Nitrogen and Phosphorus Trends of Long-Term Ambient Water Quality Monitoring Sites in Louisiana

Louisiana Department of Environmental Quality
Office of Environmental Services
Water Permits Division, Water Quality Unit

December 2015

This report '*Nitrogen and Phosphorus Trends of Long-Term Ambient Water Quality Monitoring Sites in Louisiana*' was developed in support of the Louisiana Nutrient Management Strategy, Strategic Action *5.h. Determine trends in nutrient water quality at long-term monitoring stations*.

Suggested Citation

Louisiana Department of Environmental Quality (LDEQ). 2015. *Nitrogen and Phosphorus Trends of Long-Term Ambient Water Quality Monitoring Sites in Louisiana*. Office of Environmental Services, Louisiana Department of Environmental Quality, Baton Rouge, LA.

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Abstract

Trends for total Kjeldahl nitrogen (TKN), nitrite + nitrate (NO_x), total phosphorus (TP) and concentrations were analyzed for the 21 long-term monitoring sites in the Louisiana Department of Environmental Quality's (LDEQ) ambient water quality monitoring network from 1978 to 2014. These sites represent eleven of the twelve watershed basins in Louisiana. A Mann-Kendall trend test found the majority of trends (73%) to be decreasing. All sites had a decreasing trend for TKN, twelve sites showed a decreasing trend for NO_x, and thirteen sites showed a decreasing trend for TP. Only one trend, NO_x for the Bogue Chitto River, was found to be increasing. The land use for the watershed of the eleven rivers included in this analysis was calculated and then analyzed along with the median nutrient value in a Kendall tau correlation analysis. Agriculture was found to be significantly correlated with higher concentrations of TKN and TP ($p<0.01$), while forested lands were found to be significantly correlated with lower concentrations of TKN and TP ($p<0.05$). Even though agriculture was found to be associated with higher nutrient concentrations, basins with the most agriculture also showed the most improvement in nutrient management as evidenced by decreasing or no observable increasing trends in nutrients.

1. Background

1.1 Nutrients are Essential for Life

Nitrogen (N) and phosphorus (P) are crucial elements for life as they are required by our cells to function. These nutrients are integral components in enzymes, deoxyribonucleic acid (DNA), adenosine triphosphate (ATP), and the phospholipids that comprise cell membranes; without them life would not exist. However, too much N and P in the environment can have detrimental effects such as eutrophication, oxygen depletion, and toxicity. Nutrient pollution has become one of the biggest problems facing water quality in the world today (Smith and Schindler, 2009).

Nitrogen is present in many different forms with ammonium/ammonia (NH_4^+/NH_3), nitrite/nitrate (NO_2^-/NO_3^-), organic-N, and nitrogen gas (N_2) being the most prevalent forms. The N cycle is complex as N occurs in many different oxidation states. Microorganisms capitalize on the transformation potential inherent in the range of oxidation states and use the energy released from these transformations to maintain their life processes (Schlesinger, 1997). Figure 1 shows the complexity of the N cycle as well as demonstrating potential sources of N into waterbodies. Typically, N enters the terrestrial ecosystem through fixation, either biological (through certain plant species) or industrial (through the Haber process). The Haber process is the first step in the production of fertilizers and converts N_2 to NH_3. Plants and microorganisms then utilize N forms for growth and cycle N through many different pathways. Groundwater moving through the soil subsurface provides a conduit for N to leach into the water column. Denitrification occurs in the absence of oxygen and is the only biological process returning N to the atmosphere. Anthropogenic influences also contribute a significant impact to the movement of N through the environment.

The two main forms of P include phosphate (PO_4^{3+}) and organic-P. The phosphate form present is highly dependent upon pH, occurring in various ionic forms: H_3PO_4 (phosphoric acid), $H_2PO_4^-$ (dihydrogen phosphate), HPO_4^{2-} (hydrogen phosphate), or PO_4^{3-} (phosphate). While the N cycle is largely driven by microorganisms, the P cycle is heavily influenced by terrestrial processes, such as rock weathering, sorption, desorption, or sedimentation (Schlesinger, 1997). The biota play a role in recycling P, as it is important for cell growth, but the form of P associated with organic-P is almost entirely a form of phosphate (Reddy and DeLaune, 2008). Phosphorus enters the environment (Figure 2) through weathering or mining and is then used by plants and microorganisms to fuel growth. Other than a small amount of transport through soil dust or sea spray, the P cycle does not have a significant atmospheric component. The gaseous component of phosphorus, phosphine gas (PH_3), is only produced under very extreme conditions and contributes very little to the overall movement of P through the environment (Schlesinger, 1997). Phosphorus continues the cycle through sedimentation, as dead organisms and P-containing soil particles are deposited in ocean sediments. After hundreds of millions of years, uplift occurs and P is returned to the terrestrial ecosystem.

1.2 Sources of Nutrients in the Environment

Nitrogen and P come from a variety of different sources, including runoff or leachate from waste disposal sites, animal feedlots, mines, oil fields, unsewered industrial sites, storm sewer outfalls, construction sites, agriculture, pastures, urban areas, septic tanks, and logging sites; wastewater effluent; sanitary and storm sewer overflow; and atmospheric deposition over water (Smith, et al., 1999). Fertilizer is a substantial source of both N and P. Nitrogen can be found from two sources: 1) anhydrous ammonia can be directly injected into soils or 2) ammonium salts (such as ammonium nitrate) are

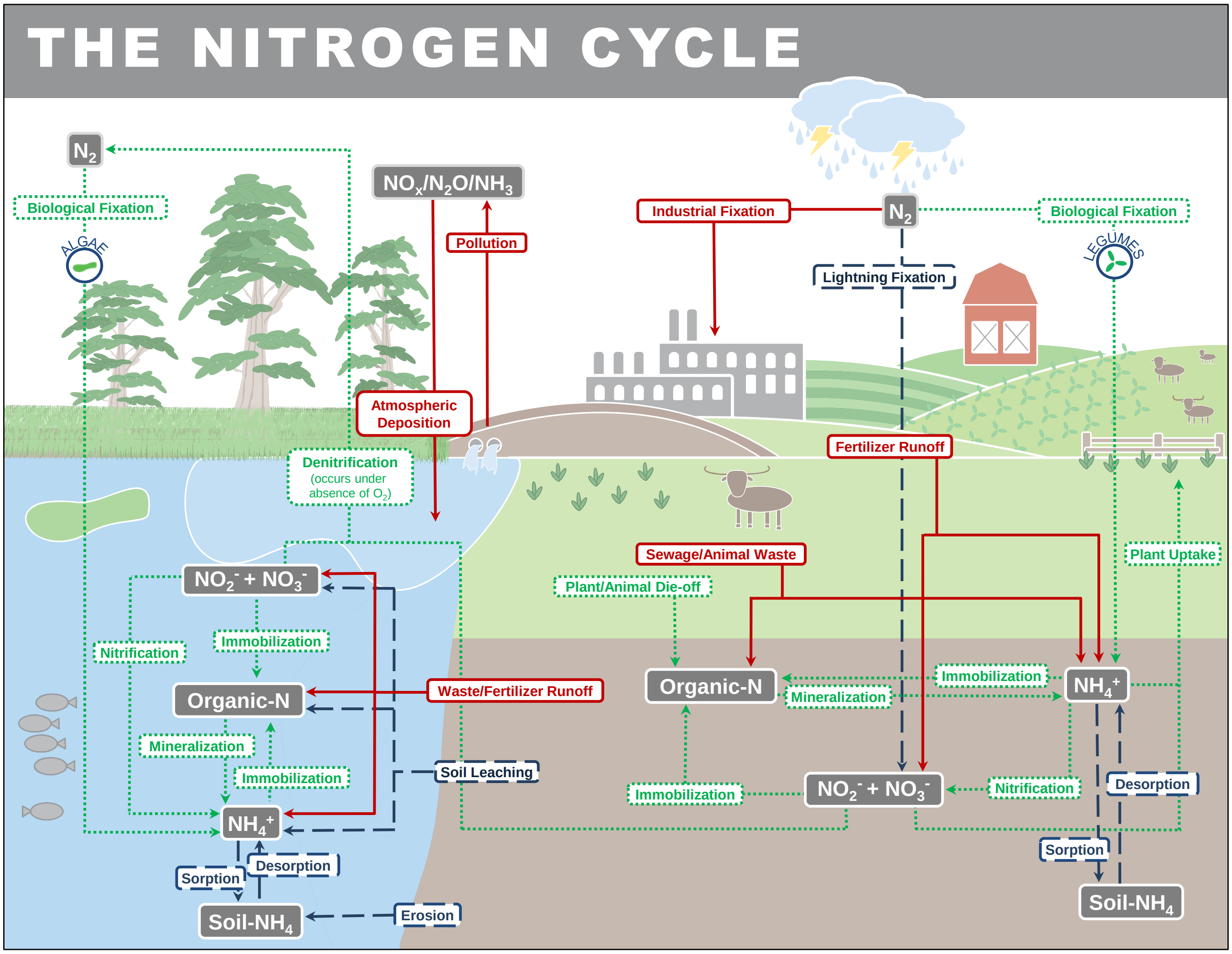


Figure 1. The nitrogen cycle. Anthropogenic inputs are shown in solid, red lines; naturally occurring physical and chemical inputs are shown in blue, dashed lines; and biological inputs are shown in green, dotted lines.

applied to the soil (Reddy and DeLaune, 2008). The ammonium applied to upland soils (i.e., aerobic) can then readily oxidize to nitrate through nitrification. Phosphates are also a primary component in most fertilizers, and thus, nitrate, ammonium, and phosphate end up in our waterbodies due to runoff from fields and stormwater runoff from urban areas. Animal (e.g., manure) and human waste (from sewage and septic systems) are sources of both inorganic and organic forms of N and P into waterways. As the combustion of fossil fuels continue to increase, currently over 20 million metric tons per year, atmospheric deposition of N into waterbodies is becoming a significant contributor to N pollution (Schlesinger, 1997, Smith, et al., 1999).

1.3 Effects of Nutrients in Aquatic Ecosystems

Eutrophication is the accumulation of excess nutrients, particularly N and P, in water bodies. Excessive levels of nutrients can promote excessive algal growth, particularly in warm, slow-moving rivers and shallow lakes. As the algae die off and decompose, microorganisms utilize the organic-N and P left behind from the dead algae and, in doing so, consume oxygen. The depletion in oxygen, or hypoxia, can then lead to the death of fish and other organisms dependent upon oxygen for life. Increases in algal growth can also lead to harmful algal blooms (HABs), which can release toxins that kill off smaller fish and shellfish. The toxins can then move up the food chain as larger animals, like

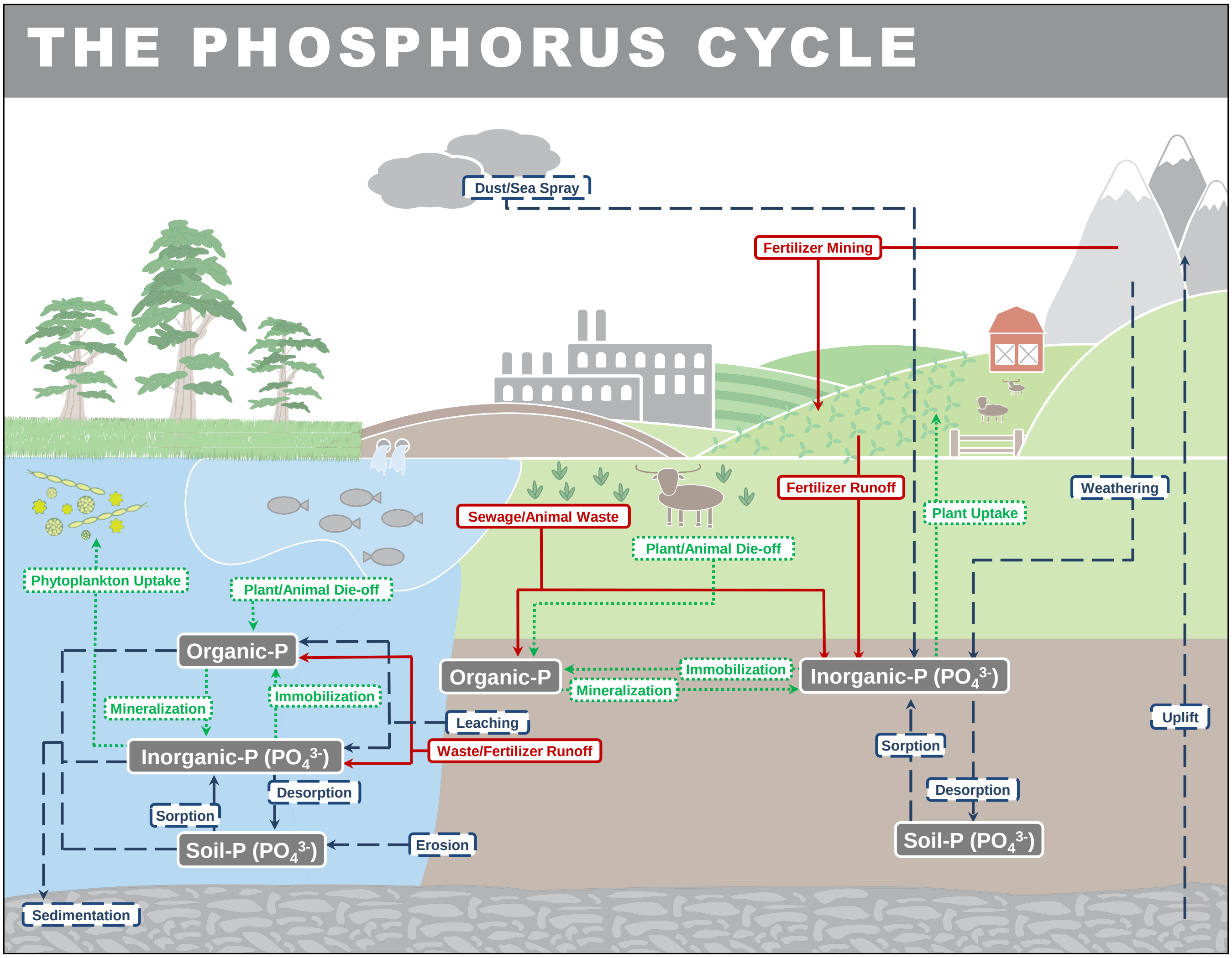


Figure 2. The phosphorus cycle. Anthropogenic inputs are shown in solid, red lines; naturally occurring physical and chemical inputs are shown in blue, dashed lines; and biological inputs are shown in green, dotted lines.

turtles, dolphins, birds, manatees, or larger fish consume the smaller contaminated organisms. Certain forms of nutrients can also cause direct impacts due to toxicity: ammonium is toxic to fish (Eddy, 2005 and references therein) and nitrate causes methemoglobinemia in humans (Bruningfann and Kaneene, 1993).

1.4 Louisiana Waters

Due to our warm climate and slow-moving waterbodies, Louisiana is especially vulnerable to eutrophication and hypoxia (low oxygen). Low dissolved oxygen is the leading suspected cause of impairment for the fish and wildlife propagation use in our waters (LDEQ, 2013). Though Louisiana has not historically witnessed the development of large numbers of HABs, nutrient load increases can lead to increases of HABs as was seen in Lake Pontchartrain during recent openings of the Bonnet Carré spillway (Bargu, et al., 2011, Dortch, et al., 1999).

Ambient surface water quality data is collected by LDEQ monthly at approximately 135 sites statewide within the Ambient Water Quality Monitoring Network (AWQMN). Water quality data is used to assess conditions in Louisiana's waterbodies. The AWQMN began monitoring in 1958 and has established over 600 monitoring sites since that time. Data is collected on a rotating basis in order to expand the coverage of our monitoring efforts. Twenty-one of the AWQMN sites (located on 16 rivers) are monitored every month of every year to monitor long-term water quality.

2. Objective

The objective of this report is to determine the long-term patterns or trends of nutrient concentrations, which includes TKN, NO_x, and TP, collected at the 21 long-term ambient water quality monitoring sites in Louisiana water bodies for the past 28 to 36 years.

3. Methods

3.1 Nutrient Data Compilation

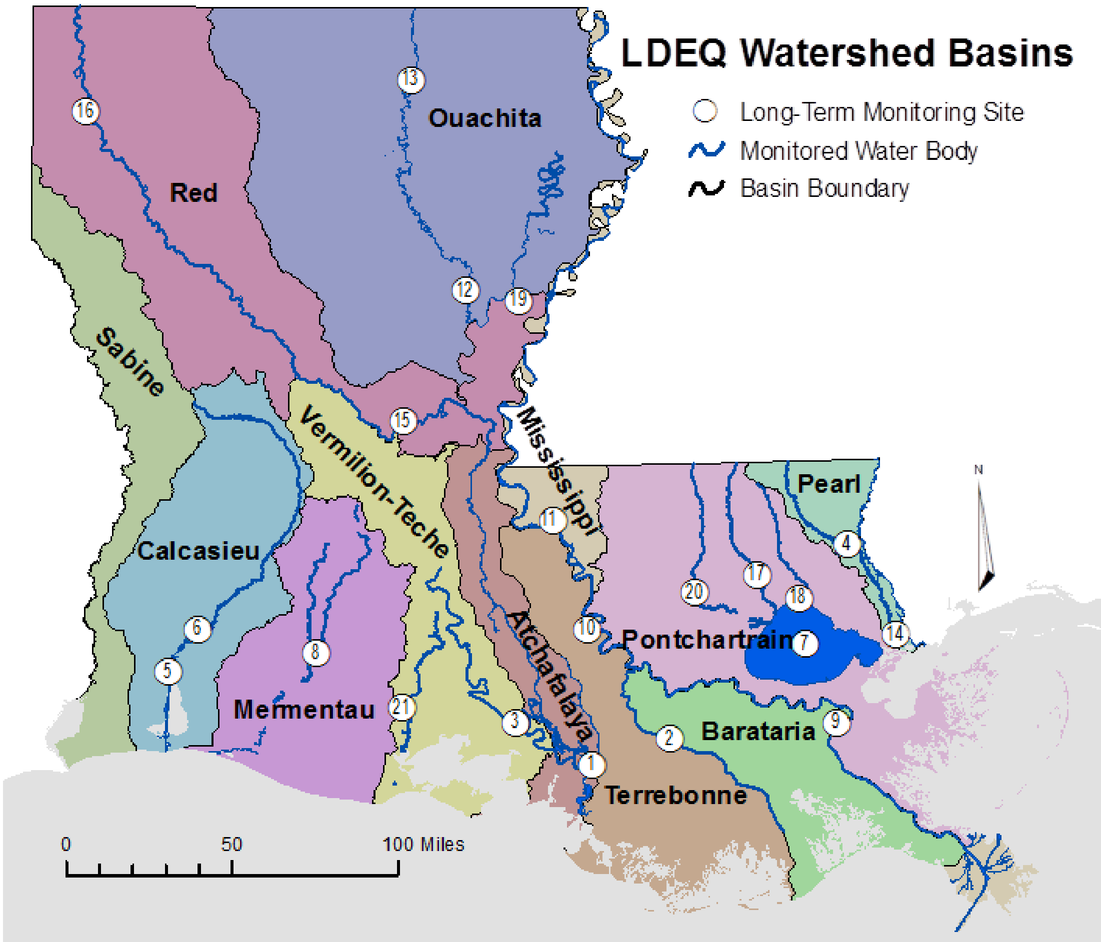
Sites were chosen based on the length and consistency of data available at 21 long-term AWQMN sites. These AWQMN sites are located in eleven of the twelve basins in the state and represent most of the major rivers within Louisiana. All TKN, NO_x, and TP data collected from January 3, 1978, to December 16, 2014, for the AWQMN was consolidated and reviewed. Based on a review of the 99th percentile for each parameter, data over 3 mg L^{-1} for both TKN (44 data points out of 8,127) and NO_x (19 data points out of 8,444) and greater than 1 mg L^{-1} for TP (25 data points out of 8,178), was considered a potential outlier and removed from subsequent data analysis. Data points that were below the detection limit were set to the highest detection limit of 0.5 mg-N L^{-1} for TKN, 0.1 mg-N L^{-1} for NO_x, and 0.1 mg-P L^{-1} for TP (Helsel and Hirsch, 2002).

3.2 Watershed Basins and Monitoring Sites

The watershed basins discussed in this report are based on the basins described in the LDEQ Water Quality Management Plan [Figure 3, (LDEQ, 2008)]; only basins surrounding long-term water quality monitoring sites were included. For this report, the Atchafalaya, Barataria, Terrebonne, and Mississippi River Basins were combined into one watershed basin due to the interconnectedness of the Mississippi, Atchafalaya, Barataria, and Terrebonne Basins (Figure 4). The Calcasieu and Mermentau Basins were combined into one watershed basin for this report due to their proximity and location in the southwestern part of the state. Hereafter, these watershed basins will be called Mississippi and Calcasieu-Mermentau Basins, respectively. The Sabine River Basin has no long-term monitoring site and, thus, was not characterized for this report. A brief description of the watershed basins used in this report follows. Throughout the report, ‘watershed basin’ will be used to indicate the river basins used by LDEQ, while ‘drainage basin’ will describe the entire basin (including portions outside of Louisiana) that drains into the river at the site indicated.

