TMDLS FOR pH FOR SUBSEGMENTS 120205 AND 120402 IN THE TERREBONNE BASIN, LOUISIANA

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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 loads (TMDLs) for those waterbodies. A TMDL is the amount of a pollutant that a waterbody can assimilate without exceeding the established water quality standards for that pollutant. Through a TMDL, pollutant loads can be allocated to point sources and nonpoint sources discharging to the waterbody.

This report presents TMDLs that have been developed for pH for Subsegments 120205 (Lake Palourde) and 120402 (Bayou Chene, from the Intracoastal Waterway to Bayou Penchant) in the Terrebonne basin in southern Louisiana. Both subsegments are located near Morgan City, Louisiana. Land in these subsegments is primarily wetlands or covered by water. Subsegment 120205 encompasses approximately 74 square miles, and Subsegment 120402 encompasses approximately 91 square miles.

These subsegments were included on the Louisiana Department of Environmental Quality (LDEQ) final 2004 303(d) list as not supporting their fish and wildlife propagation designated uses due to high pH, and were ranked as priority #1 for TMDL development. Crop production was identified as the suspected source of high pH values in Subsegment 120205. The maximum pH criteria are 8.5 su for Subsegment 120205 and 8.0 su for Subsegment 120402. These maximum pH criteria are lower than the maximum criterion for most Louisiana waterbodies (9.0 su).

In these TMDLs, it is assumed that the exceedences of the maximum pH criteria in Subsegments 120205 and 120402 occur because high algal production, which is supported by nutrient inputs to the waterbodies, depletes free carbon dioxide in the water column and elevates the pH. Therefore, the pollutant loads specified for these TMDLs are loads of nutrients (total phosphorus and total nitrogen). The computer model QUAL-2Kw version 5.1 was used to evaluate the linkages between nutrient inputs, algal productivity, and pH levels in Lake Palourde (Subsegment 120205) and Bayou Chene (Subsegment 120402). The critical period for these TMDLs is the period of high productivity during the summer. The nutrient loads from runoff within the city limits of Morgan City was included in the wasteload allocation for point sources because the Morgan City is regulated by a Municipal Separate Storm Sewer System (MS4) permit. The TMDLs and percent reductions needed are summarized in Table ES.1. These TMDLs include a 10% explicit margin of safety and 10% future growth component.

Table ES.1. Summary of TMDLs and percent load reductions.

	Subsegment 120205		**Subsegment 120402**	
	Phosphorus (kg/day)	**Nitrogen (kg/day)**	**Phosphorus (kg/day)**	**Nitrogen (kg/day)**
TMDL	893	9,676	4,920	37,000
MOS	89	968	492	3,700
FG	89	968	492	3,700
WLA	12	77	0	0
LA	703	7,664	3,936	29,600
Reduction	58%	31%	76%	44%

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1.0 INTRODUCTION

This report presents total maximum daily loads (TMDLs) for pH for Subsegments 120205 (Lake Palourde) and 120402 (Bayou Chene from the Intracoastal Waterway to Bayou Penchant) in the Terrebonne basin of southern Louisiana. The pH, which is the negative logarithm of the hydrogen ion concentration, is an indicator of the acidity (acidic) and alkalinity (basic) of the waterbody. pH is measured on a scale of 0 to 14, whereby a measure of 7.0 indicates neutrality. A pH value less than 7.0 indicates acidic conditions and a value greater than 7.0 indicates alkaline conditions.

Subsegments 120205 and 120402 were listed on the 2004 Integrated Report Modified Court Ordered 303(d) List for Louisiana (USEPA 2004) as not fully supporting the designated use of propagation of fish and wildlife, and were ranked as priority #1 for TMDL development. The suspected cause of the impairment for each subsegment is pH exceedances. Included in Table 1.1 is a summary of the suspected sources and suspected causes for impairment in the 303(d) List. 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 in Title 40 Code of Federal Regulations (CFR) Part 130.7.

Table 1.1. Summary of 303(d) Listing of Subsegments 120205 and 120402 (USEPA 2004).

Subsegment Number	Waterbody Description	Suspected Sources	Suspected Causes	Priority Ranking (1 = highest)
120205	Lake Palourde	Non-irrigated crop production	pH	1
120402	Bayou Chene – from Intracoastal Waterway to Bayou Penchant	Source Unknown	pH	1

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), future growth (FG), 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, including natural background. The FG allows for FG in loads to the waterbody. The MOS is a percentage of the TMDL that takes into account uncertainty concerning the relationship between pollutant loadings and water quality.

