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Spatial assessment and analysis of pollution sources and water quality in the Bogue Falaya River and Abita River watersheds, St. Tammany Parish, LA

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SPATIAL ASSESSMENT AND ANALYSIS OF POLLUTION SOURCES AND WATER QUALITY IN THE BOGUE FALAYA RIVER AND ABITA RIVER WATERSHEDS, ST. TAMMANY PARISH, LA

A Thesis

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For the two Core men, together and at peace.
We love you…

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ABSTRACT

Watershed planning is an important ongoing process for enabling communities to repair polluted waterways and ensuring the health and vitality of waterways for future generations. This study defines a process to spatially track pollution sources entering into our waterways. An essential tool used in the watershed planning process is geographic information systems. It is important to gather spatial information to illustrate where all potential pollution sources are located within each watershed. The data for this study were assembled into a database and mapped to locate pollution sources including: commercial/small business wastewater treatment plants; subdivisions without community wastewater treatment; and individual home sewer treatment systems within the Bogue Falaya River and Abita River watersheds located in St. Tammany Parish, Louisiana. Water quality monitoring data, collected by the Lake Pontchartrain Basin Foundation, were also mapped and analyzed to identify correlations between fecal coliform, turbidity, and specific conductance to pollution source locations and densities.

The Bogue Falaya River and Abita River watersheds were further delineated into six sub-watersheds. Land use percentages for the study area were calculated using tools in ArcMap. Community wastewater treatment plants, sewered vs. unsewered subdivisions, and home treatment systems were identified and mapped for each sub-watershed using ArcMap. Water quality correlations were produced using non-parametric statistical tests, including the Spearman's rank correlation coefficient, and the Kruskal–Wallis one-way analysis of variance. A Kernel density layer was created using ArcMap's Spatial Analysis tool for the commercial wastewater treatment plants and the individual home systems.

Results showed poorest water quality and the densest pollution sources occurred in the most urban areas of the watersheds (the southernmost portions of the study area). An important

finding identified to reduce pollution sources within the Bogue Falaya and Abita Rivers is the large-scale regionalization of wastewater treatment facilities. This study provides a comprehensive approach to locating, characterizing, and spatially assessing sources of water quality impairment for a watershed-based management planning process and will be referenced by future watershed protection plans written for the Pontchartrain Basin.

CHAPTER 1: INTRODUCTION

1.1 Background

In 1972, the United States established the Clean Water Act (CWA) as the basis for water quality protection. The Act's focus is the regulation of pollutants entering into the nation's waterways by either "point sources" that include wastewater treatment plants (WWTPs), industrial plants, and other discharges from localized sources (such as pipes) or "nonpoint sources" such as runoff from urbanization, agriculture, and development/construction (U.S. EPA 2008a). The United States Environmental Protection Agency (U.S. EPA) links urbanization/development to water pollution. When urban and suburban areas are developed, buildings and pavement cover the surface of the land. These impermeable surfaces do not allow rain to seep into the ground. Most areas that are developed utilize storm drain networks to capture runoff from roofs and paved areas. Stormwater runoff drains directly into rivers and streams carrying pollution such as oil, dirt, chemicals, lawn fertilizers, pet waste, etc., which degrades water quality (U.S. EPA 2011). Therefore, pollution is influenced by the geography of the watershed where the sources originate.

John Wesley Powell, scientist/geographer, described a watershed as that area of land, a bounded hydrologic system, within which all living things are inextricably linked by their common water course and where, as humans settled, simple logic demanded that they become part of a community (Figure 1.1) (U.S. EPA 2012a). A watershed is the geographic area within which all waterways drain into a central body of water, such as a river or lake. Watersheds vary in size and can intersect county, state, and national boundaries. The U.S. EPA (2012a) defines 2,110 watersheds in the continental U.S., and 2,267 including Hawaii, Alaska, and Puerto Rico. Programs to reduce pollution loads in waterways such as the Total Maximum Daily Loads

(TMDL) (described in Section 2.1) use a holistic watershed-based approach. According to the CWA, these approaches not only focus on restoring impaired waterways but also protecting healthy waters (U.S. EPA 2008a).

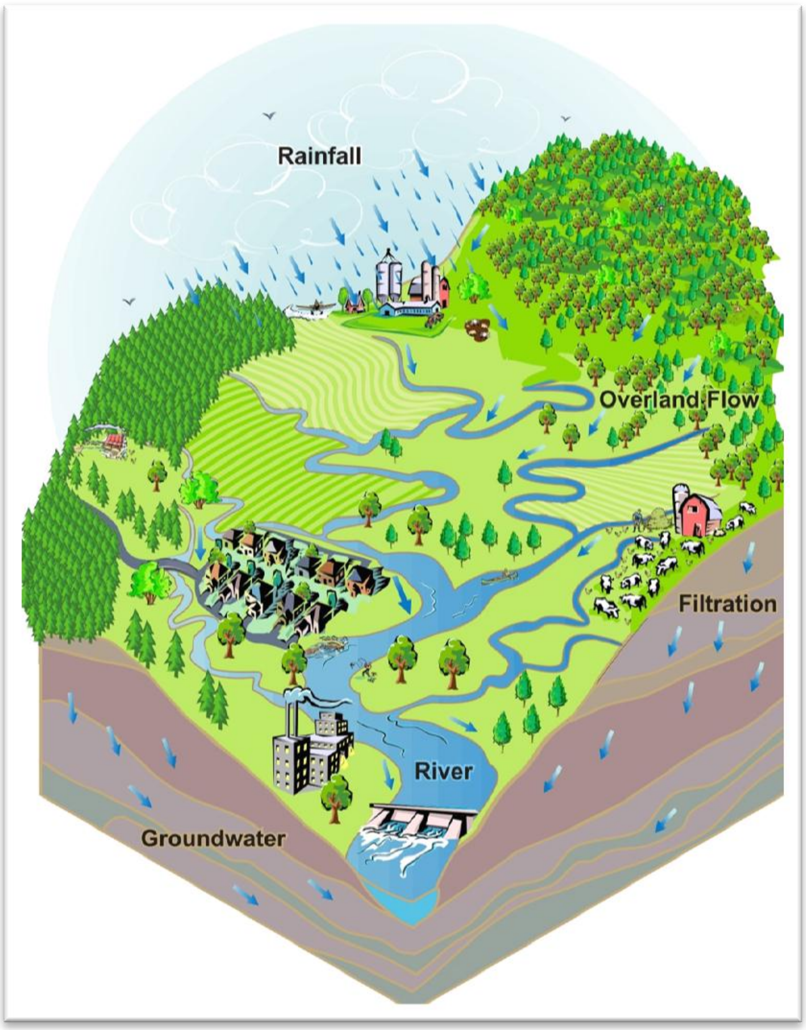


Figure 1.1 Illustration of a Watershed (Arkansas Watershed Advisory Group 2011).

Louisiana has over 1,684 mi^2 of lakes, nearly 7,656 mi^2 of estuaries, 8,673 mi^2 of wetlands, and 66,294 miles of rivers, as stated in the Louisiana's Nonpoint Source Management Plan 2011-2016. According to this plan, Louisiana is committed to the preservation and improvement of its water resources even though it is a challenge as Louisiana's coastal and inland waters are utilized for a variety or recreational and commercial uses (LDEQ 2011a).

Coastal areas have different hydrologic dynamics than swift moving upland rivers. These dynamics must be taken into consideration when addressing a system's health.

Of Louisiana's 64 parishes, St. Tammany Parish, on the north shore of Lake Pontchartrain has experienced a particularly increase in development over the past 30 years. Development in that parish occurs in the southern portion of the Parish, through the Tchefuncte River watershed to the Causeway Bridge, the main connection between the Greater New Orleans area and St. Tammany Parish. This study focuses on the watersheds of the Bogue Falaya River and its major tributary – the Abita River – both of which are tributaries of the Tchefuncte River located in western St. Tammany Parish, with its most upstream portion in Washington Parish (Figure 1.2). The City of Covington and the Village of Folsom are located in the Bogue Falaya River watershed; the Town of Abita Springs is located in the Abita River watershed. Poorly planned development has led to degraded water quality.

One of the major reasons that most rivers on the north shore of Lake Pontchartrain were closed to swimming and other water-related activities by the mid-1980s was the inadequately treated sewage caused by sprawl and poorly-planned development. This led to many, cumulative pollution sources. In order to identify pollution sources, the Lake Pontchartrain Basin Foundation (LPBF) is utilizing three tracking tools including: water quality monitoring; source identification inspections; and GIS mapping. Studies in these watersheds indicate that water quality falls under two categories of impairments: those caused by wastewater (treated and untreated sanitary and industrial/commercial) introduced to the system by discharges and those caused by stormwater in the form of runoff. Both wastewater and stormwater include point and nonpoint sources and can severely affect watersheds' vitality (Bourgeois-Calvin and Core 2012).

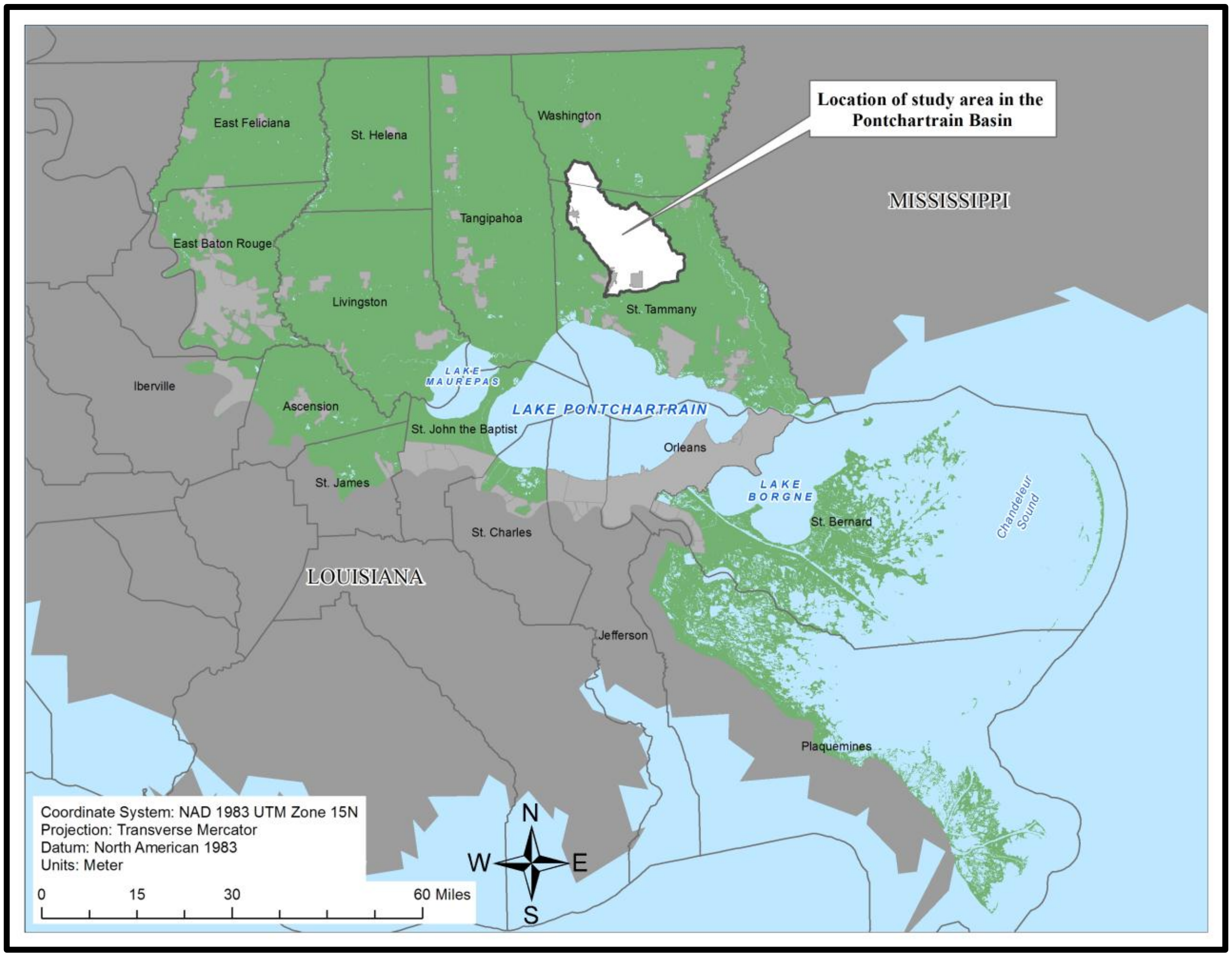


Figure 1.2 Location of Study Area.

1.2 Wastewater Background

This study focuses on commercial/small business WWTPs, home systems, and subdivisions using individual sewer systems, which are probable sources of fecal bacteria inputs into watersheds based on previous work done by the LPBF. Commercial/small business wastewater treatment plants, as defined by the LPBF, are wastewater treatment package plants that service small business buildings, small office complexes, or small subdivisions (Figure 1.3). Typically these plants treat less than 5,000 gallons per day (gpd). Plants usually include an aeration process to break down waste, a clarifier to clear the water, and are supposed to utilize a tertiary disinfection process to minimize the amount of bacteria in the water to be discharged into the environment.

Figure 1.3 Wastewater Plants, Regional Plant (left) Smaller Plants (right) (Google 2011).

1.3 Study Objective

The objective of this study is to inventory all potential point and nonpoint sources within a developing watershed in Louisiana and explore relationships to water quality in order to target future cleanup efforts for local and regional agencies including the U.S. EPA, Louisiana Department of Environmental Quality (LDEQ), and the St. Tammany Parish Government.

1.4 Research Questions

1. What is the spatial distribution of the commercial/small business WWTPs (point sources) and what is their density in the watersheds?
2. What is the spatial distribution of the subdivisions (with and without community wastewater treatment) in the study area and what is the relationship to the home densities

in the sub-watersheds (nonpoint sources)?

3. What is the relationship between the point and nonpoint sources and water quality data for the sub-watersheds?
4. What cleanup/management strategies can be recommended for the study area?

1.5 Answering the Research Questions

Answering the research questions was accomplished by obtaining and ground-truthing pertinent databases. The commercial/small business wastewater treatment plants point source raw dataset was acquired from LDEQ. Subdivision location and utility data were acquired from St. Tammany Parish Government and LPBF field reconnaissance. The water quality data were obtained from the LPBF water quality department. The data were organized, consolidated, mapped, and spatially analyzed to determine possible areas of degraded water quality. Results from the analysis were used to recommend management strategies and clean-up efforts for the study area.

The research questions were selected to attempt to locate and categorize all potential point and nonpoint source loads in the watersheds. The water quality analyses provide data that can be correlated to the location and concentration of potential sources. The result of the spatial comparison was then used to select management strategies.

1.6 How Does This Add to Knowledge of the Topic?

When assessing a pollution load into a waterway, knowledge of all possible sources that enter into that system is paramount. In a rapidly developing environment, especially one that falls under different jurisdictions, a holistic watershed picture is not usually defined. After reviewing various methods shown in previous U.S. EPA, LDEQ and LPBF research, this study provides an innovative approach to spatially assessing pollution sources within a watershed.

This research presents a comprehensive view of inputs into a watershed that is used to determine the sources of current pollution loads into that system and recommends methods to address those loads. This study will be used as a model plan for other watersheds in the Pontchartrain Basin.

The following chapters discuss previous research, methods, results, and a discussion of the results. Chapter 2 identifies previous research on water quality parameters and associated spatial comparisons to potential sources. In Chapter 3, the study area is defined and the data and methods used to determine spatial correlations between point and nonpoint sources and water quality are described. Chapter 4 contains the results. Lastly, Chapter 5 is the discussion of the results including recommendations for the use of best management practices (BMPs) to control inputs into the Bogue Falaya River and Abita River watersheds.

CHAPTE 2: LITERATURE REVIEW

2.1 Clean Water Act

To fulfill the Clean Water Act (CWA), "states, territories, and authorized tribes, collectively referred to in the act as "states," are required to develop lists of impaired waters" (U.S. EPA 2012b). Every two years, the Louisiana Department of Environmental Quality (LDEQ) releases an "impaired water bodies" list called the Integrated (305b and 303d) Report (IR) for the State of Louisiana. Section 303(d) of the CWA requires states to list these impaired water bodies and to develop Total Maximum Daily Loads (TMDLs) for each. That section also states that TMDL models are calculated based on the "maximum amount of a pollutant that a water body can receive and still safely meet water quality standards" (U.S. EPA 2012b).

A court order in a lawsuit of the Sierra Club, et al. versus Clifford, et al. (Civil Action No. 96-0527) claimed the U.S. EPA violated the CWA and failed to adequately identify water bodies that still require TMDLs in Louisiana. The court order/consent decree ordered the following:

> WHEREAS, Section 303(d) of the CWA, 33 U.S.C. § 1313(d), and EPA's implementing regulations, 40 C.F.R. § 130.7, provide for (1) identification of waters for which applicable technology-based and other required controls are not stringent enough to implement water quality standards (the "Section 303(d) List"); (2) establishment of priority ranking for such waters; and (3) establishment of TMDLs for pollutants for which those waters are not in attainment with water quality standards (LDEQ 2000: 1-2).

The Consent Decree State target completion date was listed as March 31, 2011 for the Pontchartrain Basin. In executing the Consent Decree, TMDLs take into account unique parameters of Louisiana's coastal waterways. A Use Attainability Analysis (UAA) was completed for the Barataria-Terrebonne Bay located in southeast Louisiana to establish realistic/healthy dissolved oxygen criteria for wetlands (LDEQ 2008). The Pontchartrain Basin UAA is currently being produced.

The LDEQ's Louisiana Nonpoint Source Annual Report (2011) states that the 1999/2000 Integrated Report (IR) listed 155 non-point source (NPS)-related impaired water bodies in the state. Since then, 26 of those have been fully restored and 109 partially restored. From 2000-2011 LDEQ has monitored and assessed 476 water bodies. Approximately 295 of the 476 have had one or more impairment delisted since 2004, according to Appendix C of the 2010 IR. Since 2000, LDEQ has seen improvements in the Lake Pontchartrain, Mermentau, Ouachita, Vermilion-Teche, Terrebonne, and Barataria Basins (LDEQ 2011b).

According to the 2010 IR, the EPA mandates that states place water quality standard regulations that designate uses for all water bodies within their jurisdiction.

> Louisiana water quality standards define eight designated uses for surface waters: primary contact recreation (PCR), secondary contact recreation (SCR), fish and wildlife propagation (FWP) (with "subcategory" of limited aquatic and wildlife use (LAW), drinking water supply (DWS), oyster propagation (OYS), agriculture (AGR), and outstanding natural resource (ONR). Designated uses and criteria for each water body subsegment are listed in Louisiana's ERC 33:IX.1123. Designated uses have a specific suite of ambient water quality parameters used to assess their support. (LDEQ 2010: 54).

The criteria for each use are shown in Appendix A. Two of the designated uses are important to highlight for the purpose of this study: PCR and FWP. According to LDEQ Title 33, Part IX, Subpart 1, *Section 1109*, PCR is defined as "any recreational activity which involves or requires prolonged body contact with the water, such as swimming, water skiing, tubing, snorkeling, and skin-diving." FWP consists of the preservation and reproduction of aquatic biota such as invertebrates and species of fish that are indigenous to the given water body. This designation also includes reptiles, amphibians, and other wildlife that propagate in that environment. In addition, the designation promotes water quality maintenance to prevent contamination of aquatic biota that may be consumed by humans (LDEQ 2011c). Designated uses are affected by sources of pollution, such as the impacts of numerous or elicit WWTP discharges entering a water body.

2.2 Lower Tchefuncte River

The daft TMDL for the Lower Tchefuncte River was completed on 10 August 2011. According to the findings, a large number of sources discharge directly or indirectly into the watershed. According to the TMDL, sources causing impacts to the Lower Tchefuncte River include commercial package plants (described in Section 1.3) and individual home treatment systems. The TMDL included facilities that were located in subsegment 040801 (Bogue Falaya River) and 040804 (Figure 2.1). As a result, the LDEQ recommends that St. Tammany Parish start to regionalization of wastewater treatment (LDEQ 2011d).

The LDEQ also determined that a significant amount of the loading is attributed to anthropogenic sources that include “many permitted and unpermitted dischargers located within the watershed” (LDEQ 2011d). The Bogue Falaya River is the largest tributary of the Tchefuncte River, which suggests that the Bogue Falaya River (and its tributary, the Abita River) are largely contributing to the load within the Lower Tchefuncte River system.

> Most of the urban development and dischargers are located along major highways that drain into the tributaries of the Tchefuncte to include Hwy 190, Hwy 59, Hwy 1022, and Hwy 22. The combination of urban development and stagnant flow is causing a significant reduction in water quality in the tributaries, neighboring mainstream reaches, and upper tidal reaches (LDEQ 2011d: 105).

The breakdown of the source allocations and the respective pollution load reductions are illustrated in Table 2.1.

Two parameters associated with water quality impairment are fecal coliform bacteria, “…which can impair waters for recreational use and contaminate shellfish…” and dissolved oxygen (measured in milligram per liter [mg/L]), which necessary for organisms’ respiration

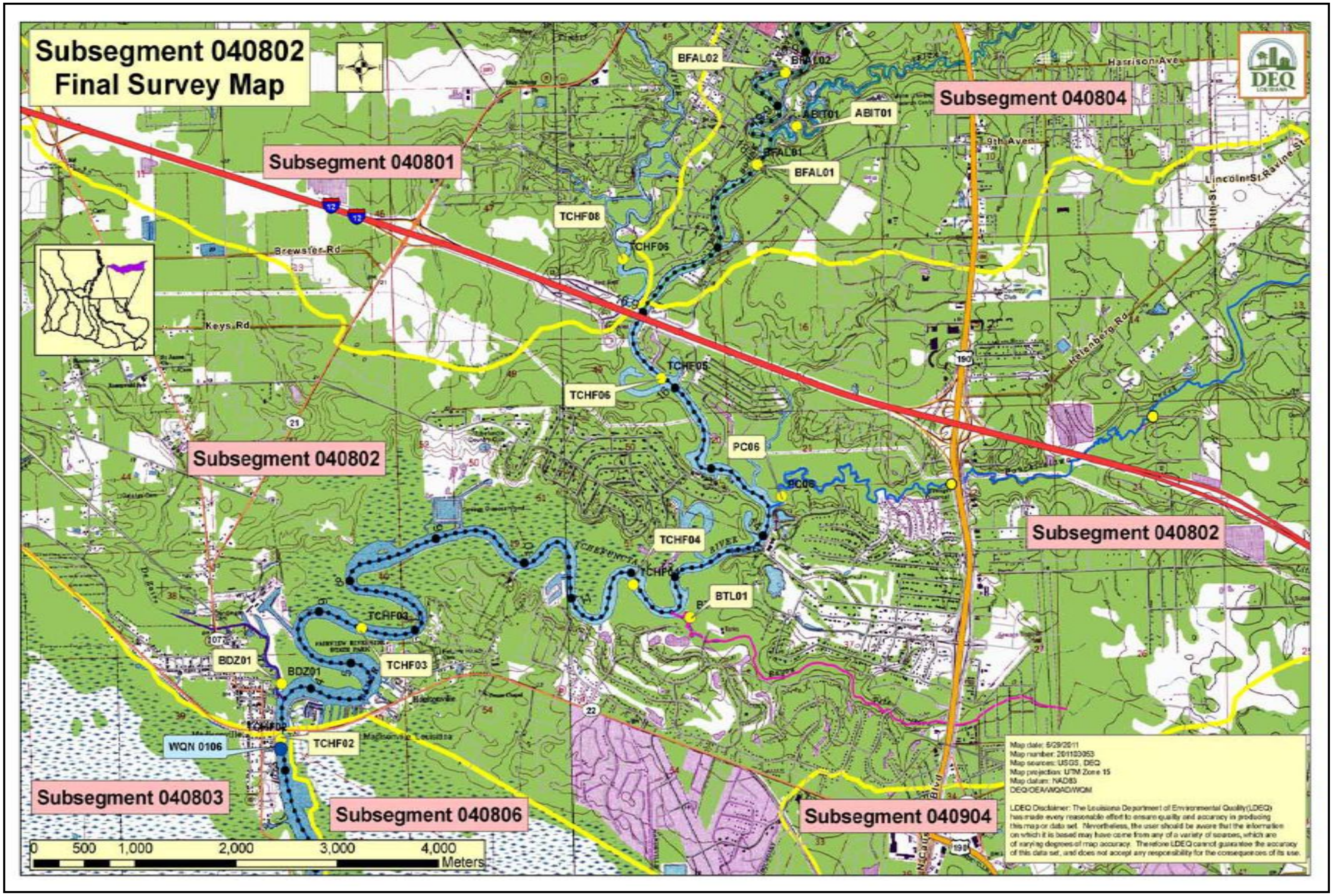


Figure 2.1 Segments Listed for the Lower Tchefuncte River Draft (LDEQ 2011d).

Table 2.1 Subsegment 040802 TMDL (Sum of UCBOD1, UNBOD, and SOD) for a 5.0 mg/L Dissolved Oxygen Standard. (LDEQ 2011d).

ALLOCATIONS	SUMMER		WINTER	
	% Reduction Required	(MAY-OCT) (lbs/day)	% Reduction Required	(NOV-APR) (lbs/day)
Point Source Wasteload Allocation (WLA)	Tchefuncte River 67% above Hwy 22, 85% for Ponchitolawa Creek, 85% for Bayou Tete L'Ours above Hwy 190, 76% for Bayou Tete L'Ours below Hwy 190, and 76% for Bayou DeZaire	682	Tchefuncte River 67% above Hwy 22, 85% for Ponchitolawa Creek, 85% for Bayou Tete L'Ours above Hwy 190, 76% for Bayou Tete L'Ours below Hwy 190, and 76% for Bayou DeZaire	682
Point Source Reserve MOS (20%)		171		171
St. Tammany Parish MS4 WLA (Nonpoint Loads)	Tchefuncte River 67% above Hwy 22, 85% for Ponchitolawa Creek, 85% for Bayou Tete L'Ours above Hwy 190, 76% for Bayou Tete L'Ours below Hwy 190, and 76% for Bayou DeZaire	2,552	Tchefuncte River 67% above Hwy 22, 85% for Ponchitolawa Creek, 85% for Bayou Tete L'Ours above Hwy 190, 76% for Bayou Tete L'Ours below Hwy 190, and 76% for Bayou DeZaire	1,963
St. Tammany Parish MS4 MOS (Nonpoint Source Reserve MOS) (20%)		642		491
City of Mandeville MS4 WLA (Nonpoint Loads)	Tchefuncte River 67% above Hwy 22, 85% for Ponchitolawa Creek, 85% for Bayou Tete L'Ours above Hwy 190, 76% for Bayou Tete L'Ours below Hwy 190, and 76% for Bayou DeZaire	169	Tchefuncte River 67% above Hwy 22, 85% for Ponchitolawa Creek, 85% for Bayou Tete L'Ours above Hwy 190, 76% for Bayou Tete L'Ours below Hwy 190, and 76% for Bayou DeZaire	130
City of Mandeville MS4 MOS (Nonpoint Source Reserve MOS) (20%)		43		33
Nonpoint Loads	Tchefuncte River 67% above Hwy 22, 85% for Ponchitolawa Creek, 85% for Bayou Tete L'Ours above Hwy 190, 76% for Bayou Tete L'Ours below Hwy 190, and 76% for Bayou DeZaire	6,365	Tchefuncte River 67% above Hwy 22, 85% for Ponchitolawa Creek, 85% for Bayou Tete L'Ours above Hwy 190, 76% for Bayou Tete L'Ours below Hwy 190, and 76% for Bayou DeZaire	4,895
Nonpoint Source Reserve MOS (20%)		1,601		1,224
TMDL		12,225		9,588

***Note1: UCBOD as stated in this allocation is Ultimate CBOD.
UCBOD to $CBOD_5$ ratio = 2.3 for all treatment levels
Permit allocations are generally based on $CBOD_5$***

and other important biological processes (Bourgeois-Calvin 2008: 1). Fecal coliform (measured in the most probable number *[MPN]*), an indication of sewage contamination, is the main focus of this study, although it is important to mention other influential parameters in the area. Currently, the Bogue Falaya and Abita Rivers are not listed for stormwater impairments including total dissolved solids (TDS) and sedimentation. However, rapid development occurring in the region coupled with the lack of or improper utilization of stormwater pollution prevention best management practices (BMPs), has historically led to sedimentation in the rivers. In the 2010 draft 303 (d) list, the Tchefuncte River was listed for impairments including low dissolved oxygen, high TDS, and high chlorides. This implies that, as large tributaries to the Tchefuncte watershed, the Bogue Falaya and Abita Rivers are presumably contributing loads into the system (LDEQ 2011d). According to the LDEQ 2010 IR, the impairments listed above impact PCR and FWP designated stream uses.

2.3 Growth in St. Tammany Parish

Throughout the 1980s and 1990s, historically rural St. Tammany Parish experienced significant urban growth or sprawl, and as a result, began resembling a more urbanized landscape (Figure 2.2). St. Tammany Parish continues to have rapid development and growth. The 2010 Census indicated a population of 233,740 people; this represents a growth of 22 percent between 2000 and 2010, ranking the St. Tammany Parish as the fifth-fastest growing parish in the state (USBC 2010).