3.2.1 Red Watershed Basin

The Red River drains approximately 42,374,000 acres (171,480 km^2) of land in the states of New Mexico, Oklahoma, Texas, Arkansas, and Louisiana. The Red River enters Louisiana in the northwestern part of the state and flows southeastward until meeting the Atchafalaya River. The drainage basin land use consists of 24% forest, 3% wetlands, 51% grasslands/pasture, 17% agriculture, and 5% developed. Two long-term monitoring sites are present within the Red Watershed Basin: map number 16 located near Shreveport and map number 15 located near Marksville. Data collection is from July 12, 1981, to April 15, 2014, and March 6, 1978, to April 2, 2014, for the monitoring sites near Shreveport and Marksville, respectively.



Site Name	Map #	LDEQ Site #	LDEQ Subsegment	LDEQ Watershed
Atchafalaya River – Morgan City	1	0039	LA010501_00	Atchafalaya
Bayou Lafourche – Thibodaux	2	0293	LA020401_00	Barataria
Bayou Teche – Adeline	3	0030	LA060401_00	Vermilion-Teche
Bogue Chitto River – Bush	4	0064	LA090501_00	Pearl
Calcasieu River – Burton Landing	5	0026	LA030304_00	Calcasieu
Calcasieu River – Moss Bluff	6	0093	LA030201_00	Calcasieu
Lake Pontchartrain –Metairie	7	0138	LA041001_00	Pontchartrain
Mermentau River – Mermentau	8	0003	LA050401_00	Mermentau
Mississippi River – Belle Chasse	9	0051, 0320	LA070301_00	Mississippi
Mississippi River – Plaquemine	10	0053, 0319	LA070301_00	Mississippi
Mississippi River – St. Francisville	11	0055, 0318, 4031	LA070201_00	Mississippi
Ouachita River – Harrisonburg	12	0085	LA080201_00	Ouachita
Ouachita River – Sterlington	13	0013	LA080101_00	Ouachita
Pearl River – Slidell	14	0105	LA090202_00	Pearl
Red River – Marksville	15	0024	LA100201_00	Red
Red River – Shreveport	16	0120	LA100101_00	Red
Tangipahoa River –Robert	17	0033	LA040701_00	Pontchartrain
Tchefuncte River – Madisonville	18	0106	LA040802_00	Pontchartrain
Tensas River – Clayton	19	0159	LA081201_00	Ouachita
Tickfaw River – Springville	20	0116	LA040501_00	Pontchartrain
Vermilion River – Perry	21	0001	LA060802_00	Vermilion-Teche

Figure 3. The locations of LDEQ's long-term monitoring sites and watersheds and a listing of each site's name, map number, and LDEQ site number, subsegment, and watershed.

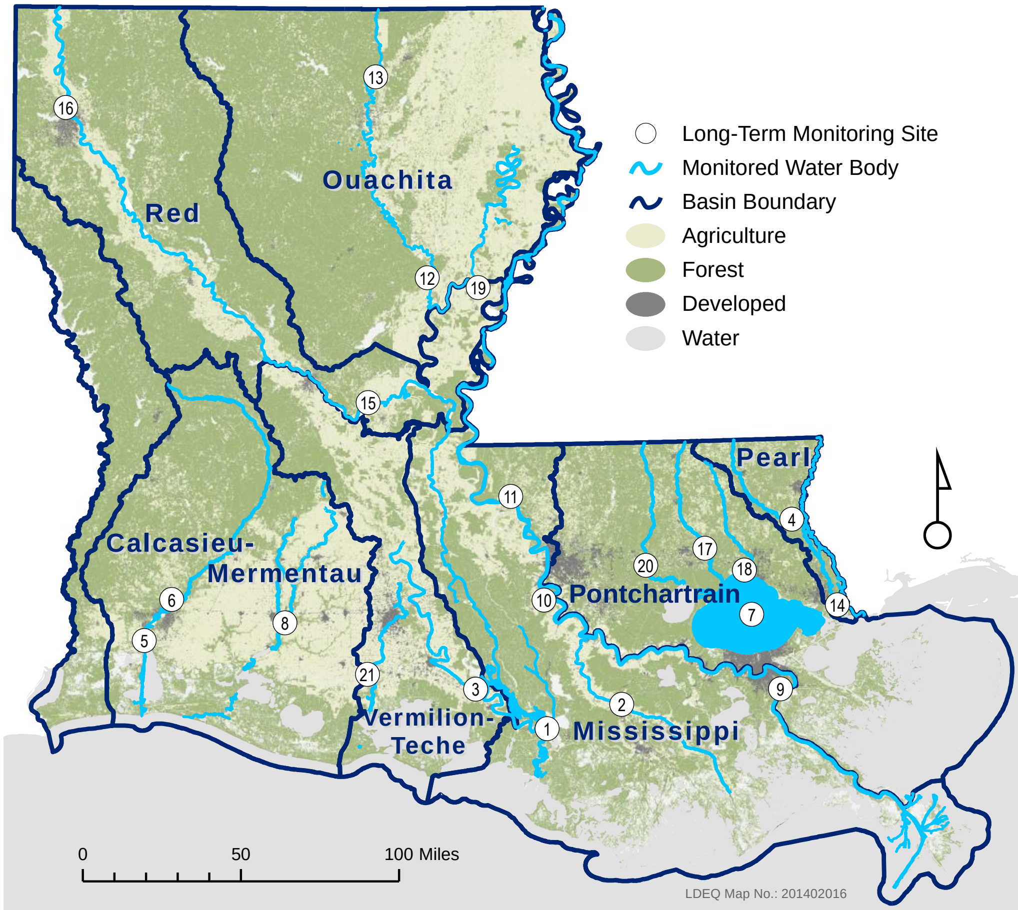


Figure 4. The long-term monitoring stations, general land use, and watersheds used in this report. Forested areas include wetlands and rangeland, while agriculture areas include cropland and pasture. Site names and map numbers are as follows: 1) Atchafalaya River-Morgan City; 2) Bayou Lafourche-Thibodaux; 3) Bayou Teche-Adeline; 4) Bogue Chitto River-Bush; 5) Calcasieu River-Burton Landing; 6) Calcasieu River-Moss Bluff; 7) Lake Pontchartrain - Metairie; 8) Mermentau River-Mermentau; 9) Mississippi River-Belle Chasse; 10) Mississippi River-Plaquemine; 11) Mississippi River-St. Francisville; 12) Ouachita River-Harrisonburg; 13) Ouachita River-Sterlington; 14) Pearl River-Slidell; 15) Red River-Marksville; 16) Red River-Shreveport; 17) Tangipahoa River -Robert; 18) Tchefuncte River-Madisonville; 19) Tensas River-Clayton; 20) Tickfaw River-Springville; and 21) Vermilion River-Perry.

3.2.2 Ouachita Watershed Basin

The Ouachita River drains approximately 13,383,000 acres (54,160 km^2) of land from the states of Arkansas and Louisiana. The watershed basin includes the Ouachita and Tensas Rivers. The Ouachita River enters Louisiana in the northeastern part of the state and flows south where it joins the Tensas River, which begins in northeast Louisiana. The land use of the drainage basin consists of 53% forest, 16% wetlands, 12% grasslands/pasture, 14% agriculture, and 6% developed. Three long-term monitoring sites are present within the Ouachita Watershed Basin: map numbers 12 and 13 are located on the Ouachita River near Harrisonburg and Sterlington, respectively, and map number 19 located on the Tensas River near Clayton. Data collection is from March 7, 1978, to April 2, 2014 for Harrisonburg; January 6, 1978 to April 1, 2014 for Sterlington; and November 16, 1988, to April 2, 2014, for Clayton.

3.2.3 Calcasieu-Mermentau Watershed Basin

The Calcasieu and Mermentau Rivers are located in southwestern Louisiana and are contained entirely within the state. The rivers drain approximately 3,959,000 acres (11,980 km^2) upstream of the sites shown in Figure 3. The land use of the drainage basin consists of 30% forest, 21% wetlands, 24% grasslands/pasture, 17% agriculture, and 8% developed. Three long-term monitoring sites are present within the watershed basin: Calcasieu River at Moss Bluff (map number 6), Calcasieu River at Burton Landing (map number 5), and Mermentau River at Mermentau (map number 8). Data collection is from January 13, 1978, to April 1, 2014, for both Calcasieu sites and January 4, 1978, to April 9, 2014, for Mermentau.

3.2.4 Vermilion-Teche Watershed Basin

Both the Vermilion and Teche Rivers comprise the Vermilion-Teche Watershed Basin. The rivers lay in south-central Louisiana and drain approximately 1,558,370 acres (6,300 km^2). The land use of the drainage basin consists of 8% forest, 29% wetlands, 23% grasslands/pasture, 30% agriculture, and 10% developed. Two long-term monitoring sites are present within the watershed basin, one at Perry on the Vermilion and the other at Adeline on Bayou Teche. Data collection is from January 10, 1978, to April 9, 2014, and March 7, 1978, to April 8, 2014, for Vermilion and Teche, respectively.

3.2.5 Mississippi Watershed Basin

The Mississippi Watershed Basin drains 716,000,000 acres (2,900,000 km^2) of land, from over 40% of the continental United States and contains three rivers: the Mississippi River, Atchafalaya River, and Bayou Lafourche. The Atchafalaya currently receives up to 30% of the Mississippi's flow, while nearly all of Bayou Lafourche's flow is from the Mississippi. The land use of the drainage basin consists of 22% forest, 3% wetlands, 40% grasslands/pasture, 29% agriculture, and 6% developed. Five long-term monitoring sites are present within the Mississippi Watershed Basin: map number 1 located at Morgan City along the Atchafalaya River, map number 2 located at Thibodaux along Bayou Lafourche, and map numbers 9, 10, and 11 located along the Mississippi River at Belle Chasse, Plaquemine, and St. Francisville, respectively. Data collection is from March 8, 1978, to April 8, 2014; February 4, 1981, to April 9, 2014; January 9, 1978, to April 8, 2014; January 3, 1978, to April 1, 2014; and January 3, 1978, to April 1, 2014, for the Atchafalaya, Lafourche, Mississippi—Belle Chasse, Mississippi—Plaquemine, and Mississippi—St. Francisville sites, respectively.

3.2.6 Pontchartrain Watershed Basin

The Tangipahoa, Tchefuncte, and Tickfaw Rivers flow into Lake Pontchartrain, an estuarine lake that is also influenced by waters from the Gulf of Mexico. The three rivers drain part of the State of Mississippi and southeastern Louisiana. The Pontchartrain Watershed Basin is approximately 3,116,000 acres (13,000 km^2). The land use of the drainage basin consists of 24% forest, 35% wetlands, 26% grasslands/pasture, 1% agriculture, and 14% developed. Four long-term monitoring sites are present within the Pontchartrain Watershed Basin: map number 7 located north of Metairie in the middle of Lake Pontchartrain, map number 17 located near Robert along the Tangipahoa River, map number 18 located near Madisonville along the Tchefuncte River, and map number 20 near Springville located along the Tickfaw River. Data collection is from January 13, 1986, to April 8, 2014, for Lake Pontchartrain; March 6, 1978, to April 1, 2014, for the Tangipahoa and Tickfaw Rivers; and March 6, 1978, to April 8, 2014, for the Tchefuncte River.

3.2.7 Pearl Watershed Basin

The Pearl Watershed Basin includes the Bogue Chitto and Pearl Rivers from 5,416,000 acres (22,200 km^2) of land in Louisiana and Mississippi. The basin lies along the southeastern corner of Louisiana. The land use of the drainage basin consists of 45% forest, 15% wetlands, 31% grasslands/pasture, 1% agriculture, and 7% developed. Two long-term monitoring sites are present within the basin: Map number 4 located near Bush and map number 14 located near Slidell. Data collection is from March 6 and 7, 1978, to April 8, 2014, for the Bogue Chitto and Pearl River, respectively.

3.3 Water Quality Methods

A single grab sample was collected from the center of the main flow at one-half the total depth of the stream if the stream was less than two meters deep or at one meter depth when the stream was over two meters deep. Samples were preserved with H_2SO_4 (pH < 2), kept on ice, and transferred to a laboratory for analysis (LDEQ, 2014). Total Kjeldahl nitrogen (TKN) was measured using either USEPA Method 351.2, SM4500-NH_3-C, or SM4500-NH_3-D (AWWA and APHA, 1999, USEPA, 1993). Nitrite + nitrate (NO_x) was measured using USEPA Method 353.2, SM4500-NO_3-F, SM4500-NO_3-E, or easy (1-Reagent) method (AWWA and APHA, 2005, Chinchilla, 2008, USEPA, 1993). Total P (TP) was measured using USEPA Method 365.4, or SM4500-P-E (AWWA and APHA, 2005, USEPA, 1993). Total suspended solids (TSS) were measured using USEPA Method 160.2 or SM2540-D (AWWA and APHA, 1999, USEPA, 1971).

3.4 Land Use Methods

Land use was calculated utilizing the USDA 2013 Crop Data Layer (CDL), Light Detection and Ranging Digital Elevation Model (LiDAR-DEM) and Hydrologic Unit Code (HUC)-8, 10, and 12 layers in ArcGIS 10.1 (ESRI, 2012, LOSCO, 2009, USDA-NASS, 2013). The hydrologic units were selected and segmented upstream of each long-term monitoring site with the delineation of each segment confirmed using LiDAR-DEM to determine drainage areas. The selected hydrologic units were then dissolved to create a single watershed above each site (Figure A.1). A subset of the CDL was then created for each watershed and areas for each land use class were calculated. The sum of all areas was then used to calculate the total drainage basin area, which was subsequently used to find the relative proportion (as a percentage) for each land use class.

The drainage basins for the following rivers were used for the correlation analysis between land use and nutrients: Bayou Teche, and the Calcasieu, Mermentau, Mississippi, Ouachita, Pearl, Red, Tangipahoa, Tchefuncte, Tensas, and Tickfaw Rivers. Bayou Lafourche and Atchafalaya River were not included in the analysis as they receive the majority of their input from other rivers included in the analysis (e.g., the Atchafalaya River receives water from the Mississippi, Red, and Ouachita Rivers). The Bogue Chitto River drainage basin is contained within the Pearl River drainage basin. In order to achieve a more independent analysis, the Tickfaw, Tchefuncte, and Tangipahoa Rivers were included individually, as opposed to grouped together within the Pontchartrain Watershed Basin, as Lake Pontchartrain receives some input from the Gulf of Mexico, potentially including input from the Pearl and Mississippi Rivers. The headwaters of Bayou Teche and the Vermilion River overlap; therefore, these two rivers were lumped together for this analysis, as it is nearly impossible to tease out the exact land use for each river. Appendix A contains a listing of each river's drainage basin and its land use in more detail. Total suspended solids (TSS) were also included in the correlation analysis only to determine any influence between TSS and nutrients; TSS trends were not determined as part of this analysis.

3.5 Statistical Analysis

All statistical analysis was performed using SAS Enterprise Guide, Version 4.1 (SAS Institute, 2006) at an $\alpha = 0.05$, unless otherwise noted. Trends were analyzed with the Kendall trend test (Hirsch and Slack, 1984) using nutrient concentrations not adjusted for discharge. Data was analyzed utilizing SAS code from St. Johns River Water Management District (Winkler, 2004). The code was modified to run all tests at $\alpha = 0.05$. The code written by Winkler first tests the data sets for the presence of seasonality. If seasonality is present, the data set is run using the Seasonal Kendall test modification. If seasonality is not present, the data set is run using the Mann-Kendall test. A minimum period of ten years is required for the trend to be valid. The slopes were found using the same program following the Sen test (Sen, 1968, Winkler, 2004). Kendall tau was found by running correlation analysis for each nutrient individually with year.

Kendall correlation coefficients were calculated for land use within each river watershed and the median nutrient value since 2000 (this date was chosen as the land use data is from 2001-2013). The major land use classes include agriculture, grasslands/pasture/shrublands, forest, developed, and wetlands. Agriculture was further broken down into three categories: N-fixing crops, non N-fixing crops, and rice/aquaculture. These categories were chosen due to the differences in how these crops function. Crops that fix their own nitrogen are legumes (N-fixing crops) and include alfalfa, beans, clover, lentils, peas, peanuts, soybeans, and vetch (Havlin, 2005). All other crops are listed as non N-fixing crops, such as corn, cotton, sugarcane, and wheat (see Appendix A for a list of all non N-fixing crops). Rice is grown under flooded conditions. Aquaculture is grouped with rice as rice fields are often used for aquaculture purposes when rice is not grown and both aquaculture and rice are flooded for the majority, if not all, of the year. Flooding allows anaerobic conditions to predominate, which plays an important role in nutrient cycling for N. Under anaerobic conditions, NO_x is typically converted to N_2, which is lost to the atmosphere.

4. Results & Discussion

4.1 Nutrient Trends

The majority of nutrient trends (73%) for the 21 long-term monitoring sites show a decreasing trend, sixteen (25%) trends show no change, and only one trend (2%) showed an increasing trend (Table 1). All sites show a decreasing trend for TKN. Eight sites (38%) show no trend, one (5%) shows an increasing trend, and twelve (57%) show a decreasing trend for NO_x. Eight sites (38%) show no trend while thirteen (62%) show a decreasing trend for TP. Appendix B provides a listing of the Kendall tau, Sen slopes, and seasonality along with significance for each station. Overall site medians ranged from 0.45 to 1.11 mg N-TKN L^{-1}, 0.05 to 1.34 mg N-NO_x L^{-1}, and 0.07 to 0.38 mg P L^{-1}. The Mississippi River Basin has the highest values for NO_x, while the Vermilion River, Mermentau River, and Bayou Teche the highest values for TP and TKN (Figure 5). It should also be noted here the differences in scale between P and N. Overall TP and NO_x (excluding the Mississippi River Basin) median values are all below 0.5 mg-P or N L^{-1}, while overall TKN medians fall between 0.5 to 1.1 mg-N L^{-1}. Values of NO_x in the Mississippi River Basin range from 0.8 to 1.3 mg-N L^{-1}. Appendix C lists the annual median of TKN, NO_x, and TP for each site.

Table 1. Minimum, median, maximum, and Kendall trend results for all nutrients and sites. Decreasing trends (↓) are highlighted in blue, increasing (↑) in red, and insignificant (−) in gray.

Site	Map Number	Total Kjeldahl Nitrogen Min	Median	Max	Trend	Nitrite + Nitrate Min	Median	Max	Trend	Total Phosphorus Min	Median	Max	Trend
All sites		**BDL**[a]	**0.73**	**3.00**		**BDL**	**0.22**	**3.00**		**BDL**	**0.13**	**1.00**	
Atchafalaya	1	BDL	0.68	1.88	↓	BDL	0.85	2.38	↓	BDL	0.17	0.64	↓
Lafourche	2	BDL	0.54	2.42	↓	BDL	0.98	2.54	−	BDL	0.14	0.88	↓
Teche	3	BDL	1.05	2.84	↓	BDL	0.28	2.38	−	BDL	0.30	0.90	↓
Bogue Chitto	4	BDL	BDL	3.00	↓	BDL	0.27	1.84	↑	BDL	BDL	0.62	−
Calcasieu—BL	5	BDL	0.84	2.82	↓	BDL	0.13	0.74	↓	BDL	0.11	0.82	↓
Calcasieu—MB	6	BDL	0.70	2.72	↓	BDL	BDL	1.13	↓	BDL	BDL	0.61	−
Lake Pontchartrain	7	BDL	BDL	1.72	↓	BDL	BDL	1.30	−	BDL	BDL	0.73	−
Mermentau	8	BDL	1.10	2.99	↓	BDL	0.17	1.13	↓	BDL	0.24	0.97	↓
Mississippi—BC	9	BDL	0.68	2.75	↓	BDL	1.35	2.98	−	BDL	0.20	0.88	↓
Mississippi—Pla	10	BDL	0.77	2.90	↓	0.13	1.31	3.00	−	BDL	0.19	0.94	↓
Mississippi—SF	11	BDL	0.76	2.73	↓	BDL	1.30	2.94	−	BDL	0.20	0.80	↓
Ouachita—H	12	BDL	0.72	2.71	↓	BDL	0.15	2.10	↓	BDL	0.13	0.54	−
Ouachita—S	13	BDL	0.68	2.60	↓	BDL	0.12	2.35	↓	BDL	BDL	0.76	−
Pearl	14	BDL	0.64	2.68	↓	BDL	0.15	1.80	−	BDL	BDL	0.38	−
Red—M	15	BDL	0.80	2.91	↓	BDL	0.16	0.90	↓	BDL	0.14	0.95	↓
Red—S	16	BDL	0.83	2.33	↓	BDL	BDL	1.12	↓	BDL	0.13	0.80	↓
Tangipahoa	17	BDL	BDL	2.08	↓	BDL	0.28	0.82	↓	BDL	BDL	0.72	↓
Tchefuncte	18	BDL	0.69	2.60	↓	BDL	0.12	0.65	−	BDL	BDL	0.80	−
Tensas	19	BDL	0.95	2.54	↓	BDL	0.26	2.70	↓	BDL	0.26	0.89	−
Tickfaw	20	BDL	0.52	1.73	↓	BDL	0.21	0.82	↓	BDL	BDL	0.78	↓
Vermilion	21	BDL	1.12	2.84	↓	BDL	0.42	1.92	↓	BDL	0.38	1.00	↓

[a] BDL = below detection limit. Detection limits are 0.5 mg-N L^{-1} for total Kjeldahl nitrogen and 0.1 mg-N or -P L^{-1} for nitrite+nitrate or total phosphorus.