2.0 BACKGROUND INFORMATION

2.1 General Information

Lake Palourde (Subsegment 120205) and Bayou Chene (Subsegment 120402) are located in the Terrebonne basin in southern Louisiana, near Morgan City, and approximately 50 miles south of Baton Rouge (Figure A.1, Appendix A). Subsegment 120205 (Lake Palourde) includes portions of four parishes: St. Martin, Assumption, St. Mary, and Lafourche. The western edge of the subsegment includes Morgan City. The area included in Subsegment 120205 is approximately 74 square miles (192 square kilometers). Lake Palourde itself has a surface area of approximately 17 square miles.

Subsegment 120402 (Bayou Chene from the Intracoastal Waterway to Bayou Penchant) is located south of Morgan City and includes portions of St. Mary Parish and Terrebonne Parish. Bayou Chene is located in the northeast corner of the subsegment, which extends south to the Gulf of Mexico and includes a number of small tributaries and waterbodies connected to Bayou Chene. The subsegment encompasses an area of approximately 91 square miles (236 square kilometers). The Intracoastal Waterway flows along the northern portion of this subsegment and Bayou Avoca is along the western edge.

2.2 Land Use Information

Land use characteristics for Subsegments 120205 and 120402 of the Terrebonne basin were compiled using the United States Geological Survey (USGS) 2001 National Land Cover Dataset (USGS 2006). A map depicting the land use designations for Subsegments 120205 and 120402 is included in Appendix A (Figure A.2). As shown in Table 2.1, the primary land uses in Subsegments 120205 and 120402 are water and wetlands (over 90%). These subsegments are located in lower Louisiana near or along the Gulf of Mexico coast (Figure A.1), so this is not unexpected. A portion of Morgan City is located in Subsegment 120205, although the majority of the subsegment, as well as Subsegment 120402, is very rural and unpopulated.

Table 2.1. Land uses percentages in Subsegments 120205 and 120402 (USGS 2006).

Land Use Type	Lake Palourde Subsegment 120205	Bayou Chene Subsegment 120402
Water	24.6%	20.4%
Urban	7.3%	0.1%
Barren	0.0%	1.1%
Forest	0.0%	0.0%
Grassland/Pasture	0.9%	0.3%
Cultivated Crops	0.5%	0.0%
Wetlands	66.7%	78.1%
TOTAL	**100.0%**	**100.0%**

2.3 Water Quality Standards

The numeric water quality criteria and designated uses for the subsegments are shown in Table 2.2. The primary numeric criterion for the TMDLs presented in this report is the pH range, which can vary by subsegment, and is applicable year round. Both Subsegments 120205 and 120402 have pH water quality criteria that are different than the general criteria (6.0-9.0 su) (LAC 33:IX.1123).

The Louisiana water quality standards also include an antidegradation policy (LAC 33: IX.1109.A). This policy states that state 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 the 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.

Table 2.2. Water quality criteria and designated uses for TMDL subsegments (LDEQ 2006).

	Subsegment 120205	**Subsegment 120402**
Waterbody Description	Lake Palourde	Bayou Chene from Intracoastal Waterway to Bayou Penchant
Designated Uses	ABCD	ABC
Criteria:		
Chloride	100 mg/L	250 mg/L
Sulfate	75 mg/L	75 mg/L
DO	5.0 mg/L (year-round)	5.0 mg/L (year-round)
pH	6.0-8.5 su	6.5-8.0 su
Temperature	32 °C	32 °C
TDS	350 mg/L	500 mg/L

USES: A – primary contact recreation; B – secondary contact recreation; C – propagation of fish and wildlife; D – drinking water supply; E – oyster propagation; F – agriculture; G – outstanding natural resource water; L – limited aquatic life and wildlife use.

2.4 Point Sources

A listing of NPDES permits point source dischargers in the Terrebonne basin of Louisiana was prepared by the Louisiana Department of Environmental Quality (LDEQ) using their internal databases. The list generated was used as the basis for a search through LDEQ's Electronic Document Management System (EDMS) in order to extract relevant permit information, (i.e., flows, permit limits, facility location, and receiving stream). Eight permitted dischargers that could contribute nutrient loads (the suspected cause of pH impairment) to Subsegment 120205 were identified for inclusion in the TMDL calculations (Table B.1, Appendix B). None were identified for Subsegment 120402. Point sources were not identified as suspected sources of the pH impairments in these subsegments in the 2004 Louisiana 303(d) List (USEPA 2004).

