mg/L)	Total N/ total P ratio
120405	Lake Hatch and Lake Theriot	0.11	0.37	0.89	1.25	11.36
120406	Lake de Cade	0.11	0.19	0.95	0.82	7.45

Because of the lack of flow data for the Terrebonne Basin, the monthly water yield (runoff in millimeters) was used to obtain TMDL loadings. The monthly water yield for the Southeast Climate Division was obtained from the Louisiana Office of State Climatology. The monthly water yield was divided by the number of days in the month to obtain runoff intensity. The average water yield was 2.402 millimeters.

The nutrient TMDLs are presented in Table 6-8. The water yield was used with the mean reference stream concentration to determine the LA portion of the TMDL. Because no reductions to nutrients were required, 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 nutrient effluent concentrations could require additional monitoring and modeling and a revision to this TMDL.

Table 6-8. Summary of nutrient TMDLs, WLAs, LAs, MOSs, and FGs for the lower Terrebonne Basin

Subsegment	∑ WLA (lb/d)	∑ LA (lb/d)	MOS	FG (10%) (lb/d)	Total allowable loading(lb/d)	Percent reduction
Total phosphorus						
120405	0.000	0.096	Implicit	0.011	0.106	0.000
120406	0.000	0.158	Implicit	0.018	0.176	0.000
Total nitrogen						
120405	0.000	0.868	Implicit	0.10	0.96	0.000
120406	0.000	1.403	Implicit	0.16	1.56	0.000

7 FUTURE ACTIVITIES

7.1 TMDL Implementation Strategies

EPA Region 6 has funded a use attainability assessment (UAA) study for the *Development of Site-Specific Dissolved Oxygen Criteria for the Terrebonne Basin, Louisiana*. On January 31, 2008, the contractor (Tetra Tech, Inc.) submitted a draft report for EPA'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 EPA approves the revised dissolved oxygen criteria, LDEQ will reassess the 303(d) listed subsegments for dissolved oxygen 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 dissolved oxygen and nutrients TMDLs may be withdrawn, and EPA 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 dissolved oxygen and nutrients TMDLs may be revised, and EPA will publish a public notice.

Reasonable assurance is needed that the water quality criterion will be attained. As a first step to implement these dissolved oxygen and nutrients TMDLs, it is recommended that LDEQ complete a reassessment of the 303(d)-listed subsegments in the Terrebonne Basin using the new adopted dissolved oxygen criteria to verify if the subsegment is not impaired or still considered impaired. WLAs will be implemented through Louisiana Pollutant Discharge Elimination System (LPDES) permit procedures. Part of the LAs might be implemented through the LDEQ 305(b) program and set priorities for the Clean Water Act section 319 program. BMPs from the implementation plan will be implemented throughout the subsegment. This approach will reduce the loadings and improve dissolved oxygen levels in the subsegment and subsequent downstream subsegments.

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 percent 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 EPA and LDEQ, are engaged in collecting environmental data and assessing the recovery of the Gulf of Mexico waters.

The proposed TMDLs in this report were developed on the basis of pre- and post-hurricane water quality conditions. Some point sources in this TMDL have been updated with post-hurricane information, where available. Post-hurricane water quality conditions and other factors could delay the implementation of these proposed TMDLs, render some proposed 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.

7.2 Environmental Monitoring Activities

LDEQ uses funds provided under section 106 of the Clean Water Act and under the authority of the Louisiana Environmental Quality Act to run a program for monitoring the quality of Louisiana's surface waters. The LDEQ Surveillance Section collects surface water samples at various locations using appropriate sampling methods and procedures to ensure 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 database for water quality trend analysis, and to monitor the effectiveness of pollution controls. The data obtained through the surface water monitoring program are used to develop the state's biennial section 305(b) report (*Water Quality Inventory*) and section 303(d) list of impaired waters.

LDEQ has implemented a watershed approach to surface water quality monitoring. Through the approach, the entire state is sampled on a 4-year cycle. Long-term trend monitoring sites at various locations on the large rivers and Lake Pontchartrain are sampled throughout the 4-year cycle. Sampling is conducted monthly to yield approximately 12 samples per site during each year the site is monitored. Sampling sites are located where they are considered representative of the waterbody. Under the current monitoring schedule, approximately one-half of the state's waters are newly assessed for section 305(b) and section 303(d) listing purposes during each biennial cycle; sampling occurs 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.
Monitoring will allow LDEQ to determine whether there has been any improvement in water quality following TMDL implementation. As the monitoring results are evaluated at the end of each year, waterbodies might be added to or removed from the section 303(d) list of impaired waterbodies.

8 PUBLIC PARTICIPATION

Federal regulations require EPA to notify the public and seek comments concerning TMDLs that the Agency prepares. These TMDLs were developed under contract to EPA, and EPA 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.

LDEQ submitted the only comments received during the public comment period. Comments and additional information submitted during this public comment period were used to inform or revise this TMDL document. The comments and responses to these TMDLs, along with comments on similar TMDLs with the same public review period, will be included in the document: *EPA Responses to Comments for Dissolved Oxygen, Nutrients, pH, and Mercury TMDLs in the Red River, Sabine River, and Terrebonne Basins, Louisiana.*

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

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