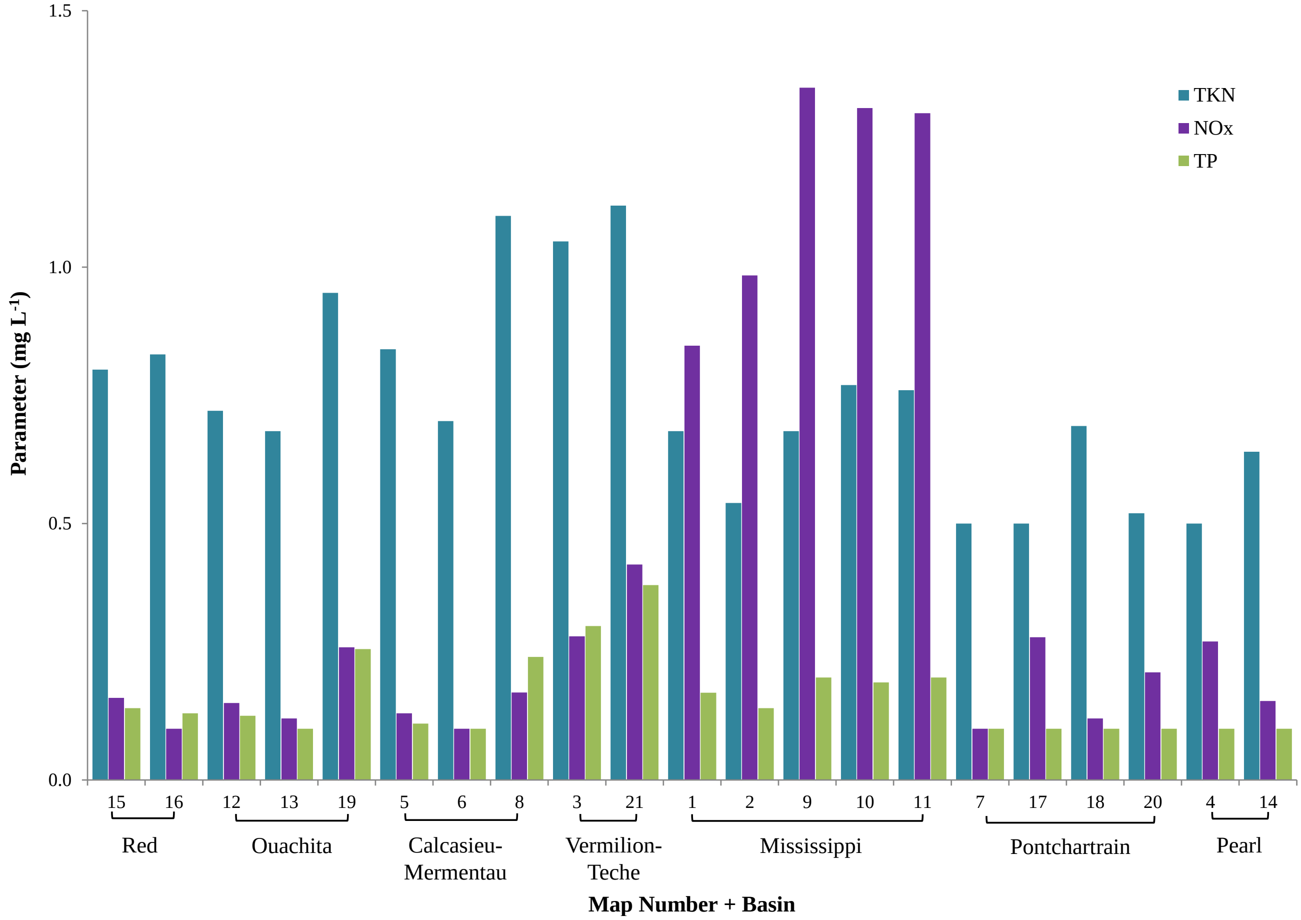


Figure 5. Overall medians for the entire length of data available for total phosphorus (TP), nitrite + nitrate (NO_x), and total Kjeldahl nitrogen (TKN).

4.1.1 Trends for Red Watershed Basin

Total Kjeldahl N values for Marksville range from < 0.50 to 2.91 mg N-TKN L^{-1} and < 0.10 to 2.33 mg N-TKN L^{-1} for Shreveport (Table 1). Nitrite + nitrate values for Marksville range from < 0.10 to 0.90 mg N-NO_x L^{-1} and < 0.10 to 1.12 mg N-NO_x L^{-1} for Shreveport. Total P values for Marksville range from < 0.10 to 0.95 mg P L^{-1} and < 0.10 to 0.80 mg P L^{-1} for Shreveport. Total P, NO_x, and TKN all show significant decreasing trends for the Red River. A distinct drop occurs between 1990 and 1995 for TP (Figure 6); however, this drop is not reflected in the TKN or NO_x data for both sites. Both TKN and NO_x have been steadily decreasing, with NO_x being at or near the detection limit in the past few years. The Red River ranks near the middle of the 21 long-term sites for all nutrients (Figure 6).

4.1.2 Trends for Ouachita Watershed Basin

Total Kjeldahl N values range from < 0.50 to 2.71, < 0.50 to 2.60, and < 0.50 to 2.54 mg N-TKN L^{-1} for the Harrisonburg, Sterlington, and Tensas sites, respectively. Nitrite + nitrate values range from < 0.10 to 2.10, < 0.10 to 2.35, and < 0.10 to 2.70 mg N-NO_x L^{-1} for the Harrisonburg, Sterlington, and Tensas sites, respectively. Total P values range from < 0.10 to 0.54, < 0.10 to 0.76, and < 0.10 to 0.89 mg P L^{-1} for the Ouachita at Harrisonburg and Sterlington and for the Tensas, respectively. Both N forms show a significant decreasing trend while TP shows no significant trend for the Ouachita sites and the Tensas site (Table 1, Figure 7). The decreasing trend for both TKN and NO_x is not as steep as other sites, but the downward trend is continuing. The Tensas River has a higher TKN, NO_x, and TP

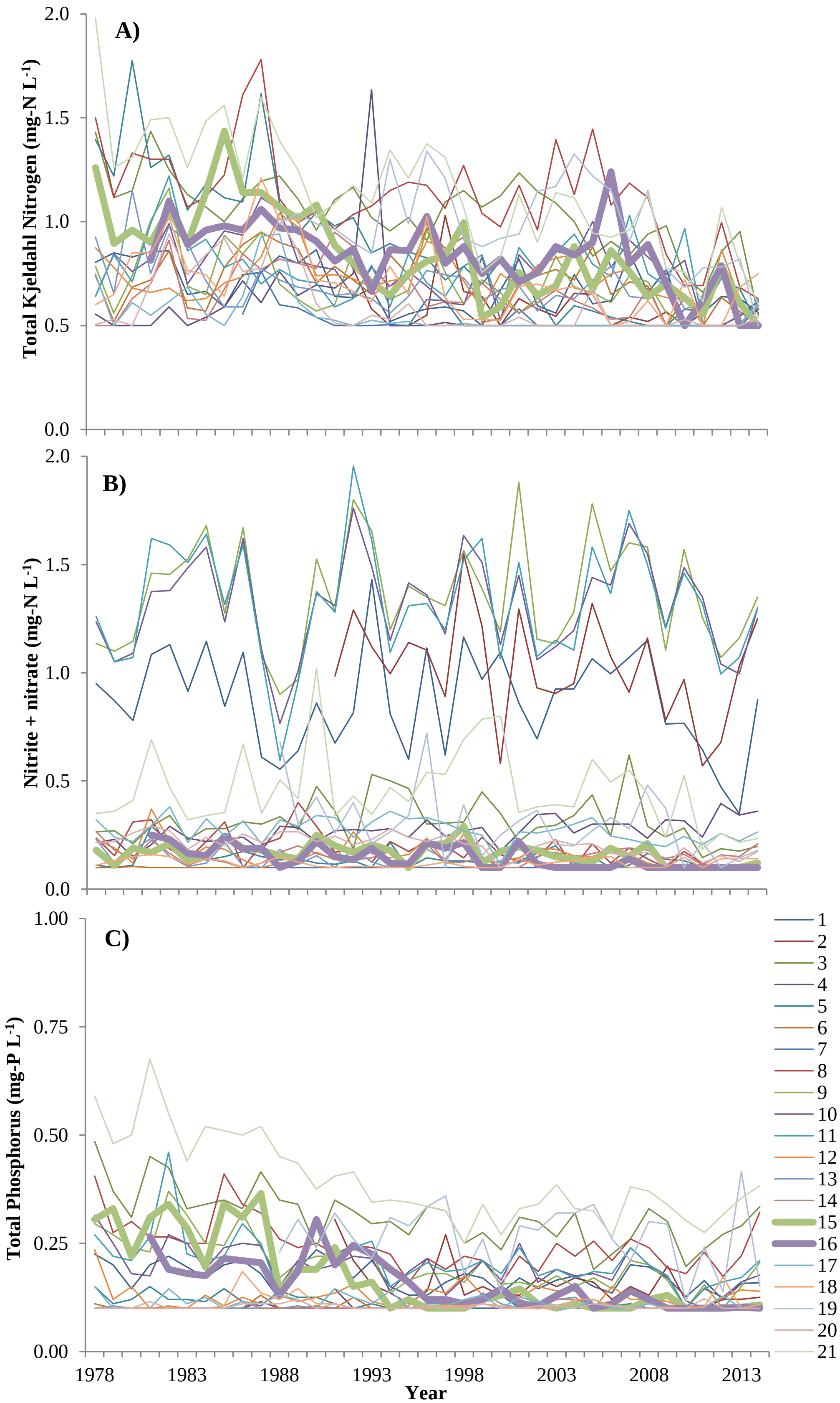


Figure 6. Yearly median total Kjeldahl nitrogen (A), nitrite + nitrate nitrogen (B), and total P (C) values since 1978. Red River-Shreveport (#16) is highlighted in purple and Red River-Marksville (#15) is in green.

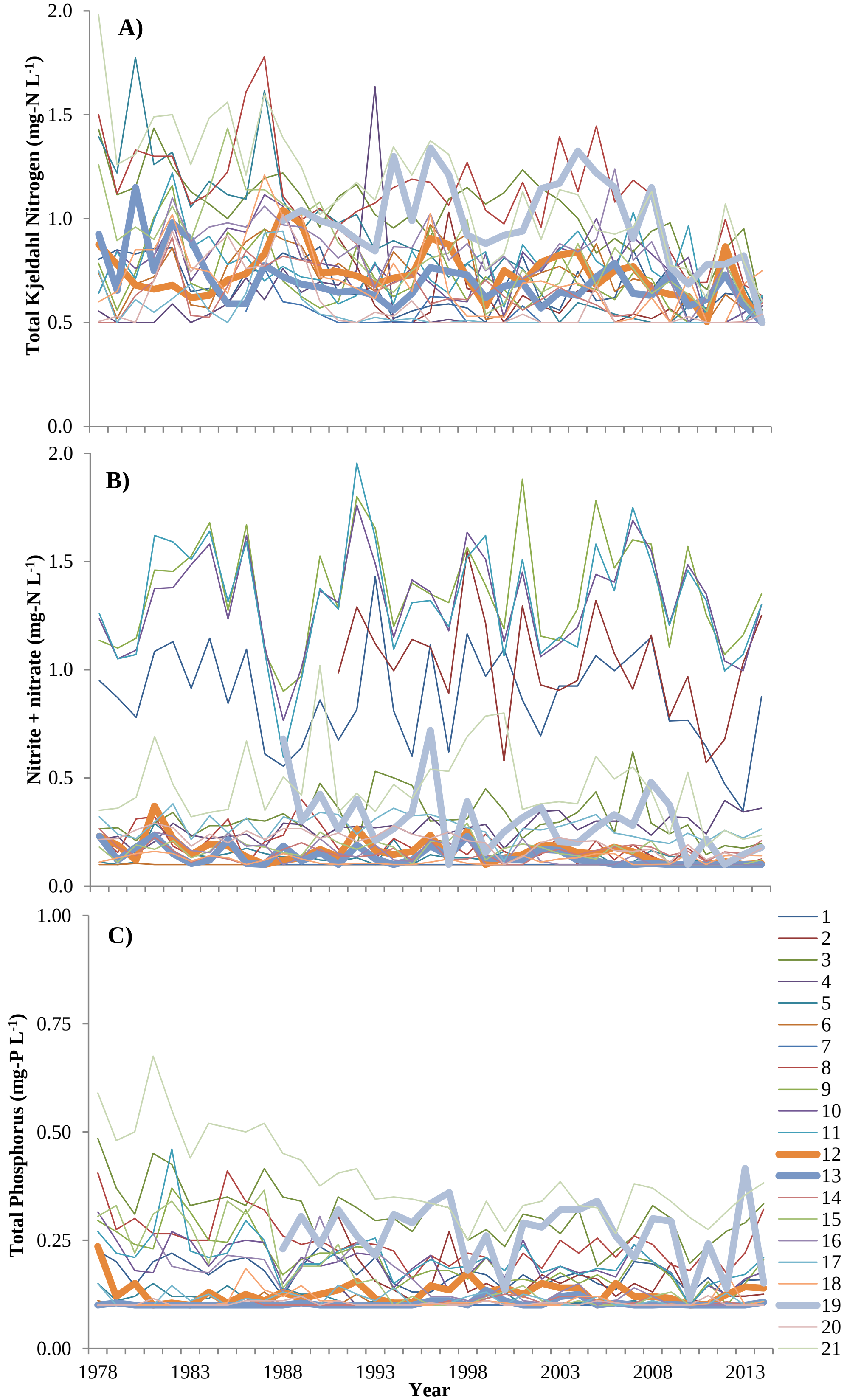


Figure 7. Yearly median total Kjeldahl nitrogen (A), nitrite + nitrate nitrogen (B), and total P (C) values since 1978. Ouachita River-Harrisonburg (#12) is highlighted in orange, Ouachita River-Sterlington (#13) is in dark blue, and Tensas River (#19) is in light blue.

concentration than the Ouachita River. The Harrisonburg site (which is further south, Figure 3) also has a higher nutrient concentration, for most years, than the more northerly Sterlington site. In comparison to the other sites, the Tensas River ranks near the top for TP and TKN and near the middle for NO_x (Figure 7), while the Ouachita River ranks near the middle for the Harrisonburg site and the bottom for the Sterlington site.

4.1.3 Trends for Calcasieu-Mermentau Watershed Basin

Total Kjeldahl N values for Calcasieu River-Burton Landing, Moss Bluff, and Mermentau sites range from < 0.50 to 2.82, < 0.50 to 2.72, and < 0.05 to 2.99 mg N-TKN L^{-1}. Nitrite + nitrate values range from < 0.10 to 0.74, < 0.10 to 1.13, and < 0.10 to 1.13 mg N-NO_x L^{-1}. Total P values range from < 0.10 to 0.82, < 0.10 to 0.61, and < 0.10 to 0.97 mg P L^{-1}. All trends for the Calcasieu and Mermentau Rivers are significantly decreasing, excluding the Moss Bluff site's insignificant TP trend (Table 1, Figure 8). The Mermentau and Calcasieu-Burton Landing site both show a marked drop in the TKN concentration, while the Moss Bluff site only shows a small decrease for TKN. Total P and NO_x show a small decrease in concentration over time. The Mermentau has a higher TKN, NO_x, and TP concentration than either Calcasieu site, while the more southerly Burton Landing site has a higher TKN, NO_x, and TP concentration than the more northern Moss Bluff site. In comparison to the other sites, the Mermentau River ranks near the top for TP and TKN and near the middle for NO_x, excluding the Mississippi River. In the Calcasieu River, Moss Bluff ranks near the middle for TKN and the bottom for TP and NO_x, while the Burton Landing site ranks near the middle for all nutrients, excluding the Mississippi River for NO_x.

4.1.4 Trends for Vermilion-Teche Watershed Basin

Total Kjeldahl N values range from < 0.50 to 2.84 mg N-TKN L^{-1} for both. Nitrite + nitrate values range from < 0.10 to 2.38 and < 0.10 to 1.92 mg N-NO_x L^{-1} for Teche and Vermilion. Total P values range from < 0.10 to 0.90 and < 0.10 to 1.00 mg P L^{-1} for Bayou Teche and Vermilion. The TKN and TP trends for Bayou Teche and the Vermilion River and the NO_x trend for the Vermilion are significantly decreasing, while the NO_x trend for Teche shows no significant change. There is a steady drop in both the TKN and TP over time, though TP shows a leveling off or possibly even a slight increase in the past several years (Figure 9). The TKN, NO_x, and TP concentrations are generally higher for the Vermilion site. In comparison to the other sites, both the Vermilion River and Bayou Teche rank at or near the top for TP and TKN and at the top (after the Mississippi River and receiving rivers) for NO_x (Figure 9).

4.1.5 Trends for Mississippi Watershed Basin

Total Kjeldahl N values for the Atchafalaya River, Mississippi River – Belle Chasse, Mississippi River – Plaquemine, Mississippi River—St. Francisville, and Bayou Lafourche sites range from < 0.50 to 1.88, < 0.50 to 2.75, < 0.50 to 2.90, < 0.50 to 2.73, and < 0.50 to 2.42 mg N-TKN L^{-1}, respectively. Nitrite + nitrate values range from < 0.10 to 2.38, < 0.10 to 2.98, 0.13 to 3.00, < 0.10 to 2.94, and < 0.10 to 2.54 mg N-NO_x L^{-1} for the Atchafalaya, Belle Chasse, Plaquemine, St. Francisville, and Lafourche sites, respectively. Total P values range from < 0.10 to 0.64, < 0.10 to 0.88, < 0.10 to 0.94, < 0.10 to 0.80, and < 0.10 to 0.88 mg P L^{-1} for the sites. The TKN and TP trends for all sites are significantly decreasing and show a steady drop over time. The NO_x trend for the Atchafalaya is significantly decreasing, while the trends for all the Mississippi sites and Lafourche show no change. The decrease in NO_x is slight for the Atchafalaya and Lafourche (Figure 10). The NO_x concentrations for the Mississippi basin sites rank the highest in the state, while the concentrations for TKN and TP rank near the middle.

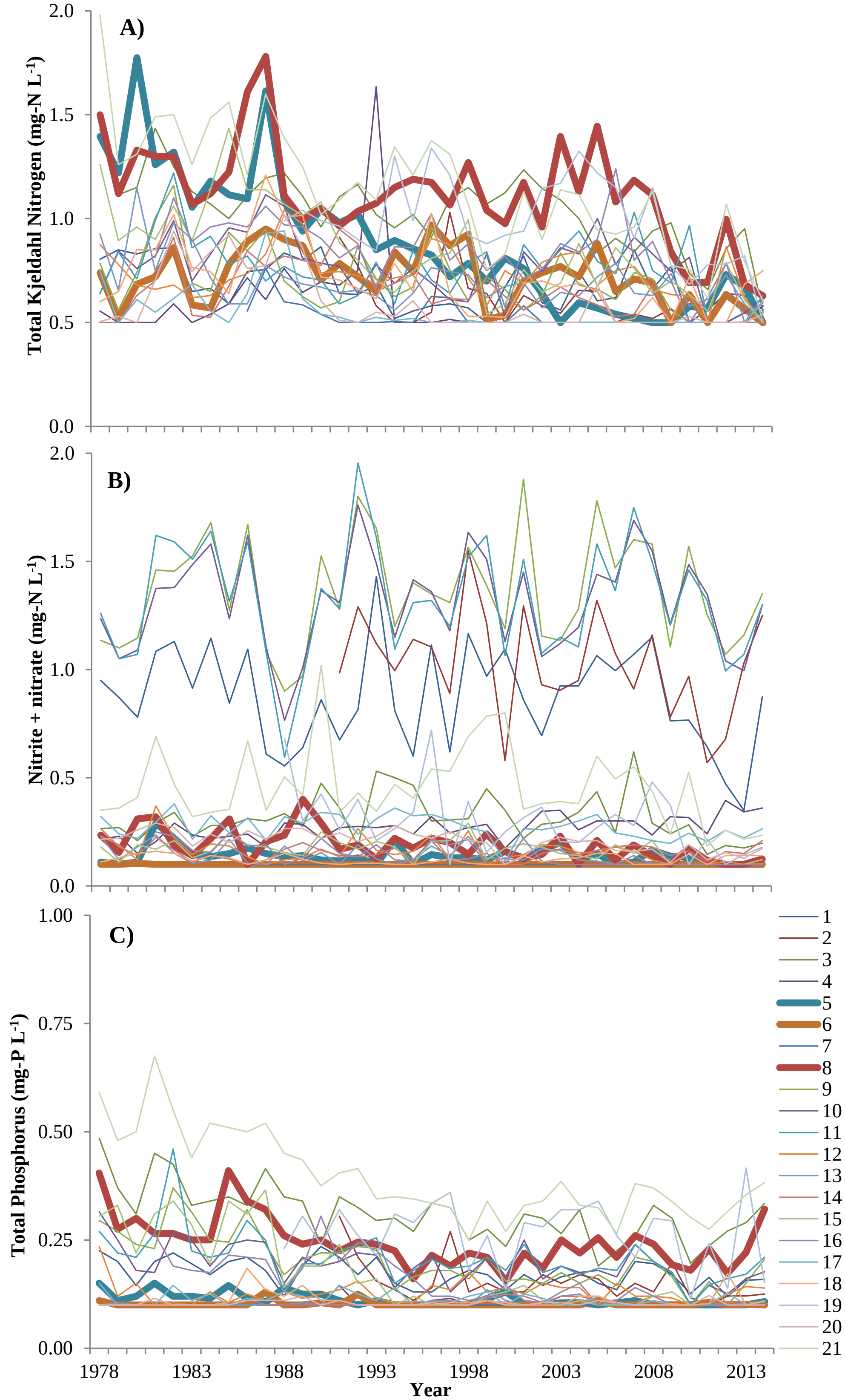


Figure 8. Yearly median total Kjeldahl nitrogen (A), nitrite + nitrate nitrogen (B), and total P (C) values since 1978. Calcasieu River-Burton Landing (#5) is highlighted in blue, Calcasieu River – Moss Bluff (#6) is in orange, and Mermentau River (#8) is in red.