2.5 Nonpoint Sources

The only suspected nonpoint source specifically identified on the 303(d) List for Louisiana (USEPA 2004) was non-irrigated crop production for Subsegment 120205 (See Table 1.1). No suspected sources of pH impairment in the Subsegment 120402 have been identified. The high pH values are likely related to excessive algal activity resulting from nutrient inputs.

2.6 Description of Hydrology

No published flow data were found for these subsegments, which are in low gradient areas with tidal influences. These characteristics, along with the fact that there is a high degree of interconnection among channels and wetlands in this area of Louisiana, mean that hydrology in these subsegments is complex and changeable.

2.7 Historical Data

Historical water quality data for both Subsegment 120205 and 120402 are available. The water quality data being collected from LDEQ Station 0338 on Lake Palourde near Morgan City is from 1991 until 2005. In Subsegment 120402, two LDEQ stations provide water quality data. LDEQ Station 0342, located on Bayou Chene southeast of Morgan City, includes water quality data collected from 1991 to 1998. LDEQ station 0933 is located on Bayou Avoca, which is a tributary of Bayou Chene at Sword Bayou, and includes water quality data collected from 2000 and 2005. Locations of LDEQ water quality stations are shown in Figure A.1 (Appendix A). Table 2.3 is a summary of the pH data collected at these stations, including percentages of pH values above the pH criteria. Plots of these data are included in Appendix C.

It is important to note that the water quality standards upper limit for pH for both subsegments (8.5 and 8.0 su) is lower than the general criterion (9.0 su). The historical water quality data collected at LDEQ station 0338 in Subsegment 120205 indicates that of the 76 measured values, a pH greater than 9.0 su only occurred eight times (approximately 11%). In Subsegment 120402, the measured pH data from LDEQ station 0342 shows no occurrences where the pH is greater than 9.0 su. In addition, at LDEQ station 0933, also in Subsegment 120402, of the 33 collected pH values only two were greater than 9.0 su. While the historical pH measurements in the subsegments do appear to exhibit increasing trends (Appendix C), even the oldest data exceed the criteria approximately once per year.

Table 2.3. Summary of available pH data.

Description	Station 0338	Station 0342	Station 0933
Station Description	Lake Palourde near Morgan City, LA (Subsegment 120205)	Bayou Chene southeast of Morgan City, LA (Subsegment 120402)	Bayou Avoca at Sword Bayou, LA (Subsegment 120402)
Subsegment Period of Record	2/5/91-12/6/06	2/5/91-4/14/98	1/18/00-12/6/06
No. of Values	76	43	33
Minimum (su)	7.20	7.24	7.05
Maximum (su)	9.71	8.62	9.05
Median (su)	8.30	7.70	7.93
No. values > pH criterion	31	13	15
% values > pH criterion	40.8%	30.2%	45.5%
No. values > 9 su	9	0	2
% Values > 9 su	11.8%	0%	6.1%

Other water quality data relevant to these TMDLs is summarized in Table 2.4. Alkalinity data gives an indication of the buffering capacity of the waterbodies, their ability to maintain neutral range pH. Nutrient concentrations are of interest because high algal productivity resulting from nutrient loads to the waterbodies is suspected to be the cause of the pH criteria exceedences. Historical alkalinity and TKN appear to exhibit increasing trends at all of the water quality stations. Total phosphorus in Lake Palourde also appears to exhibit an increasing trend. Total phosphorus in Bayous Chene and Avoca does not exhibit significant change over time (Appendix C).

2.8 Previous Studies

No previous water quality studies were found for either of these subsegments.

Table 2.4. Summary of alkalinity and nutrient data for LDEQ water quality stations in impaired subsegments.