Urban sprawl occurred rapidly, and much of the new development within the Parish was not connected to municipal or regional sewer systems. Individual homes, subdivisions, and small developments utilized small package wastewater systems. Over time and without proper oversight, many plants were not functioning properly and not fully treating the water. This led to small cumulative sources of bacteria entering the watersheds. Bacterial contamination from wastewater was one reason the LDEQ added the Bogue Falaya River to Louisiana's 303(d) list of impaired waters in 1992 (Bourgeois-Calvin 2011).

2.4 Past Work in the Bogue Falaya and Abita River Watersheds

The Lake Pontchartrain Basin Foundation (LPBF), a non-profit organization established in 1989, has a mission to restore and preserve the water quality, coast, and habitats of the entire

Figure 2.2 Urban Development (with no BMPs) on Hwy 21, between Hwy 190 and I-12 in the Tchefuncte Watershed (western St. Tammany) (2011).

Pontchartrain Basin. Water quality issues occurring in St. Tammany watersheds led the organization to start a program to track and correct sources of pollution entering the Basin's waterways in 2002. From 2002 to 2005, the LPBF piloted the program on Bogue Falaya and Tchefuncte River watersheds, combining water quality monitoring and pollution source tracking. The program identified the main sources to be small numerous wastewater treatment plants (WWTPs). Approximately 250 commercial WWTPs ranging from small plants (500-1500 gpd) to larger municipal plants (>1,000,000 gpd) were located and assisted by the LPBF.

Through previous work, LPBF found that the Louisiana Department of Health and Hospitals (LDHH) was the agency responsible for permitting WWTPs to be built according to the Louisiana Sanitary Code. In accordance with the Louisiana Pollutant Discharge Elimination System (LPDES) program of the Clean Water Act of 1972, LDEQ is responsible for permitting the WWTPs to discharge into waters of the state (Bourgeois-Calvin 2008). According to Dr. Bourgeois-Calvin, this permitting process "has caused a historic disconnect between these two agencies [LDHH and LDEQ] to where plants were routinely permitted to be built but not to discharge. This meant that these plants did not have their effluent tested for years to decades, a provision of the LPDES permit" (2008: 59). LPBF's efforts led to substantial reductions of fecal coliform on eight waterways within the watershed (Bourgeois-Calvin, Mastrototaro, & Briuglio 2004). In 2008, the Bogue Falaya River was removed from the 303(d) list as impaired for fecal coliform for primary contact recreation (U.S. EPA 2009).

While water quality improvement is evident and the river has been "delisted", it is persistently subjected to multiple wastewater sources and must be monitored to remain off of the 303(d) list. The Abita River is also not listed for fecal coliform but is faced with the same threat. Therefore, continual water quality improvement is important for both rivers to remain off the list. To ensure that the waterways remain off of the 303(d) list, the LPBF partnered with LDEQ to write a Watershed Protection Plan (WPP), *The Bogue Falaya and Abita Rivers Watershed Protection Plan*, which includes the implementation of BMPs for the watersheds. The WPP focuses on wastewater and stormwater issues influencing water quality within the chosen watersheds. The WPP's wastewater issues are highlighted in this study.

2.5 GIS and Watersheds

An essential tool used in the watershed planning process is geographic information systems (GIS). It is important to gather spatial information to illustrate where all potential pollution sources are located within each watershed. Kelsey et al. (2004) explored the use of spatial analysis (GIS) to evaluate the relationships between land use and fecal coliform pollution in South Carolina. GIS techniques were used for the identification and calculation of land use and spatial variables. These variables, along with water quality data, were then used in a regression analysis to identify relationships (Kelsey et al. 2004).

In some studies, spatial analysis is use in correlation to water quality data to identify pollution within spatial boundaries such as watersheds and sub-watersheds. A 2002 study by Tong and Chen used a comprehensive watershed-based approach to identify the hydrological effects of different land uses types within watersheds and sub-watersheds. Tong and Chen (2002) used statistical (non-parametric correlation analysis and analysis of variance) and spatial analysis (GIS) to examine the general association between land use, flow data, and water quality to identify watersheds inundated with contaminates that correlate to land use types. ArcView GIS was used to analyze the data spatially and identify spatial relationships between land use, water quality, and map areas with high contamination levels based on the spatial relationships at the 11-digit HUC level (Figure 2.3). For the purpose of this study, ArcInfo GIS was used to spatially identify and analysis densities of pollution sources with 10-digit and 12-digit HUC level boundaries within the Bogue Falaya River and Abita River.

2.6 Water Quality and Watersheds

For this study, water quality monitoring data were collected, mapped, and analyzed to identify correlations between fecal coliform, turbidity, and specific conductance to pollution source locations and densities. In a comparable study, Mallin et al. (2000) discussed how enteric pathogen indicators (fecal coliform and *E.coli*) were related to physiochemical water quality, demographics, and land use throughout a system of coastal creeks in southeastern North Carolina. For that project, five waterways were monitored monthly for water quality physiochemical parameters (water temperature, salinity, dissolved oxygen, and turbidity) and enteric pathogen indicators (fecal coliform and *E.coli*) for a period of four years. The study utilized yearly

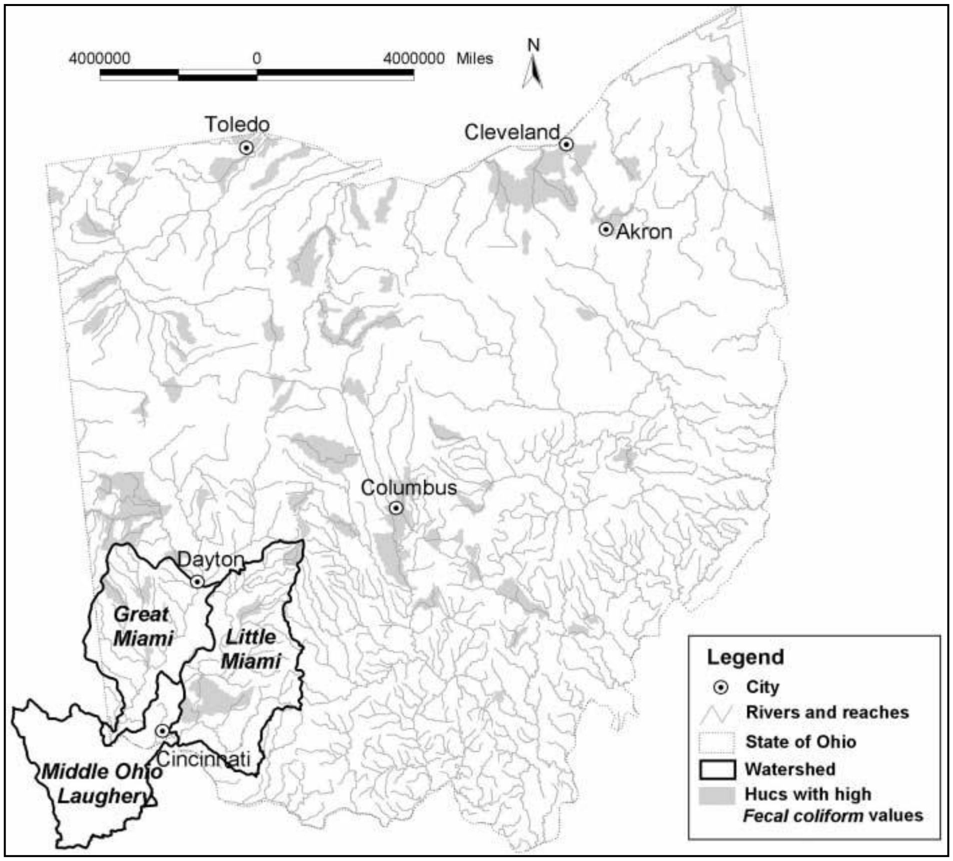


Figure 2.3 HUCs with High Fecal Coliform Counts in the State of Ohio (Tong and Chen 2002).

geometric means for fecal coliform in correlations with land use variables. Results revealed bacteria counts decreased away from upstream sites (the source) and that both fecal coliform and *E.coli* values were inversely correlated with salinity (Mallin et al. 2000). The study by Mallin et al. (2000) found that turbidity and nitrate correlated strongly with enteric pathogen indicators, while orthophosphate correlated weakly.

Similar to water quality methodology in this study, Tong and Chen (2002) used statistical analysis, non-parametric correlation analysis, analysis of variance, and Spearman's rank correlation to explore the relationship between land use and water quality. Analyses from Tong and Chen (2000) revealed a relationship between land use and in-stream water quality parameters (nitrogen, phosphorus, and fecal coliform). GIS-based spatial analyses and statistical analyses revealed that land use types were significantly correlated to several water quality variables in the watershed (Table 2.2; Tong and Chen 2002). Sub-watersheds in Ohio that had high percentages of urban and agricultural lands yielded high levels of pollution, while forestlands were least impacted by contaminants (Tong and Chen 2002). Commercial, residential, and agricultural lands positively related to total nitrogen, total phosphorus, and fecal coliform. These variables had a negative relationship to forest land use. Tong and Chen (2002) also correlated land use and other environmental variables in the sub-watersheds including: conductivity, pH, lead, manganese, sodium, cadmium, lead, biological oxygen demand (BOD), and zinc.

This study investigated the land use types found within the Bogue Falaya River and Abita River watersheds and correlated the uses to water quality analysis. This approach was seen in other studies. Kelsey et al. (2004) investigated land use variables which consisted of: distance to nearest urban and rural land uses; weighted distances to areas of urbanized land in nearest sub-watersheds; weighted distances to number of housing units and population and housing density in nearest sub-watersheds; weighted distance to septic density in nearest sub-watersheds; and nearest distance to sewer system lift stations, roads, marinas, and boat landings. One of the water quality parameters monitored in the study by Kelsey et al. (2004) was fecal coliform and sampling was performed on a monthly basis for a period of ten years. The results of the regression analysis in the study by Kelsey et al. (2004) revealed that land in the vicinity of septic tanks and the potential for rainfall runoff had the most potential to contain high fecal coliform densities within the study area. According to the Kelsey et al. (2004) study, sample sites located closer to the urban land uses tended to have higher fecal counts. Variables (including parameters such as tide, salinity, rainfall, weighted septic tank/distance, weighted urbanized area/distance, etc.) retained in the water quality regression models explained 45-50 percent of the variability of the observed fecal coliform in the areas of the Murrells Inlet in South Carolina (Kelsey et al. 2004).

Table 2.2 Results of Spearman's Rank Correlation Analysis on Water Quality Variables and Land-use Types in All Sub-watersheds in the State of Ohio[a] (Tong and Chen 2002).

Water quality variables	Land-use types			
	Residential	Commercial	Forest	Agriculture
Conductivity	0·2266*	0·2094*	−0·3757*	0·2854*
BOD	0·2078*	0·2088*	−0·2073*	0·0938
pH	0·0318	0·0070	−0·2181*	0·2266*
Total nitrogen	0·2265*	0·2054*	−0·3279*	0·1913*
Total phosphorus	0·3379*	0·2905*	−0·2850*	0·1563*
Sodium	0·3654*	0·3988*	−0·0607	−0·2276
Cadmium	0·2504*	0·2596*	0·0240	−0·1891*
Lead	0·2345*	0·2538*	0·0294	−0·1995*
Manganese	−0·1822	−0·1677	0·4602*	−0·3579*
Zinc	0·1915*	0·1893*	0·0315	−0·1444*
Fecal coliform	0·2660*	0·2541*	−0·3295*	0·1768*

a Only significant relationships are listed.

• Denotes significant relationships at a probability level of <0.0001.

2.7 Impervious Surfaces

The adverse effects of impervious surface runoff have become an important focus in growth management and watershed planning. Mallin et al. (2000) found that fecal coliform levels correlated significantly with population and strongly with percent developed land within a watershed. In the study by Mallin et al. (2000), the strongest relationship; however, was between fecal coliform and the percent impervious surface within a watershed. When bacteria are deposited on an impervious surface, the surface provides a means of concentration and rapid conveyance of the bacteria and other pollutants to downstream water bodies. These results led Mallin et al. (2000) to conclude that the way in which land is developed is the most influential factor on urban and suburban nonpoint source fecal coliform bacterial pollution. According to the Mallin et al. research, acceptable water quality for these coastal systems is found when the percentage of impervious surface of a watershed is less than 10 percent. Impaired water quality occurs above 10 percent impervious surface, and highly degraded water quality occurs above 20 percent impervious surface. To further refine the findings of Mallin et al. (2000), Paul and Meyers (2001) found that an impervious cover of 10-20 percent in a previously forested area doubles surface runoff, while an impervious cover of 35-50 percent triples runoff and 75-100 percent cover quintuples runoff (Figure 2.4).

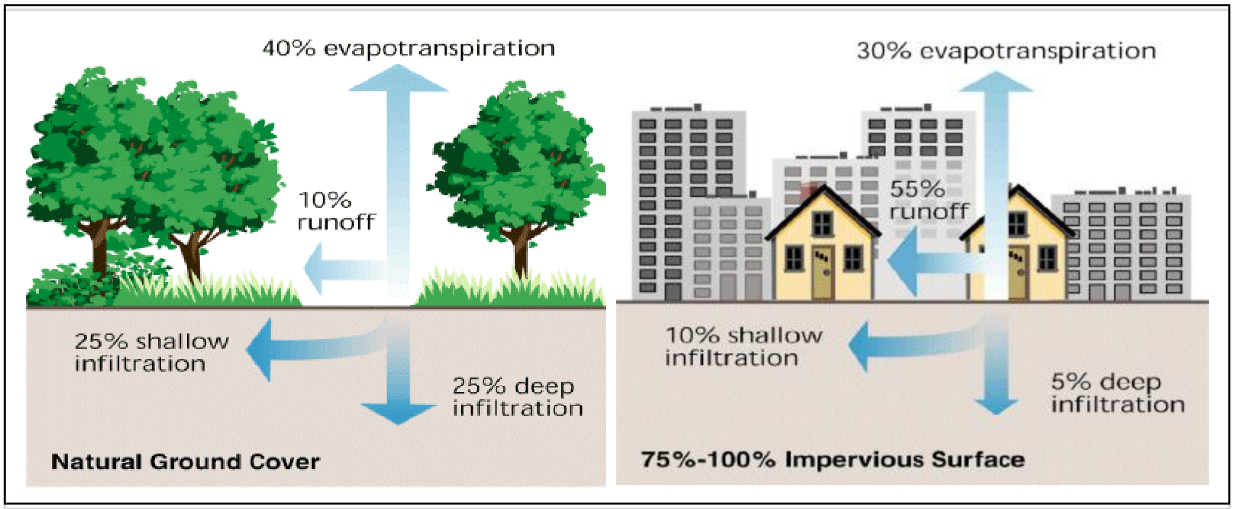


Figure 2.4 Land Use and Water Flow. As Impervious Cover Increases in a Watershed, More Surface Runoff is Funneled Straight to Waterways and Does Not Infiltrate into Groundwater (Bourgeois-Calvin 2008).

In a comparable study, Brabec et al. (2002) introduced a ranking system, which characterized a stream as “protected” (less than 10 percent impervious cover), “impacted” (10-30 percent impervious cover), or “degraded” (greater than 30 percent impervious cover). “Impacted” was defined as the point at which degradation first occurs, and “degraded” was used when the stream degradation became severe. Values for impervious surface were applied within the LPBF’s WPP. The St. Tammany Parish Tchefuncte and Bogue Falaya Implementation Project (2007) utilized nationally accepted effective imperviousness calculations for different land use types (Table 2.3).

Table 2.3 Percent Effective Imperviousness. *St. Tammany Parish Tchefuncte and Bogue Falaya Watershed Implementation Project* (CFMS Cooperative Agreement No. 608669).

Percent Effective Imperviousness
St. Tammany Parish Tchefuncte River and Bogue Falaya Watershed Implementation Project

Land Use Name	Fraction EIA
Commercial	0.25
Industrial	0.33
Transportation	0.70
Low Density Residential	0.05
High Density Residential	0.15
Agriculture	0.00
Forest	0.00
Wetland	0.00

2.8 The Watershed Plan

As stated earlier in this study (Chapter 1), watershed protection falls under the authority of the CWA. Several programs are included in the Act such as the Nonpoint Source Program, National Estuary Program, Total Maximum Daily Loads Program (TMDL), and the National Pollution Discharge Elimination System (NPDES). The CWA also encourages states to develop their own programs to promote watershed protection. The U.S. EPA aids organizations and agencies with the watershed approach through the publication of planning guidebooks, training courses, and tools available on the Internet. These locally driven plans serve as mechanisms for addressing complex water quality problems that cross multiple jurisdictions. According to the U.S. EPA, "...communities, watershed organizations, and state, local, tribal and federal environmental agencies develop and implement watershed plans to meet water quality standards and protect water resources" (2008b).

The U.S. EPA promotes the development of watershed plans through the watershed planning process. The process utilizes stakeholder involvement, the scientific processes, and proper technological analyses to identify water quality goals and formulate specific environmental management actions required to solve pollution problems (U.S. EPA 2008c). For example, most WPPs have separate components for water monitoring, water quality analysis, and spatial analysis. The three components are utilized in the LPBF's WPP. The U.S. EPA requires that all WPPs address nine environmental, educational, and implementation elements. As described in Chapter 2 of the U.S. EPA *Handbook for Developing Watershed Plans to Restore and Protect our Waterways* (2008b), the nine elements are as follows:

> Element A. Identification of causes of impairment and pollutant sources or groups of similar sources that need to be controlled to achieve needed load reductions, and any other goals identified in the watershed plan.
>
> Element B. An estimate of the load reductions expected from management measures.
>
> Element C. A description of the nonpoint source management measures that will need to be implemented to achieve load reductions, and a description of the critical areas in which those measures will be needed to implement the plan.
>
> Element D. Estimate of the amounts of technical and financial assistance needed, associated costs, and/or the sources and authorities that will be relied upon to implement the plan.
>
> Element E. An information and education component used to enhance public understanding of the project and encourage their early and continued participation in selecting, designing, and implementing the nonpoint source management measures that will be implemented.
>
> Element F. Schedule for implementing the nonpoint source management measures identified in this plan that is reasonably expeditious.
>
> Element G. A description of interim measurable milestones for determining whether nonpoint source management measures or other control actions are being implemented.
>
> Element H. A set of criteria that can be used to determine whether loading reductions are being achieved over time and substantial progress is being made toward attaining water quality standards.

Element I. A monitoring component to evaluate the effectiveness of the implementation efforts over time, measured against the criteria established under element h.

CHAPTER 3: STUDY AREA, DATA, AND METHODS

3.1 Watershed Classification

In the 1970s, the United States Geological Survey (USGS) developed a hierarchical hydrologic unit code (HUC) based on surface hydrologic features, to assist in the delineation of watersheds in the U.S. and the Caribbean. The first four types of hydrologic units included: first-field (region), second-field (sub-region), third-field (accounting unit), and fourth-field (cataloguing unit). The smallest USGS unit (fourth-field, 8-digit HUC), which averaged approximately 450,000 acres, was further delineated by the Natural Resource Conservation Service (NRCS) into an 11-digit HUC used for mapping purposes in the 1980s. The advent of GIS in the 1990s provided a more convenient way to map watershed boundaries, which led to the NRCS delineating a (fifth-field, 10-digit HUC) classification called a watershed (40,000-250,000 acres) and (sixth-field, 12-digit HUC) classification called a sub-watershed (10,000-40,000 acres) (USGS 2011). Watersheds in this study area are delineated by 12-digit HUCs.

3.2 Louisiana and the Pontchartrain Basin

Louisiana has twelve major basins that are delineated into 484 watersheds (Figure 3.1). Those watersheds can be further delineated into 1,741 sub-watersheds. The study area is located in the Pontchartrain Basin, a 25,900 km^2 (10,000 mi^2) estuarine ecosystem in southeast Louisiana and southern Mississippi. The Pontchartrain and Pearl River basins are comprised of 122 watersheds (Figure 3.2).

The Pontchartrain Basin is bordered by the Mississippi River and its artificial levees to the west, and by the Pearl River watershed to the east, which acts as the Louisiana-Mississippi state line. The basin gets its fresh water from several rivers north and west of the bay. Lake Pontchartrain gets its saltwater from the Gulf of Mexico via two natural inlets, the Chef Menteur and Rigolets passes. The man-made Mississippi River Gulf Outlet (MRGO) was also a source of saltwater until a rock wall dammed it off in 2009. Effects from the MRGO's closure are currently being studied.

Figure 3.3 displays the 16 Louisiana parishes that are located within the Pontchartrain Basin, of all which drain into Lake Pontchartrain, an inland bay that measures 1,632 km^2 (630 mi^2) in size. The two water bodies located respectively to the west and east of Lake Pontchartrain are Lakes Maurepas and Borne. Several large rivers drain into the estuary. The Amite, Tickfaw, Natalbany, Comite, Lacombe, and Bonfouca/Liberty Rivers drain into Lake Maurepas while the Tangipahoa, Tchefuncte, and Bogue Falaya Rivers drain into Lake Pontchartrain. The Pearl and West Pearl Rivers drain from the north into Lake Borgne. There are also twelve municipal storm water canals in the Greater New Orleans Area (Jefferson and Orleans Parishes), several bayous along the south shore, and occasional diversion canals via the Bonnet Carre' Spillway that also contribute to an influx of fresh water (Bourgeois-Calvin 2008).

The Pontchartrain Basin's topography ranges from approximately 300 feet above sea level at the Louisiana-Mississippi state line to approximately 10 feet below sea level within certain areas in the City of New Orleans. The habitat ranges from rolling woodlands in the northern region of the basin to coastal marshes along the south. Large urban areas within the Pontchartrain Basin include the Greater New Orleans Metropolitan Area (GNOMA) on Lake Pontchartrain's south shore and Baton Rouge Metropolitan Area (BRMA) in the northwest (Figure 3.3). Development outside of the larger urban areas is occurring rapidly in places like St. Tammany Parish, situated north of Lake Pontchartrain (Bourgeois-Calvin et al. 2004).

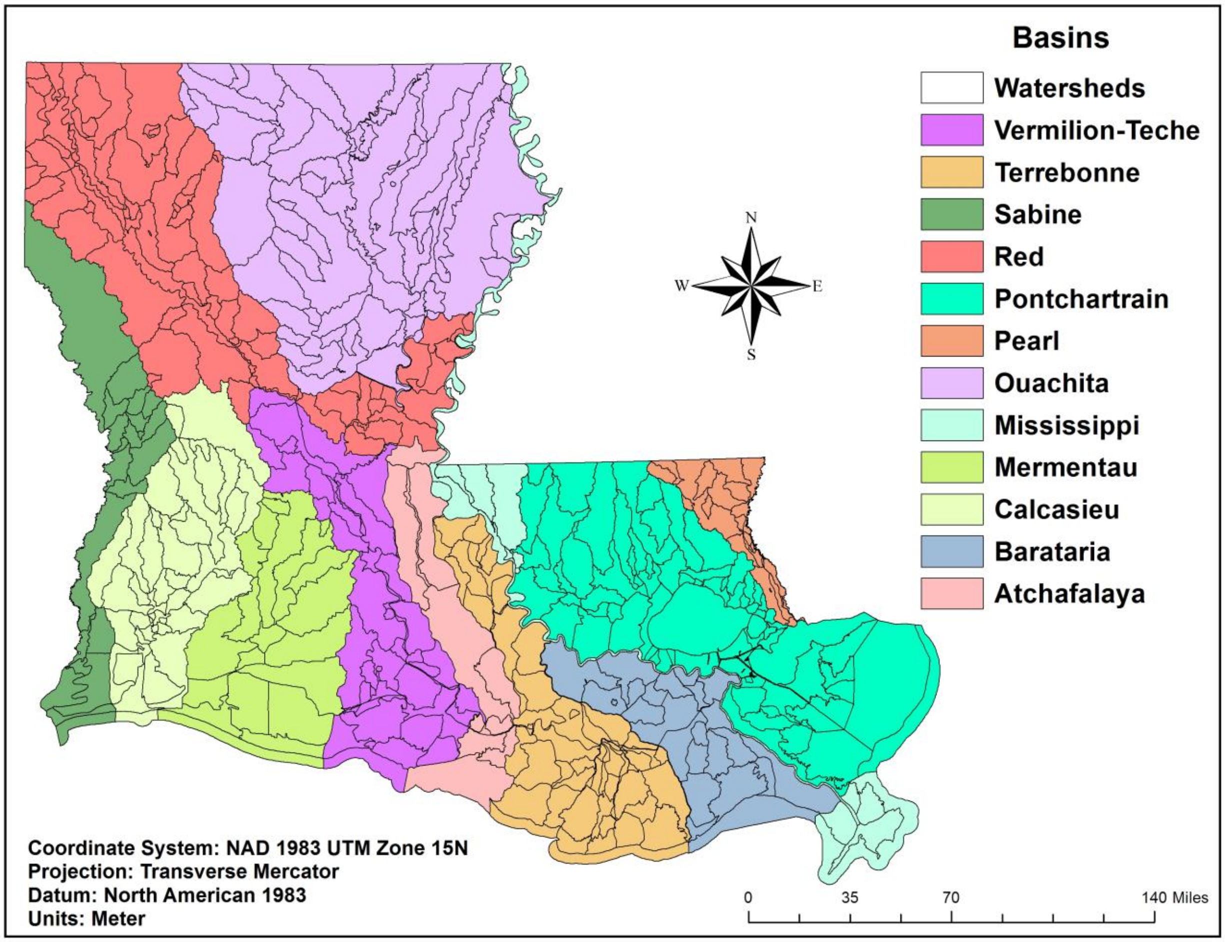


Figure 3.1 Louisiana Basins and Watersheds.

3.3 St. Tammany Parish

Covering approximately 2,900 km^2 (1,120 mi^2), St. Tammany Parish is located within the jurisdiction of two water quality management basins, the Pearl River Management Basin and the Pontchartrain Management Basin. Important watersheds within St. Tammany Parish for this study include: Tchefuncte, Bogue Falaya, Abita, Bayou Castine, Bayou Cane, Bayou LaCombe, Bayou Bonfuca, and Bayou Liberty. Additionally, Grand Lagoon, W-1 drainage canal, the Main diversion Canal, Salt Bayou, and the Pearl River watershed are located in the eastern part of St. Tammany Parish (Figure 3.4).

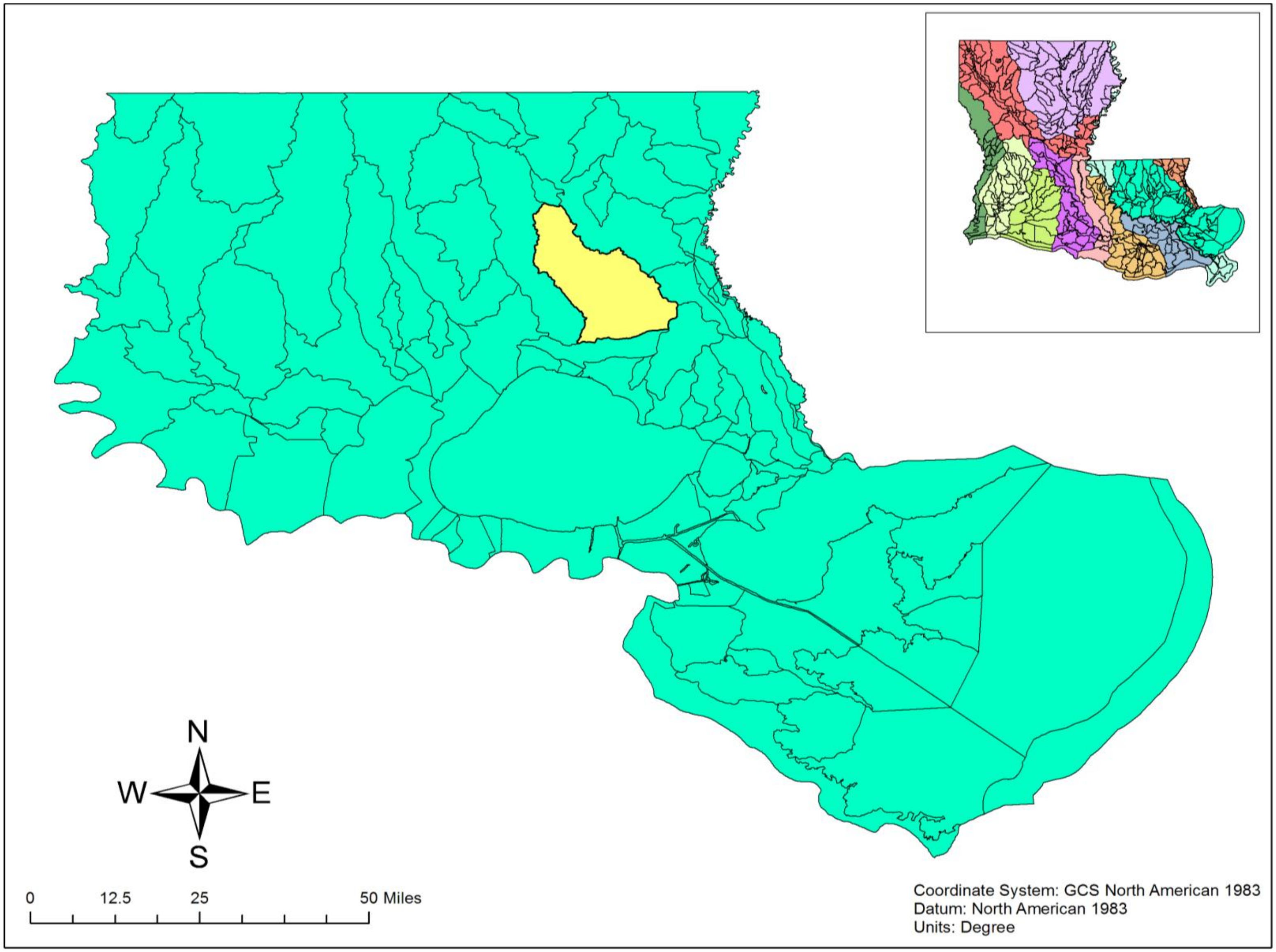


Figure 3.2 The Pontchartrain and Pearl River Basin Watersheds (LPBF combines the two because the Pearl River empties into the Pontchartrain Basin). Highlighted in Yellow is the Bogue Falaya River and Abita River Watersheds.