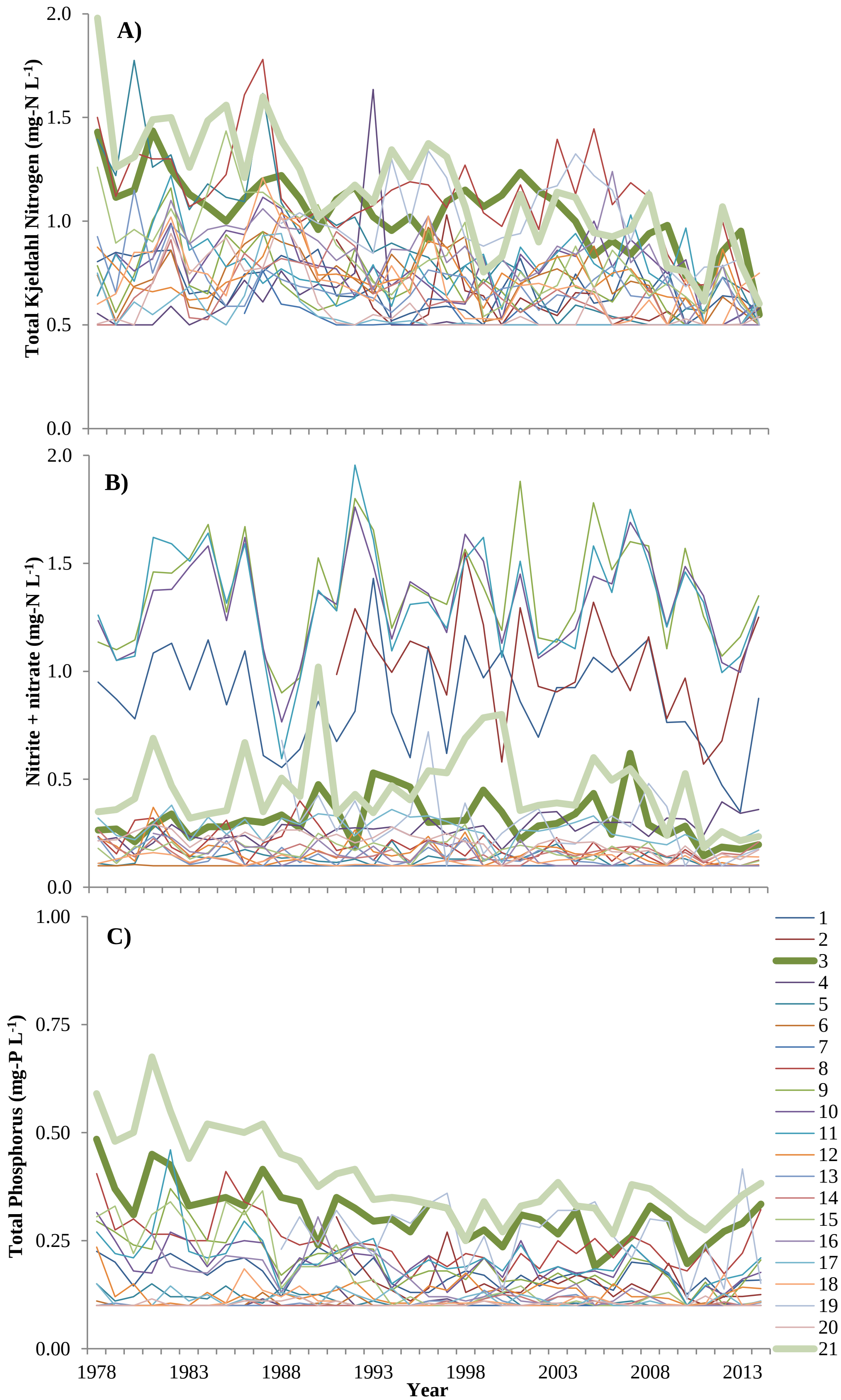


Figure 9. Yearly median total Kjeldahl nitrogen (A), nitrite + nitrate nitrogen (B), and total P (C) values since 1978. Bayou Teche (#3) is highlighted in dark green and Vermilion River (#21) is in light green.

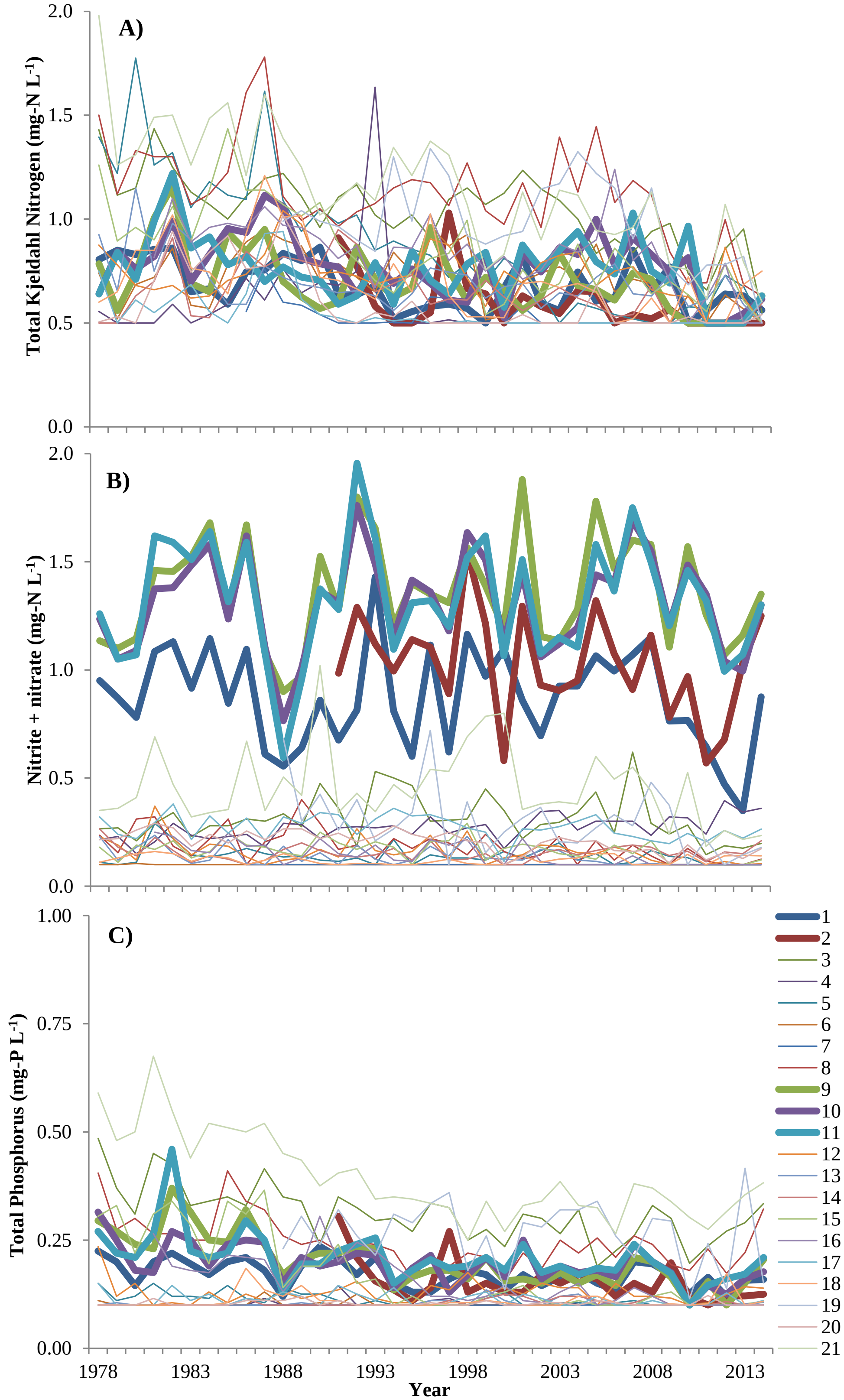


Figure 10. Yearly median total Kjeldahl nitrogen (A), nitrite + nitrate nitrogen (B), and total P (C) values since 1978. Atchafalaya River (#1) is highlighted in dark blue, Bayou Lafourche (#2) is in red, Mississippi River-Belle Chasse (#9) is in green, Mississippi River-Plaquemine (#10) is in purple, and Mississippi River-St. Francisville (#11) is in teal.

4.1.6 Trends for Pontchartrain Watershed Basin

Total Kjeldahl N values for the Lake Pontchartrain, Tangipahoa River, Tchefuncte River, and Tickfaw River sites range from < 0.50 to 1.72, < 0.50 to 2.08, < 0.50 to 2.60, and < 0.50 to 1.73 mg N-TKN L^{-1}, respectively. Nitrite + nitrate values range from < 0.10 to 1.30, < 0.10 to 0.82, < 0.10 to 0.65, and < 0.10 to 0.82 mg N-NO_x L^{-1} for the sites, respectively. Total P values range from < 0.10 to 0.73, < 0.10 to 0.72, < 0.10 to 0.80, and < 0.10 to 0.78 mg P L^{-1} for the sites. The TKN trend for all the sites in the Pontchartrain basin is significantly decreasing (Table 1, Figure 11). Lake Pontchartrain and the Tangipahoa and Tickfaw Rivers have significantly decreasing NO_x and TP trends, while these trends show no significant change for the Tchefuncte River. There has been a steady drop in TKN over time. The drops seen for TP and NO_x are slight. In comparison to the other sites, Lake Pontchartrain ranks at the bottom for TP, NO_x, and TKN. Tangipahoa and Tickfaw rank near the bottom for TKN, while Tchefuncte is near the middle. Tangipahoa, Tchefuncte, and Tickfaw rank toward the bottom of the middle for TP. Tangipahoa Ranks near the top for NO_x (excluding the Mississippi River and receiving rivers), while Tickfaw ranks near the middle, and Tchefuncte near the bottom (Figure 11).

4.1.7 Trends for Pearl Watershed Basin

Total Kjeldahl N values for the Bogue Chitto and Pearl River sites range from < 0.50 to 3.00 and < 0.50 to 2.68 mg N-TKN L^{-1}, respectively (Table 1, Figure 12). Nitrite + nitrate values range from < 0.10 to 1.84 and < 0.10 to 1.80 mg N-NO_x L^{-1} for the sites, respectively. Total P values range from < 0.10 to 0.62 and < 0.10 to 0.38 mg P L^{-1} for the sites, respectively. The TKN trend for all the sites in the Pearl Basin is significantly decreasing. The Bogue Chitto has a significant increasing NO_x trend and an insignificant trend for TP, while neither trend shows a significant change for the Pearl River. The drop in TKN has been steadily decreasing for all sites since the early 1990s, prior to that there was an increasing trend. The Bogue Chitto has seen a slight, but steady increase for both NO_x and TP. In comparison to all other sites, the Pearl and Bogue Chitto rank near the bottom for TP and TKN and in the middle for NO_x (Figure 12). The cause of the TKN peak for the Bogue Chitto in 1993 is unclear as neither TP nor NO_x shows an increase for that year, precipitation data indicates there was no flood that year, and the raw data does not indicate there was a problem with the analysis in the laboratory.

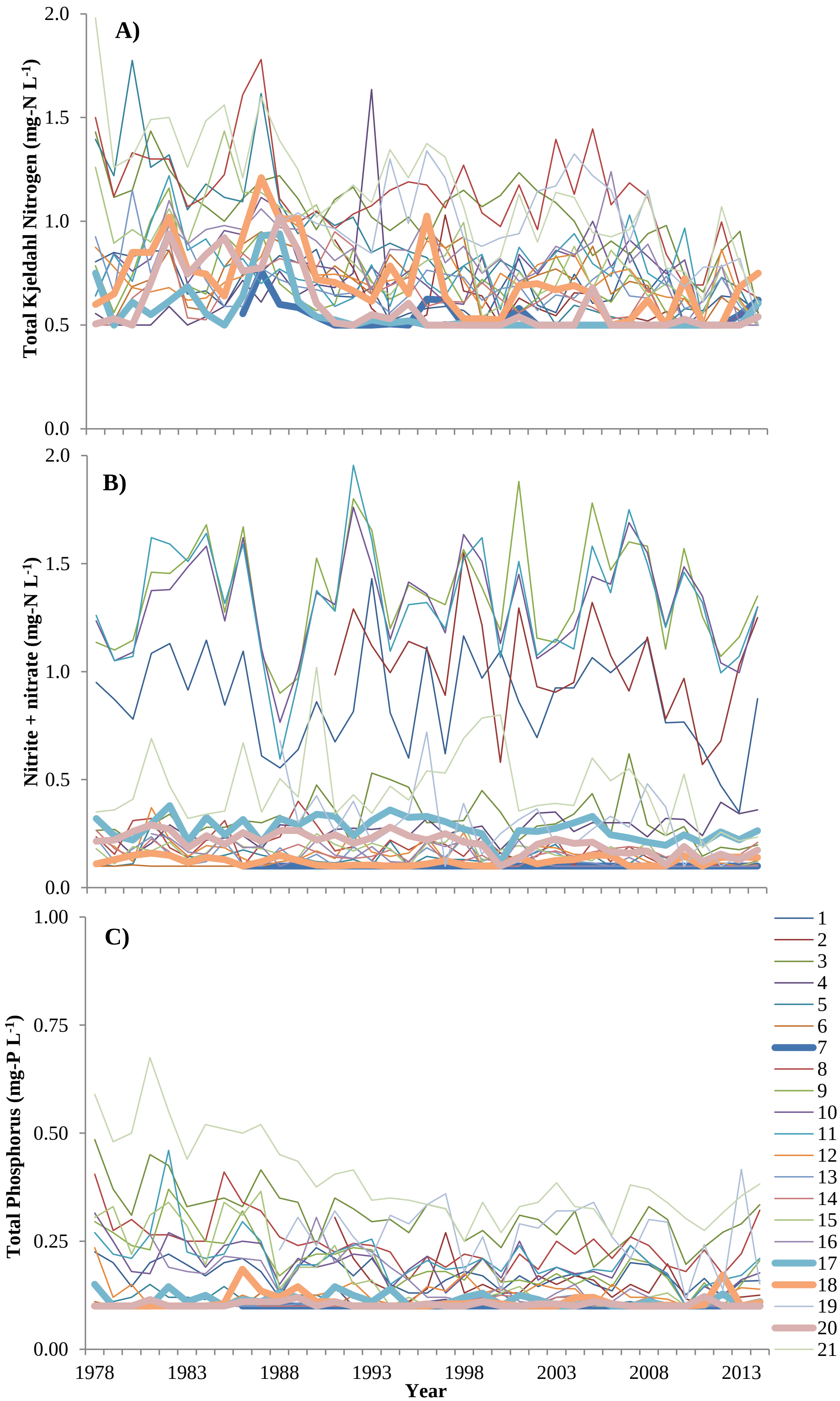


Figure 11. Yearly median total Kjeldahl nitrogen (A), nitrite + nitrate nitrogen (B), and total P (C) values since 1978. Lake Pontchartrain (#7) is highlighted in dark blue, Tangipahoa River (#17) is in light blue, Tchefuncte River (#18) is in orange, and Tickfaw River (#20) is in pink.

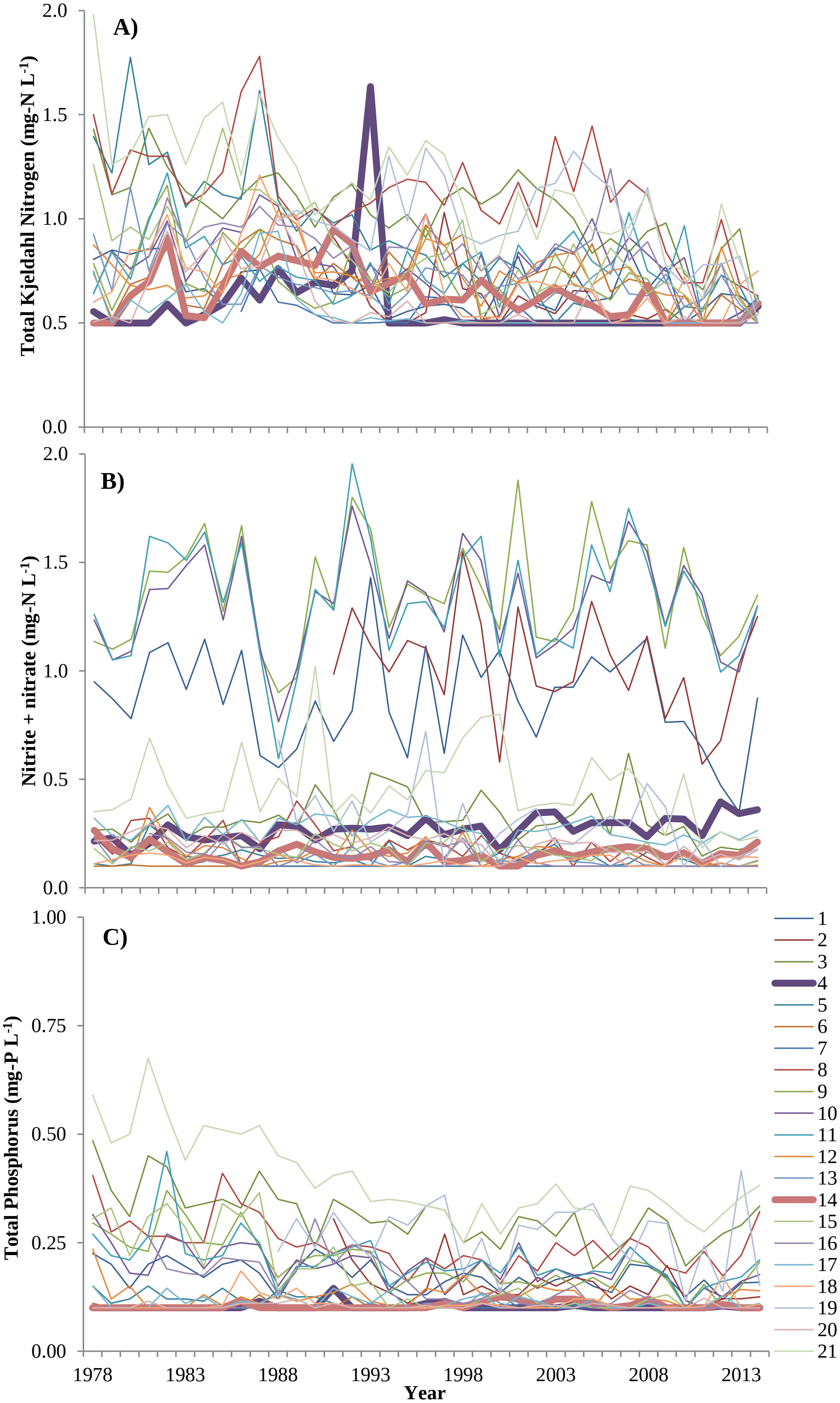


Figure 12. Yearly median total Kjeldahl nitrogen (A), nitrite + nitrate nitrogen (B), and total P (C) values since 1978. Bogue Chitto River (#4) is highlighted in purple and Pearl River (#14) is in pink.

4.1.8 Discussion of Trends

Overall, nutrient concentrations for N and P in major water bodies of Louisiana are generally not increasing. A number of regulations were passed that have helped drive the reduction of nutrients and improvements to water quality in Louisiana water bodies. The biggest driver was the Clean Water Act (the Act), passed in 1972, that allowed implementation of both nonpoint source and point source programs to protect and restore water quality. Though the long-term nutrient data available begins in 1978, the reduction of nutrients in Louisiana waters can still be observed, especially for TKN and TP (Figure 6 to Figure 12, Appendix C). The Act required point source dischargers to meet specific effluent limits through the National Pollutant Discharge Elimination System (NPDES). Louisiana was delegated to administer the NPDES in 1996 under their own program, the Louisiana Pollutant Discharge Elimination System (LPDES). All point source pollutant dischargers are required to obtain a permit from LDEQ under the LPDES program under industrial, municipal, or general water permits.

The Act also created an avenue through which funds were available to assist in the building of publicly owned treatment works (POTWs). Additionally, it required POTWs to reach their effluent limits based on secondary treatment of wastewater. Secondary treatment of wastewater leads to a substantial reduction in the amount of organic matter in wastewater, and subsequently nutrients, as two of the major components of organic matter are N and P. The combination of requiring point source dischargers and POTWs to treat their effluents prior to discharging into waterbodies provided a reduction in the load of many pollutants, including nutrients (USEPA, 2000). However, municipal discharges and sewage are still listed in the top ten sources of impairment for waterbodies in the National Water Quality Inventory: Report to Congress (USEPA, 2009). As POTWs age, facilities need upgrades to continue proper treatment. Additionally, treatment beyond secondary treatment is needed to provide further reduction of nutrients (USEPA, 2009).