Station	Description	Parameter[1]	Begin	End	Count	No. Values Below Detection	Min	Avg	Max
0338	Lake Palourde near Morgan City, LA (subsegment 120205)	Alkalinity (mg/L as CaCO3)	2/5/91	11/14/06	77	0	48	94	128
		Total phos. (mg/L)	2/5/91	7/18/06	73	1	0.02	0.14	0.32
		NO2+NO3 (mg/L)	2/5/91	7/18/06	73	17	0.01	0.13	0.68
		TKN (mg/L)	2/5/91	11/14/06	76	0	0.44	1.17	2.49
		NH3 (mg/L)	1/18/00	8/8/06	32	30	0.05	0.06	0.18
0342	Bayou Chene southeast of Morgan City, LA (subsegment 120402)	Alkalinity (mg/L as CaCO3)	2/5/91	4/14/98	43	0	53	88	130
		Total phos. (mg/L)	2/5/91	2/10/98	42	0	0.07	0.15	0.62
		NO2+NO3 (mg/L)	2/5/91	2/10/98	42	4	0.01	0.42	1.52
		TKN (mg/L)	2/5/91	2/10/98	42	0	0.26	0.87	1.69
		NH3 (mg/L)	See note 2						
0933	Bayou Avoca at Sword Bayou, LA (subsegment 120402)	Alkalinity (mg/L as CaCO3)	1/18/00	11/14/06	34	0	64	105	137
		Total phos. (mg/L)	1/18/00	7/18/06	31	0	0.06	0.15	0.26
		NO2+NO3 (mg/L)	1/18/00	7/18/06	31	0	0.06	0.80	2.23
		TKN (mg/L)	1/18/00	11/14/06	34	1	0.05	0.81	1.78
		NH3 (mg/L)	1/18/00	8/8/06	31	30	0.05	0.05	0.11

NOTES:
1. All values below the detection limit were set equal to half the detection limit for calculating statistics.
2. LDEQ did not collect ammonia data until 2000; thus there is no ammonia data for this station since no water quality data was collected after February 1998.

3.0 FIELD SURVEYS

FTN collected field data in Subsegments 120205 and 120402 during two intensive field surveys in the Terrebonne basin, one in July 2006 and another in September 2006. These dates were chosen to represent periods of high productivity likely to produce pH water quality criteria exceedences. The data that were collected included grab samples and continuous monitoring in situ measurements. The data collection sites were LDEQ sampling Stations 0338 and 0933 (Figure A.1, Appendix A). Table 3.1 summarizes the laboratory analyses results for the grab samples. Plots of the data collected by the continuous monitors for five in situ parameters: DO, DO percent saturation (which in two cases was estimated from the hydrolab temperature data), temperature, pH, and specific conductivity are included in Appendix D (Figures D.1 through D.20). These data are summarized in Table 3.2. The data collected during the field surveys exhibit high pH values consistent with excessive algal productivity. There were no large storms or other atypical weather during or immediately prior to either field survey.

Depth measurements were also made during the July field survey, in addition to the water quality measurements. Depth measurements were taken at the time the continuous monitors were deployed. In Lake Palourde, a survey rod was used to measure depths at several locations in the main body of the Lake. In Bayou Avoca, a transect was run using an acoustic Doppler instrument.

Table 3.1. Summary of laboratory results for grab samples.

Site No.	Site Name	Date	Time	Depth	Secchi (inches)	Alkalinity as $CaCO_3$ (mg/L)	Chlorophyll a (mg/L)	Total phosphorus (mg/L)	TKN (mg/L)
338	Lake Palourde near Morgan City, Louisiana	7/14/2006	1030	--	--	100	0.068	0.25	1.8
338	Lake Palourde near Morgan City, Louisiana	7/18/2006	733	2.5	9.6	110	0.065	0.36	2.1
338	Lake Palourde near Morgan City, Louisiana	9/25/2006	1333	5.8	12	120	0.045	0.28	2.4
338	Lake Palourde near Morgan City, Louisiana	9/27/2006	1541	5.8	12	120	0.055	0.25	1.7
933	Bayou Avoca at Sword Bayou, Louisiana	7/14/2006	919	--	--	120	0.07	0.16	1.9
933	Bayou Avoca at Sword Bayou, Louisiana	7/18/2006	939	1	10.8	110	<0.02	0.13	1.4
933	Bayou Avoca at Sword Bayou, Louisiana	9/25/2006	1503	8.5	11	120	0.065	0.22	1.6
933	Bayou Avoca at Sword Bayou, Louisiana	9/27/2006	1708	8.5	12	120	0.077	0.22	1.7

Table 3.2. Summary of continuous monitoring data.