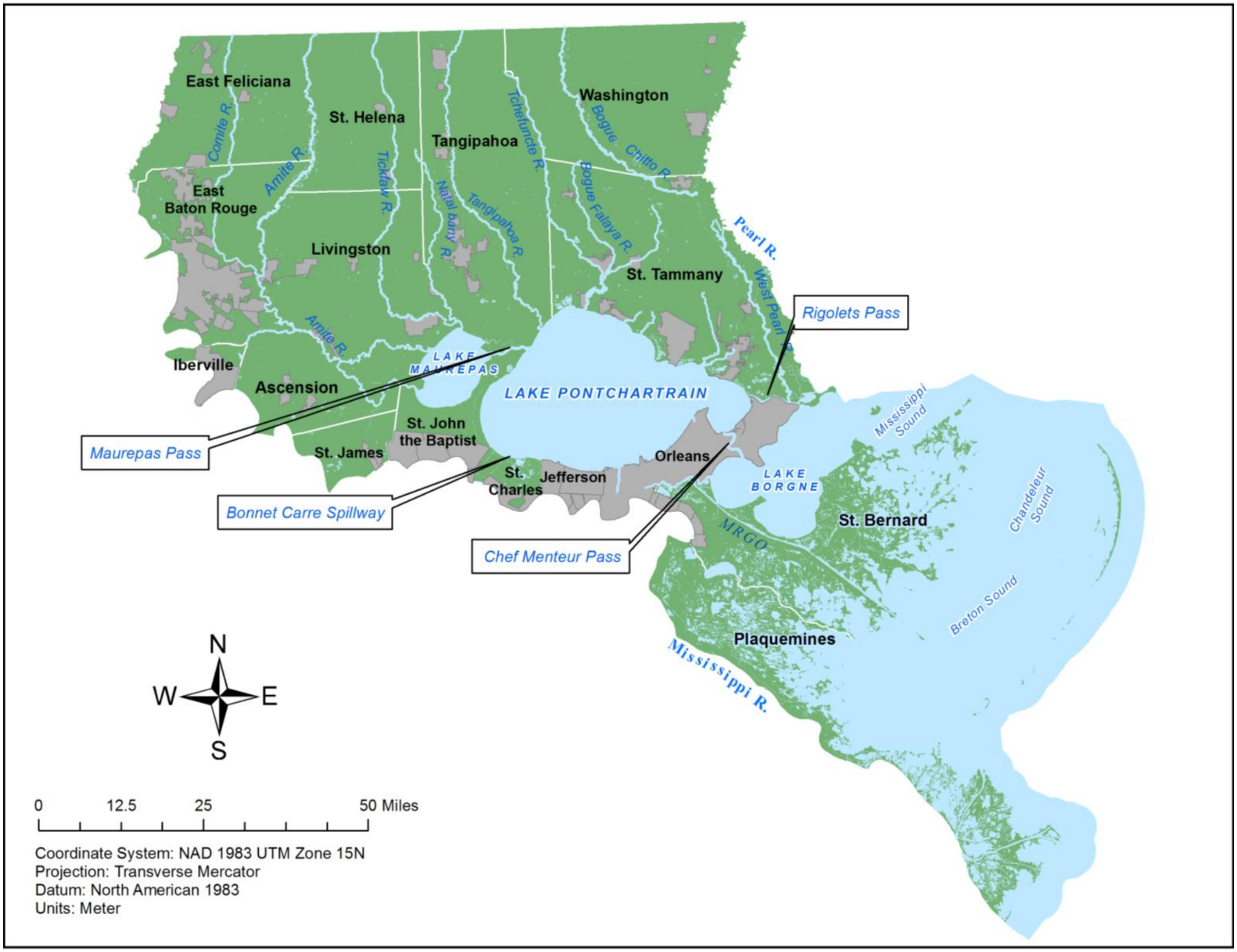


Figure 3.3 The Pontchartrain Basin and its 16 Louisiana Parishes.

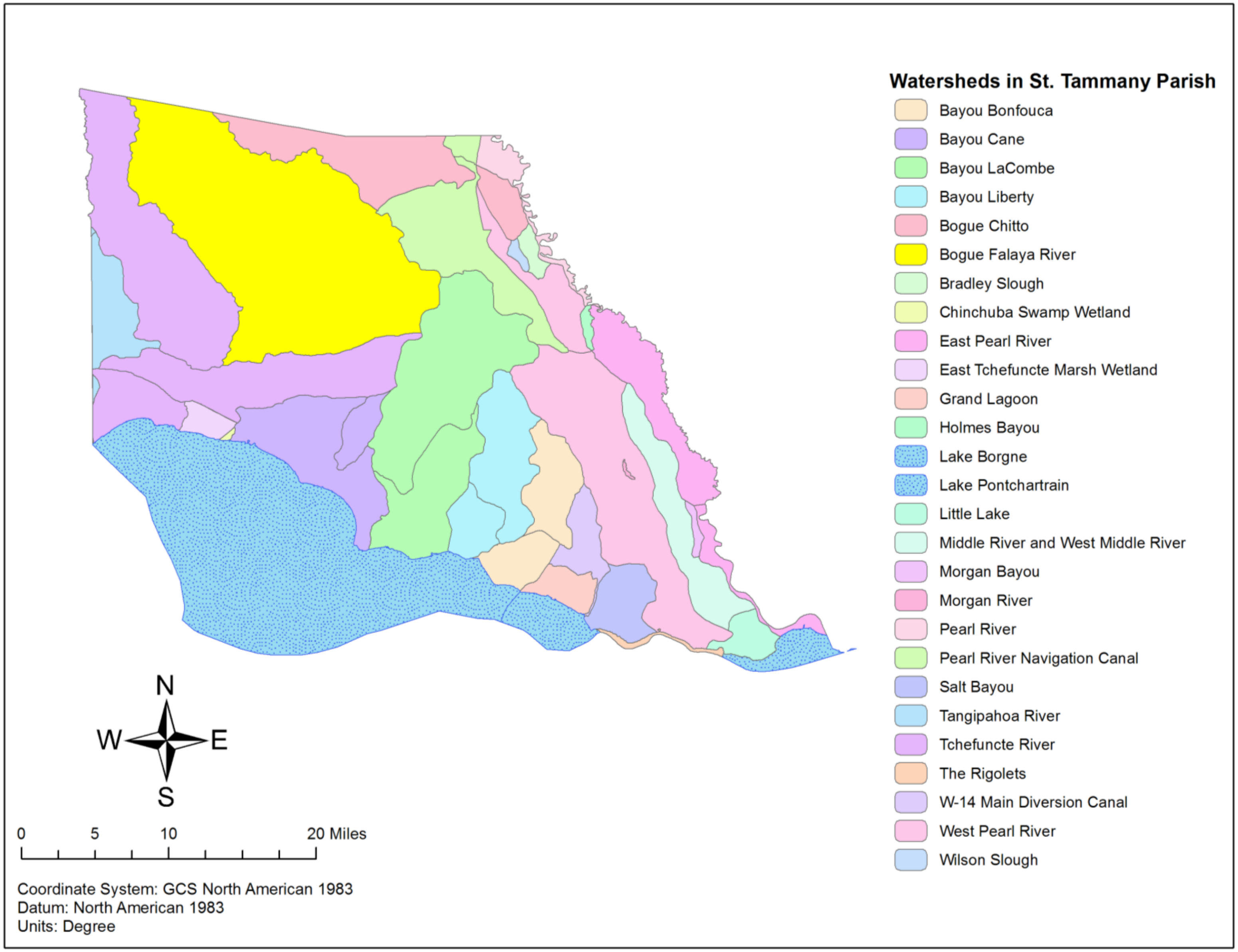


Figure 3.4 Watersheds in St. Tammany Parish.

3.4 The Study Area: Bogue Falaya River and Abita River Watersheds

The Tchefuncte River watershed (1,130 km^2, 436 mi^2) comprises much of western St. Tammany Parish and is within the Pontchartrain Management Basin. Within the watershed is the Tchefuncte River, measuring approximately 77 km (48 miles). The river defines parts of the western boundaries of St. Tammany and Washington Parishes. As the river flows south through St. Tammany Parish, it passes the City of Covington, the Town of Madisonville, and out into Lake Pontchartrain. The Tchefuncte River connects to its largest tributary, the Bogue Falaya River, at the southernmost point of the City of Covington. The Bogue Falaya River flows from the southwestern region of Washington Parish into St. Tammany Parish, past the Village of Folsom and joins its major tributary, the Abita River, shortly before merging into the Tchefuncte River.

The Bogue Falaya River is 54.15 km (34 miles) long and its watershed encompasses 349 km^2. Its two-year input flow ranges from 9,000-20,000 cubic feet per second (cfs). East of the City of Covington and joined by urban development is the Town of Abita Springs, on the Abita River. The Abita River is 33.7 km (21 miles) long and its watershed is 164 km^2, located within the larger Bogue Falaya 10-digit HUC watershed (Bourgeois-Calvin and Core 2012). The Abita River has a two-year input flow of 5,000 (cfs). Also to note, the Abita River is designated as a "Natural and Scenic River" by the Louisiana Legislature, which prohibits certain activities (channelization, clearing and snagging, channel realignment, reservoir construction, and commercial tree cutting within a 100 ft. buffer) in order to preserve the vitality of the water body (LWLF 2012).

The Bogue Falaya River watershed is delineated into four 12-digit HUC sub-watersheds: the Upper and Lower Bogue Falaya River, Little Bogue Falaya River, and Simalusa Creek

(USDA/NRCS 2008). The Abita River watershed contains the Abita River and English Branch 12-digit HUC sub-watersheds (Figure 3.5) (USDA/NRCS 2008).

3.5 Data and Methods

GIS allows users to view, understand, question, interpret, and visualize data in ways that reveal relationships, patterns, and trends in the form of maps, globes, reports, and charts (ESRI 2009). When applied to a watershed approach, GIS lends the opportunity to spatially reference, track, and manage sources of pollution. In this study, GIS processes were used to locate, quantify, and qualify point and nonpoint sources of pollution, including sewered and unsewered subdivisions, commercial/small business wastewater treatment plants, and individual home sewer systems and make spatial correlations to water quality within the Bogue Falaya River and Abita River watersheds.

This study also compared the results of statistical analyses of fecal coliform to mapped point and nonpoint source pollution in the Bogue Falaya River and Abita River watersheds. Spatial information, including point and nonpoint source data (commercial WWTPs, unsewered subdivisions, and individual home wastewater systems), water quality field data, raster imagery, and existing GIS data and newly created data layers (shapefiles produced by the LPBF) were used to produce mapped results for this project. The information produced by spatial analysis in conjunction with water quality data was used to target areas requiring water quality improvement.

3.5.1 Watershed and Sub-watershed Classification

To classify the Bogue Falaya River and Abita River watersheds, GIS base maps were created with the following layers: land/water, municipalities, streams, parish boundaries, roads, and 10 and 12-digit HUCs. These layers were accessed through the Louisiana State University GIS data-clearing house, *Atlas, The Louisiana Statewide GIS* (2008). Other layers including

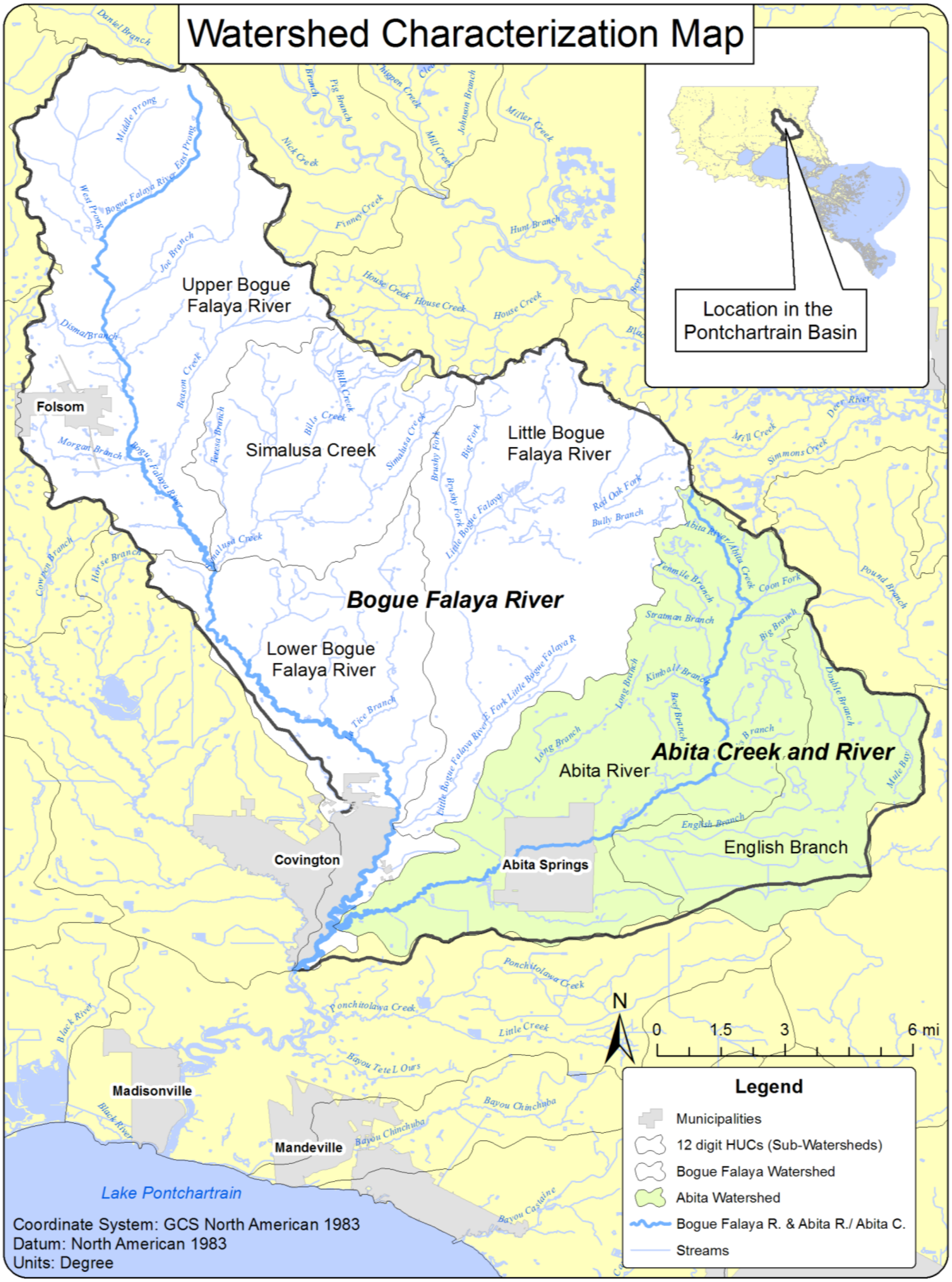


Figure 3.5 Bogue Falaya River and Abita River Watersheds with 12-Digit HUCs, Located in St. Tammany Parish, Louisiana, 2010.

local roads, HUCs, and census data were available through the LPBF's GIS databases, TIGER Census data files, and LDEQ's GIS Department. These maps were used to identify and characterize the specified study area. Metadata and a geodatabase were compiled to contain all base map information (Appendix B).

3.5.2 Land Use Classification

The study area's six 12-digit HUCs (English Branch, Lower Bogue Falaya, Abita, Little Bogue Falaya, Simalusa Creek, and Upper Bogue Falaya River) were overlaid onto the LDEQ land use layer. The following steps were used to calculate the percent land use for the Bogue Falaya River and Abita River watersheds:

1. The LDEQ 2007 land use raster shapefile was converted to a vector shapefile using the Raster to Polygon function (found under: ArcToolbox >Conversion Tools > From Raster).
2. The six 12-digit HUCs were extracted from the shapefile using the Clip function (found under: ArcToolbox >Analysis Tools >Extract).
3. The vector layer was added to the map and the land use values were displayed using the Symbology function in ArcMap. Area (in U.S. acres) was calculated for each 12-digit HUC by using the Calculate Geometry function (found under: Open Attribute Table >Right Click on Area Tab).
4. Any unwanted areas (Clouds and Lake Pontchartrain) were selected out and assigned a "null" value.
5. The area for each land use was calculated using the Select by Attribute function (found under: Attribute Table > Options) and the sum of the acres was displayed in the Statistics function.

6. The percentage of each land use class was calculated for the six 12-digit HUCs. The total acres of the Bogue Falaya River and Abita River watersheds were divided by each classified land use and the acreage, which was then multiplied by 100 (Appendix C).

The LPBF's combined classifications include: Wetlands (Wetlands Non-forested) in light green, Forest Land (Deciduous Forest Land, Evergreen Forest Land) in medium green, Forested Wetland in the darkest green, Developed Open Space (Transitional Areas, Urban or Built-up Land) in light pink, Low Density (Developed Low Density) in light red, Medium Density (Developed Medium Density) in red, High Density (Developed High Density) in maroon, and Agriculture (Pasture/Hay, Soybeans, Nurseries, Sugarcane, Corn) in beige. Water is represented in light blue and Gravel Pit/Strip Mine in yellow. The finalized map is shown in the Results Chapter, Figure 4.2.

3.5.3 Point Source Classification

GIS was used to create a comprehensive map containing fecal pollution sources, both point and nonpoint, in the Bogue Falaya River and Abita River watersheds. LDEQ/Office of Environmental Compliance (OEC)/Surveillance Division supplied LPBF with an Excel database containing permitted wastewater treatment plants within St. Tammany Parish in 2009. A second list was given to LPBF in 2011 that included plant size classifications. LPBF combined the 2009 and 2011 list by using LDEQs unique identification number, which is called an Agency Interest (AI) number. Both the 2009 and 2011 lists included small business/commercial WWTPs, subdivision/small community WWTPs, and larger Regional/Municipal plants. Most of the address information was incomplete and there were few GPS coordinates existing for mapping purposes. Addresses that were complete were geocoded using a website called *GPS Visualizer (http://www.gpsvisualizer.com/)*. LPBF staff went into the field to locate facilities to complete address and coordinate information for the remaining WWTPs. The WWTP database was populated with GPS coordinates (decimal degrees) and completed address information. The coordinates were mapped to acquire an accurate geographic representation of all WWTPs located within the study area. Subsets of these coordinates were selected randomly and ground-truthed using a GARMIN eTrex Legend HCx handheld (Wide Area Augmentation System-WAAS, <10 meter accuracy). WWTPs from the 2011 list were also mapped according to plant size. The finalized map is shown in the Results Chapter, Figure 4.3.

3.5.4 Subdivision Classification

Another common source of urban pollution is improperly sited, designed, and maintained home wastewater treatment systems. A second database was created with all subdivision locations within the study area. LPBF used the St. Tammany Parish Government website to find a list of subdivisions and utility provider information, *Sewerage and Water Providers by Subdivision,* 2010. The subdivision and sewer data were used in combination with a subdivision shapefile layer acquired from the St. Tammany Parish Department of Geographic Information Services to produce a map illustrating which subdivisions had community sewerage versus those in which homes were on individual sewer/septic systems. More subdivisions were discovered in a local atlas; *The Complete Maps of St. Tammany Parish, 4th Ed (2009),* and these subdivisions were also included within the map layer (Appendix D). The finalized map is shown in the Results Chapter, Figure 4.4.

3.5.5 Home Wastewater System Classification

The LPBF was provided access to the St. Tammany Parish Communication District's 911 home address data. The individual home addresses were extracted from a GIS shapefile point layer, which included all structures within the parish. The structures fell into two classifications, “residential” and “business.” This study focused on the individual home systems; therefore, only the classifications labeled “homes”, “mobile homes”, and “verify” were selected to create a new shapefile point layer. The “verify” layer consisted of structures that the St. Tammany Parish Communication District has not yet verified for final classification. To utilize this unverified information, the LPBF randomly selected several points from the both the “homes” and “verify” layers and compared the locations to high-resolution 2009 aerial imagery produced by ESRI to verify that homes existed in those locations. Although there were very few mobile homes located in the watershed, these were also compared to the imagery for verification. The LPBF did take into account the notion that some commercial businesses might be mixed in with individual home systems within the study area. This potential impact is further clarified in the Results Chapter, Section 4.4.

The home address point layer was imported into ArcMap. ArcMap tools were used to remove all points that were located within sewered subdivisions and municipal boundaries. This procedure ensured the exclusion of all home systems that are considered to be on community/regional sewer service. The resulting point layer was overlaid onto a map of the Bogue Falaya River and Abita River watersheds, which is shown in the Results Chapter, Figure 4.5.

3.5.6 Water Quality Classification

Water quality defines the chemical, physical, and biological components of water and is referenced by a set of standards used to protect human uses as well as ecological health of water bodies. An integral component of the WPP is to track and monitor pollution sources within the Bogue Falaya River and Abita River watersheds. Water quality monitoring is a crucial component to accomplish that task. According to LDEQ’s Nonpoint Source Program:

> Nonpoint source pollution is a type of water pollution that is not generated from a discrete conveyance, such as a discharge pipe, but is generated during rainfall events. Section 319 of the Clean Water Act (CWA) required that the states develop a NPS Management Plan to reduce and control nonpoint sources of pollution from the various types of land-uses that contribute to water quality problems across the United States. Some of these categories can also be defined as point source discharges and may require a storm water permit. Louisiana determined that agriculture, forestry, urban runoff, home sewage systems, sand and gravel mining, construction and hydromodification all contribute to nonpoint source pollution problems across the state. Nonpoint source pollution is the largest remaining type of water pollution that needs to be addressed within Louisiana and across the nation in order to restore the designated uses (i.e. fishing and swimming) to the impaired water bodies (LDEQ 2012).

LPBF started monitoring water quality on the north shore of Lake Pontchartrain in several sub-watersheds in 2002 to investigate significantly high fecal coliform counts. The LPBF has continued monitoring in the Bogue Falaya River watershed and started monitoring in the Abita River watershed in 2010. The LPBF selected 10 sample sites (BFAB1-BFAB10) along the Bogue Falaya and Abita Rivers and their major tributaries (Figure 3.6). BFAB1-6 was located within the Bogue Falaya River watershed and sites BFAB7-10 in the Abita River watershed. Coordinates for each site were obtained via Google Earth and then ground-truthed using the GARMIN eTrex Legend HCx handheld. Coordinates (decimal degrees) were used to map the sample site point layer in ArcMap 10. Water quality data were collected (33 samples at each of the 10 sites) from September 2010 through December 2011.

Statistical analyses on the water quality data provided spatial indicators of water quality within the watersheds. Tributaries were monitored bi-weekly (by car); water quality parameters monitored included water temperature, dissolved oxygen, specific conductance (a proxy for the presence of saltwater, because on a YSI 85 handheld salinity, conductivity, dissolved oxygen, and temperature system salinity is calculated from specific conductance), turbidity, fecal coliform, *E. coli*, and a suite of nutrients (See Appendix E). All data were collected using

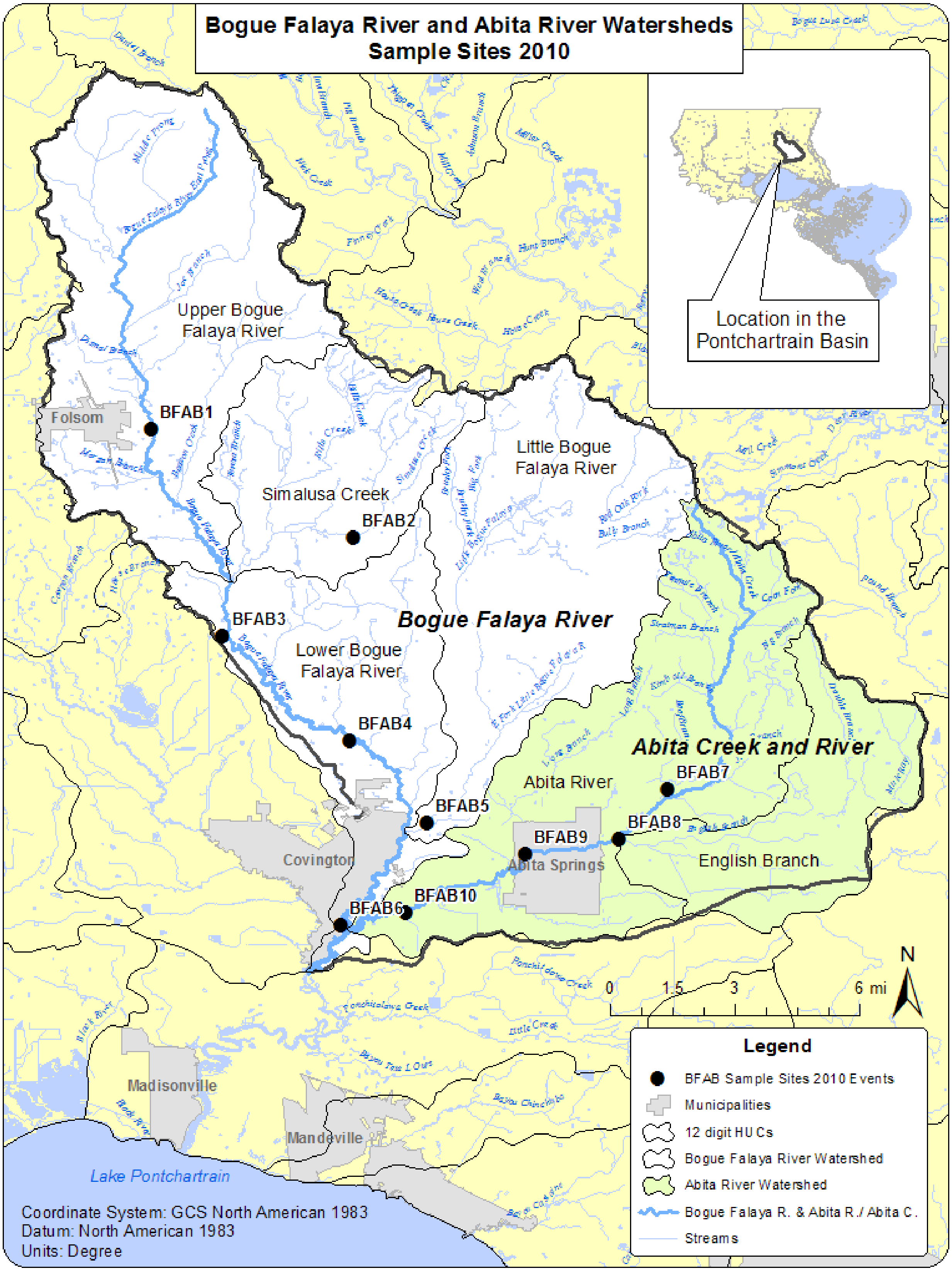


Figure 3.6 Water Quality Sample Sites.

standard methods as found in the American Public Health Association's (APHA), *Standard Methods for the Examination of Water and Wastewater, 20th Edition*, 1998.

3.6 Correlation of Water Quality and Sources

Two non-parametric statistical methods were used to find 1) correlations among the water quality parameters, and 2) variations among sample sites to reveal sources of pollution within the Bogue Falaya River and Abita River watersheds. Because water quality data are not normally distributed and variables take on extreme values (U.S. EPA 2012d), the two types of non-parametric statistical methods used for this study were Spearman's rank correlation coefficient (Spearman's rho), and the Kruskal–Wallis one-way analysis of variance.

According to the Handbook of Biological Statistics, Spearman's rho is used when there are two measured variables, including at least one nominal value. This method shows whether two variables "covary," meaning, "…as one variable increases, the other variable tends to increase or decrease" (McDonald 2009). For this study, dissolved oxygen, specific conductance, turbidity, and fecal coliform were compared in pair-wise correlations for each site (Appendix F). The second method, the Kruskal–Wallis one-way analysis of variance, was used to compare more than two populations that are independent, or not related. The Kruskal–Wallis method showed the differences in fecal coliform counts, dissolved oxygen, specific conductance, and turbidity among the ten sample locations and determined whether any were significantly different (Appendix F).

A box and whisker plot graphically displays metrics that include median, variability of the data around the median, skew of the data, range of the data, and size of the data set (Figure 3.7). For this study, box and whisker plots from a one-way analysis by site were produced for fecal coliform, dissolved oxygen, specific conductance and turbidity (Section *4.5.1*).