The introduction of a permitting system that capped point source effluent into waterbodies provided one part of the reduction in the nutrient load, as wastewater and sewage are among the primary sources of point source pollution (Smith, et al., 1999). Nonpoint sources covers the other main source of nutrients, including agriculture, urban runoff/stormwater, and atmospheric deposition. In the most recent national water quality report to Congress, these three sources are listed among the top ten sources of impairment for water bodies (USEPA, 2009). In 1987, Section 319 of the Act was added and called on states to develop nonpoint source management programs. Funding for these programs began in 1990. As management programs have been introduced and conservation practices implemented, the nutrient load from fertilizers has been reduced (LDEQ, 2013).

4.2 Land Use Correlation

The correlation analysis between land use and nutrients (median from 2000-2014, Table A.1) found a significant positive correlation between TP and agriculture and TKN and agriculture, whereas TP and TKN showed a significant negative correlation with forests (Table 2). Total P and TKN showed a significant positive correlation with TSS. Briefly, recall the drainage basins used for the land use analysis were included only the area draining into the southernmost site located on each river, (from Section 3.2 for a more detailed description). The drainage basins (Figure A.1) for the Mermentau, Vermilion-Teche, Tensas, Mississippi, and Red have the highest occurrence of agriculture, while the drainage basins of the Ouachita, Calcasieu, Pearl, Tchefuncte, Tickfaw, and Tangipahoa have the highest occurrence of forest. Grasslands make up a large portion of the Red, Mississippi, and Tangipahoa drainage basins. The percentage of developed area for all watersheds is small. Wetlands have the smallest representation in the Red and Mississippi drainage areas (Figure 13).

Table 2. Correlation results of Kendall analysis between land use, total suspended solids (TSS), and nutrients. Significant results (at p<0.05) are highlighted in red italics. Agriculture was broken down into three categories to find the individual significance of these components.

	Total Kjeldahl Nitrogen (TKN)	Nitrite + Nitrate (NO_x)	Total Phosphorus (TP)
TSS	0.35	0.35	0.47
p-value	0.1367	0.1367	0.0583
Wetlands	0.00	0.15	0.06
p-value	1.0000	0.5322	0.8054
Forest	*-0.48*	-0.33	*-0.58*
p-value	*0.0423*	0.1599	*0.0173*
Developed	-0.07	-0.11	-0.14
p-value	0.7548	0.6394	0.5655
Agriculture	*0.77*	0.11	*0.78*
p-value	*0.0010*	0.6394	*0.0014*
Grasslands	-0.29	0.00	-0.34
p-value	0.2115	1.0000	0.1628

	TKN	NO_x	TP
Non N-fixer	*0.59*	0.11	*0.66*
p-value	*0.0125*	0.6394	*0.0067*
N-fixer	*0.73*	0.11	*0.78*
p-value	*0.0018*	0.6394	*0.0014*
Rice/Aqua	0.47	-0.20	0.20
p-value	0.1885	0.5730	0.5730

Agriculture is cited as the top source of water body impairment and is linked to high nutrient values (Howarth, et al., 2002, USEPA, 2009). The correlation analysis between nutrients and land use presented in this report supports this linkage as higher concentrations of TP and TKN are significantly correlated to the presence of agriculture within the state. The Ouachita and Calcasieu-Mermentau drainage areas are good examples of the relationship between nutrients and land use. Both drainage areas have a greater acreage of agriculture occurring primarily near one river within the watershed (the Tensas River in the Ouachita Basin and Mermentau River in the Mermentau Basin, Figure 4) and those

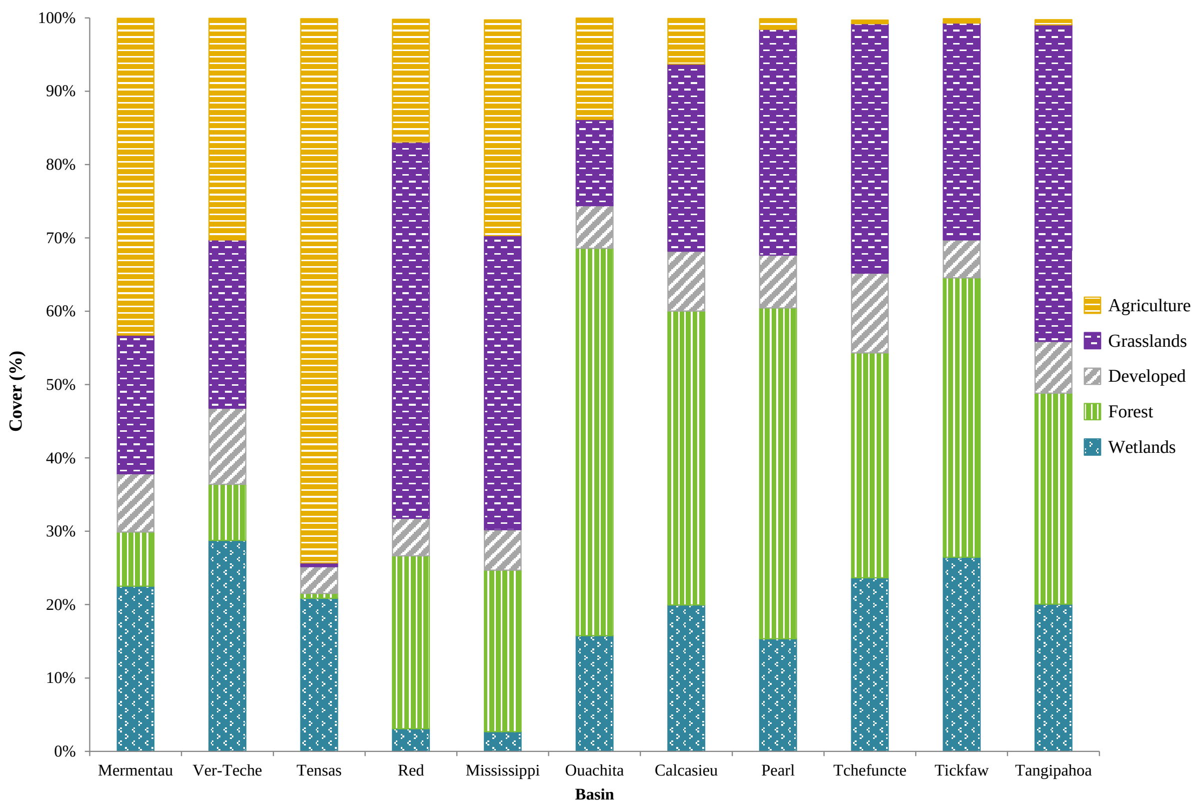


Figure 13. Percent cover of each major land use class for the major drainage areas within Louisiana. The Vermilion-Teche drainage area is abbreviated as Ver-Teche.

rivers also have higher TP and TKN concentrations than the Calcasieu and Ouachita Rivers (Figure 14). When agriculture was further broken down by crop type (e.g., N-fixer, non N-fixer, and rice and/or aquaculture), both N-fixers and non N-fixers crops were significantly correlated with higher TKN and TP values, while rice/aquaculture was not (Table 2). The significant correlation of increased TKN associated with N-fixing crops is unexpected. Nitrogen fixing crops are able to obtain their own N from the atmosphere through the biological process of N fixation that occurs in root nodules. Specialized bacteria, *Rhizobia*, which live in these nodules, are the organisms responsible for fixing atmospheric N, converting N_2 to NH_4^+. Because these plants are able, through their symbiotic relationship with *Rhizobia*, to fix their own N, less N, if any, is needed from fertilizer applied to these crops (Havlin, 2005). The application of fertilizer containing N is not recommended by the LSU AgCenter (Padgett, et al., 2014); therefore, the source of TKN is unclear and may warrant further investigation.

The Vermilion-Teche and Tensas drainage areas have nearly identical TKN median values from 2000 to 2014, but the amount of agriculture occurring is over double in the Tensas drainage area compared to the Vermilion-Teche. Neither watershed is significantly heavier in N-fixing crops versus non N-fixing crops (Figure 14). However, the drainage area with the highest TKN value (Mermentau) also has the highest rice production. Rice is grown in flooded soils, which typically equates to anaerobic (no oxygen) conditions. Under anaerobic conditions, NO_x will be converted to N_2 via denitrification and be lost to the atmosphere. In order for rice to receive any N from fertilizer, it must be in the form of NH_4^+, which could be contributing to the higher TKN values found in the Mermentau watershed.

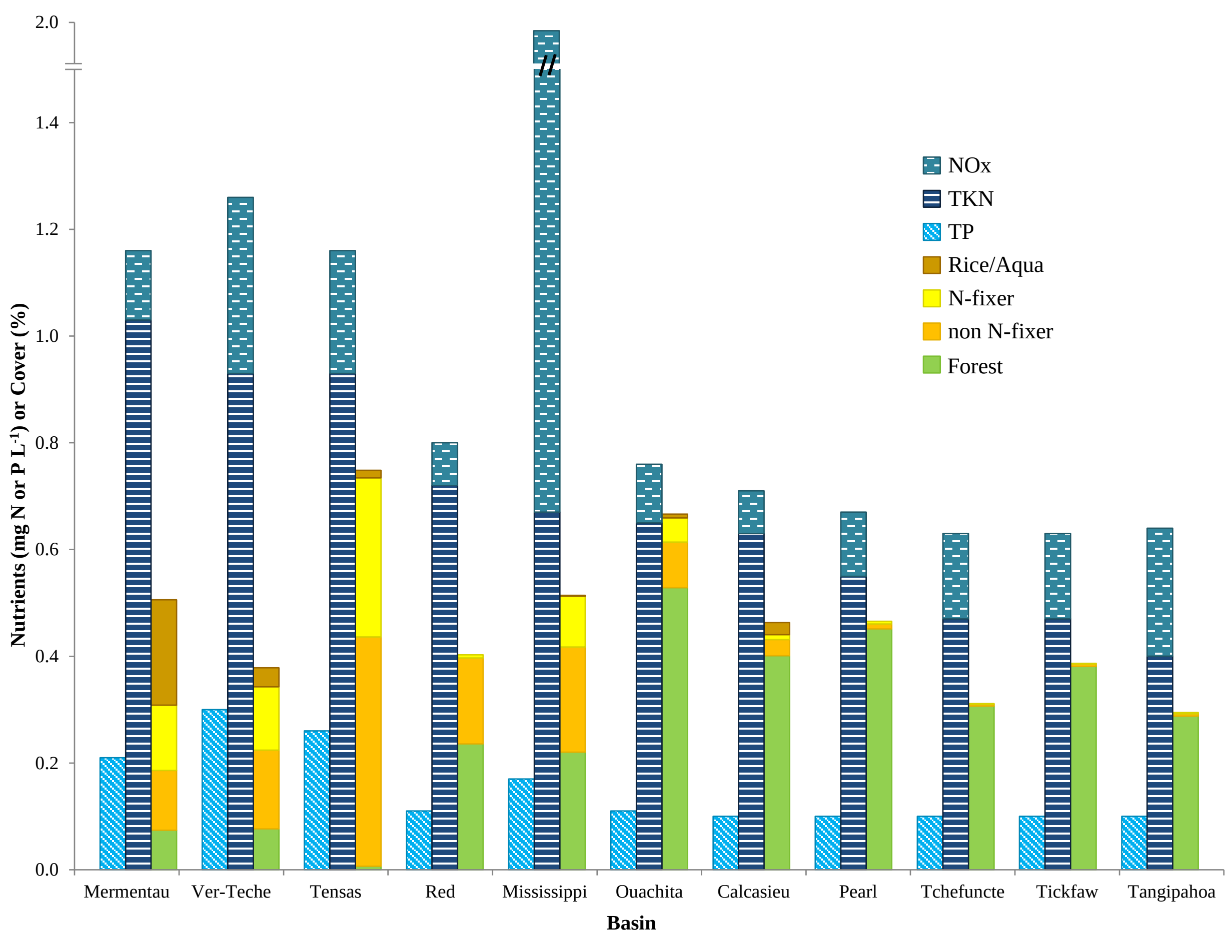


Figure 14. Comparison of the median TP, TKN, and NO_x concentrations from 2000 to 2014 with percent cover (in decimal form) of significant land use classes for each watershed used in the correlation analysis.

Total suspended solids are positively correlated with TKN and TP (Table 2). Both PO_4^{3+} and NH_4^+ sorb to soil. Ammonium sorbs to negatively charged clays via an ion exchange reaction, whereas phosphate forms sorb to the various metals (e.g., Fe, Ca, Al, etc.) present in soil particles (Havlin, 2005). Higher amounts of TSS present in the water column would, therefore, be associated with higher amounts of PO_4^{3+} and NH_4^+ also present in the water column. Agriculture is often associated with higher amounts of soil erosion (Howarth, et al., 2002), thus the strong correlation between TP, TKN, TSS, and agriculture is not surprising. However, the extent to which PO_4^{3+} and NH_4^+ are present as a soil-bound form as opposed to a dissolved form is unknown because all nutrients collected and analyzed for the AWQMN are unfiltered, so there is no knowledge of the proportion of dissolved to particulate (soil-bound) forms. It is, therefore, unclear if the increased PO_4^{3+} and NH_4^+ presence in the water column is due to soil erosion or a different source.

The correlation analysis also shows that forested areas are associated with a lower TKN and a lower TP. The drainage areas with the highest proportion of forest (Ouachita, Calcasieu, Red, Pearl, Tchefuncte, Tickfaw, and Tangipahoa) all have the lowest TKN (BDL to 0.67 mg N L^{-1}) and TP (0.1 mg P L^{-1}), whereas the drainage areas with a higher agriculture component (Mississippi, Tensas, Mermentau, and Vermilion-Teche) all have higher, and in some cases double, amounts of TKN (0.73 to 1.05 mg N L^{-1}) and nearly double or triple the amount of TP (0.17 to 0.3 mg-P L^{-1}) (Figure 14). The lesser occurrence of soil erosion that occurs in forested ecosystems probably accounts for most of the lower TKN concentrations present, but trees are also known to provide a sink for NH_4^+ (Nadelhoffer, et al., 1984). Forested watersheds are also known to conserve P as less soil erosion occurs and, subsequently, less transport of soil-bound P into waterbodies (Howarth, et al., 2002 and references therein). Though a higher TP is significantly correlated with the presence of agriculture, four out of the five watersheds with the highest agriculture (Vermilion-Teche, Mermentau, Mississippi, and the Red) show a decreasing trend for TP whereas four out of the six watersheds with the greatest proportion of forest (Ouachita, Calcasieu, Pearl, and Tchefuncte) showed no trend for TP. Accordingly, even though TP is higher where agriculture predominates, there is also progress in decreasing the amount of TP that is entering our waterbodies.

Nitrite + nitrate shows no significant correlation to any land use. This could be due to the confounding influence of atmospheric deposition, which is becoming an important pathway for entry of NO_x into water bodies. Atmospheric deposition is listed in the top ten sources of impairment for rivers and streams; lakes, ponds, and reservoirs; and estuaries by the EPA (USEPA, 2009). Deposition could be contributing to the higher NO_x concentration in the Calcasieu River at Burton Landing in comparison to the site further upstream at Moss Bluff. There are few agricultural sources of N between Moss Bluff and Burton Landing on the Calcasieu River, which points to atmospheric deposition, stormwater/urban runoff, or point sources as a source of the increase. Most of the development in the Calcasieu watershed is located between the Moss Bluff and Burton Landing sites around the City of Lake Charles (which accounts for 6% of the high, medium, and low intensity development land use). The Air Permits Division at LDEQ maintains an emission inventory of actual criteria and toxic air pollutant emissions in the Emissions Reporting and Inventory Center (ERIC), which was used to investigate the atmospheric deposition of NO_x. Using data from LDEQ's website for the past five years, the mean NO_x emitted from 2009 to 2013 was calculated for a radius of 50,000 m from a point halfway between the Moss Bluff and Burton Landing sites on the Calcasieu River (LDEQ, 2015). The mean NO_x emissions for the Lake Charles area were 23,054 tons of NO_x. Whereas, the Bogue Chitto watershed contains little development (1% of high, medium, and low intensity) and the mean NO_x emissions (from the long-term monitoring station near Bush) in this area were only 3,993 tons of NO_x. Additionally, two models created to pinpoint sources of N pollution (the SPAtially Referenced Regressions On Watersheds (SPARROW) and Nutrient Export from WatershedS (NEWS) models) show atmospheric deposition as a primary source of N in the southwestern part of Louisiana, further supporting deposition as the primary source of increased NO_x for the Lake Charles area along the Calcasieu River (McCrackin, et al., 2013).

An increasing trend for NO_x was found in the Bogue Chitto River. The reasons for this are unclear. The Bogue Chitto watershed is primarily forest (38%), woody wetlands (14%), grassland/pasture (23%), and shrubland (17%). Less than 2% is related to agriculture and only 7% is developed (Appendix A). Atmospheric deposition of NO_x is not likely to be a large contributor given the amount of NO_x that is emitted in the area. Potential sources of nutrient increases could result from failures of municipal wastewater treatment plants, leakage from off-site sewage treatment, or runoff from animal manure activities; however, in these scenarios, TKN would also be expected to increase and TKN shows a significant decrease. Additional studies have yet to occur to investigate the sources of the increases, but would be warranted in order to target the specific cause of the NO_x increase.

Further review and research may be warranted to explain the water quality improvements realized through implementation of water quality programs and best management and conservation practices. Speciation of TKN and TP could potentially help narrow down specific sources of N or P. Both TKN and TP consist of an organic and inorganic form: TKN of organic-N and ammonium (NH_4^+) and TP of organic-P and phosphate (PO_3^{4-}). Similarly, water samples collected are unfiltered (particulate, sorbed to soil) as opposed to filtered (dissolved, bioavailable). Knowledge of the proportion of organic versus inorganic or dissolved versus particulate could point to potential nutrient sources, such as manure (higher organic proportion) or soil runoff (more particulate than dissolved). Further studies may be useful to determine the sources of nutrient pollution in order to achieve continued improvement of nutrients in our waters.

5. Conclusion

Louisiana has made great strides in managing nutrient pollution in our water bodies. Trends of TKN, NO_x, and TP concentrations show significant decreases for the majority of the long-term monitoring sites within the state. While the state has made great progress in managing nutrients, continued programs targeting best management and conservation practices to agricultural areas in the state may further the nutrient management effort in Louisiana. Participation by all watershed stakeholders is needed from state and local governments, industry, and the public to continue to achieve reductions of nutrients. Work has already begun on implementation strategies for nutrient management. Together with the Coastal Protection and Restoration Authority of Louisiana (CPRA), the Louisiana Department of Agriculture and Forestry (LDAF), and the Louisiana Department of Natural Resources (LDNR), LDEQ has formed the Louisiana Nutrient Management Strategy Interagency Team and is implementing a Nutrient Management Strategy to address water quality and manage nutrient pollution in our waters through a variety of avenues including nonpoint source, point source, and coastal protection and restoration management. The nutrient trend analyses presented in this report will help to document observed nutrient trends in water bodies in Louisiana and to help pinpoint areas where current strategies are working or need improvement.

6. References

AWWA (American Water Works Association) and APHA (American Public Health Association), editor. 1999. Standard Methods for the Examination of Water and Wastewater. 20th ed. APHA, Washington, DC

AWWA (American Water Works Association) and APHA (American Public Health Association), editor. 2005. Standard Methods for the Examination of Water and Wastewater 21st ed. APHA, Washington, DC.

Bargu, S., J.R. White, C.Y. Li, J. Czubakowski and R.W. Fulweiler. 2011. Effects of freshwater input on nutrient loading, phytoplankton biomass, and cyanotoxin production in an oligohaline estuarine lake. Hydrobiologia 661: 377-389. doi:10.1007/s10750-010-0545-8.

Bruningfann, C.S. and J.B. Kaneene. 1993. The effects of nitrate, nitrite and N-nitroso compounds on human health - A review. Vet. Human Toxicol. 35: 521-538.

Chinchilla, C.R. 2008. Automated colorimetric method for nitrate analysis. Lab Manager 3: 24-27.

L. P. Rozas, J. A. Nyman, C. E. Proffitt, N. N. Rabalais, D. J. Reed and R. E. Turner. 1999. What is the threat of harmful algal blooms in Louisiana coastal waters? Recent Research in Coastal Louisiana Symposium: Natural System Function and Response to Human Influences, Louisiana Sea Grant College Program, Baton Rouge, LA.

Eddy, F. 2005. Ammonia in estuaries and effects on fish. Journal of Fish Biology 67: 1495-1513.

ESRI. 2012. ArcGIS 10.1 esri, Redlands, CA.

Havlin, J. 2005. Soil Fertility and Fertilizers: An Introduction to Nutrient Management. 7th ed. Pearson Prentice Hall, Upper Saddle River, N.J.

Helsel, D. and R. Hirsch. 2002. Statistical methods in water resources, Chapter A3USGS, Washington, DC.

Hirsch, R.M. and J.R. Slack. 1984. A nonparametric trend test for seasonal data with serial dependence. Water Resources Research 20: 727-732. doi:10.1029/WR020i006p00727.

Howarth, R.W., A. Sharpley and D. Walker. 2002. Sources of nutrient pollution to coastal waters in the United States: Implications for achieving coastal water quality goals. Estuaries 25: 656-676. doi:10.1007/bf02804898.