Parameter	Statistic	Station 0338	Station 0338	Station 0933	Station 0933
Monitoring Period		12:05pm 7/16/06 - 7:35am 7/18/06	2:00pm 9/25/06 - 3:00pm 9/27/06	9:50am 7/14/06 - 9:20am 7/18/06	2:00pm 9/25/06 - 4:00pm 9/27/06
Temperature, C	Minimum	30.31	24.86	29.9	26.18
	Maximum	35.47	28.69	34.44	30.3
	Average	32.57	26.66	31.48	27.25
PH, su	Minimum	8.92	8.49	7.93	6.76
	Maximum	9.51	9.05	8.87	8.46
	Average	9.18	8.82	8.45	8.04
Specific Conductance, umhos/cm	Minimum	380	403	436	465
	Maximum	391	420	468	615
	Average	385	412	457	524
DO, mg/L	Minimum	3.92	5.58	5.62	6.04
	Maximum	13.27	11.67	14.04	9.41
	Average	7.89	7.90	8.35	6.81
DO Saturation, %	Minimum	52.6	67.9	73.6	76.2
	Maximum	189.6	151.0	194.7	120.2
	Average	108.6	98.9	112.6	85.9

4.0 CALIBRATION OF WATER QUALITY MODEL

In these TMDLs, it is assumed that pH excursions occur because of algal production depleting free carbon dioxide (CO_2) in the water column and elevating pH. The waterbodies in Subsegments 120205 and 120402 are not strongly buffered systems, with alkalinity concentrations typically less than 100 mg/L (Section 2.7, Appendix C), so algal production could result in elevated pH values (i.e., depletion of hydrogen ion). In part, this theory is corroborated by data showing dissolved oxygen (DO) supersaturation corresponding with elevated pH. Significant algal production results in DO supersaturation. Algal production is usually driven by nutrient loading. The pollutant loads for pH will be specified as loads of nutrients (e.g., total phosphorus) rather than hydrogen ion because the nutrient concentrations appear to be the indirect source of the pH excursions.

In order to evaluate the linkage between nutrient inputs, algal productivity, and pH levels, a computer simulation model was used. The model used for these TMDLs was QUAL-2Kw version 5.1 (Pelletier et al. 2006). QUAL-2Kw was set up to model Lake Palourde in Subsegment 120205, and Bayou Avoca in Subsegment 120402.

4.1 Calibration Period and Calibration Targets

The critical period for these TMDLs is the period of high algal productivity, during the summer. 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.

The data from the July and September field surveys (Section 3.0) were used as the calibration targets. The data collected during the surveys was representative of the critical period for these TMDLs. However, not all of the parameters modeled were measured during the survey, i.e., detritus, organic nitrogen, and inorganic and organic phosphorus. These parameters were estimated from those that were measured during the survey, as indicated in Table 4.1.

Table 4.1. Methods for estimating calibration targets for parameters not measured during surveys.

Model Parameter	Estimation Method
Organic nitrogen	Organic nitrogen = TKN - NH_4 - algal N Algal N estimated by converting chlorophyll a to biomass dry wt and using stoichiometric relationship of 72 Φg N / mg dry wt
Inorganic phosphorus	Total phosphorus * 0.333
Organic phosphorus	Total phosphorus * 0.667
Detritus	Detritus = Particulate Organic Carbon Particulate Org C = Particulate Org N * 5.7 (Redfield Ratio) Particulate Org N = TKN - NH4

4.2 Model Setup

The QUAL-2Kw model was set up to simulate nitrogen, phosphorus, and carbon cycling; DO; pH; and phytoplankton (algae) in the water column. Separate models were set up for Lake Palourde and Bayou Avoca. The models were set up with only two reaches, a 0.1 km headwater reach, and a second reach for the rest of the water body. Printouts of the model input worksheets are included in Appendix E.

4.2.1 Temperature Correction of Kinetics

The temperature correction factors used in the model were consistent with the Louisiana Technical Procedures Manual (the “LTP,” LDEQ 2005). These correction factors are listed Appendix E. These are the default temperature correction factors for the model. The same temperature correction factors were used in both the Lake Palourde and Bayou Avoca models.

4.2.2 Hydraulics

Hydraulics in the models were simulated using rating curves to estimate velocity and depth. This method uses the same equations used in the LA-QUAL model. The depth coefficients were based on the depths measured during the July field survey (see Section 3.0), and the exponents set to zero. Lake Palourde depth coefficient was also based on depths shown on the USGS 1:24,000 quadrangle map of the area. Bayou Avoca depth coefficient was based on the average depth reported by the acoustic Doppler instrument used in the field survey.

The velocity coefficients were set to the inverse of the cross sectional area, and the velocity exponents were set to 1.0. Lake Palourde cross sectional area was estimated based on widths measured from USGS digital ortho quarter quads and the depth measurements described above. Bayou Avoca velocity coefficient was calculated using the cross sectional area reported by the acoustic doppler. The same hydraulic equations were used for both model reaches (see Appendix E).