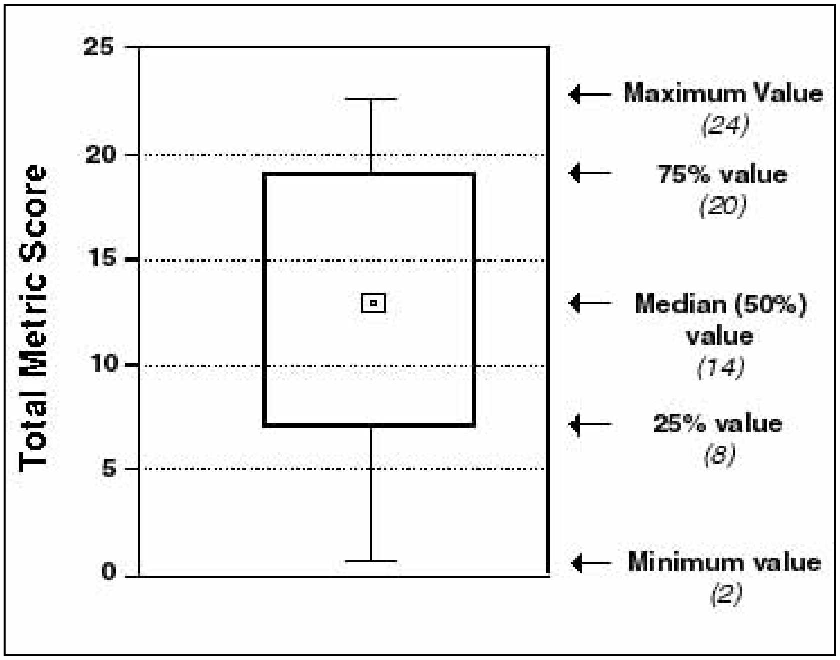


Figure 3.7 Example of a Box Plot (U.S. EPA 2012d).

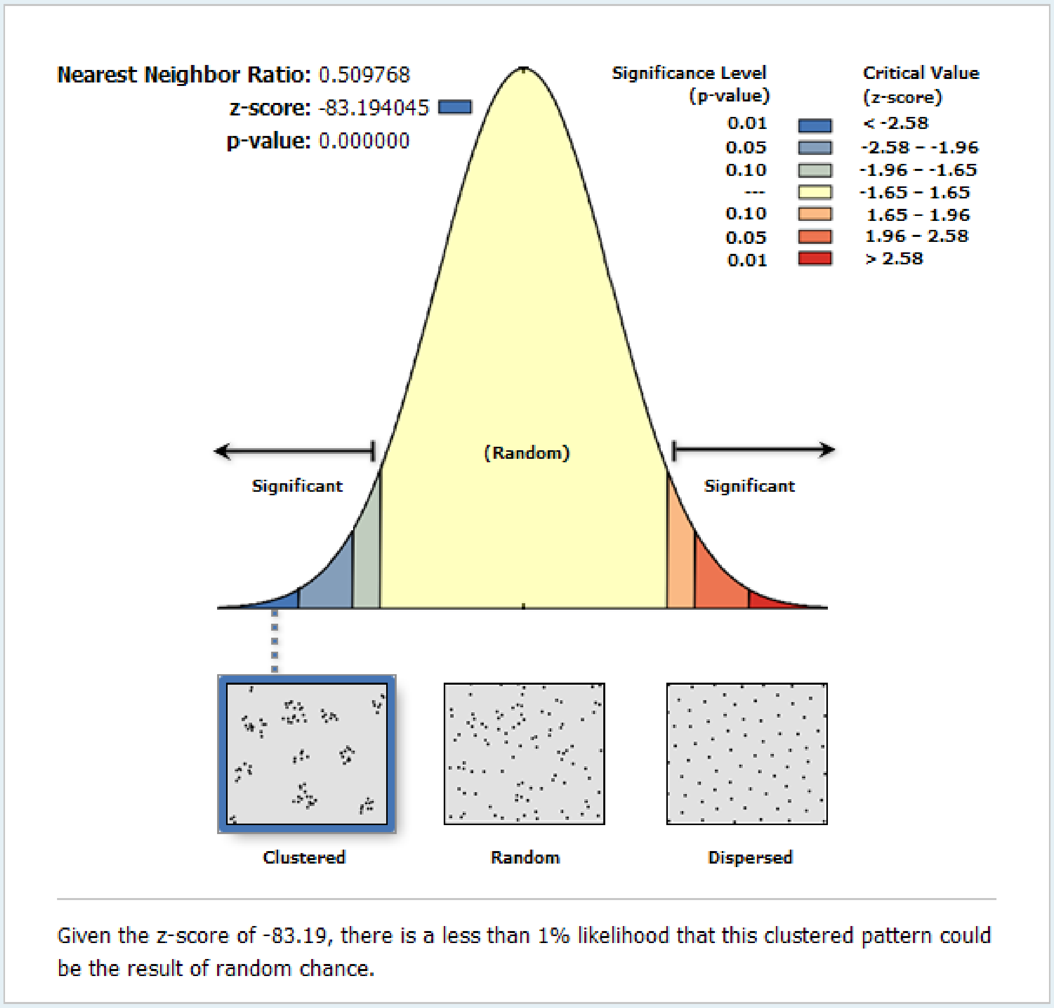
3.7 Density Analysis

Using the Kernel Density tool found in the ArcGIS Spatial Analyst toolbox density toolset, density surfaces for both individual home sewer systems and WWTPs within the study area were identified. The method was used to create a smooth, curved density surface that is fitted over each point. The sum of intersecting spreads was calculated for each output raster cell. Density surface values were greatest at each point location and diminished to zero at specified search radii. “The kernel function is based on the quadratic kernel function described in Silverman (1986, p. 76, equation 4.5)” (ESRI 2011a).

The search radius distance for the kernel density analysis was calculated using the Average Nearest Neighbor tool found in the ArcGIS Spatial Statistics toolbox, Analyzing Patterns. The Average Nearest Neighbor function “[c]alculates a nearest neighbor index based on the average distance from each feature to its nearest neighboring feature” (ESRI 2011b). Results from the nearest neighbor test for the individual home systems point layer are shown in

Figure 3.8. The individual home system layer is highly clustered and has an expected mean distance between points of approximately 500 feet and an observed mean distance of approximately 260 feet. The results of the nearest neighbor analysis for the WWTP are shown in Figure 3.9. The WWTP point layer is also clustered and has an expected mean distance of approximately 2,400 ft. and an observed mean distance of approximately 1,190 ft. The nearest neighbor averages for both point layers were used as a valid starting point to define the kernel density search radius. After running several kernel density analyses with search radii between 500 ft. and 1,000 ft., 750 ft. was deemed to have the optimal density surface for the individual home systems and WWTPs, shown in the Results Chapter, Section 4.6. The output cell size was set to 100 ft. for the density surfaces.

Average Nearest Neighbor Summary



Average Nearest Neighbor Summary

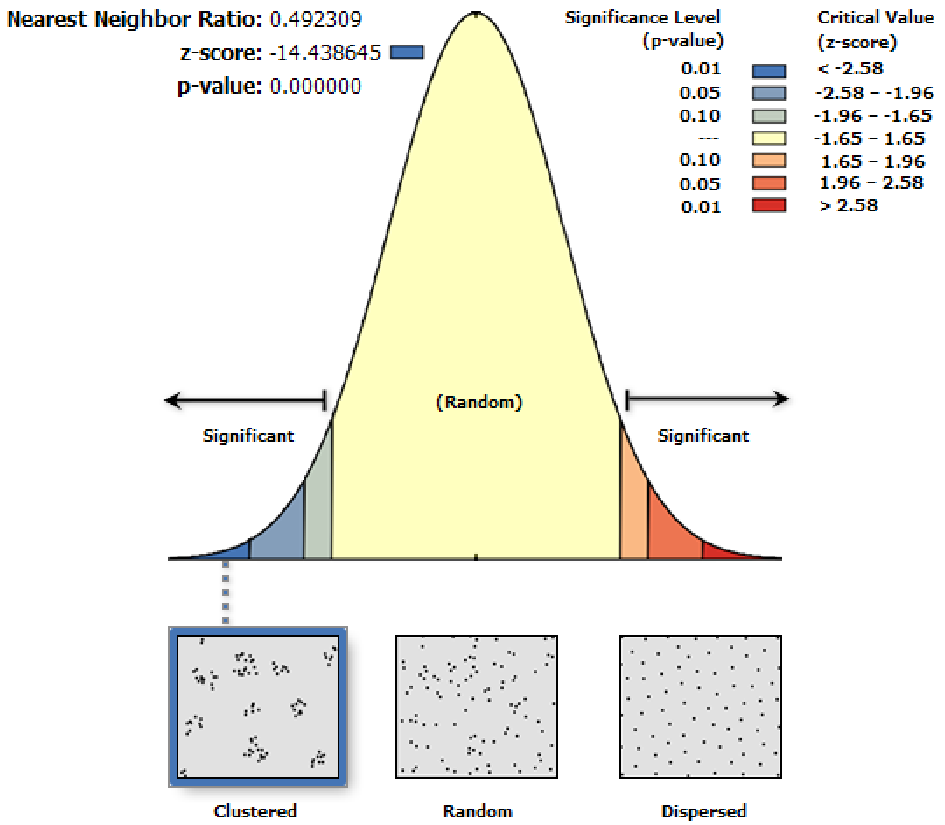
Observed Mean Distance:	260.546481
Expected Mean Distance:	511.107875
Nearest Neighbor Ratio:	0.509768
z-score:	-83.194045
p-value:	0.000000

Dataset Information

Input Feature Class:	Individual Home Systems
Distance Method:	EUCLIDEAN
Study Area:	8222515136.871190

Figure 3.8 Results from Individual Home Systems Average Nearest Neighbor Analysis.

Average Nearest Neighbor Summary



Given the z-score of -14.44, there is a less than 1% likelihood that this clustered pattern could be the result of random chance.

Average Nearest Neighbor Summary

Observed Mean Distance:	1187.474640
Expected Mean Distance:	2412.051172
Nearest Neighbor Ratio:	0.492309
z-score:	-14.438645
p-value:	0.000000

Dataset Information

Input Feature Class:	WWTP's (projected in feet)
Distance Method:	EUCLIDEAN
Study Area:	5143103916.408524

Figure 3.9 Results from WWTPs Average Nearest Neighbor Analysis.

CHAPTER 4: RESULTS

4.1 Land Use Classification

Percentages were calculated for the LPBF land use classifications in Figure 4.1. At 53 percent, the majority of the land use for the study area was considered Forest Land (Evergreen Forest Land). The next largest classification in the watersheds was Agricultural Lands, accounting for 25 percent of the total area. A collective 17 percent of the area was Deciduous Forests and Forested Wetlands. Developed areas (Low, Medium, and High Density) combined for 5 percent of the area.

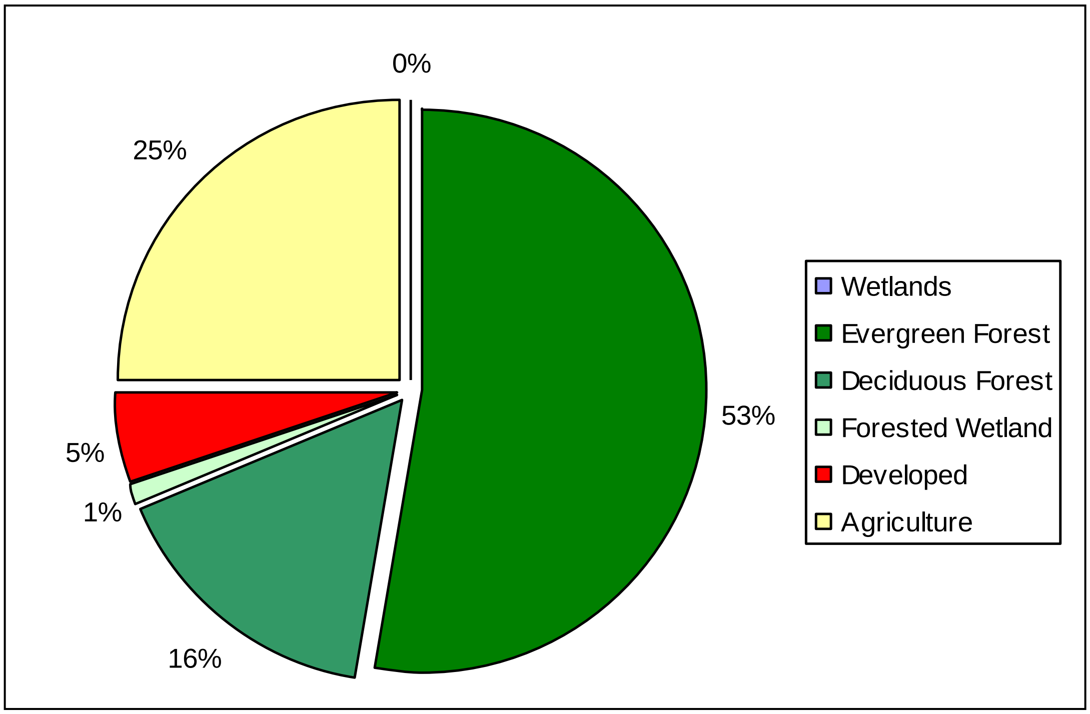


Figure 4.1 Land use Break-Down in Bogue Falaya River and Abita River Watersheds (Bourgeois-Calvin and Core 2012).

Table 4.1 illustrates each of the six 12-digit HUCs broken down by land use percentages. The land use for each 12-digit HUC within the study area was predominantly Forest Land followed by Agriculture. In Table 4.1, the percentages highlighted in yellow represent the urban components within the sub-watersheds. The highest percentages were in the Lower Bogue

Falaya River sub-watershed containing 12 percent and the Abita River sub-watershed containing 11 percent**.**

Table 4.1 Land use Break-Down in the six 12-Digit HUCs within the Bogue Falaya River and Abita River Watersheds (Bourgeois-Calvin and Core 2012).

Classes	**English Branch**	**Lower Bogue**	**Abita**	**Little Bogue**	**Simalusa Creek**	**Upper Bogue**
Wetlands	0	0	0	0	0	0
Forest Land	87%	64%	75%	58%	47%	75%
Forested Wetland	4%	1%	2%	1%	0	1%
Developed Open	1%	8%	8%	2%	2%	1%
Low Density	0	2%	2%	0	0	0
Med Density	0	2%	1%	0	0	0
High Density	0	0	0	0	0	0
Agriculture	8%	22%	12%	39%	51%	23%
Total acreage	11,992	11,376	21,145	13,937	13,303	30,027

Figure 4.2 shows the land use map for the Bogue Falaya River and Abita River watersheds. The upstream portions of both watersheds contain the majority of agricultural and forested land. The downstream portion of the watersheds, where the Bogue Falaya River converges with the Abita River near the City of Covington, shows more areas of urban development.

4.2 Point Source Classification

There are numerous point sources located within the Bogue Falaya River and Abita River watersheds. Most of these sources are small, commercial WWTPs that discharge into the local waterways. Based on data collected from LDEQ/OEC/Surveillance Division and the LPBF, there are 221 commercial wastewater facilities that discharge into waters of the state located within the Bogue Falaya River and Abita River watersheds. A total of 86 fall within the Abita River watershed and 135 are within the Bogue Falaya River watershed (Figure 4.3). Most of these facilities have a Louisiana Pollutant Discharge Elimination System (LPDES) permit and are considered small systems that discharge 25,000 gallons per day (gpd) or less. Table 4.2

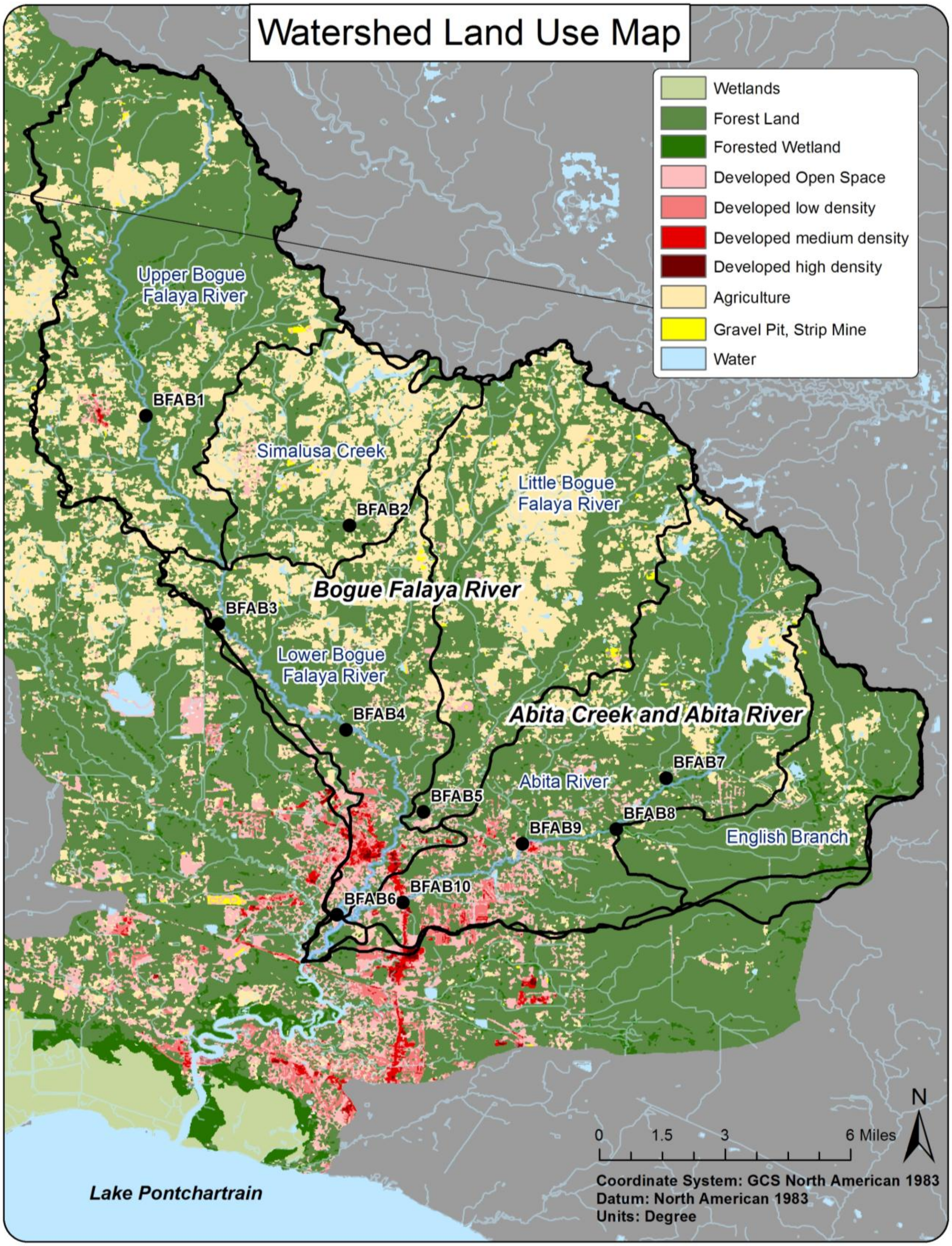


Figure 4.2 Land use in the Bogue Falaya River and Abita River Watersheds (Bourgeois-Calvin and Core 2012).

shows the breakdown of plant size by sub-watershed. Highlighted in yellow are the highest totals, which fall in the Lower Bogue Falaya River and Abita River sub-watersheds.

Table 4.2 LDEQ Plant Size Classifications in the six 12-Digit HUCs within the Bogue Falaya River and Abita River Watersheds.

Gallons per Day (GPD)	**English Branch**	**Lower Bogue**	**Abita**	**Little Bogue**	**Simalusa Creek**	**Upper Bogue**
Sanitary Class I (< 5000)	1	66	42	5	2	2
Sanitary Class II (< 25,000)	0	2	3	2	0	0
Sanitary Class III (< 50,000)	0	0	0	0	0	0
Sanitary Class IV (< 100,000)	0	6	1	1	1	0
Minor Sanitary (<1,000,000)	0	1	6	0	0	2
Major Sanitary (1,000,000)	0	0	1	0	0	0
No Class Info.	2	33	30	6	0	6
Total	3	108	83	14	3	10

Two municipal WWTPs and one regional plant have discharges located within the watersheds. The municipal plants include the Town of Abita Springs (design capacity of 0.4 MGD, million gallons per day) and the Village of Folsom (design capacity of 0.4 MGD). According to reports filed by LDEQ, the Village of Folsom plant is in good working order but the facility in the Town of Abita Springs is operating poorly and needs to be replaced. Both municipalities are aging and have outdated infrastructure; however, all municipal WWTPs within the study area have had funded upgrades to treatment and collection systems.

Regional WWTPs are larger systems for wastewater collection and treatment. The regional treatment facility, Arrowwood (design capacity of 2 MGD), is operating well and takes in some unincorporated communities and subdivisions near the Town of Abita Springs. Based

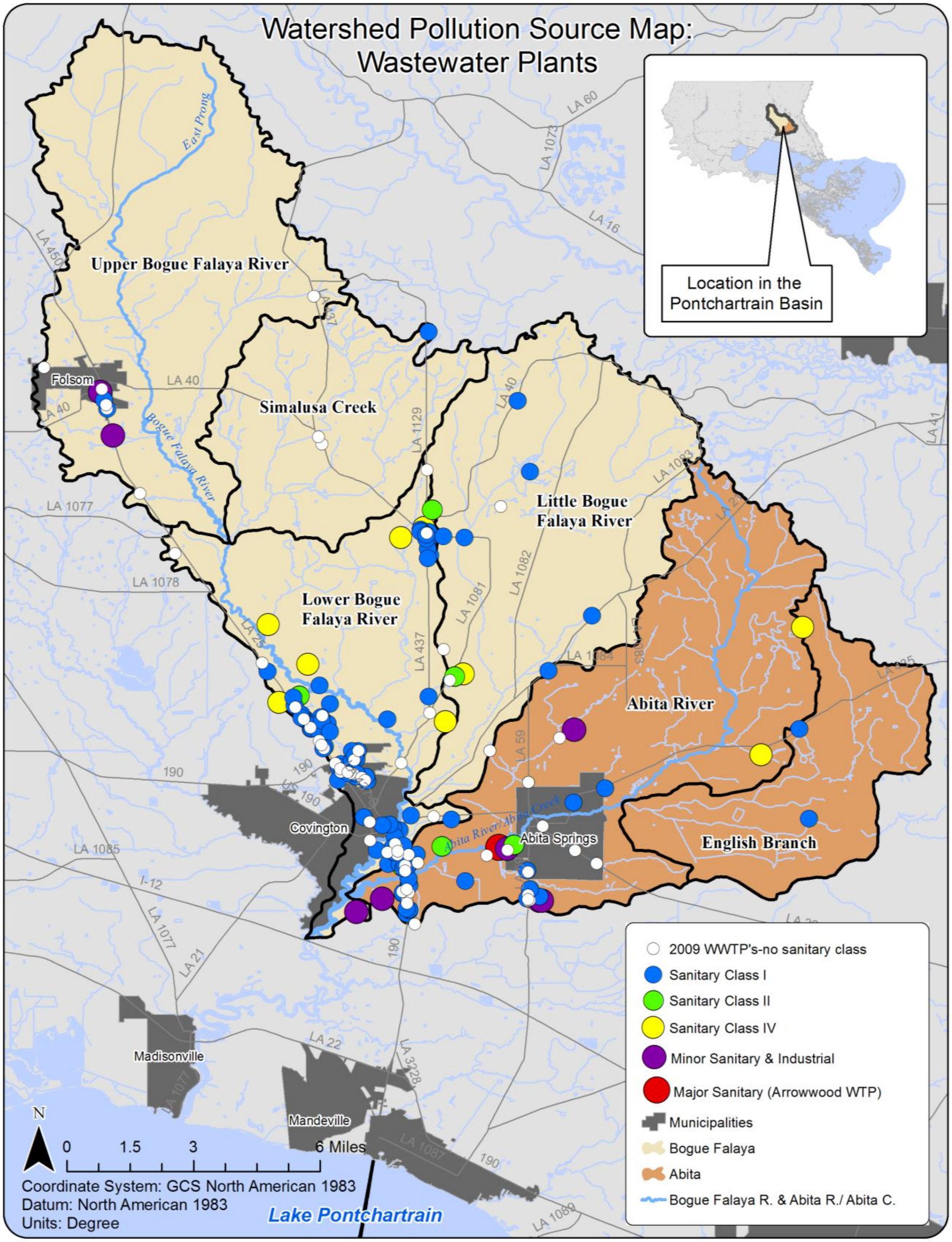


Figure 4.3 Wastewater Treatment Plants in the Bogue Falaya and Abita River Watersheds.

on the recent acquisition of the Sewer District 6 facility, the Arrowwood plant is projected to process 2.3 MGD (Bourgeois-Calvin and Core 2012) (Red dot on Figure 4.3).

4.3 Subdivision Classification

Based on several subdivision source lists compiled by the LPBF, within the study area there were a total of 114 subdivisions. Of that total, 94 (82.5 percent) were on individual home wastewater treatment systems (aka unsewered or individually sewered) and 20 (17.5 percent) have a sewer service provider. The Abita River watershed had the majority of the subdivisions, containing 76 (66 percent of the total). Of the Abita subdivisions, 14 (18.4 percent) had a sewer service provider and 62 (81.6 percent) were on individual home treatment. The remaining subdivisions were spread out in the larger Bogue Falaya River watershed, accounting for 38 (33.3 percent of the total). Only 6 (15.8 percent) of those subdivisions had a sewer provider and the remaining 32 (84.2 percent) were individually sewered (Figure 4.4, Appendix D).

ArcMap tools were used to count the sewered and unsewered subdivisions in each 12-digit HUC. Numbers were given instead of percentages because some subdivisions fell within multiple HUCs. Table 4.3 shows that the Abita River sub-watershed had the majority of both sewered (16) and unsewered (39) subdivisions. The Lower and Little Bogue Falaya River watersheds also had high numbers of unsewered subdivisions, (34) and (24) respectively.

Table 4.3 Sewered and Unsewered Subdivisions in Each Six 12-Digit HUCs within the Study Area.

	English Branch	Lower Bogue	Abita River	Little Bogue	Simalusa Creek	Upper Bogue
Sewered	1	5	16	2	0	0
Unsewered	6	34	39	24	9	7

4.4 Home Wastewater System Classification

Within the study area, the number of individual treatment systems was estimated using St. Tammany Parish Emergency 911 home address data. Based on these data, the LPBF estimated

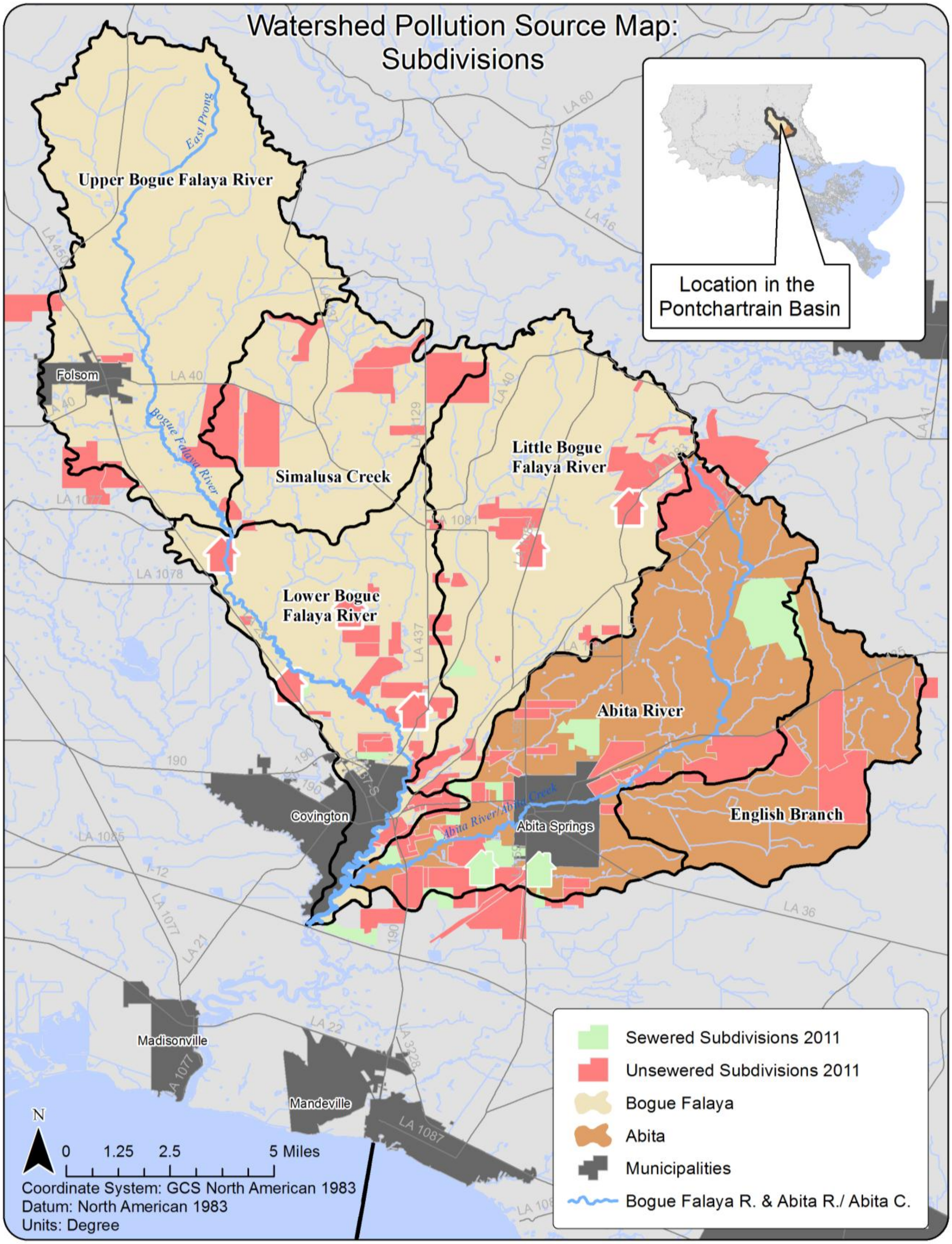


Figure 4.4 Subdivisions within the Bogue Falaya and Abita River Watersheds.

that there were a total of 7,869 structures (excluding municipalities and subdivisions with provided sewer service) located within the study area. Of these, 3,593 fell within subdivisions that were defined as having individual sewer treatment. The remaining 4,276 structures were located outside of any subdivision or municipal boundary. The Abita River watershed contained 2,897 of the 7,869 structures and the Bogue Falaya River watershed had the remaining 4,972 structures within its boundaries (Figure 4.5). The Lower Bogue Falaya River and Abita River 12-digit HUCs had the greatest number of individual home systems. The breakdown of structures in each of the six 12-digit HUC is listed in Table 4.4.