LDEQ (Louisiana Department of Environmental Quality). 2015. Emissions Reporting and Inventory Center: Actual Emissions Report. LDEQ, Available at http://business.deq.louisiana.gov/Eric/EricReports/RadiusReport (accessed February 23, 2015), Baton Rouge, LA.

LDEQ (Louisiana Department of Environmental Quality). 2013. Louisiana Nonpoint Source Annual Report: Federal Fiscal Year 2013. In: N. S. Program, editor LDEQ, Baton Rouge, LA.

LDEQ (Louisiana Department of Environmental Quality). 2008. Water Quality Management Plan: Basin and Subsegment Boundaries. In: Water Permits Division, Office of Environmental Services, editor LDEQ, Baton Rouge, LA.

LDEQ (Louisiana Department of Environmental Quality). 2013. 2012 Louisiana Water Quality Inventory: Integrated Report. In: Water Permits Division, Office of Environmental Services, editor LDEQ, Baton Rouge, LA.

LDEQ (Louisiana Department of Environmental Quality). 2014. Quality Assurance Project Plan for the Ambient Water Quality Monitoring Network. In: Water Permits Division, Office of Environmental Services and Inspection Division, Office of Environmental Compliance, editors, LDEQ, Baton Rouge, LA.

LOSCO (Louisiana Oil Spill Coordinators Office). 2009. LiDAR derived Digital Elevation Map (DEM) of Louisiana, UTMz15n - NAD83. Louisiana Oil Spill Coordinators Office, Baton Rouge, LA.

McCrackin, M.L., J.A. Harrison and J.E. Compton. 2013. A comparison of NEWS and SPARROW models to understand sources of nitrogen delivered to US coastal areas. Biogeochemistry 114: 281-297. doi:10.1007/s10533-012-9809-x.

Nadelhoffer, K.J., J.D. Aber and J.M. Melillo. 1984. Seasonal patterns of ammonium and nitrate uptake in nine temperate forest ecosystems. Plant Soil 80: 321-335. doi:10.1007/bf02140039.

Padgett, B., J. Lofton, T. Price, D. Harrell, J. Stevens, D. Stephenson, et al. 2014. 2015 Soybean Variety Yields and Production Practies. LSU AgCenter, Baton Rouge, LA.

Reddy, K.R. and R.D. DeLaune. 2008. Biogeochemistry of Wetlands: Science and Applications. 1 ed. CRC Press, Taylor and Francis Group, Boca Raton, FL.

SAS Institute, I. 2006. SAS Enterprise Guide 4.1. SAS Institute, Inc, Cary, NC.

Schlesinger, W.H. 1997. Biogeochemistry: An Analysis of Global Change. 2nd ed. Academic Press, San Diego, CA.

Sen, P.K. 1968. Estimates of regression coefficient based on Kendall's tau. J. Am. Stat. Assoc. 63: 1379-1389.

Smith, V.H. and D.W. Schindler. 2009. Eutrophication science: Where do we go from here? Trends Ecol. Evol. 24: 201-207. doi:10.1016/j.tree.2008.11.009.

Smith, V.H., G.D. Tilman and J.C. Nekola. 1999. Eutrophication: Impacts of excess nutrient inputs on freshwater, marine, and terrestrial ecosystems. Environmental Pollution 100: 179-196.

USDA-NASS (U. S. Department of Agriculture-National Agricultural Statistics Service). 2013. USDA National Agricultural Statistics Service Cropland Data Layer. USDA-NASS, Available at http://nassgeodata.gmu.edu/CropScape/ (accessed December 2, 2014), Washington, DC.

USEPA (U. S. Environmental Protection Agency). 1971. Methods for the Chemical Analysis of Water and Wastes. USEPA, Washington, DC.

USEPA (U. S. Environmental Protection Agency). 1993. Methods for the Determination of Inorganic Substances in Environmental Samples. USEPA, Washington, DC.

USEPA (U.S. Environmental Protection Agency). 2009. National Water Quality Inventory: Report to Congress. 2004 Reporting Cycle. In: Office of Water, editor USEPA, Washington, DC.

USEPA (U.S. Environmental Protection Agency). 2000. Progress in water quality: an evaluation of the national investment in municipal wastewater treatment. In: Office of Water Management, editor USEPA, Washington, DC.

Winkler, S. 2004. A User-Written SAS Program for Estimating Temporal Trends and Their Magnitude. St. Johns River Water Management District, Palatka, FL.

Appendix A: Detailed Land Use by Drainage Basin

Table A.1. Median water quality parameter from 2000 to 2014 and main land use classes for each basin used in correlation analysis. Agriculture was broken down into three categories (rice/aquaculture, N-fixing crops, and non N-fixing crop) for further analysis.

	Water Quality Parameter				**Land Use**							
	TP	**NO_x**	**TKN**	**TSS**	**Wetlands**	**Forest**	**Developed**	**Grasslands**	**Agriculture**	**Rice/Aqua**	**N-fixer**	**non N-fixer**
Basin	mg P L^{-1}	mg N L^{-1}	mg N L^{-1}	mg L^{-1}	% cover							
Calcasieu	0.10	0.08	0.63	14	20%	40%	8.2%	26%	6.2%	2.2%	0.9%	3.0%
Mermentau	0.21	0.13	1.03	14	23%	7.4%	7.9%	19%	43%	20%	12%	11%
Mississippi	0.17	1.31	0.67	72	2.7%	22%	5.5%	40%	29%	0.2%	10%	20%
Ouachita	0.11	0.11	0.65	17	16%	53%	5.8%	12%	14%	0.7%	4.5%	8.6%
Pearl	0.10	0.16	0.57	28	15%	45%	7.2%	31%	1.4%	—	0.5%	0.9%
Red	0.11	0.08	0.72	27	3.1%	24%	5.1%	51%	17%	—	0.6%	16%
Tangipahoa	0.10	0.24	0.40	13	20%	29%	7.1%	43%	0.7%	—	0.3%	0.4%
Tchefuncte	0.10	0.12	0.55	6	24%	31%	11%	34%	0.5%	—	0.2%	0.3%
Tensas	0.26	0.23	0.93	35	21%	0.7%	3.6%	0.5%	74%	1.4%	30%	43%
Tickfaw	0.10	0.16	0.47	13	26%	38%	5.2%	30%	0.6%	—	0.1%	0.5%
Ver-Teche	0.30	0.33	0.93	39	29%	7.6%	10%	23%	30%	3.6%	12%	15%

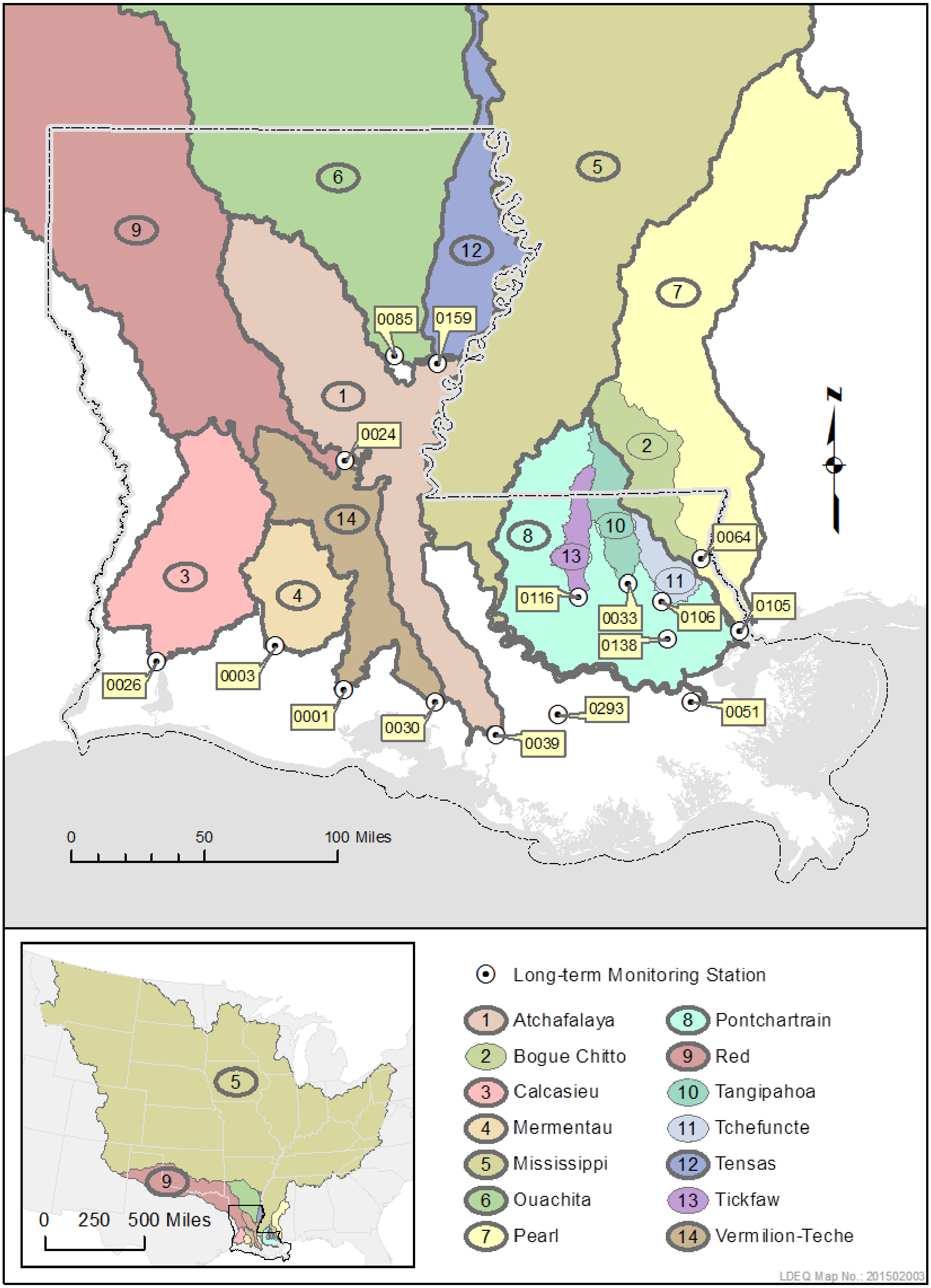


Figure A.1. Map of the drainage areas used to calculate land use classes.

Table A.2. Land use by % cover and total acres for the Mississippi, Red, Ouachita, and Tensas Rivers drainage basins. The Atchafalaya River basin only consists of land that was not included in the Mississippi, Red, Ouachita, or Tensas River basins. Blank cells represent no data.

	Mississippi		Red		Ouachita		Tensas		Atchafalaya	
Land use	**% cover**	**acres**	**% cover**	**acres**	**% cover**	**acres**	**% cover**	**acres**	**% cover**	**acres**
Barren	**0.25%**	**1,819,660**	**0.18%**	**77,511**	**0.03%**	**3,188**	**0.03%**	**416**	**0.02%**	**752**
Forest (total)	**22.03%**	**157,586,050**	**23.56%**	**9,984,051**	**52.82%**	**6,285,146**	**0.65%**	**9,647**	**32.36%**	**1,157,813**
Deciduous Forest	17.34%	124,071,000	11.97%	5,071,080	10.02%	1,192,830	0.06%	830	0.47%	16,671
Evergreen Forest	4.22%	30,193,500	10.00%	4,235,940	39.57%	4,708,900	0.06%	858	31.03%	1,110,240
Mixed Forest	0.46%	3,321,550	1.60%	677,031	3.22%	383,416	0.54%	7,959	0.86%	30,902
Wetlands (total)	**2.70%**	**19,302,210**	**3.09%**	**1,310,462**	**15.78%**	**1,877,755**	**20.89%**	**309,813**	**38.43%**	**1,375,030**
Herbaceous Wetlands	0.90%	6,412,110	0.06%	25,092	0.28%	32,895	0.10%	1,506	1.19%	42,450
Woody Wetlands	1.80%	12,890,100	3.03%	1,285,370	15.50%	1,844,860	20.78%	308,307	37.24%	1,332,580
Developed (total)	**5.51%**	**39,448,730**	**5.12%**	**2,167,780**	**5.81%**	**691,893**	**3.66%**	**54,362**	**4.34%**	**155,422**
Developed/High Intensity	0.15%	1,093,000	0.09%	38,193	0.09%	10,942	0.02%	281	0.04%	1,288
Developed/Low Intensity	1.31%	9,368,740	1.16%	492,747	2.35%	279,515	0.32%	4,702	1.16%	41,428
Developed/Med Intensity	0.41%	2,936,490	0.23%	97,660	0.30%	35,302	0.07%	980	0.12%	4,390
Developed/Open Space	3.64%	26,050,500	3.63%	1,539,180	3.08%	366,134	3.26%	48,398	3.03%	108,315
Grasslands (total)	**40.09%**	**286,826,500**	**51.32%**	**21,747,670**	**11.75%**	**1,397,997**	**0.51%**	**7,601**	**9.40%**	**336,475**
Grassland/Pasture	34.48%	246,684,000	35.98%	15,246,700	5.63%	670,456	0.22%	3,278	2.73%	97,548
Shrubland	5.61%	40,142,500	15.34%	6,500,970	6.11%	727,541	0.29%	4,323	6.68%	238,927
Agriculture: N-fixers (total)	**9.51%**	**68,039,984**	**0.58%**	**247,384**	**4.51%**	**536,361**	**29.82%**	**442,363**	**7.17%**	**256,666**
Alfalfa	0.98%	7,005,800	0.21%	87,798	0.00%	29.13	0.00%	52.49	0.00%	56.27
Clover/Wildflowers	0.00%	34,610	0.00%	425	0.00%	2,333				
Dbl Crop Barley/Soybeans	0.00%	9,398	0.00%	275						
Dbl Crop Corn/Soybeans	0.01%	42,883	0.00%	192	0.00%	303	0.01%	136		
Dbl Crop Soybeans/Cotton	0.00%	9,640								
Dbl Crop Soybeans/Oats	0.00%	3,340	0.00%	19.57	0.01%	886	0.00%	0.67	0.02%	577
Dbl Crop WinWht/Soybeans	0.56%	4,017,060	0.11%	44,809	0.59%	69,689	3.02%	44,728	1.12%	40,210
Dry Beans	0.04%	318,869	0.00%	90						
Lentils	0.03%	216,718								
Peanuts	0.00%	19,739	0.02%	8,161	0.00%	495	0.00%	7.12	0.00%	0.67
Peas	0.11%	811,861	0.00%	452	0.00%	154				
Soybeans	7.76%	55,549,700	0.25%	104,702	3.90%	464,572	26.79%	397,439	6.03%	215,823
Vetch	0.00%	366	0.00%	461						
Rice/Aquaculture (total)	**0.17%**	**1,231,207**	**0.02%**	**6,627**	**0.71%**	**84,804**	**1.47%**	**21,815**	**0.60%**	**21,494**
Aquaculture	0.00%	23,587	0.00%	932	0.01%	1,308	0.05%	695	0.09%	3,218
Rice	0.17%	1,207,620	0.01%	5,695	0.70%	83,496	1.42%	21,121	0.51%	18,276

	Mississippi		Red		Ouachita		Tensas		Atchafalaya	
Land use	**% cover**	**acres**	**% cover**	**acres**	**% cover**	**acres**	**% cover**	**acres**	**% cover**	**acres**
Agriculture: non N-fixers (total)	**19.72%**	**141,102,160**	**16.12%**	**6,832,301**	**8.59%**	**1,022,180**	**42.97%**	**637,378**	**7.67%**	**274,492**
Apples	0.00%	9,740								
Asparagus	0.00%	252								
Barley	0.16%	1,130,700	0.03%	13,389						
Blueberries	0.00%	261	0.00%	152						
Buckwheat	0.00%	6,489								
Cabbage	0.00%	2,882								
Camelina	0.00%	936								
Caneberries	0.00%	292								
Canola	0.07%	527,925	0.08%	35,552						
Cantaloupes	0.00%	1,517	0.00%	4.00						
Carrots	0.00%	3,249								
Celery	0.00%	0.22								
Cherries	0.00%	38.7								
Christmas Trees	0.00%	11,709								
Corn	10.36%	74,118,100	0.68%	286,318	3.72%		22.87%	339,244	1.73%	61,813
Cotton	0.15%	1,084,880	1.60%	677,453	0.37%		4.09%	60,620	0.99%	35,317
Cranberries	0.00%	1,726								
Cucumbers	0.00%	1,235	0.00%	1.56						
Dbl Crop Barley/Corn	0.00%	588	0.00%	1,296						
Dbl Crop Barley/Sorghum	0.00%	1,087	0.01%	2,503						
Dbl Crop Oats/Corn	0.00%	3,346	0.00%	69.61						
Dbl Crop WinWht/Corn	0.02%	147,828	0.01%	2,962	0.02%				0.01%	231
Dbl Crop WinWht/Cotton	0.00%	3,148	0.20%	85,834	0.00%		0.02%	247	0.00%	1.56
Dbl Crop WinWht/Sorghum	0.05%	389,932	0.11%	48,196	0.00%		0.00%	0.22	0.00%	85.18
Durum Wheat	0.14%	982,977								
Eggplants	0.00%	1.11								
Fallow/Idle Cropland	1.64%	11,768,900	0.80%	340,671	3.85%		13.04%	193,447	3.00%	107,261
Flaxseed	0.01%	85,738	0.00%	71.83						
Gourds	0.00%	169								
Grapes	0.00%	333	0.00%	0.22						
Greens	0.00%	1,124			0.00%					
Herbs	0.00%	14,263	0.01%	2,788	0.00%					
Millet	0.10%	688,339	0.00%	677	0.00%					
Mint	0.00%	6.67								
Misc Vegs & Fruits	0.00%	394	0.00%	0.44	0.00%				0.00%	0.89
Mustard	0.00%	19,551								
Nectarines	0.00%	0.89								

Land use	Mississippi % cover	Mississippi acres	Red % cover	Red acres	Ouachita % cover	Ouachita acres	Tensas % cover	Tensas acres	Atchafalaya % cover	Atchafalaya acres
Agriculture: non N-fixers (con'd)										
Oats	0.08%	550,751	0.02%	9,853	0.01%		0.05%	783	0.03%	1,153
Onions	0.00%	1,459								
Other Crops	0.00%	18,844	0.01%	3,556	0.00%		0.00%	4.89	0.00%	26.47
Other Hay/Non Alfalfa	2.12%	15,162,400	1.04%	441,772						
Other Small Grains	0.00%	5,757								
Other Tree Crops	0.00%	18.24								
Peaches	0.00%	769	0.00%	39.81			0.00%	0.22		
Pecans	0.00%	20,767	0.01%	4,859	0.01%	1,275	0.03%	390	0.00%	74.28
Peppers	0.00%	258								
Plums	0.00%	0.22								
Pop or Orn Corn	0.02%	147,699			0.00%	52.04	0.00%	0.44		
Potatoes	0.02%	132,308								
Pumpkins	0.00%	10,159								
Radishes	0.00%	175								
Rape Seed	0.00%	1,515								
Rye	0.05%	328,593	0.11%	47,041	0.01%	1,033			0.00%	2.22
Safflower	0.01%	49,366								
Sod/Grass Seed	0.01%	62,643	0.00%	1,853						
Sorghum	0.63%	4,537,360	0.79%	336,785	0.09%	10,433	0.64%	9,480	1.24%	44,521
Speltz	0.00%	696								
Spring Wheat	1.00%	7,121,240	0.00%	886					0.00%	11.56
Squash	0.00%	797			0.00%	1.11				
Strawberries	0.00%	1,915								
Sugarbeets	0.04%	257,196								
Sugarcane	0.00%	9,527	0.00%	1.56	0.00%	1.56			0.48%	17,062
Sunflower	0.14%	1,030,020	0.02%	8,319	0.00%	63.16	0.01%	83.18	0.00%	4
Sweet Corn	0.02%	170,569	0.00%	0.44	0.00%	48.04	0.00%	0.22	0.01%	221
Sweet Potatoes	0.00%	19,631	0.00%	0.89	0.01%	1,368	0.14%	2,039	0.00%	157
Switchgrass	0.00%	10,362	0.00%	140						
Tobacco	0.00%	16,449								
Tomatoes	0.00%	4,808			0.00%	115				
Triticale	0.01%	66,681	0.04%	15,753						
Turnips	0.00%	95.85								
Walnuts	0.00%	2,337								
Watermelons	0.00%	8,840	0.00%	74.72	0.00%	123	0.00%	0.22		
Winter Wheat	2.84%	20,340,500	10.53%	4,463,430	0.51%	60,594	2.09%	31,038	0.18%	6,550

Table A.3. Land use by % cover and total acres for Bayou Teche and the Calcasieu, Mermentau, Pearl, Bogue Chitto, and Vermillion Rivers drainage basins. Blank cells represent no data.