4.2.3 Heat Transfer Kinetics

The QUAL2Kw model simulates water temperature using meteorologic data and atmospheric radiation models. Data from three nearby meteorologic stations were used to estimate meteorologic inputs for the models (New Iberia/Acadiana, Houma-Terrebonne Airport, Baton Rouge Ryan Airport). Meteorologic input data required include hourly air temperature, dew point temperature, wind speed, and cloud cover. Hourly data could not be obtained for the nearby meteorologic stations. Hourly air temperatures were estimated by fitting sine curves to the average minimum and maximum temperatures reported at the three meteorologic stations. Hourly dew point temperatures were estimated as a percentage of the estimated air temperatures, based on the daily average air and dew point temperatures reported at the meteorologic stations. Wind speed and cloud cover were set constant at the average of the daily values reported at the meteorologic stations. The same meteorologic data were used for both the Lake Palourde and the Bayou Avoca models (see Appendix E).

The QUAL2Kw model uses latitude, longitude, and date values specified in the input to determine solar radiation and photoperiod. For the Lake Palourde and Bayou Avoca models, the Bras atmospheric attenuation model for solar shortwave radiation was used, along with the Koberg atmospheric longwave emissivity model, and the Adams1 wind speed function for evaporation and air convection/conduction (Pelletier and Chapra 2006). Other coefficients specified for light and heat transmission were set to model default values. The same coefficients were used for both the Lake Palourde and the Bayou Avoca models (see Appendix E).

One additional parameter used in the model simulation of water temperature is shade. Based on the local topography and vegetation height, the percent of solar radiation blocked due to shade from topography and/or vegetation is set to zero in the Lake Palourde and Bayou Avoca models.

4.2.4 Water Quality Kinetics

Water quality kinetics rates used in the QUAL-2Kw model include oxygen use, hydrolysis, nitrification, and denitrification rates. In addition, stoichiometry is specified for carbon, nitrogen, and phosphorus, as is a ratio for conversion of detritus to nutrients and carbon. The majority of the water quality kinetics rates were set to the model default value (see Appendix E). Table 4.2 lists the kinetics rates that were adjusted during calibration and the values used in the calibrated models. The same values were used for both the Lake Palourde and Bayou Avoca models.

Table 4.2. Water quality kinetics rates from the calibrated models.

Parameter (units)	Calibrated Rate
Slow CBOD hydrolysis (/day)	0.6
Slow CBOD oxidation (/day)	0.0
Fast CBOD oxidation (/day)	0.9
Nitrogen hydrolysis (/day)	0.01
Nitrification (/day)	2
Denitrification (/day)	0.06
Phosphorus hydrolysis (/day)	0.06
Phosphorus settling (m/day)	0
Detritus dissolution (/day)	0.003
Detritus settling (m/day)	0

4.2.5 Algal Kinetics

Kinetics rates related to algal productivity that are used in the QUAL-2Kw model include maximum growth rate, respiration, settling, half saturation constants, photosynthetically available radiation, and light extinction. Table 4.3 lists the values used for these rates in the calibrated models.

Table 4.3. Algal kinetics rates from calibrated models.

Parameter (units)	Lake Palourde (source)	Bayou Avoca (source)
Maximum growth (/day)	5 (calibration)	5 (calibration)
Death rate (/day)	0 (calibration)	0 (calibration)
Respiration (/day)	0.1 (calibration)	0.1 (calibration)
Settling (m/day)	0.55 (literature)	0.1 (literature)
Nitrogen half saturation (ΦgN/L)	60 (literature)	60 (literature)
Phosphorus half saturation (ΦgP/L)	25 (literature)	25 (literature)
Light half saturation (langleys/day)	200 (calibration)	200 (calibration)
Chlorophyll (gA)	0.5 (calibration)	0.5 (calibration)

4.2.6 Inflow

Inflows to the models were a single headwater inflow and diffuse source flows to Reach 2 (the long reach). The diffuse source flow was estimated using runoff values estimated from a long term (1895 – 2003) water balance of the area computed by the Louisiana State Office of Climatology in 2004 (unpublished). The diffuse source flows were set to the long term average runoff for July and September multiplied by the subsegment areas (estimated values are shown in Appendix E).

Lake Palourde headwater inflow was set to the average flow for July 14-18, 2006, reported at the USGS gage 073814675 in Bayou Boeuf at Amelia. This assumes that flow into Bayou Boeuf from Bayou L’Ourse is negligible, based on the width of the Bayou L’Ourse channel. September 2006 flow data for this gage was not available. It was assumed that the inflow estimated from the July 2006 measurements was reasonably representative of September 2006 flow conditions. The estimated values are shown in Appendix E.