Table 4.4 Breakdown of Individual Home Treatment Systems in the Six 12-Digit HUCs within the Bogue Falaya River and Abita River Watersheds.

	English Branch	Lower Bogue	Abita River	Little Bogue	Simalusa Creek	Upper Bogue
# of home systems	168	1,852	2,729	1,614	646	860

Because all address locations in the address point layer were not verified, an adjustment to the estimate must be made to account for commercial systems mixed in with the individual home systems. A model from the St. Tammany Parish Tchefuncte and Bogue Falaya Implementation Project (2007) utilized census records to estimate the number of home sewer treatment plants in the Bogue Falaya and Abita River watersheds to be approximately 7,200. Therefore, the LPBF implemented an 8 percent adjustment for unverified commercial systems located within the individual home system point layer, resulting in approximately 7,200 individual home systems. The St. Tammany project also estimated the average number of people per household and total persons on failed home systems. Assuming a 50 percent failure rate as utilized by the St. Tammany Parish Water Quality Model Report, approximately 3,600 homes would be on failed systems within the study area.

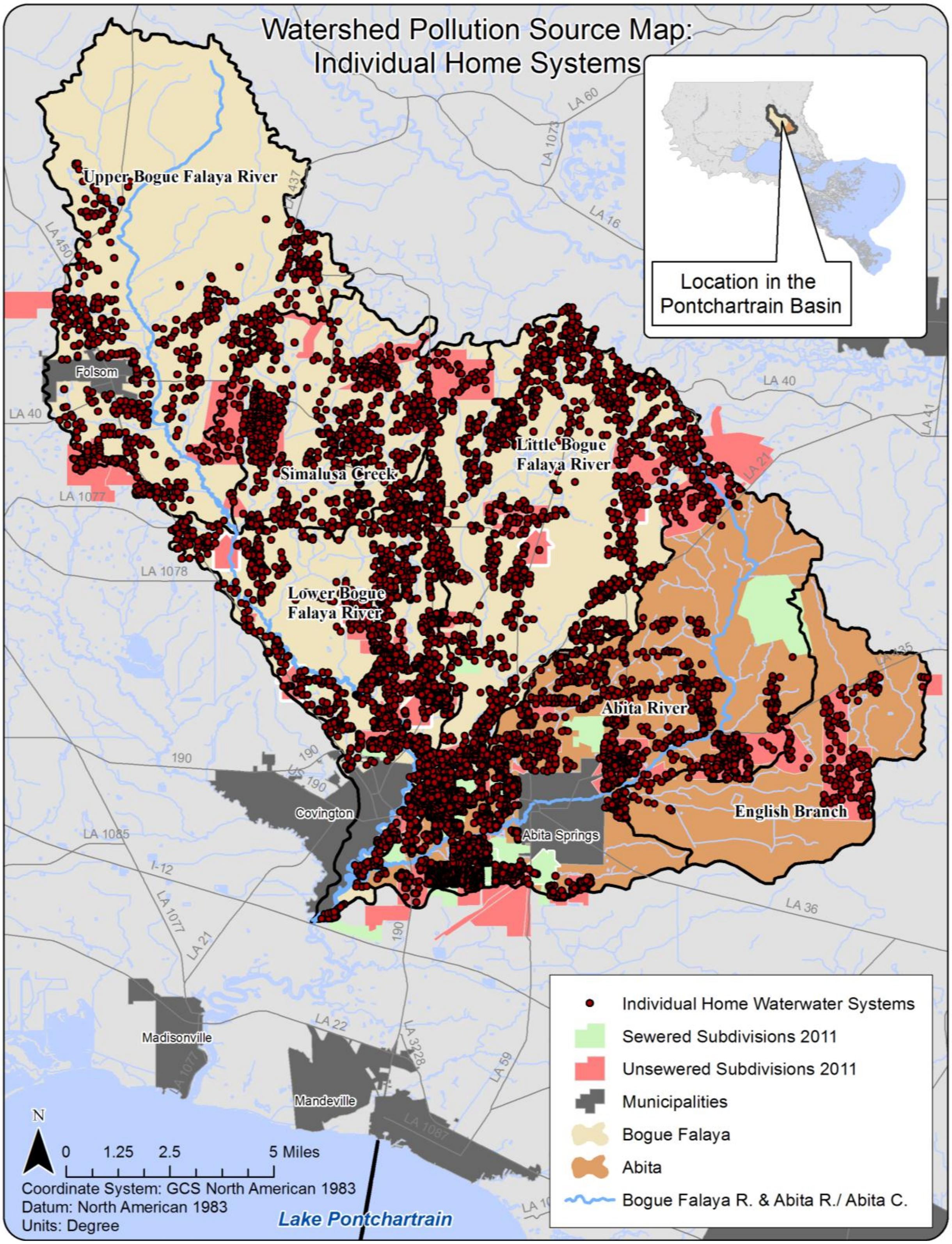


Figure 4.5 Homes on Individual Treatment Systems in the Bogue Falaya and Abita Watersheds.

4.5 Water Quality Analysis and Classification

Within the Bogue Falaya and Abita River watersheds, water quality samples were taken bi-weekly for 16 months at ten sample site locations (See Figure 3.6). Over that period, 33 samples were collected at each of the ten sample sites. Sample sites BFAB 1-6 were located in the Bogue Falaya River watershed, and sites BFAB7-10 fell within the Abita River watershed (separation shown by a solid blue line in Figures 4.6, 4.9, 4.10, and 4.11).

4.5.1 Non-Parametric Statistical Correlations

Because salty water has higher conductance than fresh water, specific conductance was measured to determine the degree to which salty water was intruding tidally upstream from Lake Pontchartrain. Specific conductance (measured in microSiemens per centimeter- $\mu S\text{-}cm^{-1}$) analyses indicated that BFAB6 (outlier points) and BFAB10 appeared to be tidally influenced by Lake Pontchartrain (Figure 4.6). Also, sites BFAB6 and BFAB10 showed both significant and negative correlations (using the Spearman’s rho method) between turbidity and specific conductance (Table 4.5a and 4.5b respectively). In general, specific conductance was slightly higher in the Abita River watershed, the lower and more tidally influenced portion of the study area (Figure 4.6). Tidal inflow is illustrated in Figure 4.7, the salty water causes the turbidity to be flushed out or fall out of the water column (Waterwatch 2007).

BFAB9 had significantly greater fecal coliform concentration than any other sample site except for BFAB5 (Figure 4.9, Kruskal-Wallis, Prob>ChiSq = <0.0001, full analysis shown in Appendix F). More than 25 percent of the samples taken at BFAB9 were above the Louisiana state standard for a single sample (400 MPN/100mL water). Results also showed that even though BFAB10 (the downstream-most site on the Abita River, Figure 4.8) met the state standard for fecal coliform (Figure 4.9), there was a significant and positive correlation between fecal coliform and turbidity (Table 4.5b). It is also important to mention that BFAB9 is sited within an urban area, the Town of Abita Springs, but is not tidally influenced by Lake Pontchartrain, as BFAB6 and BFAB10 are. BFAB9 showed an increase in fecal coliform and was significantly greater than fecal counts for BFAB7 (upstream of BFAB9) (Kruskal Wallis, p-value = 0.0110, full results shown in Appendix F).

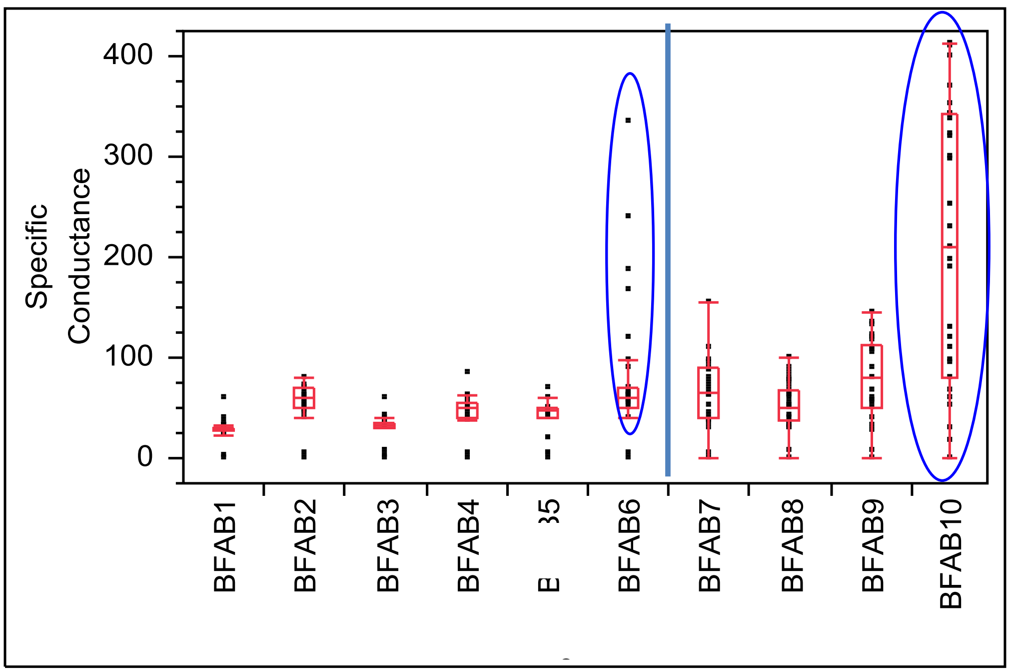


Figure 4.6 One-way Analysis of Specific Conductance by Site, (μS-cm^{-1}).

BFAB5 had significantly greater fecal coliform concentration than all other sites with the exception of site BFAB9. 75 percent of the samples for BFAB5 were slightly under the state standard. BFAB6 (the downstream-most site on the Bogue Falaya River, Figure 4.8) met the state standard for fecal coliform (Figure 4.9), but again this site is tidally influenced, as is BFAB10. The location of site BFAB5 is nearest the urban area of the City of Covington, but is not tidally influenced by Lake Pontchartrain. Sites upstream of urban areas showed similar low fecal coliform levels. Figure 4.2 shows that sites BFAB 1-3 are upstream of urban areas (the

City of Covington and the Town of Abita Springs) and all had similar low fecal coliform counts (Figure 4.9).

Overall, the Abita River watershed sites, BFAB 7-10 were at and below the state standard for dissolved oxygen (5mg/L). In the Bogue Falaya watershed, only BFAB2 was low in dissolved oxygen (Figure 4.10). Also, the Abita River watershed sample sites were generally significantly higher in turbidity (measured in NTU-nephelometric turbidity units) than those in the Bogue Falaya River watershed (Kruskal-Wallis, Prob>ChiSq = <0.0001, Figure 4.11, full results shown in Appendix F).

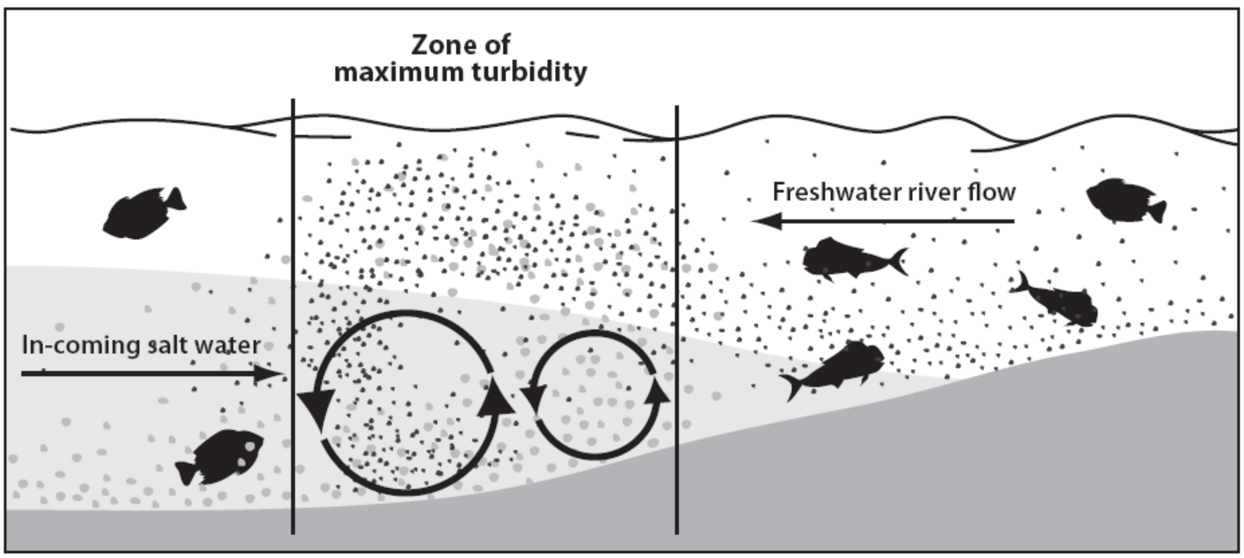


Figure 4.7 Turbidity Zones (Adapted from Waterwatch Australia National Technical Manual 2007).

Table 4.5a Results of Sperman's rho (Spear ρ, Prob>|ρ|) for Variable by Variable (Specific Conductance-SC, Dissolved Oxygen-DO, Turbidity-T, and Fecal Coliform-FC) Correlations for the Six Sample Sites in the Bogue Falaya River Watershed. Significant Results are Highlighted Starred.

		BFAB1		**BFAB2**		**BFAB3**		**BFAB4**		**BFAB5**		**BFAB6**	
Variables		**Spear ρ**	**Prob>|ρ|**	**Spear ρ**	**Prob>|ρ|**	**Spear ρ**	**Prob>|ρ|**	**Spear ρ**	**Prob>|ρ|**	**Spear ρ**	**Prob>|ρ|**	**Spear ρ**	**Prob>|ρ|**
SC	DO	0.0566	0.7544	-0.2052	0.2519	-0.3791	0.0296*	-0.0965	0.5932	-0.0883	0.6249	-0.1067	0.5544
T	DO	-0.1534	0.394	0.0182	0.9199	-0.0503	0.7809	-0.096	0.5953	-0.0336	0.8527	-0.048	0.791
T	SC	0.4961	0.0033*	0.2336	0.1908	0.5287	0.0016*	0.0393	0.828	-0.2707	0.1276	-0.6682	<.0001*
FC	DO	-0.1134	0.5299	0.2372	0.1839	0.025	0.89	0.1498	0.4053	-0.3512	0.0451*	-0.3907	0.0246*
FC	SC	-0.1467	0.4153	-0.1591	0.3765	0.0263	0.8844	0.1773	0.3235	0.0941	0.6026	-0.0092	0.9595
FC	T	0.0737	0.6837	-0.0667	0.7123	0.4338	0.0117*	0.3033	0.0862	0.1233	0.4941	-0.0187	0.9178

Table 4.5b Results of Sperman's rho (Spear ρ, Prob>|ρ|) for Variable by Variable (Specific Conductance-SC, Dissolved Oxygen-DO, Turbidity-T, and Fecal Coliform-FC) Correlations for the Four Sample Sites in the Abita River Watershed. Significant Results are Highlighted and Starred.

		BFAB7		**BFAB8**		**BFAB9**		**BFAB10**	
Variables		**Spear ρ**	**Prob>|ρ|**	**Spear ρ**	**Prob>|ρ|**	**Spear ρ**	**Prob>|ρ|**	**Spear ρ**	**Prob>|ρ|**
SC	DO	-0.314	0.0752	-0.4272	0.0132*	-0.1603	0.3729	-0.2125	0.2596
T	DO	0.0037	0.9838	-0.3204	0.0691	-0.0119	0.9477	0.2768	0.1386
T	SC	0.2194	0.22	0.5882	0.0003*	0.5036	0.0028*	-0.4337	0.0167*
FC	DO	0.3014	0.0882	-0.0647	0.7205	0.0475	0.7929	0.0993	0.595
FC	SC	-0.0881	0.626	0.041	0.8206	0.3264	0.0638	-0.0497	0.7907
FC	T	-0.0833	0.645	-0.0239	0.895	0.2923	0.0988	0.5123	0.0032*

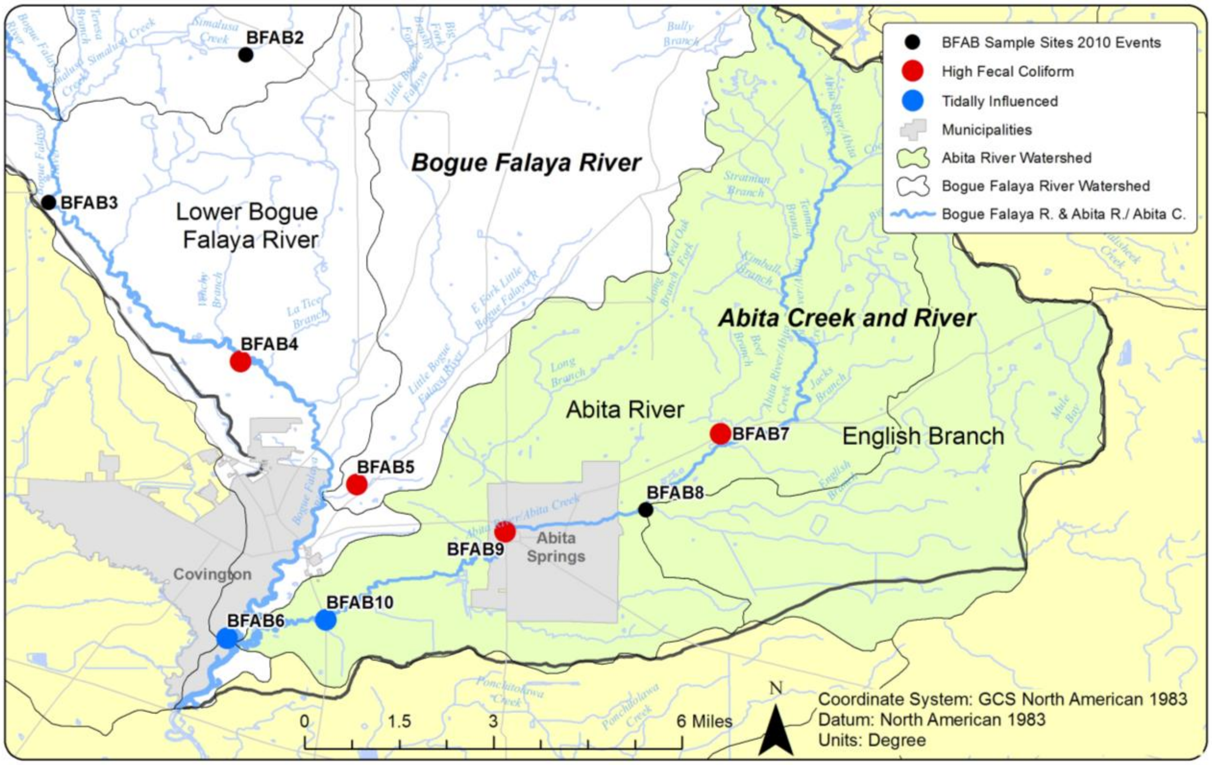


Figure 4.8 Water Quality Sample Sites.

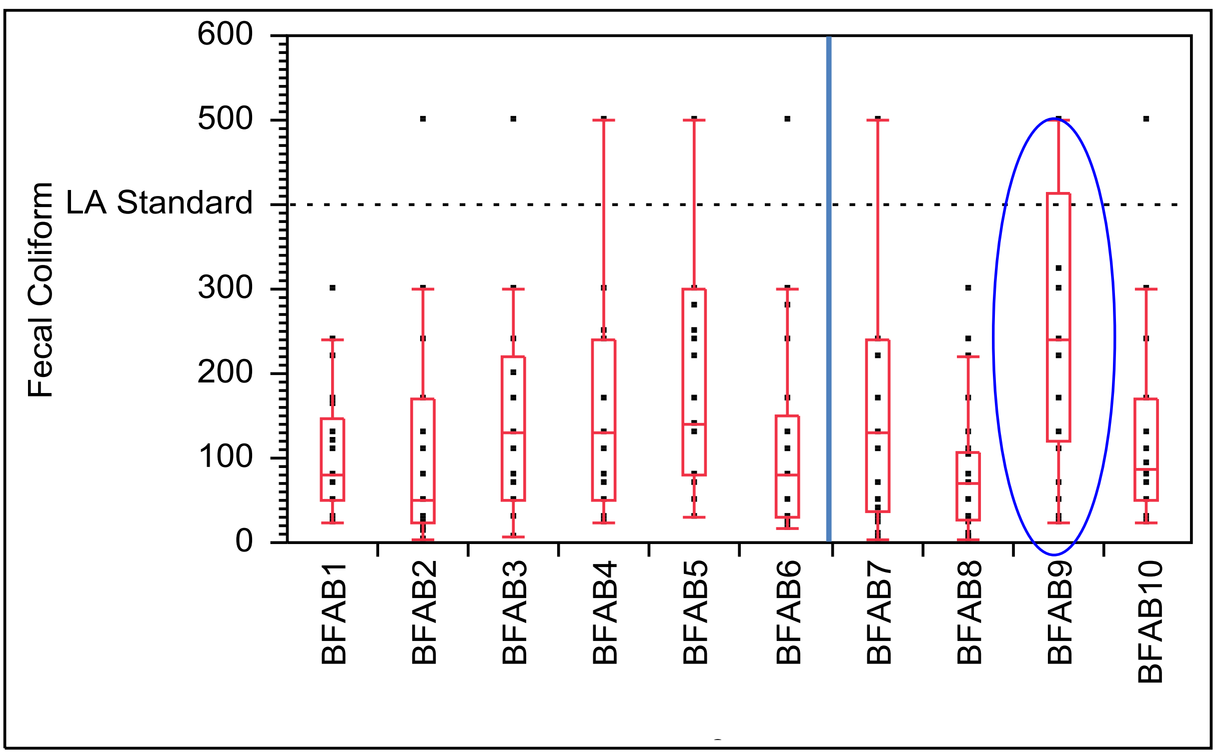


Figure 4.9 One-way Analysis of Fecal Coliform By Site; the Black Dotted Line Represents the State Standard for a Single Sample, (400 MPN/100mL).

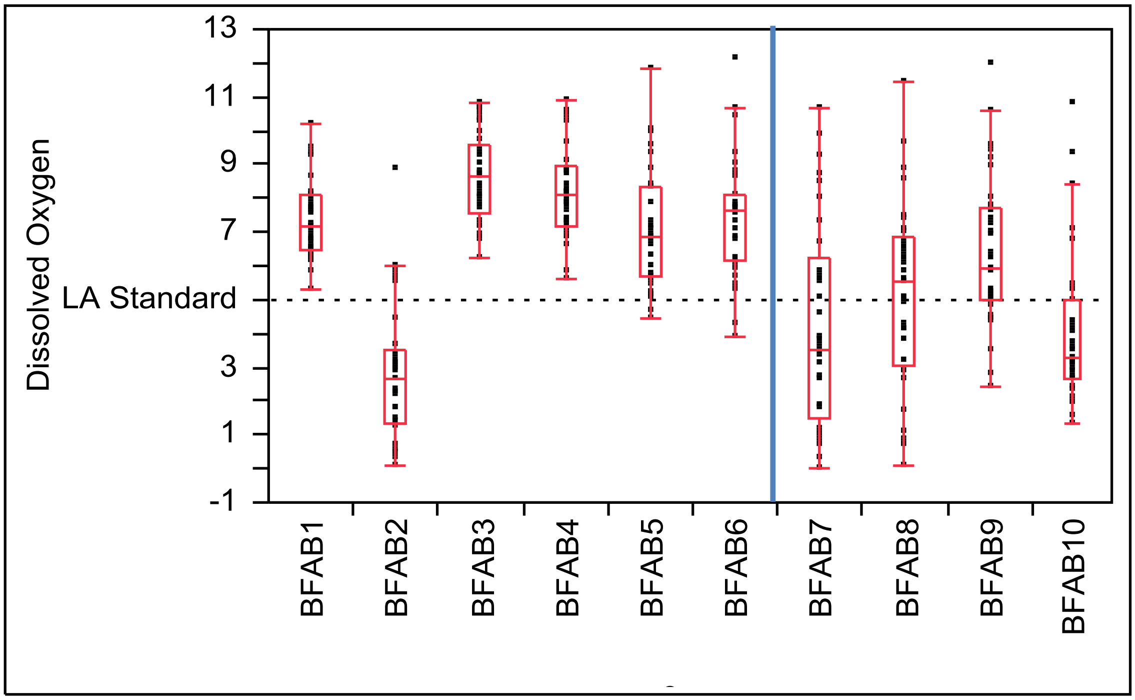


Figure 4.10 One-way Analysis of Dissolved Oxygen By Site; the Black Dotted Line Represents the State Standard for a Single Sample, (5mg/L).

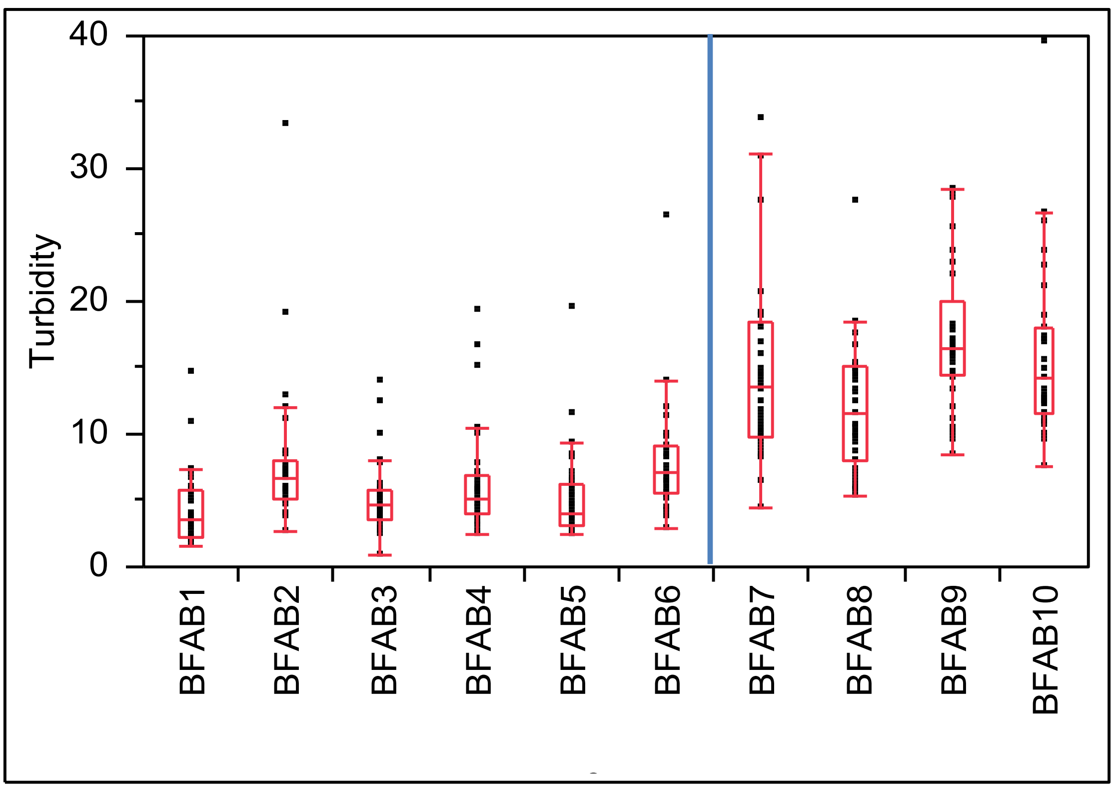


Figure 4.11 One-way Analysis of Turbidity By Site, (NTU).