	Calcasieu		Mermentau		Vermilion-Teche		Pearl		Bogue Chitto	
Land use	**% cover**	**acres**	**% cover**	**acres**	**% cover**	**acres**	**% cover**	**acres**	**% cover**	**acres**
Barren	**0.06%**	**1,326**	**0.02%**	**217**	**0.06%**	**903**	**0.11%**	**6,010**	**0.29%**	**2,157**
Forest (total)	**40.12%**	**830,773**	**7.40%**	**65,732**	**7.64%**	**119,019**	**45.13%**	**2,444,406**	**37.77%**	**284,806**
Deciduous Forest	0.03%	579	0.02%	152	0.03%	467	10.50%	568,752	2.04%	15,359
Evergreen Forest	39.50%	817,998	7.11%	63,168	7.22%	112,479	25.17%	1,363,080	27.59%	208,045
Mixed Forest	0.59%	12,197	0.27%	2,411	0.39%	6,073	9.46%	512,574	8.14%	61,402
Wetlands (total)	**19.95%**	**413,208**	**22.53%**	**200,206**	**28.77%**	**448,315**	**15.35%**	**831,148**	**13.89%**	**104,730**
Herbaceous Wetlands	0.53%	10,890	0.27%	2,371	0.98%	15,243	0.14%	7,431	0.03%	215
Woody Wetlands	19.43%	402,318	22.27%	197,835	27.79%	433,072	15.21%	823,717	13.86%	104,515
Developed (total)	**8.16%**	**168,908**	**7.93%**	**70,484**	**10.38%**	**161,720**	**7.19%**	**389,222**	**6.90%**	**51,987**
Developed/High Intensity	0.34%	7,053	0.10%	916	0.28%	4,409	0.14%	7,628	0.07%	565
Developed/Low Intensity	4.72%	97,744	5.85%	51,980	5.60%	87,285	1.32%	71,729	1.12%	8,417
Developed/Med Intensity	0.59%	12,187	0.33%	2,914	0.57%	8,824	0.44%	23,750	0.24%	1,827
Developed/Open Space	2.51%	51,925	1.65%	14,675	3.93%	61,203	5.28%	286,116	5.46%	41,177
Grasslands (total)	**25.51%**	**528,336**	**18.91%**	**168,018**	**22.95%**	**357,577**	**30.79%**	**1,667,834**	**39.64%**	**298,891**
Grassland/Pasture	10.26%	212,461	15.75%	139,922	20.01%	311,827	17.51%	948,645	22.76%	171,638
Shrubland	15.25%	315,875	3.16%	28,096	2.94%	45,750	13.28%	719,189	16.88%	127,253
Agriculture: N-fixers (total)	**0.94%**	**19,429**	**12.23%**	**108,694**	**11.86%**	**184,819**	**0.52%**	**28,362**	**0.38%**	**2,841**
Alfalfa										
Clover/Wildflowers										
Dbl Crop Barley/Soybeans										
Dbl Crop Corn/Soybeans										
Dbl Crop Soybeans/Cotton										
Dbl Crop Soybeans/Oats			0.00%	0.22	0.00%	10.9	0.00%	43.37	0.00%	0.22
Dbl Crop WinWht/Soybeans	0.08%	1,562	0.51%	4,488	1.05%	16,319	0.10%	5,592	0.15%	1,115
Dry Beans										
Lentils										
Peanuts							0.01%	305	0.01%	73.39
Peas							0.00%	6.89		
Soybeans	0.86%	17,867	11.73%	104,206	10.81%	168,490	0.41%	22,415	0.22%	1,652
Vetch										
Rice/Aquaculture (total)	**2.23%**	**46,187**	**19.75%**	**175,455**	**3.58%**	**55,843**	**0.00%**	**25.8**	**0.00%**	**0.22**
Aquaculture	0.54%	11,083	5.19%	46,144	1.16%	18,150	0.00%	22.02		
Rice	1.70%	35,104	14.55%	129,311	2.42%	37,693	0.00%	3.78	0.00%	0.22

Land use	Calcasieu % cover	Calcasieu acres	Mermentau % cover	Mermentau acres	Vermilion-Teche % cover	Vermilion-Teche acres	Pearl % cover	Pearl acres	Bogue Chitto % cover	Bogue Chitto acres
Agriculture: non N-fixers (total)	**3.03%**	**62,702**	**11.22%**	**99,738**	**14.77%**	**230,175**	**0.91%**	**49,249**	**1.14%**	**8,563**
Apples										
Asparagus										
Barley										
Blueberries							0.00%	0.67	0.00%	0.22
Buckwheat										
Cabbage										
Camelina										
Caneberries										
Canola										
Cantaloupes							0.00%	0.22		
Carrots										
Celery										
Cherries										
Christmas Trees										
Corn	0.07%	1,410	0.04%	349	1.27%	19,722	0.14%	7,591	0.30%	2,243
Cotton	0.00%	7.12	0.01%	59.16	0.68%	10,626	0.08%	4,151	0.00%	19.35
Cranberries										
Cucumbers										
Dbl Crop Barley/Corn										
Dbl Crop Barley/Sorghum										
Dbl Crop Oats/Corn										
Dbl Crop WinWht/Corn					0.01%	159	0.00%	11.56		
Dbl Crop WinWht/Cotton					0.00%	77.62	0.01%	316	0.00%	7.78
Dbl Crop WinWht/Sorghum	0.00%	46.48	0.00%	4.23			0.00%	61.6	0.00%	7.56
Durum Wheat										
Eggplants										
Fallow/Idle Cropland	2.89%	59,827	10.26%	91,174	3.24%	50,546	0.02%	1,071	0.07%	503
Flaxseed										
Gourds										
Grapes							0.00%	4.89	0.00%	3.34
Greens							0.00%	2.89		
Herbs							0.00%	13.12		
Millet							0.00%	38.7	0.00%	1.33
Mint										
Misc Vegs & Fruits			0.00%	2.00	0.00%	14.9				
Mustard										
Nectarines										

Land use	Calcasieu % cover	Calcasieu acres	Mermentau % cover	Mermentau acres	Vermilion-Teche % cover	Vermilion-Teche acres	Pearl % cover	Pearl acres	Bogue Chitto % cover	Bogue Chitto acres
Agriculture: non N-fixers (con'd)										
Oats	0.00%	0.22	0.00%	22.24	0.01%	90.96	0.00%	2.00	0.00%	2.00
Onions										
Other Crops					0.01%	117	0.00%	11.79	0.00%	10.9
Other Hay/Non Alfalfa							0.63%	34,080	0.73%	5,494
Other Small Grains										
Other Tree Crops							0.00%	1.11		
Peaches							0.00%	2.89	0.00%	2.67
Pecans	0.00%	5.34	0.01%	50.93	0.01%	139	0.00%	3.34		
Peppers										
Plums										
Pop or Orn Corn										
Potatoes										
Pumpkins										
Radishes										
Rape Seed										
Rye					0.00%	0.67	0.00%	180	0.01%	107
Safflower										
Sod/Grass Seed							0.02%	855	0.01%	94.52
Sorghum	0.04%	823	0.17%	1,542	2.03%	31,577	0.00%	105	0.00%	34.69
Speltz										
Spring Wheat										
Squash										
Strawberries										
Sugarbeets										
Sugarcane	0.02%	371	0.41%	3,632	7.12%	111,000	0.00%	6.00	0.00%	0.89
Sunflower			0.00%	0.22	0.00%	0.89	0.00%	6.23		
Sweet Corn							0.00%	3.34	0.00%	0.44
Sweet Potatoes			0.00%	3.34	0.09%	1,388	0.00%	160		
Switchgrass										
Tobacco										
Tomatoes										
Triticale										
Turnips										
Walnuts										
Watermelons							0.00%	14.23	0.00%	1.33
Winter Wheat	0.01%	212	0.33%	2,899	0.30%	4,716	0.01%	554	0.00%	28.02

Table A.4. Land use by % cover and total acres for Lake Pontchartrain and the Tangipahoa, Tchefuncte, and Tickfaw Rivers drainage basins. Blank cells represent no data.

	Pontchartrain		Tangipahoa		Tchefuncte		Tickfaw	
Land use	**% cover**	**acres**	**% cover**	**acres**	**% cover**	**acres**	**% cover**	**acres**
Barren	**0.23%**	**7,130**	**0.24%**	**981**	**0.26%**	**660**	**0.07%**	**173**
Forest (total)	**23.79%**	**741,188**	**28.77%**	**118,841**	**30.70%**	**78,355**	**38.10%**	**96,860**
Deciduous Forest	0.66%	20,669	0.86%	3,559	0.00%	7.12	0.15%	390
Evergreen Forest	21.61%	673,169	25.10%	103,713	30.66%	78,250	37.56%	95,497
Mixed Forest	1.52%	47,350	2.80%	11,570	0.04%	97.85	0.38%	973
Wetlands (total)	**34.82%**	**1,084,829**	**20.08%**	**82,955**	**23.67%**	**60,425**	**26.49%**	**67,360**
Herbaceous Wetlands	3.88%	120,783	0.05%	214	0.22%	566	0.03%	67.61
Woody Wetlands	30.94%	964,046	20.03%	82,742	23.45%	59,859	26.47%	67,293
Developed (total)	**14.06%**	**438,081**	**7.05%**	**29,131**	**10.88%**	**27,778**	**5.17%**	**13,154**
Developed/High Intensity	0.71%	22,077	0.10%	408	0.15%	385	0.01%	18.9
Developed/Low Intensity	5.15%	160,440	1.56%	6,453	2.11%	5,388	0.81%	2,066
Developed/Med Intensity	1.77%	55,243	0.38%	1,552	0.64%	1,635	0.06%	142
Developed/Open Space	6.43%	200,321	5.01%	20,718	7.98%	20,371	4.30%	10,927
Grasslands (total)	**25.98%**	**809,540**	**43.17%**	**178,349**	**34.00%**	**86,793**	**29.59%**	**75,228**
Grassland/Pasture	14.40%	448,691	24.64%	101,780	17.20%	43,892	12.47%	31,693
Shrubland	11.58%	360,849	18.53%	76,569	16.81%	42,901	17.12%	43,535
Agriculture: N-fixers (total)	**0.26%**	**7,959**	**0.28%**	**1,170**	**0.17%**	**442**	**0.12%**	**301**
Alfalfa								
Clover/Wildflowers								
Dbl Crop Barley/Soybeans								
Dbl Crop Corn/Soybeans								
Dbl Crop Soybeans/Cotton								
Dbl Crop Soybeans/Oats	0.00%	74.95	0.02%	74.28	0.00%	0.22		
Dbl Crop WinWht/Soybeans	0.11%	3,448	0.15%	634	0.01%	29.13	0.01%	22.68
Dry Beans								
Lentils								
Peanuts	0.00%	1.78	0.00%	0.89				
Peas								
Soybeans	0.14%	4,434	0.11%	462	0.16%	413	0.11%	278
Vetch								
Rice/Aquaculture (total)	**0.02%**	**576**	**0.00%**	**0.89**				
Aquaculture	0.02%	557	0.00%	0.22				
Rice	0.00%	18.68	0.00%	0.67				

Land use	Pontchartrain % cover	Pontchartrain acres	Tangipahoa % cover	Tangipahoa acres	Tchefuncte % cover	Tchefuncte acres	Tickfaw % cover	Tickfaw acres
Agriculture: non N-fixers (total)	**0.84%**	**26,258**	**0.41%**	**1,712**	**0.31%**	**789**	**0.46%**	**1,173**
Apples								
Asparagus								
Barley								
Blueberries								
Buckwheat								
Cabbage								
Camelina								
Caneberries								
Canola								
Cantaloupes								
Carrots								
Celery								
Cherries								
Christmas Trees								
Corn	0.09%	2,665	0.09%	358	0.13%	319	0.22%	566
Cotton	0.00%	13.79	0.00%	1.11			0.00%	5.34
Cranberries								
Cucumbers								
Dbl Crop Barley/Corn								
Dbl Crop Barley/Sorghum								
Dbl Crop Oats/Corn								
Dbl Crop WinWht/Corn								
Dbl Crop WinWht/Cotton	0.00%	0.89						
Dbl Crop WinWht/Sorghum	0.00%	1.78	0.00%	0.44				
Durum Wheat								
Eggplants								
Fallow/Idle Cropland	0.20%	6,076	0.10%	413	0.18%	461	0.01%	20.46
Flaxseed								
Gourds								
Grapes	0.00%	4.45	0.00%	0.22			0.00%	0.67
Greens								
Herbs								
Millet								
Mint								
Misc Vegs & Fruits								
Mustard								
Nectarines								

Land use	**Pontchartrain % cover**	**Pontchartrain acres**	**Tangipahoa % cover**	**Tangipahoa acres**	**Tchefuncte % cover**	**Tchefuncte acres**	**Tickfaw % cover**	**Tickfaw acres**
Agriculture: non N-fixers (con'd)								
Oats	0.00%	50.48	0.01%	50.48				
Onions								
Other Crops	0.00%	40.03	0.01%	32.91	0.00%	2.45	0.00%	1.78
Other Hay/Non Alfalfa	0.07%	2,213	0.19%	804			0.16%	414
Other Small Grains								
Other Tree Crops								
Peaches								
Pecans	0.00%	0.89						
Peppers								
Plums								
Pop or Orn Corn								
Potatoes								
Pumpkins								
Radishes								
Rape Seed								
Rye	0.00%	3.11	0.00%	2.00				
Safflower								
Sod/Grass Seed	0.00%	68.05	0.00%	18.01			0.00%	5.12
Sorghum	0.01%	317	0.01%	28.91			0.06%	158
Speltz								
Spring Wheat								
Squash								
Strawberries								
Sugarbeets								
Sugarcane	0.47%	14,677	0.00%	0.22	0.00%	4.89	0.00%	0.89
Sunflower								
Sweet Corn								
Sweet Potatoes	0.00%	0.67						
Switchgrass								
Tobacco								
Tomatoes								
Triticale								
Turnips								
Walnuts								
Watermelons	0.00%	0.44	0.00%	0.22				
Winter Wheat	0.00%	125	0.00%	3.11	0.00%	1.56	0.00%	1.11

Appendix B: Detailed Results of Mann-Kendall Trend Test

Table B.1. Kendall tau, seasonality, Sen slopes, number of years, and number of values for each parameter at each site for each site and parameter. Significant results (p<0.05) are shown in red and italics.

Site Name	Map #	# yrs	Nitrite + Nitrate				Total Kjeldahl Nitrogen				Total Phosphorus			
			Kendall tau	seasonal	slope	n	Kendall tau	seasonal	slope	n	Kendall tau	seasonal	slope	n
Atchafalaya	1	36	*-0.06*	✓[a]	*-0.004*	388	*-0.13*	✓	*-0.002*	374	*-0.14*	✓	*-0.001*	375
Lafourche	2	23	-0.01	✓	-0.006	242	*-0.15*	✗[b]	*0.000*	233	*-0.12*	✓	*-0.001*	232
Teche	3	36	-0.02	✓	0.000	440	*-0.24*	✓	*-0.012*	430	*-0.22*	✓	*-0.004*	429
Bogue Chitto	4	36	*0.22*	✓	*0.003*	392	*-0.17*	✗	*0.000*	373	0.09	✗	0.000	379
Calcasieu–BL	5	36	*-0.16*	✓	*0.000*	428	*-0.47*	✓	*-0.022*	417	*-0.23*	✗	*0.000*	418
Calcasieu–MB	6	36	*-0.15*	✓	*0.000*	428	*-0.15*	✓	*-0.002*	419	0.04	✓	0.000	419
Lake P.	7	28	-0.02	✗	0.000	343	*-0.15*	✗	*0.000*	326	0.10	✗	0.000	330
Mermentau	8	36	*-0.21*	✓	*-0.001*	434	*-0.21*	✓	*-0.007*	409	*-0.19*	✓	*-0.002*	426
Mississippi–BC	9	36	0.05	✓	0.000	427	*-0.18*	✓	*-0.004*	411	*-0.27*	✓	*-0.004*	417
Mississippi–Pla	10	36	0.03	✓	0.000	435	*-0.11*	✓	*-0.004*	415	*-0.13*	✓	*-0.002*	413
Mississippi–SF	11	36	0.03	✓	0.000	433	*-0.06*	✗	*-0.002*	411	*-0.15*	✓	*-0.002*	413
Ouachita–H	12	36	*-0.18*	✓	*-0.001*	435	*-0.09*	✓	*-0.001*	422	0.01	✓	0.000	417
Ouachita–S	13	36	*-0.24*	✓	*0.000*	434	*-0.16*	✓	*-0.003*	402	0.05	✓	0.000	426
Pearl	14	36	0.02	✓	0.000	433	*-0.16*	✓	*-0.003*	418	0.12	✗	0.000	416
Red–M	15	36	*-0.12*	✓	*0.000*	422	*-0.34*	✗	*-0.012*	413	*-0.44*	✓	*-0.005*	409
Red–S	16	33	*-0.28*	✓	*0.000*	387	*-0.20*	✗	*-0.007*	378	*-0.29*	✓	*-0.002*	373
Tangipahoa	17	36	*-0.12*	✓	*-0.002*	440	*-0.22*	✓	*0.000*	423	*-0.12*	✓	*0.000*	427
Tchefuncte	18	36	0.00	✓	0.000	394	*-0.23*	✗	*-0.006*	378	0.05	✓	0.000	377
Tensas	19	26	*-0.09*	✓	*0.000*	258	*-0.14*	✓	*-0.011*	263	-0.01	✓	0.000	262
Tickfaw	20	36	*-0.17*	✓	*-0.002*	393	*-0.20*	✓	*0.000*	376	*-0.03*	✓	*0.000*	377
Vermilion	21	36	*-0.04*	✓	*-0.002*	433	*-0.31*	✓	*-0.019*	415	*-0.32*	✓	*-0.006*	423

[a] ✓=seasonal
[b] ✗ =non-seasonal

Appendix C: Annual Nutrient Medians for Each Site

Table C.1. Annual medians of total Kjeldahl nitrogen (TKN), nitrate + nitrite (NO_x) and total phosphorus (TP) from 1978 to 2014 for the Atchafalaya, Mississippi, and Red Rivers and Bayou Lafourche. TKN, NO_x, and TP are presented in mg-N or P L^{-1}.