Bayou Avoca headwater inflow was estimated using a UNET model of the Terrebonne basin calibrated to July 2006 conditions during the FTN field surveys (FTN unpublished). Bayou Avoca flows were not calculated by this UNET model, but flows in Bayou Chene and Bayou Penchant were. Bayou Avoca flows were estimated as the difference between average flows modeled for Bayou Chene and Bayou Penchant over a 75-hour period (three tidal cycles). It was assumed that the estimated July 2006 inflow was also reasonably representative of September 2006 flow conditions. The estimated values are shown in Appendix E.

Point sources were included only in the Lake Palourde model (see Section 2.4). The only point source modeled for Lake Palourde was Municipal Separate Storm Sewer System (MS4) loads from Morgan City. The flow for this point source was set to the runoff estimated for the area of Morgan City located within the subsegment. Flow data from USGS flow gage 07379660 on Dawson Creek, an urban stream in Baton Rouge, Louisiana, was used to estimate a value for urban runoff. The average flow from this gage for the period 2002 – 2005 was divided by the watershed area to derive an average urban runoff rate of 2.43 cfs/sq mi. This rate was multiplied by the urban area in Subsegment 120205 (5.4 sq mi) to get a point source flow of 0.372 cms.

4.2.7 Inflow Water Quality

Inflow water quality data used in the models were from several sources. Water quality of the headwater was set to the values measured in Lake Palourde and Bayou Avoca during the field surveys (see Section 3.0). For the most part, water quality for the diffuse sources was the same as the headwater. However, in the Lake Palourde model, organic nitrogen, organic phosphorus, and inorganic phosphorus concentrations were increased to calibrate the model. In the Bayou Avoca model, organic nitrogen, organic phosphorus, and detritus concentrations were increased to calibrate the model. For the Morgan City MS4 point source in the Lake Palourde model, values for all of the water quality parameters except nutrients were the same as for the headwater inflows. The nutrient inputs for the Morgan City MS4 were derived from typical total phosphorus and total nitrogen concentrations found in urban storm water (USEPA 2005). The point source input nitrogen parameter concentrations were derived by dividing the total concentrations using proportions derived from the measured water quality in Lake Palourde. The point source input phosphorus parameter concentrations were derived from total phosphorus as described in Section 4.1.

4.3 Model Calibration

4.3.1 Temperature

Water temperature was the first parameter to be calibrated, because temperature affects all of the process rates simulated in the QUAL2Kw model. Plots of the measured and simulated diel temperatures from the calibrated models are included in Appendix F. The models reproduce the general shape of the observed diurnal temperature fluctuations, and are close to reproducing the range of temperatures observed. Based on the way the model simulated water temperature, it appeared that in July a smaller volume of water was affected by surface heat transfer. Although temperature profiles were not collected during the field surveys, the modelers suspect that temperature stratification during the July field survey could explain this phenomenon. However, since changes in depth affect a number of the processes modeled, depth was not changed to improve the temperature calibration. Lack of local hourly meteorologic measurements is believed to limit the ability to more closely reproduce the observed diel temperature fluctuations.

4.3.2 Steady-state Water Quality

As noted in Section 4.2.4, water quality kinetic rates were adjusted to calibrate nutrients, detritus, and phytoplankton in the steady-state portion of the model. These parameters were primarily calibrated prior to modifying the models to reproduce diel DO and pH measurements. However, some of these parameters (i.e., nitrate and inorganic phosphorus) were also affected by model adjustments made to calibrate DO and pH (i.e., productivity). Plots of the measured and simulated steady-state water quality parameters from the calibrated models are included in Appendix F.

4.3.3 Diel DO and pH

In the model calibration, diel DO and pH were closely linked and were primarily fine tuned by changing reaeration models, light limitation models, and coefficients (to adjust DO production). The final selections for these elements of the model are shown in Appendix E. Plots of measured and simulated diel DO and pH values are included in Appendix F.

5.0 WATER QUALITY MODEL PROJECTION

To determine the reductions in nutrient loads to the modeled water bodies that would be required to achieve the subsegment pH water quality criteria, projection simulations were run with decreased diffuse source nutrient concentrations. The reductions were made primarily to those nutrient parameters that had been increased during the calibration (see Section 4.2.7). All other inputs and coefficients were unchanged from the calibrated values. If the simulated maximum pH could not be lowered sufficiently by reducing or eliminating the diffuse source nutrient concentrations, headwater nutrient concentrations were also reduced. Table 5.1 summarizes the results of these projection simulations. Printouts of the projection simulation inputs are included in Appendix G and the outputs are included in Appendix H.