4.6 Density Analysis Hot Spots

The resulting kernel density surface colors ranged from cold colors (light blue) to warm colors (red), indicating low to high densities for the commercial WWTPs. Lighter colors (tan) to darker colors (red) illustrated low to high densities for the individual home system's surface. Two observed density "hotspots" within the study area were circled in red (Figure 4.12). The individual home system density surface (tan to red) was most dense between the City of Covington and the Town of Abita Springs and north of the City of Covington heading toward the Village of Folsom. The density surface for commercial WWTPs (light blue to red) indicated that densities were greatest along major roadway corridors (North Highway 190 between the City of Covington and Abita Springs, Louisiana Highway 25 heading towards the Village of Folsom, and Louisiana Highways 59 and 36 near the Town of Abita Springs). These areas of density were consistent with the findings of sources in the LDEQ draft TMDL for the Lower Tchefuncte, mentioned in Section 2.1.

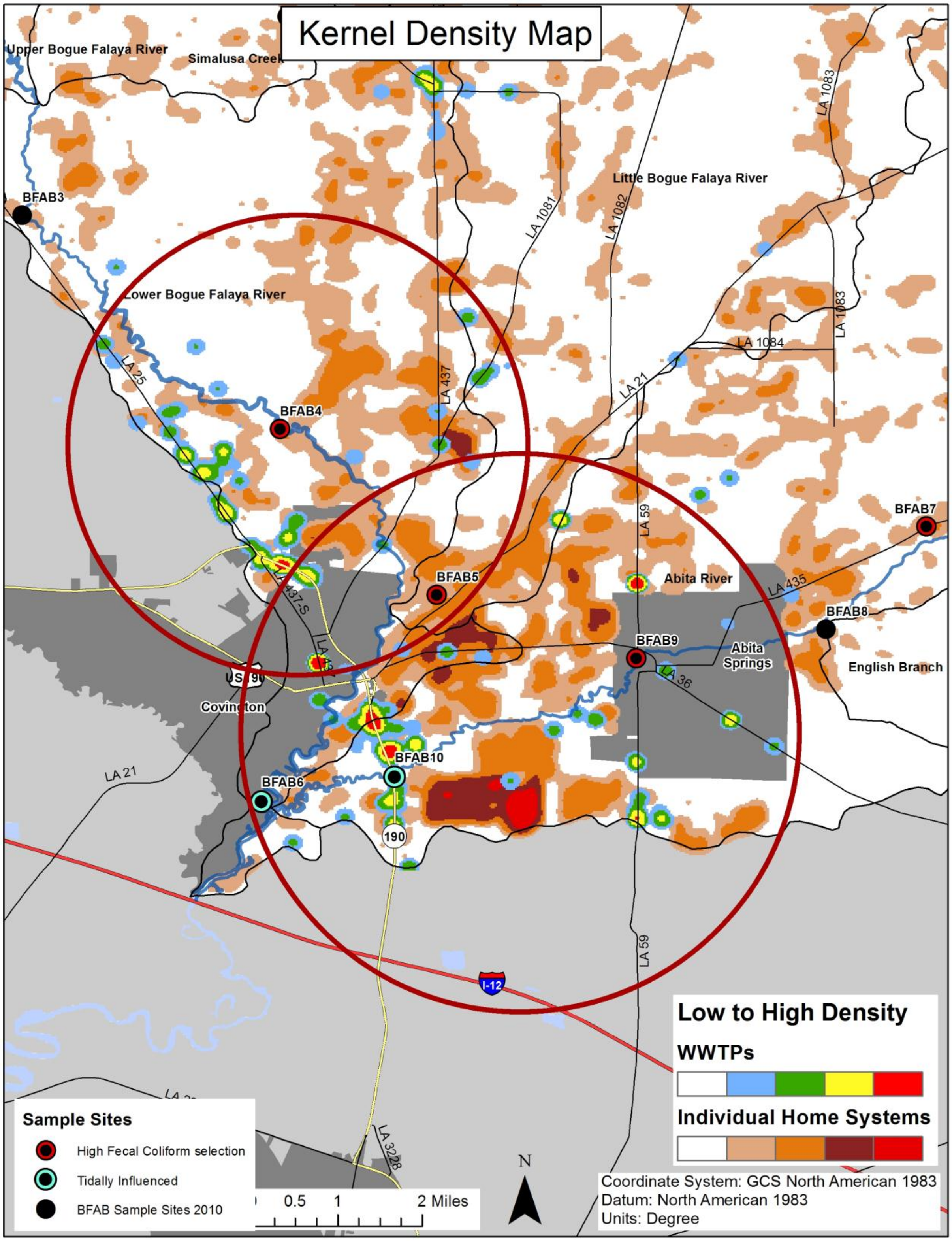


Figure 4.12 Kernel Density Results for Commercial WWTPs and Individual Homes within the Study Area. Density "Hotspots" are Illustrated within the Red Circles.

CHAPTER 5: DISCUSSION

5.1 Linking the Results: Upper vs. Lower Watersheds

The results of this study provide a clearer understanding of the spatial distribution and densities of point and nonpoint pollution sources within the Bogue Falaya River and Abita River watersheds. This answers research question 1, 2, and 3 (Section1.4). Within the upstream areas of the watersheds, results indicated there were lower fecal coliform counts, lower numbers of treatment facilities, and less dense areas of commercial treatment facilities and individual home sewer systems. Results also indicated higher fecal coliform counts, greater numbers of treatment facilities, and the more dense areas of commercial WWTPs and individual home systems in the more urbanized Lower Bogue Falaya River and Abita River 12-digit HUCs according to Tables 4.3 and 4.4, and Figure 4.10. Figure 4.10 illustrates that the maximum density of individual home systems fell within the Abita River 12-digit HUC and the commercial WWTPs densities were concentrated along corridors in the Lower Bogue Falaya River and Abita River 12-digit HUCs. In the Abita River watershed, fecal coliform counts were highest in the Abita River 12-digit HUC at sample site BFAB9 (Figure 4.9). In the Bogue Falaya River watershed, fecal coliform counts were highest in the Lower Bogue Falaya River 12-digit HUC at sample site BFAB5 (Figure 4.9).

5.2 Water Quality and Pollution Source Correlations

Results from the correlations between spatial and water quality analysis also provide answers to research question 3 (Section1.4). Areas in the Lower Bogue Falaya and Abita River sub-watersheds showed the greatest percentage of urban land use (Table 4.1). The Lower Bogue Falaya River sub-watershed contains the City of Covington and the Abita River sub-watershed contains the Town of Abita Springs. Water quality results from this study revealed that BFAB9, located in the Town of Abita Springs, had the highest fecal coliform counts for the Abita River watershed and BFAB5, located right outside the City of Covington, had the highest fecal coliform counts for the Bogue Falaya River watershed. Sample sites BFAB6 and BFAB10 should show high fecal coliform counts because of urban location; however, as described in Section *4.5.1*, the water quality correlations indicated that these sites were tidally influenced.

Although lower in fecal coliform counts than BFAB9, BFAB10 (the most downstream sample site in the Abita River sub-watershed) had significant and positive correlations between fecal coliform and turbidity, indicating the influence of stormwater runoff (highlighted in blue, (Table 4.5b). Previous studies also showed positive correlations between turbidity and fecal coliform, such as the Mallin et al. (2000) study described in Section 2.5. Mallin et al. (2000) established that turbidity was significantly and positively related to fecal coliform abundance and was supported by findings that suggested fecal bacteria indicators were associated with and transported via suspended sediments within the water column. Correlations were also supported by research from the 2006 Allison Creek TMDL, which found that:

> …positive correlation implicates nonpoint sources of pollution related to rainfall runoff. Heavy rain can wash fecal matter that has collected on the land surface into the stream, increasing any recreational activity which involves or requires prolonged body contact with the water, such as swimming, water skiing, tubing, snorkeling, and skin-diving counts. The rain would also cause increased turbidity levels by suspending particles in the stream and by the sediment-laden runoff (Allison Creek TMDL: 9).

The correlation between turbidity and fecal coliform was not seen in the urban area of the Bogue Falaya River watershed. The Bogue Falaya River's discharge is at least twice that of the Abita River (Section 3.4). Also, results from this study show that the Abita River watershed is more densely developed than the Bogue Falaya River watershed. Turbidity in the Abita River watershed is pointedly higher than in the Bogue Falaya River watershed (Figure 4.11). Therefore, the situation described above in the Mallin et al. (2000) study and the 2006 Allison Creek TMDL is more evident in the Abita River watershed. However, in the Bogue Falaya River watershed, there is a significant and negative correlation between fecal coliform and dissolved oxygen at sites BFAB5 and BFAB6 (Table 4.5a). According to similar correlations previously observed by the LPBF, as fecal coliform increases, the dissolved oxygen decreases, thus reveling a relationship that is expected in a polluted waterway (LDEQ 2011d).

Fecal coliform densities were highest near the densest areas of individual home systems, as opposed to the densest commercial WWTPs. This could be because there is many more homes than commercial systems and also commercial systems have all recently been systematically documented and inspected whereas the home systems have not.

Results of this study were consistent with previous work highlighted in Chapter 2. Similar findings from Kelsey et al. (2004), Tong and Chen (2002), and Mallin et al. (2000) showed that the bacteriological parameter, fecal coliform, had the strongest relationships to urban land uses and high population and residential density. Additionally, these studies suggested that stormwater runoff is the main source of pollution entering the waterways. Kelsey et al. (2004) found that a major source of fecal coliform pollution was stormwater runoff in areas with urban land-use characteristics and that study's regression modeling results suggested that important contributors included septic tanks and sewage systems. Tong and Chen (2002) also echoed that fecal coliform had strong positive relationships with commercial and residential lands.

Mallin et al. (2000) stated that, "…watershed population and watershed size were significantly related to average fecal coliform abundance…" and that there are more numerous and robust correlations between fecal coliform geometric means and the percentage of development in individual creeks within the study (pg. 1052). However, Mallin et al. (2000) also noted that the strongest correlations were between average fecal coliform abundance and percentage of watershed-impervious surface, which consists of roofs, paved drives, sidewalks, roads, and parking lots. Data from the Mallin et al. (2000) study revealed that the amount of developed land and impervious surfaces increases the conveyance and abundance of fecal coliform bacteria and other pollutant. In connection to findings in Mallin et al. (2000), this study discovered sub-watersheds that consisted of more than 10 percent urban landuse (Table 4.2) were correlated to poorer water quality than sub-watersheds that were less developed.

5.3 Looking to the Future

As St. Tammany Parish develops and grows in population, pollution from urban land use will continue to put pressure on the water quality of the Bogue Falaya River and Abita River watersheds. Water quality management goals of this research were to locate point and nonpoint pollution sources and identify strategies to reduce or intercept inputs. The results of this study highlighted the relationship of high fecal coliform counts in correlation to individual home system densities. This relationship is also discussed in the Lower-Tchefuncte Draft TMDL for dissolved oxygen. After the TMDL acknowledges the sources, it recommends a solution:

> LDEQ recommends that the primary solutions to the water quality problems for Subsegments 040802 and 040803 include the large-scale regionalization of sewage treatment and the rehabilitation and upgrade of existing problematic (leaks, overflows, improperly sized pipes, etc.) sewage collection and/or treatment systems (LDEQ 2011d: xliii).

TMDLs will be an important tool for water quality improvement in the Bogue Falaya, Abita, and Lower-Tchefuncte River watersheds. Reductions in pollution loads provided by TMDLs will be enforceable and must be met by the municipalities. The Lower-Tchefuncte River TMDLs are similar to those of several urban watersheds in south Louisiana. All show similar issues of high numbers and densities of individual home systems and poorly functioning commercial WWTPs, leading to low dissolved oxygen and/or high fecal coliform levels. To answer research question 4 (Section 1.4), regionalization is imperative management strategy for the improvement of water quality in watersheds throughout the Pontchartrain Basin and south Louisiana. St. Tammany Parish is being proactive and has developed plans to regionalize a large portion of the southern end of the parish. Future research needs to include continued water quality monitoring of the Bogue Falaya River and Abita River watersheds as St. Tammany Parish moves forward in the regionalization of its wastewater to satisfy the TMDLs.

The first step in the U.S. EPAs watershed protection planning guidelines is to characterize the watershed and find all sources contributing to pollution loads. This document provides a holistic methodology for locating, characterizing, and spatially assessing sources of water quality impairment for a watershed-based management planning process. The methods produced in this study are an integral part of *The Bogue Falaya and Abita Rivers Watershed Protection Plan*, and the LPBF will continue to use the methods and strategies from this study to produce other WPPs in the Pontchartrain Basin.

REFERENCES

American Public Health Association (APHA). 1998. *Standard Methods for the Examination of Water and Wastewater, 20th edition*. Eds. Clesceri, L., Greenberg, A., and A. Eaton. APHA, Washington D.C

Arkansas Watershed Advisory Group. 2011. *Watershed Illustration*. Arkansas.gov, Web. http://www.awag.org/Education/Watershed_diagram.jpg.

Atlas, The Louisiana Statewide GIS. 2008. LSU CADGIS Research Laboratory, Baton Rouge, LA. Web. January 2010. http://atlas.lsu.edu.

Bourgeois-Calvin, Andrea., Mastrototaro, J., and S. Briuglio. 2004. A Non-Profit Approach To Addressing The Effects of Urbanization in the Lake Pontchartrain Basin, Louisiana. *Urban Ecosystems*, (7) pp. 157-167.

Bourgeois-Calvin, Andrea. 2008. *Relationship between land-use and surface water quality in a rapidly developing watershed in southeast Louisiana*, Dissertation, University of New Orleans: Retrieved from ProQuest Dissertations and Theses. (Publication No. 3332381).

Bourgeois-Calvin Ph. D, Andrea. 2011. Lake Pontchartrain Basin Foundation, Water Quality Director. Metairie, LA: Personal Communication, March 2.

Bourgeois-Calvin, Andrea. and Chelsea Core. 2012. *Draft-Bogue Falaya and Abita Rivers Watershed Protection Plan* (unpublished) Lake Pontchartrain Basin Foundation, Metairie, LA.

Brabec, E., Schulte, S., and P.L. Richards. 2002. Impervious surfaces and water quality: a review of current literature and its implications in watershed planning. *Journal of Planning Literature*, (15) pp. 499-514.

ESRI. *What is GIS?*. gis.com., Web. November 2009. http://www.gis.com/content/what-gis.

_____. 2011a. *How Kernel Density works*. Web. April 2011. http://help.arcgis.com/en/arcgisdesktop/10.0/help/index.html#/How_Kernel_Density_works/009z00000011000000/.

_____. 2011b. *Average Nearest Neighbor (Spatial Statistics)*. Web. January 2012. http://help.arcgis.com/en/arcgisdesktop/10.0/help/index.html#/How_Kernel_Density_works/009z00000011000000/.

Fontcuberta, B. 2009. *The Complete Maps of St. Tammany*. 4th Edition. Navigator Street Maps, Mapman, LLC. Covington, LA.

Kelsey, H., Porter, D.E., Scott, G., Neet, M., and D. White. 2004. Using geographic information systems and regression analysis to evaluate relationships between land use and fecal coliform bacterial pollution. *Journal of Experimental Marine Biology and Ecology*, 298(2): 197-209.

Louisiana Department of Environmental Quality (LDEQ). 2000. *EPA Region 6 TMDL Consent Decree*. PDF.LDEQ, Web. April 2012. http://www.deq.louisiana.gov/portal/DIVISIONS/WaterPermits/TotalMaximumDailyLoadTMDLProgram.aspx.

_____. 2008. Barataria-Terrebonne-Use Attainability Analysis. LDEQ, Web. April 2012. http://www.deq.louisiana.gov/portal/DIVISIONS/WaterPermits/WaterQualityAssessment/BaratariaTerrebonneUseAttainabilityAnalysis.aspx.

_____. 2010. *2010 Louisiana Water Quality Inventory: Integrated Report*. PDF. LDEQ, Web. July 2010. http://www.deq.louisiana.gov/portal/LinkClick.aspx?fileticket=vmsh5Pdagig%3d&tabid=3141

_____. 2011a. *Louisiana's Nonpoint Source Management Plan 2011-2016*. PDF. LDEQ, Web. April 2012. http://nonpoint.deq.state.la.us/wqa/NPSManagementPlan.pdf.

_____. 2011b. *Nonpoint Source Annual Report Federal Fiscal Year (FFY) 2011*. PDF. LDEQ, Web. April 2012. http://nonpoint.deq.state.la.us/wqa/links/AnnualReports/2011%20NPS%20Annual%20Report.pdf

_____. 2011c. *Title 33: Environmental Regulatory Code*. PDF. LDEQ, Web. June 2010. http://www.deq.louisiana.gov/portal/LinkClick.aspx?fileticket=eRiJ6m2tb_U%3d&tabi=1674.

_____. 2011d. *Draft-Lower Tchefuncte River Watershed TMDL for Biological Oxygen-Demanding Substances-Phase I Subsegments 040802 and 040803, Technical Summary*. Louisiana Department of Environmental Quality Office of Environmental Assessment, Baton Rouge, LA.

_____. *Louisiana's Nonpoint Source Pollution Unit*. LDEQ, Web. June 2012. http://nonpoint.deq.louisiana.gov/wqa/default.htm.

Louisiana Department of Wildlife and Fisheries. 2012. "Scenic Rivers." Department of Natural Resources. LWLF, Web. March 2011. http://www.wlf.louisiana.gov/wildlife/scenic-rivers.

Mallin, M.A., Williams, K.E., Esham, E.C., and R.P. Lowe. 2000. Effect of human development on bacteriological water quality in coastal waters. *Ecological Applications*, (9) pp. 1047-1056.

McDonald, J.H. 2009. Handbook of Biological Statistics (2nd ed.). Sparky House Publishing, Baltimore, Maryland. pp. 221-223. Web. Jan 21st 2012. http://udel.edu/~mcdonald/statspearman.html.

Paul, M. and J. Meyer. 2001. Streams in the Urban Landscape. *Annual Review of Ecology and Systematics*, (32) pp. 333-365.

Schneider, A. (2003). GPSVisualizer: Do it-Yourself Mapping, Web. November 2009. http://www.gpsvisualizer.com/.

South Carolina Department of Health and Environmental Control. 2006. *Total Maximum Daily Load – Allison Creek (Hydrologic Unit Code 0305010115) Station CW-249 Fecal Coliform Bacteria*. Bureau of Water SCDHEC Technical Document Number: 007-07.

St. Tammany Parish Government. 2007. *St. Tammany Parish Tchefuncte and Bogue Falaya Watershed Implementation Project (CFMS Cooperative Agreement No. 608669)*. St Tammany Parish Department of Environmental Services. Mandeville, LA: CH2M Hill, Inc.

_____. 2010. *Sewerage and Water Providers by Subdivision*. PDF. Tammany Utilities, Web. February 2010. http://www.stpgov.org/pdf/1273855273.pdf.

Tong, T.Y. Susanna and Wenli Chen. 2002. Modeling the relationship between land-use and surface water quality. *Journal of Environmental Management*, (16) pp. 377-393.

U. S. Census Bureau. 2010. *Census 2010 Data for the State of Louisiana*. U.S. Census Bureau, Web. July 2011. http://2010.census.gov/2010census/data/.

USDA/NRCS-National Cartographic & Geospatial Center "12-Digit Watershed Boundary Data 1:24,000, The 8, 10, and 12-digit hydrologic unit boundaries for the Louisiana Edition 1" [ESRI Shapefile] 2008.

U.S. Environmental Protection Agency. (U.S. EPA). 2000. BASINS Technical Note 6: Estimating Hydrology and Hydraulic Parameters for HSPF. Office of Water. EPA-823-R00-012.

_____. 2008a. *Introduction to the Clean Water Act Module*. Watershed Academy Web. US EPA, Web. November. 2009. http://www.epa.gov/owow/watershed/wacademy/acad2000/cwa/index.htm.

_____. 2008b. *Handbook for Developing Watershed Plans to Restore & Protect Our Waterways*. US EPA, Web. September 2010. http://water.epa.gov/polwaste/nps/handbook_index.cfm.

_____. 2008c. *Introduction to Watershed Planning Module*. Watershed Academy Web. US EPA, Web. December 2009. http://www.epa.gov/owow/watershed/wacademy/acad2000/planning/

_____. 2009. *Fixing On-site Sewage Systems Restores Popular New Orleans Area Rivers. EPA 841-F-09-001S*. Section 319 Nonpoint Source Program Success Story Louisiana. PDF, US EPA. Web. June 2010. http://www.epa.gov/owow/NPS/success/state/pdf/la_tchef.pdf.

_____. 2011. *Protecting Water Quality from Urban Runoff*. *EPA 841-F-03-003*. US EPA,Web. March. 2011. http://www.epa.gov/owow/NPS/urban_facts.html.

_____. 2012a. *What is a Watershed*?. US EPA, Web. November 2009. http://water.epa.gov/type/watersheds/whatis.cfm.

_____. 2012b. *Water: Total Maximum Daily Loads (303d). Overview of Impaired Watersheds and Total Daily Maximum Loads Program*. US EPA, Web. July 2010. http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/intro.cfm.

_____. 2012d. *Water: Monitoring and Assessment. 6.2 Presenting the Data*. US EPA, Web. September 2010. http://water.epa.gov/type/rsl/monitoring/vms62.cfm.

U.S. Geological Society. 2011. *Overview and History of Hydrologic Units and the Watershed Boundary Dataset (WBD)*. USGS, Web. September 2010. http://nhd.usgs.gov/wbd_history.html.

Waterwatch Australia National Technical Manual. 2007. *Turbidity Zones*. PDF, Web. February 2012. http://www.environment.nsw.gov.au/resources/waterwatch/estuaryGuide/20100685EstuaryGuide_S2.pdf.

APPENDIX A: LDEQ CRITERIA FOR DESIGNATED USES

Water Use Designations

A. There are seven water uses designated for surface waters in Louisiana: agriculture, drinking water supply, fish and wildlife propagation, outstanding natural resource waters, oyster propagation, primary contact recreation, and secondary contact recreation. Designated uses assigned to a subsegment apply to all water bodies (listed water body and tributaries/distributaries of the listed water body) contained in that subsegment unless unique chemical, physical, and/or biological conditions preclude such uses. However, the designated uses of drinking water supply, outstanding natural resource waters, and/or oyster propagation apply only to the water bodies specifically so designated in LAC 33:IX.1123, Table 3, and not to any tributaries or distributaries to such water bodies. The water use designations are defined as follows.

Agriculture—the use of water for crop spraying, irrigation, livestock watering, poultry operations, and other farm purposes not related to human consumption.

Drinking Water Supply—the use of water for human consumption and general household use. Surface waters designated as drinking water supplies are specifically so designated in LAC 33:IX.1123, Table 3; this designation does not apply to their tributaries or distributaries unless so specified.

Fish and Wildlife Propagation—the use of water for aquatic habitat, food, resting, reproduction, cover, and/or travel corridors for any indigenous wildlife and aquatic life species associated with the aquatic environment. This use also includes the maintenance of water quality at a level that prevents damage to indigenous wildlife and aquatic life species associated with the aquatic environment and contamination of aquatic biota consumed by humans. The use subcategory of *limited aquatic life and wildlife* recognizes the natural variability of aquatic habitats, community requirements, and local environmental conditions. *Limited aquatic life and wildlife* use may be designated for water bodies having habitat that is uniform in structure and morphology, with most of the regionally expected aquatic species absent, low species diversity and richness, and/or a severely imbalanced trophic structure. Aquatic life able to survive and/or propagate in such water bodies includes species tolerant of severe or variable environmental conditions. Water bodies that might qualify for the *limited aquatic life and wildlife* use subcategory include intermittent streams, and naturally dystrophic and man-made water bodies with characteristics including, but not limited to, irreversible hydrologic modification, anthropogenically and irreversibly degraded water quality, uniform channel morphology, lack of channel structure, uniform substrate, lack of riparian structure, and similar characteristics making the available habitat for aquatic life and wildlife suboptimal.

Outstanding Natural Resource Waters—water bodies designated for preservation, protection, reclamation, or enhancement of wilderness, aesthetic qualities, and ecological regimes, such as those designated under the Louisiana Natural and Scenic Rivers System or those designated by the department as waters of ecological significance. Characteristics of *outstanding natural resource waters* include, but are not limited to, highly diverse or unique instream and/or riparian habitat, high species diversity, balanced trophic structure, unique species, or similar qualities.

This use designation shall apply only to those water bodies specifically so designated in LAC 33:IX.1123, Table 3 and not to their tributaries or distributaries unless so specified.

Oyster Propagation—the use of water to maintain biological systems that support economically important species of oysters, clams, mussels, or other mollusks so that their productivity is preserved and the health of human consumers of these species is protected. This use designation shall apply only to those water bodies specifically so designated in LAC 33:IX.1123, Table 3 and not to their tributaries or distributaries unless so specified.

Primary Contact Recreation—any recreational or other water contact activity involving prolonged or regular full-body contact with the water and in which the probability of ingesting appreciable amounts of water is considerable. Examples of this type of water use include swimming, skiing, and diving.

Secondary Contact Recreation—any recreational or other water contact activity in which prolonged or regular full-body contact with the water is either incidental or accidental, and the probability of ingesting appreciable amounts of water is minimal. Examples of this type of water use include fishing, wading, and boating.

Table 3.2.2. Decision process for evaluating use support, showing measured parameters for each designated use; *Louisiana's 2006 Integrated Report.*

Designated Use	Measured Parameter	Support Classification for Measured Parameter Fully Supporting	Partially2	Not Supporting
Primary Contact Recreation (PCR) (Designated swimming months of May-October, only.)	Fecal coliform1 Temperature Metals5 and Toxics	0-25% do not meet criteria 0-30% do not meet criteria < 2 exceedences of chronic or acute criteria in most recent consecutive 3-year period, or 1-year period for newly tested waters	- >30-75% do not meet criteria	>25% do not meet criteria >75% do not meet criteria 2 or more exceedences of chronic or acute criteria in most recent consecutive 3-year period, or 1-year period for newly tested waters
Secondary Contact Recreation (SCR) (All months)	Fecal coliform1 Metals5 and Toxics	0-25% do not meet criteria < 2 exceedences of chronic or acute criteria in most recent consecutive 3-year period, or 1-year period for newly tested waters	- -	>25 % do not meet criteria 2 or more exceedences of chronic or acute criteria in most recent consecutive 3-year period, or 1-year period for newly tested waters

Fish and Wildlife Propagation (FWP)	Dissolved oxygen3 Dissolved oxygen4 Temperature, pH, chloride, sulfate, TDS, turbidity Metals5 and Toxics	0-10% do not meet minimum of 3.0 ppm and median > criteria of 5.0 ppm 0-10% do not meet criteria 0-30% do not meet criteria < 2 exceedences of chronic or acute criteria in most recent consecutive 3-year period, or 1-year period for newly tested waters	- >10-25% do not meet criteria >30-75% do not meet criteria -	>10% do not meet minimum of 3.0 ppm or median < criteria of 5.0 ppm >25% do not meet criteria >75% do not meet criteria 2 or more exceedences of chronic or acute criteria in most recent consecutive 3-year period, or 1-year period for newly tested waters
Drinking Water Source (DWS)	Color, Fecal coliform Metals and Toxics	0-30% do not meet criteria < 2 exceedences of drinking water criteria in most recent consecutive 3-year period, or 1-year period for newly tested waters	>30-75% do not meet criteria	>75% do not meet criteria 2 or more exceedences of drinking water criteria in the most recent consecutive 3-year period, or 1-year period for newly tested waters
Outstanding Natural Resource (ONR)	Turbidity	0-10% do not meet criteria	>10-25% do not meet criteria	>25% do not meet criteria
Agriculture (AGR)	None	-	-	-
Oyster Production (OYS)	Fecal coliform1	Median fecal coliform < 14 MPN/100 mL; and < 10% of samples < 43 MPN/100 mL	-	Median fecal coliform > 14 MPN/100 mL; and > 10% of samples > 43 MPN/100 mL
Limited Aquatic Life and Wildlife (LAL)	Dissolved oxygen4	0-10% do not meet criteria	>10-25% do not meet criteria	>25% do not meet criteria

Footnotes to Table 3.2.2.:

1. For most water bodies, criteria are as follows: PCR, 400 colonies/100 mL; SCR, 2,000 colonies/100 mL; DWS, 2,000 colonies/100 mL; SFP, 43 colonies/100 mL (see ERC 33:IX.1123).

2. While the assessment category of “Partially Supporting” is included in the SAS statistical assessment programming, any use support failures were recorded in ADB as “Not Supporting.” This procedure

was first adopted for the 2002 §305(b) cycle because “partially supported” uses receive the same TMDL treatment as “not supported” uses.

3. Water bodies with a D.O. criterion of 5.0 mg/L. This assessment method differs from U.S. EPA guidance.

4. Estuarine waters with a D.O. criterion of 4.0 mg/L and water bodies for which a special study has been conducted to establish site-specific criteria for D.O.

5. Marine metals criteria were used for all water bodies with an average salinity greater than or equal to 16.0 ppt. Freshwater metals criteria were used for all other water bodies.
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5. Marine metals criteria were used for all water bodies with an average salinity greater than or equal to 16.0 ppt. Freshwater metals criteria were used for all other water bodies.