	Atchafalaya			Lafourche			Mississippi-BC			Mississippi-Pla			Mississippi-SF			Red-M			Red-S		
Year	TKN	NOx	TP	TKN	NOx	TP	TKN	NOx	TP	TKN	NOx	TP	TKN	NOx	TP	TKN	NOx	TP	TKN	NOx	TP
1978	0.81	0.95	0.23	-	-	-	0.79	1.14	0.30	0.64	1.24	0.32	0.64	1.26	0.27	1.26	0.18	0.31	-	-	-
1979	0.85	0.87	0.20	-	-	-	0.56	1.10	0.27	0.85	1.05	0.25	0.84	1.05	0.22	0.90	0.11	0.33	-	-	-
1980	0.83	0.78	0.15	-	-	-	0.74	1.15	0.24	0.76	1.09	0.18	0.71	1.07	0.21	0.96	0.19	0.22	-	-	-
1981	0.86	1.09	0.20	-	-	-	1.01	1.46	0.23	0.82	1.38	0.18	0.99	1.62	0.27	0.90	0.17	0.31	0.82	0.25	0.27
1982	0.86	1.13	0.22	-	-	-	1.16	1.46	0.37	0.99	1.38	0.27	1.22	1.59	0.46	1.06	0.21	0.34	1.10	0.23	0.19
1983	0.65	0.92	0.20	-	-	-	0.69	1.53	0.32	0.70	1.49	0.25	0.86	1.51	0.23	0.90	0.13	0.29	0.89	0.17	0.18
1984	0.67	1.15	0.17	-	-	-	0.65	1.68	0.25	0.83	1.58	0.19	0.92	1.64	0.21	1.14	0.16	0.20	0.96	0.16	0.18
1985	0.59	0.85	0.20	-	-	-	0.94	1.28	0.25	0.96	1.24	0.24	0.78	1.32	0.22	1.44	0.25	0.34	0.98	0.25	0.22
1986	0.75	1.10	0.21	-	-	-	0.85	1.67	0.32	0.94	1.62	0.25	0.82	1.59	0.30	1.14	0.19	0.31	0.96	0.19	0.21
1987	0.76	0.61	0.18	-	-	-	0.95	1.08	0.24	1.12	1.11	0.25	0.70	1.08	0.25	1.14	0.18	0.37	1.06	0.19	0.21
1988	0.84	0.56	0.12	-	-	-	0.70	0.90	0.17	1.06	0.77	0.15	0.77	0.60	0.13	1.07	0.16	0.14	0.97	BDL	0.13
1989	0.80	0.64	0.19	-	-	-	0.63	0.97	0.21	0.81	1.01	0.21	0.72	0.96	0.20	1.02	0.14	0.19	0.96	0.13	0.19
1990	0.87	0.86	0.24	-	-	-	0.57	1.53	0.22	0.79	1.37	0.19	0.71	1.38	0.20	1.08	0.25	0.19	0.91	0.22	0.31
1991	0.64	0.68	0.21	0.91	0.99	0.31	0.60	1.28	0.22	0.77	1.31	0.20	0.59	1.28	0.23	0.89	0.20	0.24	0.81	0.15	0.20
1992	0.64	0.82	0.17	0.78	1.29	0.21	0.87	1.80	0.24	0.64	1.76	0.22	0.63	1.96	0.24	0.80	0.17	0.15	0.87	0.14	0.25
1993	0.68	1.43	0.21	0.58	1.12	0.16	0.71	1.66	0.23	0.78	1.49	0.22	0.79	1.61	0.26	0.71	0.21	0.16	0.67	0.19	0.23
1994	0.52	0.81	0.15	BDL	1.00	0.14	0.63	1.20	0.14	0.69	1.15	0.14	0.59	1.10	0.15	0.65	0.18	BDL	0.87	0.12	0.19
1995	0.56	0.60	0.13	BDL	1.14	0.11	0.67	1.40	0.17	0.76	1.42	0.19	0.85	1.31	0.18	0.75	BDL	0.12	0.86	0.12	0.16
1996	0.58	1.12	0.13	0.55	1.11	0.14	0.96	1.35	0.18	0.69	1.36	0.22	0.71	1.32	0.21	0.81	0.21	BDL	1.03	0.22	0.12
1997	0.59	0.62	0.16	1.03	0.89	0.27	0.76	1.31	0.18	0.61	1.18	0.13	0.64	1.20	0.19	0.84	0.21	BDL	0.80	0.19	0.12
1998	0.57	1.17	0.18	0.67	1.55	0.13	0.61	1.57	0.16	0.60	1.64	0.17	0.79	1.52	0.19	1.00	0.29	BDL	0.88	0.22	0.11
1999	BDL	0.97	0.17	0.64	1.22	0.15	0.72	1.39	0.21	0.83	1.51	0.21	0.84	1.62	0.21	0.54	0.12	0.12	0.75	BDL	0.12
2000	0.67	1.10	0.14	BDL	0.58	0.13	0.66	1.19	0.16	0.53	1.13	0.17	0.58	1.07	0.18	0.59	0.18	0.13	0.82	BDL	0.15
2001	0.82	0.86	0.17	0.63	1.30	0.13	0.56	1.88	0.16	0.84	1.45	0.25	0.88	1.51	0.24	0.76	0.20	0.15	0.71	0.22	0.11
2002	0.60	0.70	0.15	0.58	0.93	0.17	0.63	1.16	0.15	0.75	1.06	0.16	0.76	1.08	0.18	0.65	0.18	0.11	0.76	0.12	0.11
2003	0.56	0.93	0.17	0.55	0.91	0.15	0.84	1.14	0.18	0.86	1.12	0.19	0.85	1.15	0.19	0.69	0.15	BDL	0.88	BDL	0.13
2004	0.75	0.93	0.18	0.66	0.95	0.17	0.68	1.28	0.15	0.83	1.20	0.18	0.94	1.11	0.17	0.88	0.14	0.11	0.84	BDL	0.15
2005	0.61	1.07	0.15	0.65	1.32	0.16	0.66	1.78	0.17	1.00	1.44	0.18	0.80	1.58	0.19	0.68	0.13	BDL	0.90	BDL	BDL
2006	0.62	1.00	0.14	BDL	1.08	0.12	0.61	1.47	0.15	0.78	1.41	0.17	0.74	1.37	0.18	0.86	0.19	BDL	1.24	BDL	0.11
2007	0.85	1.07	0.20	0.54	0.91	0.15	0.74	1.60	0.21	0.91	1.69	0.24	1.03	1.75	0.24	0.76	0.15	BDL	0.80	0.14	0.14
2008	0.66	1.15	0.20	0.52	1.16	0.13	0.71	1.58	0.20	0.83	1.55	0.20	0.75	1.50	0.20	0.64	0.21	0.12	0.89	BDL	0.12
2009	0.77	0.76	0.17	0.57	0.78	0.20	0.56	1.11	0.16	0.75	1.21	0.18	0.69	1.21	0.17	0.70	BDL	0.13	0.70	BDL	BDL
2010	BDL	0.77	0.13	BDL	0.97	0.12	BDL	1.57	BDL	0.81	1.49	BDL	0.97	1.46	BDL	0.63	BDL	BDL	BDL	BDL	BDL
2011	0.56	0.64	0.16	BDL	0.57	BDL	BDL	1.26	0.15	BDL	1.35	0.15	BDL	1.32	0.15	0.55	BDL	BDL	0.62	BDL	BDL
2012	0.64	0.47	0.12	BDL	0.68	0.12	BDL	1.07	BDL	BDL	1.04	0.13	BDL	0.99	0.16	0.79	BDL	BDL	0.79	BDL	BDL
2013	0.63	0.35	0.16	BDL	1.03	0.12	BDL	1.16	0.15	0.55	1.00	0.16	BDL	1.07	0.17	0.61	BDL	0.10	BDL	BDL	0.10
2014	0.56	0.88	0.16	BDL	1.25	0.13	0.63	1.35	0.21	0.62	1.30	0.18	0.63	1.30	0.21	BDL	0.12	0.11	BDL	BDL	BDL

[a] BDL = below detection limit. Detection limits are 0.5 mg-N L^{-1} for total Kjeldahl nitrogen and 0.1 mg-N or -P L^{-1} for nitrite+nitrate or total phosphorus.

Table C.2. Annual medians of total Kjeldahl nitrogen (TKN), nitrate + nitrite (NO_x) and total phosphorus (TP) from 1978 to 2014 for the Calcasieu, Mermentau, Vermilion, and Ouachita Rivers and Bayou Teche. TKN, NO_x, and TP are presented in mg-N or P L^{-1}.

Year	Calcasieu-BL			Calcasieu-MB			Mermentau			Teche			Vermilion			Ouachita-H			Ouachita-S		
	TKN	NO_x	TP	TKN	NO_x	TP	TKN	NO_x	TP	TKN	NO_x	TP	TKN	NO_x	TP	TKN	NO_x	TP	TKN	NO_x	TP
1978	1.40	0.11	0.15	0.74	BDL[a]	0.11	1.50	0.24	0.41	1.43	0.27	0.49	1.98	0.35	0.59	0.88	0.23	0.24	0.93	0.23	BDL
1979	1.22	BDL	0.11	0.52	BDL	BDL	1.12	0.16	0.28	1.12	0.27	0.37	1.26	0.36	0.48	0.78	0.19	0.12	0.66	0.12	0.11
1980	1.78	0.11	0.12	0.69	0.11	BDL	1.33	0.31	0.30	1.15	0.21	0.31	1.31	0.41	BDL	0.68	0.12	0.15	1.15	0.18	BDL
1981	1.26	0.29	0.15	0.72	BDL	BDL	1.30	0.32	0.27	1.44	0.29	0.45	1.49	0.69	0.68	0.66	0.37	BDL	0.75	0.24	BDL
1982	1.32	0.22	0.12	0.86	BDL	BDL	1.30	0.19	0.27	1.25	0.34	0.43	1.50	0.47	0.55	0.68	0.22	0.11	0.98	0.15	BDL
1983	1.06	0.15	0.12	0.59	BDL	BDL	1.07	0.14	0.25	1.13	0.23	0.33	1.26	0.32	0.44	0.62	0.15	BDL	0.90	0.11	BDL
1984	1.18	0.14	0.12	0.57	BDL	BDL	1.12	0.22	0.25	1.07	0.28	0.34	1.49	0.34	0.52	0.63	0.20	0.13	0.72	0.12	BDL
1985	1.12	0.15	0.15	0.78	BDL	BDL	1.23	0.31	0.41	1.00	0.28	0.35	1.56	0.36	0.51	0.71	0.19	0.11	0.59	0.22	BDL
1986	1.10	0.18	0.12	0.89	BDL	BDL	1.61	BDL	0.34	1.11	0.31	0.33	1.21	0.67	BDL	0.74	0.14	0.13	0.59	0.11	BDL
1987	1.62	0.15	0.11	0.95	BDL	0.13	1.78	0.21	0.32	1.20	0.30	0.42	1.60	0.35	0.52	0.83	BDL	0.11	0.78	BDL	BDL
1988	1.09	0.14	0.14	0.90	BDL	BDL	1.11	0.24	0.26	1.22	0.34	0.35	1.39	0.51	0.45	1.04	0.12	0.13	0.72	0.19	BDL
1989	0.94	0.14	0.13	0.87	BDL	BDL	1.00	0.40	0.24	1.11	0.28	0.34	1.25	0.42	0.44	0.98	0.13	0.12	0.69	0.12	0.11
1990	1.05	0.12	0.13	0.71	BDL	0.11	1.05	0.29	0.25	0.96	0.48	0.24	1.02	1.02	0.38	0.74	0.17	0.13	0.67	0.16	BDL
1991	0.98	0.12	0.11	0.79	BDL	BDL	0.97	0.17	0.23	1.11	0.36	0.35	1.09	0.34	0.41	0.75	0.14	0.14	0.65	BDL	BDL
1992	1.02	0.13	BDL	0.72	BDL	0.13	1.04	0.19	0.25	1.17	0.19	0.33	1.18	0.43	0.42	0.73	0.27	0.16	0.66	0.19	BDL
1993	0.85	BDL	0.11	0.65	BDL	BDL	1.08	0.13	0.24	1.02	0.53	0.30	1.09	0.35	0.35	0.69	0.17	0.12	0.63	0.13	BDL
1994	0.90	0.22	BDL	0.84	BDL	BDL	1.15	0.22	0.23	0.96	BDL	0.30	1.35	0.47	0.35	0.72	0.15	0.11	0.56	BDL	BDL
1995	0.86	BDL	BDL	0.75	BDL	BDL	1.19	0.18	0.16	1.02	0.47	0.27	1.21	0.41	0.35	0.73	0.16	0.11	0.64	0.12	BDL
1996	0.83	0.15	BDL	0.97	BDL	BDL	1.18	0.22	0.22	0.91	0.30	0.34	1.38	0.54	0.34	0.91	0.24	0.15	0.77	0.19	0.11
1997	0.72	0.13	BDL	0.87	BDL	BDL	1.07	0.20	0.19	1.10	0.31	0.33	1.31	0.53	0.33	0.88	0.13	0.14	0.75	0.14	0.11
1998	0.79	0.13	BDL	0.93	BDL	BDL	1.27	0.15	0.22	1.15	0.31	0.25	1.07	0.69	0.25	0.72	0.26	0.18	0.73	0.23	BDL
1999	0.70	0.12	0.12	0.52	BDL	BDL	1.04	0.24	0.21	1.07	0.45	0.28	0.76	0.79	0.34	0.58	BDL	0.13	0.62	0.13	0.14
2000	0.81	0.16	0.13	0.54	BDL	BDL	0.98	0.16	0.16	1.13	0.35	0.24	0.83	0.80	0.27	0.75	0.13	0.14	0.68	0.13	0.11
2001	0.76	0.13	BDL	0.70	BDL	BDL	1.18	0.13	0.22	1.24	0.22	0.31	1.13	0.36	0.33	0.69	0.15	0.13	0.69	0.12	BDL
2002	0.64	0.17	BDL	0.74	BDL	BDL	0.96	0.15	0.19	1.15	0.29	0.30	0.90	0.38	0.34	0.79	0.19	0.15	0.57	0.17	BDL
2003	BDL	0.20	0.11	0.77	BDL	BDL	1.40	0.23	0.25	1.09	0.30	0.27	1.14	0.39	0.39	0.83	0.19	0.14	0.65	0.17	0.12
2004	0.60	0.12	0.11	0.72	BDL	BDL	1.13	BDL	0.22	1.00	0.34	0.32	1.12	0.38	0.33	0.84	0.16	0.14	0.63	0.12	0.13
2005	0.57	0.15	BDL	0.88	BDL	0.11	1.45	0.21	0.26	0.84	0.44	0.19	0.95	0.60	0.33	0.68	0.15	BDL	0.72	0.12	BDL
2006	0.54	BDL	0.11	0.65	BDL	BDL	1.08	0.12	0.21	0.91	0.25	0.23	0.93	BDL	0.27	0.75	0.18	0.15	0.79	BDL	0.11
2007	0.52	0.11	0.11	0.71	BDL	BDL	1.19	0.19	0.26	0.84	0.62	0.26	0.96	0.55	0.38	0.77	0.16	0.12	0.64	BDL	BDL
2008	BDL	0.17	BDL	0.69	BDL	BDL	1.12	0.14	0.24	0.94	0.29	0.33	1.13	0.44	0.37	0.66	0.12	0.12	0.63	0.11	BDL
2009	BDL	0.14	BDL	BDL	BDL	BDL	0.84	BDL	0.19	0.98	0.24	0.30	0.78	0.24	0.34	0.64	BDL	0.12	0.74	BDL	BDL
2010	0.58	0.13	BDL	0.63	BDL	BDL	0.69	0.17	0.18	0.74	0.28	0.20	0.76	0.53	0.30	0.63	BDL	BDL	0.58	BDL	BDL
2011	0.57	BDL	BDL	BDL	BDL	0.11	0.69	0.12	0.23	0.66	0.15	0.24	0.61	0.18	0.27	BDL	BDL	BDL	0.61	BDL	BDL
2012	0.73	BDL	BDL	0.64	BDL	BDL	1.00	BDL	0.17	0.86	0.19	0.27	1.07	0.26	0.32	0.87	0.11	0.13	0.73	BDL	BDL
2013	0.68	BDL	BDL	0.57	BDL	BDL	0.68	BDL	0.22	0.95	0.18	0.29	0.79	0.22	0.36	0.62	BDL	0.14	0.59	BDL	BDL
2014	BDL	BDL	0.11	BDL	BDL	BDL	0.63	0.12	0.32	0.55	0.20	0.33	0.60	0.23	0.38	BDL	BDL	0.14	BDL	BDL	0.11

[a] BDL = below detection limit. Detection limits are 0.5 mg-N L^{-1} for total Kjeldahl nitrogen and 0.1 mg-N or -P L^{-1} for nitrite+nitrate or total phosphorus.

Table C.3. Annual medians of total Kjeldahl nitrogen (TKN), nitrate + nitrite (NO_x) and total phosphorus (TP) from 1978 to 2014 for the Tensas, Bogue Chitto, Pearl, Tangipahoa, Tchefuncte, and Tickfaw Rivers and Lake Pontchartrain. TKN, NO_x, and TP are presented in mg-N or P L^{-1}.

Year	Tensas			Bogue Chitto			Pearl			Lake Pontchartrain			Tangipahoa			Tchefuncte			Tickfaw		
	TKN	NO_x	TP	TKN	NO_x	TP	TKN	NO_x	TP	TKN	NO_x	TP	TKN	NO_x	TP	TKN	NO_x	TP	TKN	NO_x	TP
1978	-	-	-	0.56	0.22	BDL[a]	BDL	0.27	BDL	-	-	-	0.75	0.32	0.15	0.60	0.11	BDL	0.51	0.22	BDL
1979	-	-	-	BDL	0.23	BDL	BDL	0.18	BDL	-	-	-	BDL	0.24	BDL	0.65	0.13	BDL	0.53	0.22	BDL
1980	-	-	-	BDL	0.15	BDL	0.63	0.14	BDL	-	-	-	0.61	0.22	BDL	0.85	0.15	BDL	BDL	0.26	BDL
1981	-	-	-	BDL	0.21	BDL	0.70	0.23	BDL	-	-	-	0.55	0.30	BDL	0.85	0.16	BDL	0.71	0.29	0.12
1982	-	-	-	0.59	0.29	BDL	0.91	0.17	BDL	-	-	-	0.62	0.38	0.15	1.02	0.15	BDL	0.94	0.27	BDL
1983	-	-	-	BDL	0.24	BDL	0.54	0.11	BDL	-	-	-	0.69	0.22	0.11	0.77	0.12	BDL	0.75	0.19	BDL
1984	-	-	-	0.54	0.22	BDL	0.53	0.14	BDL	-	-	-	0.56	0.33	0.13	0.75	0.14	BDL	0.84	0.24	BDL
1985	-	-	-	0.59	0.23	BDL	0.68	0.13	BDL	-	-	-	BDL	0.25	BDL	0.64	0.13	0.11	0.92	0.20	BDL
1986	-	-	-	0.72	0.24	BDL	0.85	BDL	0.12	0.56	BDL	BDL	0.64	0.32	0.12	0.93	BDL	0.19	0.76	0.26	0.11
1987	-	-	-	0.61	0.18	0.12	0.77	0.12	BDL	0.76	BDL	BDL	0.93	0.21	0.11	1.21	0.12	0.14	0.78	0.22	0.11
1988	0.99	0.68	0.23	0.76	0.29	BDL	0.82	0.17	BDL	0.60	BDL	BDL	0.94	0.32	0.13	1.01	0.15	0.12	1.02	0.27	0.11
1989	1.04	0.30	0.31	0.65	0.29	BDL	0.80	0.20	BDL	0.59	BDL	BDL	0.62	0.29	0.12	1.02	0.13	0.15	0.86	0.27	0.12
1990	0.99	0.43	0.24	0.70	0.22	BDL	0.78	0.17	BDL	0.54	BDL	BDL	0.54	0.34	BDL	0.72	0.11	0.11	0.61	0.22	BDL
1991	0.97	0.26	0.32	0.68	0.27	0.15	0.95	0.14	BDL	BDL	BDL	BDL	0.53	0.33	0.15	0.71	BDL	0.11	0.51	0.25	0.11
1992	0.90	0.40	0.26	0.75	0.28	BDL	0.88	0.14	BDL	BDL	BDL	BDL	BDL	0.24	0.13	0.67	0.11	BDL	BDL	0.21	BDL
1993	0.85	0.21	0.22	1.64	0.27	BDL	0.65	0.15	BDL	BDL	BDL	BDL	0.53	0.31	0.11	0.62	0.11	BDL	0.55	0.23	BDL
1994	1.30	0.27	0.31	BDL	0.28	BDL	0.69	0.18	BDL	0.51	BDL	BDL	0.51	0.36	0.14	0.79	BDL	BDL	0.53	0.28	BDL
1995	0.99	0.34	0.29	BDL	0.24	BDL	0.73	0.12	BDL	BDL	BDL	BDL	0.52	0.33	BDL	0.65	BDL	BDL	0.61	0.24	BDL
1996	1.34	0.72	0.34	BDL	0.32	0.11	0.59	0.21	BDL	0.63	BDL	BDL	BDL	0.33	BDL	1.03	0.11	BDL	BDL	0.22	0.11
1997	1.21	BDL	0.36	0.52	0.25	0.12	0.62	0.12	0.11	0.62	BDL	BDL	BDL	0.31	0.11	0.64	0.13	0.11	BDL	0.25	BDL
1998	0.92	0.39	0.18	BDL	0.27	BDL	0.61	0.13	BDL	BDL	BDL	BDL	0.51	0.27	0.12	0.53	0.11	0.11	BDL	0.21	BDL
1999	0.88	0.16	0.26	BDL	0.29	BDL	0.71	0.15	0.12	BDL	BDL	BDL	BDL	0.25	0.13	0.53	BDL	0.11	BDL	0.20	0.11
2000	0.92	0.25	0.14	BDL	0.18	BDL	0.63	BDL	0.13	BDL	BDL	BDL	BDL	0.12	BDL	0.53	BDL	0.11	BDL	BDL	BDL
2001	0.94	0.32	0.29	BDL	0.26	BDL	0.56	BDL	0.12	0.58	BDL	BDL	BDL	0.27	0.13	0.69	0.14	BDL	0.54	0.14	BDL
2002	1.15	0.37	0.28	BDL	0.35	BDL	0.61	0.15	0.11	BDL	BDL	BDL	BDL	0.26	0.12	0.70	0.11	BDL	BDL	0.20	0.11
2003	1.17	0.21	0.32	BDL	0.35	BDL	0.67	0.17	0.12	BDL	BDL	BDL	BDL	0.28	BDL	0.67	0.13	BDL	BDL	0.23	0.11
2004	1.33	0.20	0.32	BDL	0.26	0.11	0.62	0.15	0.12	BDL	BDL	BDL	BDL	0.30	BDL	0.69	0.13	0.12	BDL	0.21	BDL
2005	1.22	0.27	0.34	BDL	0.30	BDL	0.59	0.17	0.11	BDL	BDL	BDL	BDL	0.33	0.12	0.65	0.15	0.12	0.68	0.21	0.11
2006	1.15	0.33	0.26	BDL	0.30	BDL	0.53	0.18	BDL	BDL	BDL	BDL	BDL	0.25	BDL	BDL	0.15	0.11	BDL	0.17	0.11
2007	0.91	0.28	0.21	BDL	0.30	BDL	0.54	0.19	0.11	BDL	BDL	BDL	BDL	0.23	BDL	0.52	BDL	BDL	BDL	0.16	BDL
2008	1.15	0.48	0.30	BDL	0.24	BDL	0.68	0.18	0.12	BDL	BDL	BDL	BDL	0.21	0.11	0.62	BDL	BDL	BDL	0.17	BDL
2009	0.77	0.38	0.29	BDL	0.32	BDL	BDL	0.14	BDL	BDL	BDL	BDL	BDL	0.20	BDL	BDL	0.10	0.10	BDL	0.11	BDL
2010	0.68	BDL	0.11	BDL	0.32	BDL	BDL	0.16	BDL	BDL	BDL	BDL	BDL	0.24	BDL	0.72	0.15	BDL	0.53	0.19	BDL
2011	0.78	0.22	0.24	BDL	0.24	BDL	BDL	0.11	BDL	BDL	BDL	BDL	BDL	0.21	0.10	BDL	BDL	0.10	BDL	0.12	0.12
2012	0.78	BDL	0.14	BDL	0.40	0.10	BDL	0.16	0.11	BDL	BDL	BDL	BDL	0.26	0.13	BDL	0.14	0.17	BDL	0.16	BDL
2013	0.82	0.15	0.42	BDL	0.34	BDL	0.50	0.15	BDL	0.55	BDL	BDL	BDL	0.22	BDL	0.69	0.14	BDL	BDL	0.13	BDL
2014	BDL	0.18	0.15	0.58	0.36	BDL	0.60	0.21	BDL	0.62	BDL	BDL	0.61	0.26	0.11	0.75	0.14	0.11	0.54	0.17	BDL

[a] BDL = below detection limit. Detection limits are 0.5 mg-N L^{-1} for total Kjeldahl nitrogen and 0.1 mg-N or -P L^{-1} for nitrite+nitrate or total phosphorus.