Table 5.1. Results of inflow nutrient reduction simulations to achieve subsegment pH criteria.

Model	pH Criterion (su)	Nutrient Concentration Reductions		Maximum Simulated pH (su)
		Headwater	Diffuse Sources	
Bayou Avoca July	8.0	0%	85%	8.00
Bayou Avoca September	8.0	0%	75%	7.99
Lake Palourde July	8.5	60%	100%	8.48
Lake Palourde September	8.5	10%	100%	8.49

Louisiana general water quality criteria for pH specify a maximum value of 9.0 su. The pH criteria for Subsegments 120205 and 120402 are lower than 9.0 su. It may be worthwhile to consider modifying the pH criteria for these subsegments so that they have a maximum pH criterion of 9.0 su. To get an idea of how easy or difficult it might be to achieve a maximum pH less than or equal to 9.0 su in these subsegments, the nutrient concentrations in diffuse sources and headwater inflows were reduced until the modeled pH was less than 9.0 u. Table 5.2 summarizes the results of these projection simulations. These results indicate that significant reductions in nutrient load to Lake Palourde would be required to achieve a maximum pH of

9.0 su. No reduction in nutrient load to Bayou Avoca would be required to achieve a maximum pH of 9.0 su.

Table 5.2. Results of inflow nutrient reduction simulations to reduce maximum pH to 9.0 su.

Model	Nutrient Concentration Reductions		Maximum Simulated pH (su)
	Headwater	Diffuse Sources	
Bayou Avoca July	0%	0%	8.73
Bayou Avoca September	0%	0%	8.23
Lake Palourde July	20%	100%	9.00
Lake Palourde September	0%	0%	9.00

6.0 TMDL CALCULATIONS

The nutrient TMDLs for achieving pH criteria in Subsegments 120205 and 120402 are summarized in Table 6.1. The TMDLs were calculated using input from the July projection models that simulated maximum pH values at the water quality maximum pH criteria (see Section 5.0). The actual calculations are included as Appendix I. The elements of these TMDLs are discussed in detail in the subsections below.

Table 6.1. Nutrient TMDLs for achieving pH criteria in Subsegments 120205 and 120402.

	Subsegment 120205		Subsegment 120402	
	Phosphorus (kg/day)	**Nitrogen (kg/day)**	**Phosphorus (kg/day)**	**Nitrogen (kg/day)**
TMDL	893	9,676	4,920	37,000
MOS	89	968	492	3,700
FG	89	968	492	3,700
WLA	12	77	0	0
LA	703	7,664	3,936	29,600

6.1 MOS and FG

The MOS accounts for any lack of knowledge or uncertainty concerning the relationship between pollutant loads and water quality. In this case, it accounts for uncertainty and variability related to water quality measurements and the modeling. These TMDLs incorporate an explicit MOS factor of 10% to account for these uncertainties and variabilities. An additional 10% of each TMDL was set aside to account for uncertainty associated with FG.

6.2 WLA

The WLA for Subsegment 120205 includes the Morgan City MS4 loads that were modeled, and estimated loads for the seven permitted sewage treatment dischargers in the subsegment. The sewage treatment dischargers in Subsegment 120205 are covered by general permits (instead of individual permits) because of their small flow rates. To estimate the loads from these point sources, the maximum flow covered by the applicable general permit was used as the point source flow. The total phosphorus and total nitrogen concentrations for these point sources were set to expected values reported by USEPA (1997). The values used to calculate these loads are shown in Appendix I.

No potential permitted point sources of nutrients were identified for Subsegment 120402, so the WLA was set to zero for that subsegment.

Although the TMDL for Subsegment 120205 specifies a WLA for nutrients, it is recommended that as a first step to implement this TMDL, the point sources should be given nutrient monitoring requirements in their permits to determine if the point sources are causing or contributing nutrients. However, final decisions for point source nutrient limitations will be made by LDEQ on a case-by-case basis during the re-issuance of each permit. Because point source discharges represent a very small portion of the total nutrient loading, it is possible that no reductions of point source discharges may be needed as a result of this TMDL.

6.3 LA

The LAs for these TMDLs were set to the TMDL minus the MOS, FG, and WLA.

7.0 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.

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.

8.0 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 25, 2007, and the review period closed on November 26, 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.

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