APPENDIX B: GIS METADATA

Basemap Data:

- **Land/Water:** Land and Water Interface of Louisiana from 2002 Landsat Thematic Mapper Satellite Imagery, Geographic NAD83, LOSCO (2005) [la_landwater_3ac]' Data distributed by "Atlas: The Louisiana Statewide GIS." LSU CADGIS Research Laboratory, Baton Rouge, LA, 2008. http://atlas.lsu.edu.
- **Municipalities:** TIGER/Line Places for Louisiana, Geographic NAD83, LOSCO (2004) [tiger_places_polygons_2004].
- **Streams:** TIGER/Line Hydrography of Louisiana from Census source data, Geographic NAD83, LOSCO (2004) [tiger_water_segments_2004].
- **Parish Boundaries:** Louisiana Department of Transportation 'Parish Boundaries of Louisiana, Geographic NAD83,(2005) [parishes]' Data distributed by "Atlas: The Louisiana Statewide GIS." LSU CADGIS Research Laboratory, Baton Rouge, LA, 2008. http://atlas.lsu.edu.
- **Roads:** TIGER/Line 2006 Second Edition Road, Geographic NAD83, CENSUS (2006) [tiger_la_roads_CENSUS_2006]. Data distributed by "Atlas: The Louisiana Statewide GIS." LSU CADGIS Research Laboratory, Baton Rouge, LA, 2008. http://atlas.lsu.edu.

Hydrologic Unit Codes (HUCs):

- **10-digit HUC Watershed Boundaries:** Geographic NAD83, LOSCO (2004) [basin_subsegments_LDEQ_2004]. Distributed by LDEQ.
- **12-Digit HUC Sub-watershed Boundaries:** The 8, 10, and 12 digit hydrologic unit boundaries for the Louisiana Edition 1, 2008. Geographic NAD83, USDA/NRCS-National Cartography & Geospatial Center. [wbdhu12_a_la]. Data distributed by "Atlas: The Louisiana Statewide GIS." LSU CADGIS Research Laboratory, Baton Rouge, LA, 2008. http://atlas.lsu.edu.

Pollution Source Layers:

-LPBF Databases

- **Subdivision Layer** (acquired from the St. Tammany Navigator, MapMan, LLC), GCS_North_American_1983, 2010.
- **St Tammany Parish Subdivision Layer:** NAD_1983_StatePlane_Louisiana_South_FIPS_1702_Feet, distributed by the St. Tammany Parish Department of Geographic Information Services, 2010.
- **WWTPs:** LDEQ/OEC/Surveillance Division St. Tammany Sweep, GCS_North_American_1983, 2009 & 2011.
- **Home Wastewater Systems**: GCS_North_American_1983, distributed by the St. Tammany Parish Emergency 911 home address data, 2010.

APPENDIX C: CALCULATING LAND USE

(6) 12-Digit HUCs (inc.Wash. Parish)				
Class	**Area**	**Total**	**%**	**Classes**
Wetlands	11	125211	0	Wetland Nonforested
Forest Land	85659	125211	68	Deciduous Forest Land, Evergreen Forest Land
Forested Wetland	1337	125211	1	Forested Wetland
Developed Open	5110	125211	4	Transitional Areas, Urban or Built-up Land
Low Density	1033	125211	1	Developed Low Density
Med Density	459	125211	0	Developed Medium Density
High Density	61	125211	0	Developed High Density
Agriculture	31164	125211	25	Pasture/Hay, Soybeans, Nurseries, Sugarcane, Corn
Gravel	377	125211	0	Gravel Pit/Strip Mine
Total	**125211**		**100**	
Forest breakdown				
Deciduous	20116	125211	16	
Evergreen	65543	125211	52	
Total	**85659**		**68**	
Water(1,205) & null area(367)=1,572				
(125212 + 1,572)=126,784 total US acre				

St. Tam 12 digit HUC: English Branch				
Class	**Area**	**Total**	**%**	**Classes**
Wetlands	4	11992	0	Wetland Nonforested
Forest Land	10452	11992	87	Deciduous Forest Land, Evergreen Forest Land
Forested Wetland	422	11992	4	Forested Wetland
Developed Open	129	11992	1	Transitional Areas, Urban or Built-up Land
Low Density	0	11992	0	Developed Low Density
Med Density	0	11992	0	Developed Medium Density
High Density	0	11992	0	Developed High Density
Agriculture	973	11992	8	Pasture/Hay, Soybeans, Nurseries, Sugarcane, Corn
Gravel	12	11992	0	Gravel Pit/Strip Mine
Total	**11992**		**100**	
Forest breakdown				
Deciduous	931	11992	8	
Evergreen	9521	11992	79	
Total	10452		**87**	

St. Tam 12-Digit HUC: Lower Bogue Falaya River				
Class	**Area**	**Total**	**%**	**Classes**
Wetlands	1	17705	0	Wetland Nonforested
Forest Land	11376	17705	64	Deciduous Forest Land, Evergreen Forest Land
Forested Wetland	107	17705	1	Forested Wetland
Developed Open	1476	17705	8	Transitional Areas, Urban or Built-up Land
Low Density	404	17705	2	Developed Low Density
Med Density	272	17705	2	Developed Medium Density
High Density	52	17705	0	Developed High Density
Agriculture	3968	17705	22	Pasture/Hay, Soybeans, Nurseries, Sugarcane, Corn
Gravel	49	17705	0	Gravel Pit/Strip Mine
Total	**17705**		**100**	
Forest breakdown				
Deciduous	3231	17705	18	
Evergreen	8145	17705	46	
Total	**11376**		**64**	

St. Tam 12 digit HUC: Abita River				
Class	**Area**	**Total**	**%**	**Classes**
Wetlands	1	27979	0	Wetland Nonforested
Forest Land	21145	27979	76	Deciduous Forest Land, Evergreen Forest Land
Forested Wetland	460	27979	2	Forested Wetland
Developed Open	2295	27979	8	Transitional Areas, Urban or Built-up Land
Low Density	570	27979	2	Developed Low Density
Med Density	167	27979	1	Developed Medium Density
High Density	5	27979	0	Developed High Density
Agriculture	3272	27979	12	Pasture/Hay, Soybeans, Nurseries, Sugarcane, Corn
Gravel	64	27979	0	Gravel Pit/Strip Mine
Total	**27979**		**100**	
Forest breakdown				
Deciduous	4573	27979	16	
Evergreen	16572	27979	59	
Total	**21145**		**76**	

St. Tam 12-Digit HUC: Little Bogue Falaya River				
Class	**Area**	**Total**	**%**	**Classes**
Wetlands	5	24205	0	Wetland Nonforested
Forest Land	13936	24205	58	Deciduous Forest Land, Evergreen Forest Land
Forested Wetland	125	24205	1	Forested Wetland

Developed Open	588	24205	2	Transitional Areas, Urban or Built-up Land
Low Density	4	24205	0	Developed Low Density
Med Density	0	24205	0	Developed Medium Density
High Density	0	24205	0	Developed High Density
Agriculture	9426	24205	39	Pasture/Hay, Soybeans, Nurseries, Sugarcane, Corn
Gravel	121	24205	0	Gravel Pit/Strip Mine
Total	**24205**		**100**	
Forest breakdown				
Deciduous	4277	24205	18	
Evergreen	9660	24205	40	
Total	**13937**		**58**	

St. Tam 12-Digit HUC: Simalusa Creek

Class	Area	Total	%	Classes
Wetlands	0	13303	0	Wetland Nonforested
Forest Land	6204	13303	47	Deciduous Forest Land, Evergreen Forest Land
Forested Wetland	54	13303	0	Forested Wetland
Developed Open	275	13303	2	Transitional Areas, Urban or Built-up Land
Low Density	4	13303	0	Developed Low Density
Med Density	0	13303	0	Developed Medium Density
High Density	0	13303	0	Developed High Density
Agriculture	6722	13303	51	Pasture/Hay, Soybeans, Nurseries, Sugarcane, Corn
Gravel	44	13303	0	Gravel Pit/Strip Mine
Total	**13303**		**100**	
Forest breakdown				
Deciduous	2274	13303	17	
Evergreen	3930	13303	30	
Total	**6204**		**47**	

St. Tam 12-Digit HUC: Upper Bogue Falaya River

Class	Area	Total	%	Classes
Wetlands	0	30027	0	Wetland Nonforested
Forest Land	22547	30027	75	Deciduous Forest Land, Evergreen Forest Land
Forested Wetland	170	30027	1	Forested Wetland
Developed Open	346	30027	1	Transitional Areas, Urban or Built-up Land
Low Density	50	30027	0	Developed Low Density
Med Density	20	30027	0	Developed Medium Density
High Density	4	30027	0	Developed High Density
Agriculture	6803	30027	23	Pasture/Hay, Soybeans,

				Nurseries, Sugarcane, Corn
Gravel	87	30027	0	Gravel Pit/Strip Mine
Total	**30027**		**100**	
Forest breakdown				
Deciduous	4831	30027	16	
Evergreen	17716	30027	59	
Total	**22547**		**75**	

APPENDIX D: SUBDIVISION LIST

ST. Tammany Map Layer (Mapped)	ST. List/Found in Navigator	Utility	Lat	Long
Abita Lakes		Tammany Utilities	30.511458	-90.020461
Abita Nursery		Water District No. 2/Utilities Inc of Louisiana (W/S)	30.490010	-90.048215
Abita Springs Annex		IND		
Abita Springs Estates		IND		
Abita Springs Terrace	Abita Terrace	Tammany Utilities (W/S)		
Alexiusville		IND	30.450396	-90.080232
Alexiusville (East Addition)		IND		
Alpine Village		IND	30.471056	-90.078820
Arrow Wood Estates		Utilities Inc of Louisiana (W/S)	30.469431	-90.054061
Atlas		IND	30.499329	-90.038562
Audrey Heights		IND		
Autumn Wind		Tammany Utilities (W/S)	30.452336	-90.034820
Azalea Park		IND		
Barker's Corner Estates		IND		
Beechwood Gardens		IND	30.548417	-90.139765
Birg Boulevard (aka Helenbirg)		IND		
Blackburn Place		IND		
Bleu Lake Hills		*H2O Systems, Inc(W) / IND (S)		
Bogue Falaya		IND		
Bogue Falaya Plantation		IND	30.584822	-90.139934
Bouge Glen		*Water District No. 2 / IND (S)	30.500074	-90.079924
Calgonville		IND		
Chandler		Water District No. 2 / IND (S)		
Chenel Farms		IND		
Cherry Hill Estates		IND	30.593093	-90.203728
Claiborne Hill		*City of Covington / IND (W/S)		
Covington Acres		IND		

Covington Industrial Park (N)	Covington Industrial Park (N)	IND	30.513390	-90.116785
Covington Point		City of Covington (W/S)	30.497773	-90.089948
Crestwood Estates	Crestwood	Utilities Inc of Louisiana (W/S)		
(Not Mapped)	**Dogwood Estates(N)**	IND	30.585392	-90.004420
Emerald Creek		Utilities Inc of Louisiana (W/S)	30.461301	-90.046631
Estates of Northpark		IND		
Garland's Cov/Claiborne Addition		IND		
Garland's Covington Addition		IND		
Glendale Estates		IND	30.536034	-90.083071
Golden Oaks		IND	30.506348	-89.936249
Grande Hills		IND		
Great Southern Acres		IND		
Green Woods		IND	30.497141	-90.054590
Greenleaf Acres		IND	30.611106	-90.083326
Handsome Meadow Farms		IND		
Highland Acres		IND		
Highlands	Highlands, The	*H2O Systems, Inc (W) / IND (S)	30.644241	-90.076023
Hillcrest Country Club		IND	30.498153	-89.961282
(Not Mapped)	**Hilltop Farms**	IND	30.551538	-90.098267
Honey Suckle Estates		IND	30.580694	-90.132866
Ingram Estates		Utilities Inc of Louisiana (W/S)	30.459305	-90.051466
Lauraland Estates		*Some Phases Lee Rd Water / IND (S)	30.557856	-90.096325
Lee Road Heights		IND	30.523927	-90.083671
Lions Gate		IND		
Long Branch Acres		IND	30.491588	-90.043122
Longleaf Estates		IND	30.516041	-90.031533
Magnolia Gardens		*Water District No. 2 /IND (S)	30.500214	-90.072313
Magnolia Trace		IND	30.536670	-90.051187
Mailleville		IND	30.463242	-90.080585
Maple Ridge		Utilities Inc of Louisiana (W/S)	30.461747	-90.084343

Maplewood Estates		IND	30.445939	-90.027618
Marci Acres		IND	30.447479	-90.019606
Merrywood Estates		*Lee Road Water Corp.(limited service area, W) / IND (S)	30.603831	-90.140845
Mill Haven Heights		IND		
Money Hill Plantation		H2O Systems, Inc (W/S)	30.546159	-89.961528
(Not Mapped)	**New Abita (N)**	Town of Abita	30.459010	-90.035901
New Claiborne		IND		
Northern Homes Property		IND		
Oak Alley Estates		IND	30.500152	-90.122158
Oak Knoll Estates		IND	30.481473	-89.928393
Oak River Estates		Artesian Utility Company Inc (W/S)	30.469908	-90.070495
Old Military Heights		IND		
Old Stonehill Acres		IND		

Pailet		Williams Water Works / IND (S)		
Palm Plaza		*Lee Road Water Corp.(W) / IND (S)	30.516777	-90.069005
Not Mapped	Paloma Pines	IND	30.514205	-90.079531
Pelican Estates		IND	30.489725	-90.008524
Ponchitolawa		IND	30.453751	-90.024607
Project 59		IND		
Red Gap Acres		IND	30.446067	-90.046604
Red Gap Annex		IND		
Red Oak Estates		IND		
River Glen		IND	30.502924	-90.089348
River Heights		*Lee Road Water Corp. (W) / IND (S)	30.527555	-90.100570
River Parc Estates	River Parc	IND		
Riverbank Farms		IND	30.557950	-90.062916
Riverside Dr. Estates		IND		
Robindale		IND	30.490268	-90.061684
San Souci Forest		IND	30.518655	-90.088491
Schiro Estates		IND	30.568989	-90.146808
Not Mapped	**Shadows East**	IND	30.568989	-90.146808

Simalusa Estates		IND		
Singing Rivers		IND		
Southwind		Town of Abita Springs (W/S)	30.466896	-90.041624
Spring Clover Estates		IND		
St. Tammany Terrace	Tammany Terrace	IND	30.544374	-90.074852
St. Gertrude Heights		Tammany Utilities (W/S)	30.522680	-90.115206
Stonelake Estates		IND	30.601734	-90.189621
Sundown Farms		IND		
Sunny Meadows Acres		IND	30.494744	-89.991090
Sunrise Park		Water District No. 2/Utilities Inc of Louisiana (W/S)	30.484735	-90.061221
Tammany Hills		IND	30.454408	-90.061324
Terra Mariae		Lee Road Water/Density (W/S)	30.525444	-90.063602
(Not Mapped)	**The Plantation(N)**	IND	30.570561	-90.038623
The Savannahs		IND		
Venchy Branch Estates		IND	30.540715	-90.096159
Versailles		Utilities Inc of Louisiana (W/S)	30.435255	-90.093379
Village Farms		IND		
The Vineyards		Water District No. 2/Utilities Inc of Louisiana (W/S)	30.476737	-90.063919
(Not Mapped)	Vintage Court (retirement village?)	?	30.523359	-90.123294
(Not Mapped)	Vintage Court (Marigold, part of Ingram Est)	Utilities Inc of Louisiana (W/S) ?	30.459579	-90.055852
Waldheim Estates		IND	30.539874	-90.011145
West Abita Springs		IND		
Whippoorwill Grove		*H20 Systems Inc (Phase 7) (W) / IND (S)		
Wilsonville		IND	30.513743	-90.036783
Woodland Grove Acres		IND	30.528763	-89.902833
Yellow Pine Park		IND	30.540410	-90.072902

Tota Subdivisions in Watershed=114
94 Unsewered (82.5%)

20 Sewered (17.5%)

	Sewered=14 (18.4%)
Subs in Abita=76 (66.7% of total subs)	Unsewered=62 (81.6%)
Subs in Bogue Falaya=38 (33.3% of total subs)	Sewered=6 (15.8%)
	Unsewered=32 (84.2%)

Not Mapped	
Individual Sewer	
Found in St. Tammany Utility Provider List	

APPENDIX E: EXCERPT FROM: QUALITY ASSURANCE PROJECT PLAN

Problem Definition/Background (A5)

Lake Pontchartrain is the centerpiece of a large estuarine watershed in southeast Louisiana. On the north shore of Lake Pontchartrain is a rapidly developing region. Several major rivers of the Pontchartrain Basin run through this region and have begun to feel the effects of poorly planned development. The building of subdivisions, shopping centers, and other private and commercial developments has introduced many types of pollution into the rivers, the most prevalent of which is poorly or untreated sewage. This was a major reason most rivers were closed to primary contact use (i.e. direct body contact with water) by the mid-1980s.

The Lake Pontchartrain Basin Foundation (LPBF), in association with the Louisiana Department of Health and Hospitals (DHH), began performing intensive water quality monitoring around the Basin in 2001 (Bourgeois-Calvin, QAPP 2000). Data analysis revealed sites north of the Lake to have significantly higher fecal coliform counts than sites south of the Lake. In 2002, LPBF began to investigate the sources of fecal pollution contributing to the high counts observed on north shore waterways, breaking down the task by sub-watershed. To date, the Bogue Falaya /Tchefuncte River and the Tangipahoa River/Natalbany River sub-watersheds have undergone the pollution source tracking regime (Bogue Falaya Q-Track # 02-083; Tchefuncte Q Track # 03-090; Bogue Falaya/Tchefuncte Q Track # 04-082; Tangipahoa Q-Trak # 05-130; Tangipahoa and Natalbany Q-Trak # 07-009, Q-Trak # 09-025, Q-Trak # 10-008).

LPBF will continue the pollution source-tracking program in the Tangipahoa and Tickfaw (of which Natalbany is a tributary) watersheds in Tangipahoa, Livingston, and St. Helena Parishes and will perform the monitoring component in the Bogue Falaya and Abita watersheds in St. Tammany Parish (Figures 2a and 2b). LPBF will utilize three pollution source tracking tools-water quality monitoring; source identification with inspection, assistance, and owner/operator education; and GIS analysis - to accomplish the main goal of the study, the location and correction of pollution sources within in the waterways. Statistical analyses will document baseline conditions and changes in water quality as a result of the program.

Project/Task Description (A6)

This project will be conducted by LPBF with activities to be performed September 2010 – September 2013 in the Tangipahoa and Tickfaw watersheds (Figure 2b), as per a DEQ 319 grant. In the Bogue Falaya and Abita Watersheds (Figure 2a), monitoring is to be conducted September 2010 to August 2011 as part of the Watershed Protection Plan being written.

Sites along the Tangipahoa and Natalbany Rivers and their major tributaries (Figure 2b) have been monitored for water quality parameters since 2005. Sites along the Bogue Falaya and Abita Rivers and their major tributaries (Figure 2a) have been monitored since 2002. LPBF is using that data to track, identify, and correct sources of pollution within the watersheds. LPBF will monitor water quality at the specified sites and employ GIS and statistical analyses to document changes to water quality as a result of the program.

Figure 2a. Map of St. Tammany Parish Watersheds and Monitoring Sites.

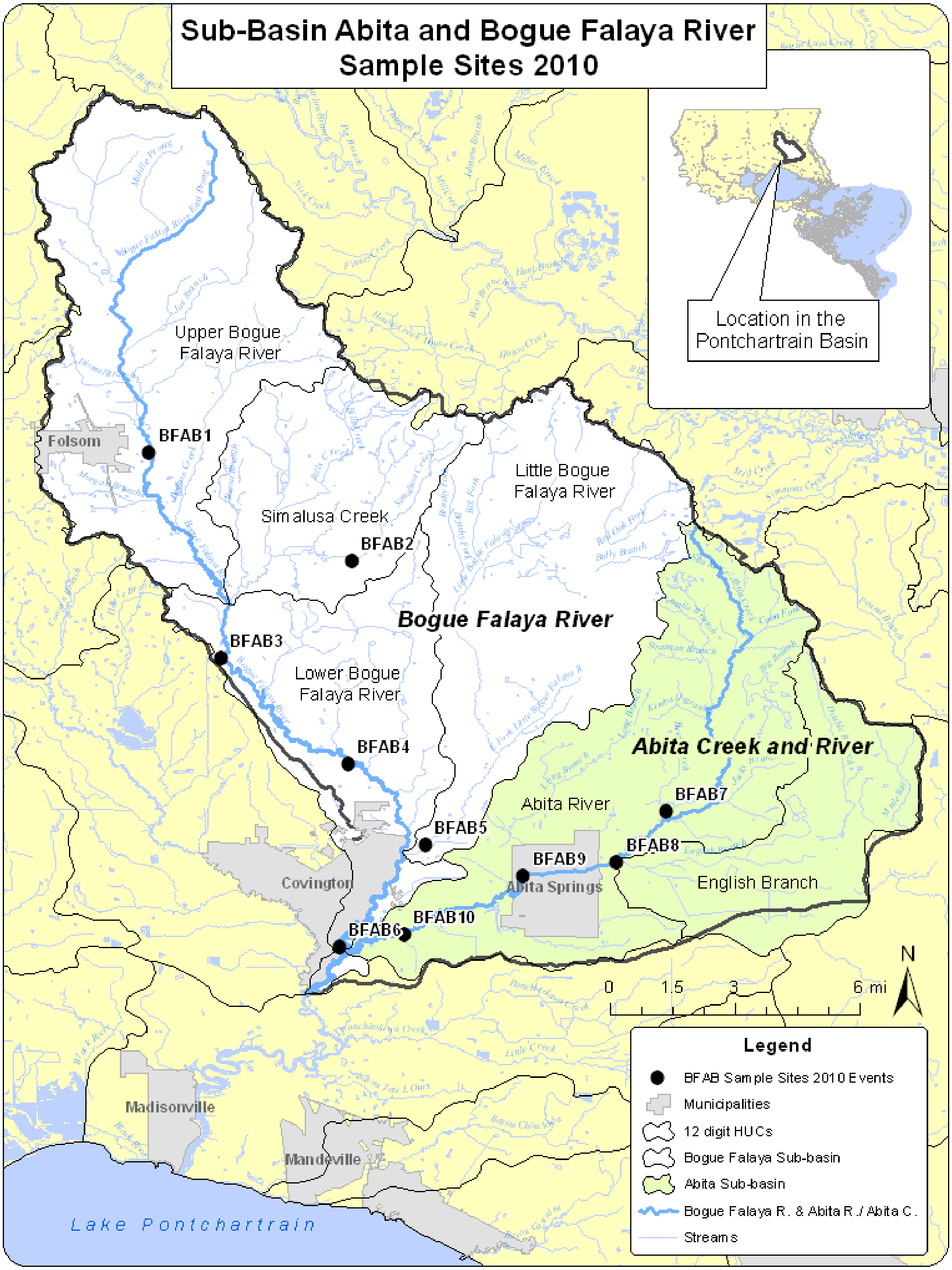
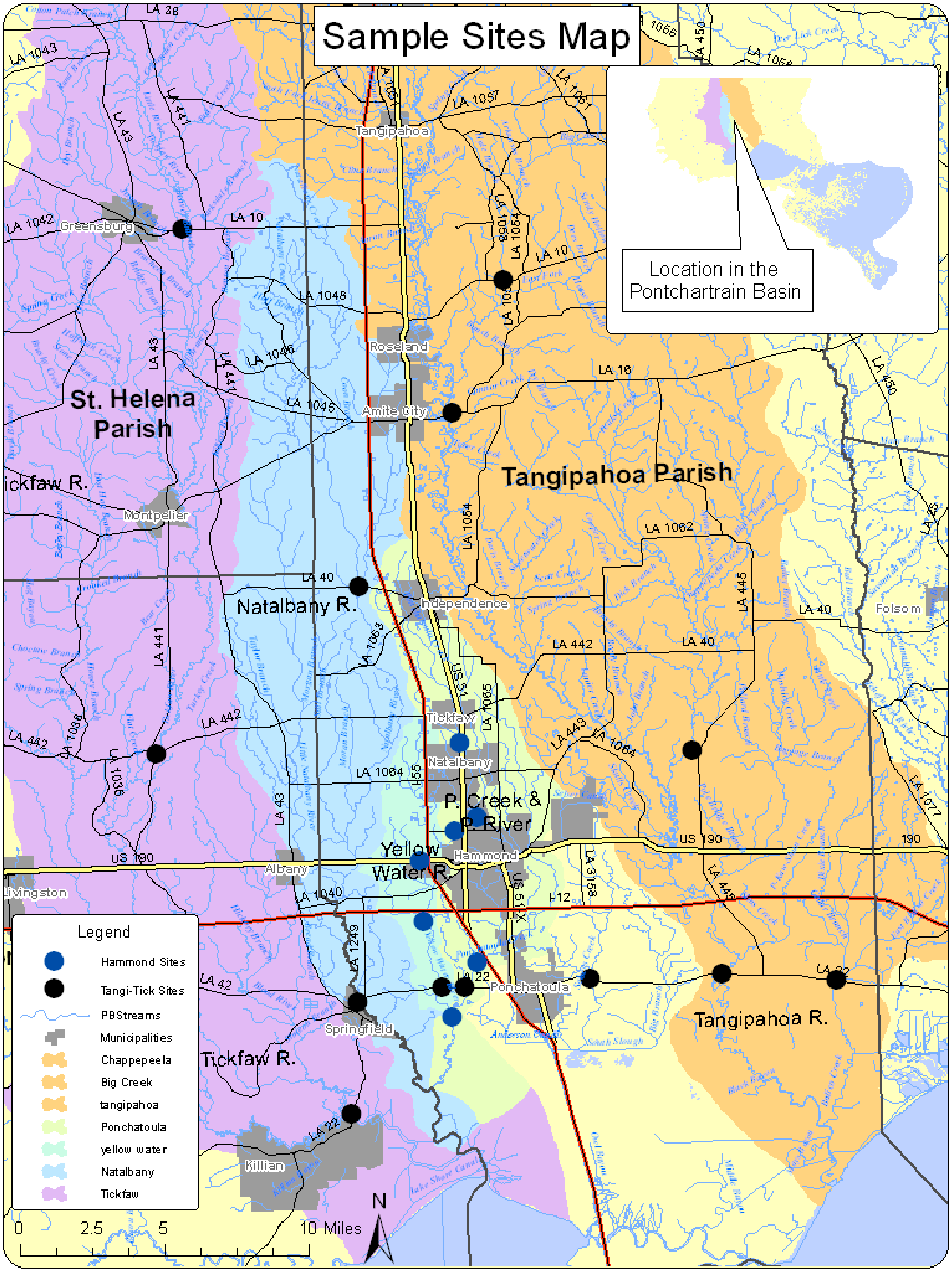


Figure 2b. Map of Tangipahoa, Livingston, and St. Helena Parishes Watersheds and Monitoring Sites.



To accomplish the major goal of this study, the tracking of pollution sources, tributaries will be monitored bi-weekly (by car) to determine input into the watersheds and help direct the investigation of sources. For this monitoring, water temperature, dissolved oxygen, specific conductance, turbidity, fecal coliform, and *E.coli*, and a suite of nutrients (nitrate, nitrite, ammonia, total nitrogen, phosphate, total organic carbon, and inorganic carbon) will be measured. This monitoring will also serve to document changes in water quality as a result of the program.

To accomplish a secondary goal of this study, stationary sites along the major rivers will be monitored for the same parameters as the tributaries. This data will be utilized to monitor changes in water quality within the river system through time and as a result of the program. Data collection methodology for this study is in accordance with *Standard Methods for the Examination of Water and Wastewater, 20th Ed*.

Concurrently, LPBF will utilize GIS to map located and potential sources of pollution (i.e. businesses, homes, developments, farms, etc.) throughout the study. LPBF will utilize and ground-truth GIS maps, digital images, and existing data layers as well as create new data layers based on our findings.

The objectives of this program are to utilize the continued water quality sampling, pollution source tracking, and GIS analysis in the watersheds to:

1) Identify and correct sources that contribute to fecal pollution in the rivers as located through water quality monitoring and GIS analysis.
2) Document a baseline condition and track changes in water quality as a result of the program through water quality monitoring.

This QAPP addresses the QA/QC requirements for the project. This data collection and analysis component of this study consists of three elements: a laboratory effort (bacteria and nutrient analyses); *in situ* measurement of the physiochemical parameters; and gathering and analysis of data for GIS/statistical analyses.

Quality Objectives and Criteria (A7)

The purpose of this project is to continue the search for and correction of pollution sources within rapidly developing watersheds on the north shore of Lake Pontchartrain. Data to be collected will include water quality testing, research of land use patterns, and identification of pollution sources. This data will be used to perform statistical and GIS analyses. Observing and recording the behavior of the actual system through the field data collected and the creation of a GIS database, as described in this QA/QC plan, will accomplish this purpose.

Sampling activities have been described above (Section A6) and data collection methodology for this study, sample size, and quality criteria are discussed in Section B. Water quality data will be stored in a Microsoft Excel spreadsheet. It will be subjected to quality control and descriptive statistics as described in *Guidance for Data Quality Assessment* (EPA QA/G-9). The mean (and/or median if using non-parametric stats.) and relative percent difference will be computed bi-annually for each parameter at each site as part of the quality assurance regime. Statistical analyses on the data will be performed using Microsoft Excel or JMP, a SAS program.

- *To address the first objective*: Fecal coliform, *E.coli*, and nutrient values from each monitored tributary will be compared to the DHH's standards for primary contact. For sites with high values (prioritized by magnitude- see below), land use will be analyzed (on the ground and through GIS) and contributing sources will be investigated.

- *To address the second objective*: Water quality monitoring will be used to establish a baseline condition against which subsequent data will be compared. This will be utilized to document changes in water quality and to potentially direct source tracking.

The investigation of pollution sources within the watersheds will be prioritized based on the results of the water quality monitoring, GIS land use analysis, and physical observation of land use. Water quality monitoring sites (including river, tributary, and drainage sites) with at least three fecal coliform counts over 1000 MPN (during dry-weather conditions) will have priority for source investigation. Sites with fecal coliform counts of 200-1000 MPN will have second priority and sites with counts < 200 (meeting primary recreation contact standards) will be considered "clean" and not investigated. For priority sites, physical observation and GIS, if needed, will be used to locate sources and assistance will be offered.

Summaries of the analyzed data will be presented in a semi-annual status report and in a final project report to EPA. Quality assurance will be maintained by the LPBF through performance evaluations, audits, and semi-annual reports made to LPBF and EPA.

Special Training Requirements (A8)

The water monitoring staff has been trained by the Southeastern Louisiana University Microbiology Laboratory on sampling procedures. The LPBF Environmental (GIS) Specialist, conducting the GIS analysis, has been trained in the use of all programs necessary to complete the project, including ArcGIS with extensions ArcMap, ArcCatalog, and ArcToolbox (ESRI). The wastewater technician contracted for the location of pollution sources has Class IV wastewater operator's certification and over 8 years experience tracking pollution sources with LPBF.

Documentation and Records (A9)

All project personnel will receive copies of this QAPP and subsequent updates/revisions. Water monitoring personnel will receive copies of the sampling standard operating procedure with all standard methods employed explained in full detail and copies of operator's manuals for all equipment. Records maintained will include the following: all data relating to sampling, analysis and quality control, documentation on equipment upkeep and calibrations for preventative maintenance, documentation of errors and corrective actions, and all performance evaluations. Project reports will be generated semi-annually to assess progress of the project. These will be submitted to EPA on or about July 15th (covering activities Jan-Jun) and January 15 (covering activities Jul-Dec) for review and approval.

Sampling Process Design (B1)

LPBF will perform intensive water quality monitoring, pollution source tracking, and GIS analysis in the Tangipahoa and Tickfaw watersheds in Tangipahoa Parish and the Bogue Falaya and Abita watersheds in St. Tammany Parish.

To achieve the first study objective, identification of sources that contribute pollution to the watersheds, LPBF will monitor discharge points (mainly tributaries) in the watersheds to assess potential input from these areas. Sites will be accessed by car and will be established with GPS coordinates. Sites will be sampled as near to their discharge point into the main river as possible at least bi-weekly or 20 times minimum in a one-year period and potentially following at least one rain event. Sites will be monitored throughout the course of the project to potentially document improvement in discharge quality as a result of intervention. Based on the findings, exploratory sites may also be monitored to help locate inputs.

To achieve the second study objective, documentation and tracking of fecal coliform/*E.coli*, nutrients, and water quality parameters within the main rivers**,** LPBF will establish monitoring sites along the main rivers. All sites will be accessible by vehicle and established with GPS coordinates. Sites will be monitored bi-weekly or at least 20 times in a one-year period.

The physiochemical parameters of water temperature, dissolved oxygen, specific conductance, pH, and turbidity and the enteric pathogen indicators of fecal coliform and *E. coli* will be taken at each site. A suite of nutrients (nitrate, nitrite, ammonia, total nitrogen, phosphate, total organic carbon, and inorganic carbon) will also be analyzed for each site. At each site, physiochemical parameters will be sampled three times *in situ*. For the fecal coliform, *E. coli*, and nutrient analysis, one 1 Liter grab sample will be taken at each site, in the area of maximum flow, and transported, on ice, to the laboratory within six hours of collection. Results will be obtained from the lab within one week of submission. Information regarding the time of analysis, and name of the person taking the measurements, and state of the site (i.e. trash/debris, wildlife, weather) will be recorded. All test results and information will be stored at LPBF in a spreadsheet where it will be quality assured.

The water monitoring regime is based on and meant to compliment past monitoring in the Bogue Falaya, Tchefuncte, Tangipahoa, and Natalbany watersheds (LPBF QAPP, 2002, 2003, 2004, 2005, 2006, 2008, 2009). All parameter measurements will be analyzed according to *Standard Methods for the Examination of Water and Wastewater, 20th Edition* (1998).

Sampling Methods Requirements (B2)

Physiochemical Parameters

Temperature, specific conductance, dissolved oxygen, pH, and turbidity will be measured *in situ* (by meters outlined in B4). For each site, three measurements will be averaged for each parameter as the daily value. All values will be recorded on the water quality data sheet (Figure

3). The Principal Investigator will be responsible for coordination of analyses and corrective action if necessary.

Microbiological and Nutrient Analysis
Grab samples of 1 liter volume will be taken at each site to be analyzed for fecal coliform and *E.coli* bacteria and a suite of nutrients (nitrate, nitrite, ammonia, total nitrogen, phosphate, total organic carbon, and inorganic carbon) in accordance with *Standard Methods for the Examination of Water and Wastewater* Methods 1060B and 9060A. Samples will be collected in a 1 liter sterilized plastic sample bottle using a fishing pole with bottle holder. In the case of non-sterile procedure or other sampling procedure failure, the collection bottle will be discarded and another will be labeled and employed. The samples will be stored on ice (< 10ºC, SM 9060B) and transported to the laboratory within six hours of collection, in accordance with *Standard Methods for the Examination of Water and Wastewater* Methods 1060C and 9060B. Upon receipt of samples in the lab, bacteria samples will either be processed immediately or placed in a refrigerator not to exceed two hours before processing. Nutrient samples will be held in accordance with their individual procedures.

Sample Handling (B3)

All physiochemical measurements are to be performed *in situ.* Data will be recorded on field data forms (Figures 3). Sample handling procedures for microbiological and nutrient analysis are presented in B2. Samples will be collected by the water monitoring personnel, delivered by him/her to the laboratory, and personally handed to the lab personnel performing the analysis. Sample labeling, handling, and disposal within the laboratory will proceed in accordance with their standard operating procedures.

Analytical Methods Requirements (B4)

Physiochemical, Microbiological, and Nutrient Analysis
The analytical methods to be employed for this study are summarized in this section (Table 1).

Table 1

Parameter	Method	Equipment
Dissolved Oxygen	Standard Methods for Examination of Water and Wastewater, 20th Ed. method 4500-OG	YSI85 S-C-DO-T Meter 0-20mg/L range, ± 0.3mg/L accuracy
Temperature	Standard Methods for Examination of Water and Wastewater, 20th Ed. method 2550B	YSI85 S-C-DO-T Meter -5 to +65°C range, 0.1°C accuracy
Specific Conductance	Standard Methods for Examination of Water and Wastewater, 20th Ed. method 2510B	YSI85 S-C-DO-T Meter 0 to 4999 µS/cm range, ± 0.5% accuracy

Turbidity	Standard Methods for Examination of Water and Wastewater, 20th Ed. method 2130 B	Hach Portable Turbidimeter 0 to 1000 NTU range, 0.01 NTU accuracy
pH	Standard Methods for Examination of Water and Wastewater, 20th Ed. method 4500-H^+B	YSI 60 pH Meter 0 to 14.00 range, 0.1pH accuracy
Alkalinity	Standard Methods for Examination of Water and Wastewater, 21th ed. Method 2320B, Titration method	Oakton pH 510 series meter Brinkman digital buret both 0-20mg/L range and >20 mg/L method used, depending on sample As per Standard method, no general precision statement can be made.
Nitrate/Nitrite	Standard Methods for Examination of Water and Wastewater, 21th ed. SM 4500-NO3 F	Hach DR5000 Spectrophotometer BioTek PowerWave HT Microplate Spectrophotometer 0.1-unlimted range (dilution scheme used for high range samples)
Orthophosphate as P	Standard Methods for Examination of Water and Wastewater, 21th ed. SM 4500-P E	Hach DR5000 Spectrophotometer BioTek PowerWave HT Microplate Spectrophotometer 0.01-unlimted range (dilution scheme used for high range samples) precision: for 0.228 ug/L sample Relative SD =3.03
TOC/IC	Standard Methods for Examination of Water and Wastewater, 20th ed. SM 5310 B	Shimadzu TOC-Vcpn Range: 0.1-unlimited range (dilution scheme for high range samples) precision: 5-10% depending on sample characteristics
TN	High Temperature Combustion/Chemilumenscence	Shimadzu TOC-Vcpn, TNM-1 module 0.1-200mg/L precision: CV 3% max
Ammonia as N	Standard Methods for Examination of Water and Wastewater, 20th ed. SM 4500-NH3 G B	Hach DR5000 Spectrophotometer BioTek PowerWave HT Microplate Spectrophotometer 0.05-unlimited range (dilution scheme used for high range samples)
Fecal coliform	Standard Methods for Examination	detection limit: MPN 2/100ml

	of Water and Wastewater, 20th ed. SM 9221-E (A1)	precision: follows MPN chart in Standard Methods
Escherichia coli	Standard Methods for Examination of Water and Wastewater, 20th ed. SM 9225-C	detection limit: MPN 2/100ml precision: follows MPN chart in Standard Methods

Quality Control Requirements (B5)

The quality control performed on a sample or set of samples is dictated by the protocols of the individual methods. All quality control methodology and statistics will be performed in accordance with: Methods 1020B&C, 1030A, the parameters' test methods in *Standard Methods for the Examination for Water and Wastewater*, the manufacturers' guides, and the *Guidance for Data Quality Assessment* (EPA QA/G-9). The laboratories will perform all of their quality control requirements in accordance with standard operating procedures/QA plans.

Field Replicates
At least once per quarter a replicate water sample will be collected (sequentially, at the same location after sample collection) at one of the sampling sites and submitted to the laboratory as a blind sample. The replicate data will be utilized and analyzed as quality control values.

Field Duplicates
All sites undergo triplicate sampling on all sampling dates for QA purposes. On a bi-annual basis, equipment will be calibrated and simultaneous sampling of the physiochemical parameters will be conducted for quality control measures at all LP sampling sites. The duplicate data will be utilized as quality control values.

Field and Laboratory Blanks
At least once per quarter, one extra sample (the blank) will be collected by pouring distilled water into the collection bottle in the field and submitting it to the lab with the other samples (blind sample). The QC goal for bacteria is no growth in the sample, which would appear as <1.8 MPN on the data form. Laboratory blanks will be run under the lab's QA plan.

Matrix Spikes/ Spike Duplicates
Matrix Spikes/ Spike Duplicates are not necessary for the analysis of physiochemical parameters as all tests are conducted *in situ*. Matrix Spikes and Spike Duplicates associated with the collection and analysis of fecal coliform and nutrients are detailed in the labs' QA plans.

Analysis of Quality Control Data
Quality control data is summarized in QA/QC reports and forwarded to the QA Senior Manager. Data from the reports are utilized to assess the overall precision, accuracy, and completeness of each particular method. For these methods, the precision and accuracy is assumed to approximate published precision and accuracy.

Assessing Data Precision, Accuracy, and Completeness

1. Precision

Precision is defined as the reproducibility of multiple data points that have been generated for a particular method under identical condition. On each sampling date, three readings for each physiochemical parameter are taken at each site. The triplicate data is subjected to precision analysis. Precision is expressed as the relative percent difference (RPD). The JMP Statistical Program, or Microsoft Excel will be used for these calculations.

$$RPD = (X^1 - X^2) / X(100)$$

Where X^1 and X^2 are maximum and minimum sample values from daily triplicate samples

2. Accuracy

Accuracy is a measure of the closeness an experimentally observed value and the actual value, the latter of which is determined by the analyst through the use of sample spikes, surrogates, or reference standards. Field meters will be considered to be giving accurate readings through calibration with NIST standards and equipment maintenance. See Calibration and Maintenance schedule (Table 2) below for upkeep activities.

3. Completeness

Completeness is the amount of valid data generated in relation to the total amount of data produced for a given analytical method. Valid data is defined as data with associate QA/QC measurements that fall within required values for the purpose of this study (Table 2). Data completeness goal for each parameter are also noted in Table 2.

Evaluation of Statistically Derived QA/QC Data

Data that has been generated for QA/QC purposes must be assessed to determine the ability of the equipment and personnel to generate reliable data. Microsoft Excel or JMP statistical program will be used for these calculations.

Table 2. Criteria for QA/QC Analyzed Parameters

Parameter	Relative % Difference	Standard Method	Completeness Goal
Specific Conductance	5	Ref1/2510B	> 90% data/ year
Turbidity	10	Ref1/2130B	> 90% data/ year
Temperature	5	Ref1/2550B	> 90% data/ year
Dissolved Oxygen	10	Ref1/4500-OG	> 90% data/ year
PH	5	Ref1/4500-H^+	> 90% data/ year
Fecal Coliform/E.coli	20	EPA corresp.	> 90% data/ year

Microbiological Analysis
The lab, in accordance with its QA plan, will conduct all quality control requirements for the microbiological portion of this research.

Instrument/Equipment Testing, Inspection, and Maintenance Requirements (B6)

Physiochemical Parameters
All equipment and associated components will be inspected, calibrated, and tested by the Principal Investigator upon receipt according to the operator's manual. Equipment will be maintained according to the operator's manuals with all calibrations and maintenance documented. If a piece of equipment gets damaged or otherwise does not perform correctly, the piece of equipment will be mailed to appropriate repairers. Equipment will be re-inspected, calibrated, and tested by the Principal Investigator or water monitoring personnel upon receipt. Back ups for all equipment and spare parts will be maintained by the LPBF at all times.

Microbiological Analysis
The labs will test, inspect, and maintain their own equipment in accordance with their QA plans.

Instrument Calibration and Frequency (B7)

Physiochemical Parameters
Calibration protocols are performed under the following conditions:
1) First use of an analytical instrument, component of the analytical instrument, or analytical method;
2) During the sample analysis procedure, as dictated by the methodology;
3) After instrument repair and/or maintenance;
4) After quality control check failure.

Additional calibration requirement and procedures recommended by the instrument manufacturers' are also followed. All calibrations are performed according to the operator's manual using standard solutions purchased from the instrument manufacturers (standardized against NIST-certified references). All calibrations are performed in accordance with the procedures specified in the analytical methodology commanding their use (Table 3).

Table 3. Physiochemical Instruments Calibration/Maintenance Procedures

Equipment	Schedule	Procedure
Dissolved Oxygen Probe	Each Use/Weekly→	- Calibrate to 100% saturation - Check against standard chart
	Tri-weekly→	- Change tip of probe
	Bi-annually→	- Clean anode/cathode, change tip of probe
Conductivity Probe	Bi-Annual/ Repair→	- Check one standard KCl solution
	Tri-weekly→	- Check salinity against distilled water

Turbidimeter	Three Months→	- Calibrate to formazin standard
	Tri-weekly→	- Check against secondary standards
pH meter	Each Use/Weekly→	- Perform two point calibration
	Tri-weekly→	- Change all buffers and solutions

Microbiological and Nutrient Analysis
The lab standardizes and calibrates all of its equipment in accordance with its QA plan.

Inspections/Acceptance Requirements for Supplies and Consumables (B8)

The Principal Investigator and the monitoring personnel will log the receipt of all new equipment and will inspect, calibrate, and test the equipment (as necessary) before accepting them. If equipment/supplies are damaged or do not pass calibration and testing, they will not be accepted. All supplies will be handled and stored according to operator's instructions.

Microbiological and Nutrient Analysis
During sample collection, the monitoring personnel are responsible for inspection and acceptance of the sample containers. The lab will inspect its own consumables and supplies in accordance with its QA plan.

Non-Direct Measures (B9)

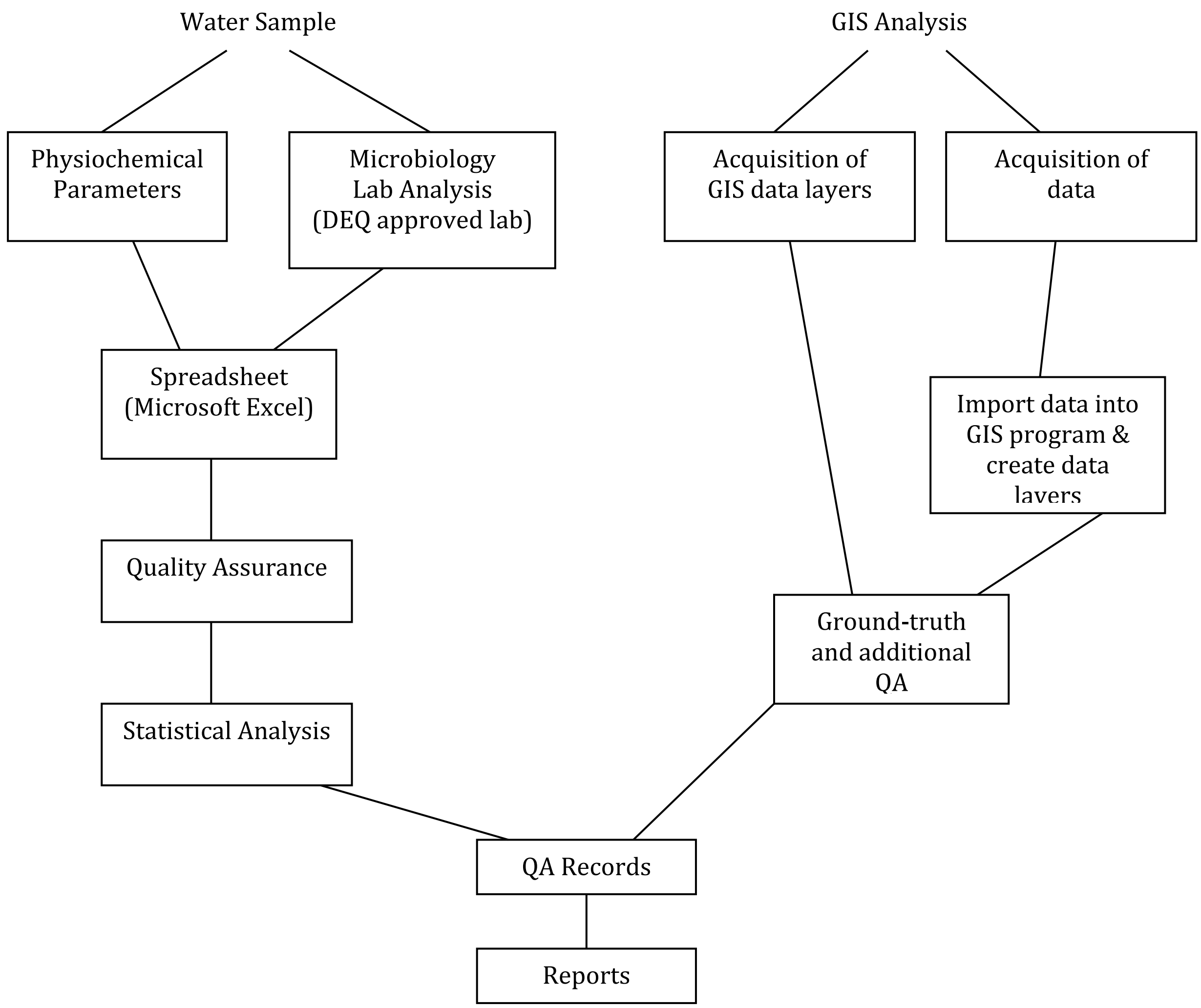
GIS
Secondary data sets are needed to accomplish the objectives of this study. In an effort not to duplicate what government entities have already produced, data sets from known, reliable government sources will be employed for the GIS portion of this study. The most recent satellite images and aerial photographs available (including Landsat TM and DOQQ images) will be utilized to most accurately reflect the current land use of the Tangipahoa and Natalbany watersheds. All non-imagery data will be ground-truthed. The primary programs to be utilized in the viewing and creation of GIS themes will be Arc GIS 10 (with Arc Map, Arc Catalog, and Arc Toolbox extensions- ESRI, 2010). Additional data sources for state compliance of WWTP's and general land patterns have been and may be obtained from the Louisiana Department of Environmental Quality (LDEQ), the Louisiana Department of Health and Hospitals (LDHH), United States Geologic Survey (USGS), and Tangipahoa Parish.

Data Management (B10)

Data management will follow the chart presented below (Figure 4). The results of both the physiochemical and microbiological analysis will be put into a spreadsheet format by the LPBF monitoring personnel for preliminary descriptive statistical analysis (Microsoft Excel). JMP, a SAS program, will be utilized for statistical analysis and ArcGIS will be used for GIS analysis.

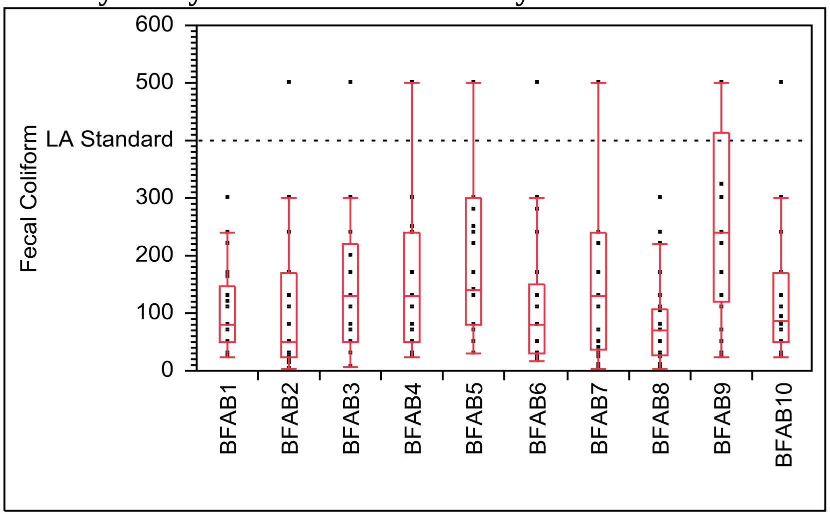
Figure 4. Data Management Flow Chart

* All steps in data flow performed by LPBF unless indicated otherwise.



APPENDIX F: STATISTICAL ANALYSIS RESULTS

Oneway Analysis of Fecal Coliform By Site



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
BFAB1	23	38	50	80	147.5	240	300
BFAB2	2	15.8	23	50	170	500	1600
BFAB3	8	30	50	130	220	420	1600
BFAB4	23	30	50	130	240	900	1600
BFAB5	30	50	80	140	300	500	1600
BFAB6	17	23	30	80	150	292	1600
BFAB7	2	15.4	35	130	240	740	1600
BFAB8	2	9.2	26.5	70	106.5	276	900
BFAB9	23	38	120	240	412.5	900	1600
BFAB10	23	25.1	50	87.5	170	300	500

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
BFAB1	33	5136.50	5445.00	155.652	-0.596
BFAB2	33	4163.00	5445.00	126.152	-2.480
BFAB3	33	5733.00	5445.00	173.727	0.556
BFAB4	33	5906.00	5445.00	178.970	0.891
BFAB5	33	6823.50	5445.00	206.773	2.667
BFAB6	33	4579.00	5445.00	138.758	-1.675
BFAB7	33	5436.00	5445.00	164.727	-0.016
BFAB8	33	3970.00	5445.00	120.303	-2.854
BFAB9	33	7575.50	5445.00	229.561	4.123
BFAB10	32	4962.50	5280.00	155.078	-0.622

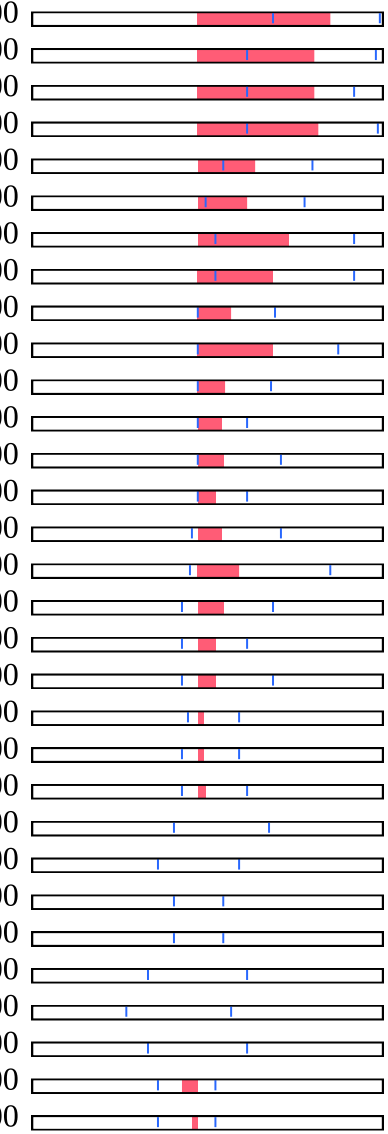
1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
38.7693	9	<.0001*

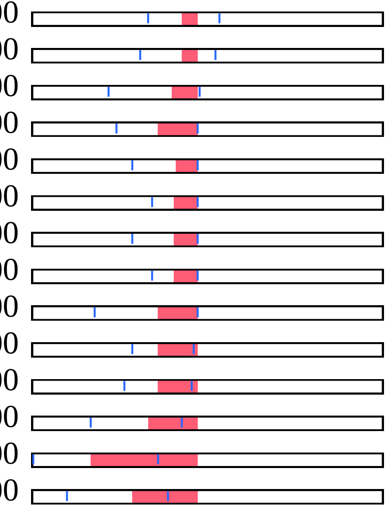
Nonparametric Comparisons For Each Pair Using Wilcoxon Method

q*	Alpha
1.95996	0.05

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value	Hodges-Lehmann	Lower CL	Upper CL	Difference
BFAB9	BFAB8	20.1515	4.713617	4.27517	<.0001*	160.000	90.000	220.000	
BFAB9	BFAB6	17.5455	4.712726	3.72299	0.0002*	140.000	60.000	215.000	
BFAB9	BFAB1	17.4848	4.712133	3.71060	0.0002*	140.000	60.000	190.000	
BFAB9	BFAB2	16.8788	4.713320	3.58108	0.0003*	147.000	60.000	218.000	
BFAB5	BFAB2	14.3030	4.707233	3.03852	0.0024*	68.000	30.000	138.000	
BFAB5	BFAB1	12.5152	4.699948	2.66283	0.0077*	60.000	10.000	130.000	
BFAB9	BFAB3	12.5152	4.708966	2.65773	0.0079*	110.000	22.000	190.000	
BFAB9	BFAB7	11.9697	4.708718	2.54203	0.0110*	90.000	20.000	190.000	
BFAB4	BFAB2	10.9394	4.707282	2.32393	0.0201*	40.000	0.000	93.000	
BFAB9	BFAB4	10.7576	4.711688	2.28317	0.0224*	90.000	0.000	170.000	
BFAB3	BFAB2	9.7576	4.705499	2.07365	0.0381*	33.000	0.000	88.000	
BFAB10	BFAB8	8.1250	4.664757	1.74178	0.0815	28.000	0.000	60.000	
BFAB5	BFAB3	7.3939	4.698708	1.57361	0.1156	30.000	0.000	100.000	
BFAB10	BFAB2	6.8939	4.668518	1.47669	0.1398	21.000	0.000	60.000	
BFAB7	BFAB2	6.6970	4.709263	1.42208	0.1550	27.000	-8.000	100.000	
BFAB9	BFAB5	6.4242	4.708025	1.36453	0.1724	50.000	-10.000	160.000	
BFAB5	BFAB4	6.0909	4.704707	1.29464	0.1954	30.000	-20.000	90.000	
BFAB4	BFAB1	4.6364	4.697914	0.98690	0.3237	20.000	-20.000	60.000	
BFAB7	BFAB6	4.6061	4.707431	0.97847	0.3278	20.000	-20.000	90.000	
BFAB6	BFAB2	3.8485	4.699402	0.81893	0.4128	7.000	-13.000	50.000	
BFAB10	BFAB6	3.8471	4.659239	0.82569	0.4090	7.000	-20.000	50.000	
BFAB3	BFAB1	3.8182	4.695581	0.81314	0.4161	10.000	-20.000	60.000	
BFAB7	BFAB1	2.0303	4.705301	0.43149	0.6661	0.000	-30.000	87.000	
BFAB4	BFAB3	1.0606	4.692900	0.22600	0.8212	0.000	-50.000	50.000	
BFAB8	BFAB2	0.2121	4.703468	0.04510	0.9640	0.000	-30.000	30.000	
BFAB10	BFAB1	-0.5232	4.666045	-0.11213	0.9107	0.000	-30.000	30.000	
BFAB7	BFAB3	-1.0606	4.702427	-0.22554	0.8216	0.000	-60.000	60.000	
BFAB10	BFAB7	-1.8158	4.672842	-0.38859	0.6976	0.000	-87.000	40.000	
BFAB7	BFAB4	-2.4545	4.703567	-0.52185	0.6018	-1.000	-60.000	60.000	
BFAB6	BFAB1	-4.5152	4.697815	-0.96112	0.3365	-20.000	-50.000	20.000	
BFAB8	BFAB6	-4.5152	4.692850	-0.96213	0.3360	-9.000	-48.000	20.000	

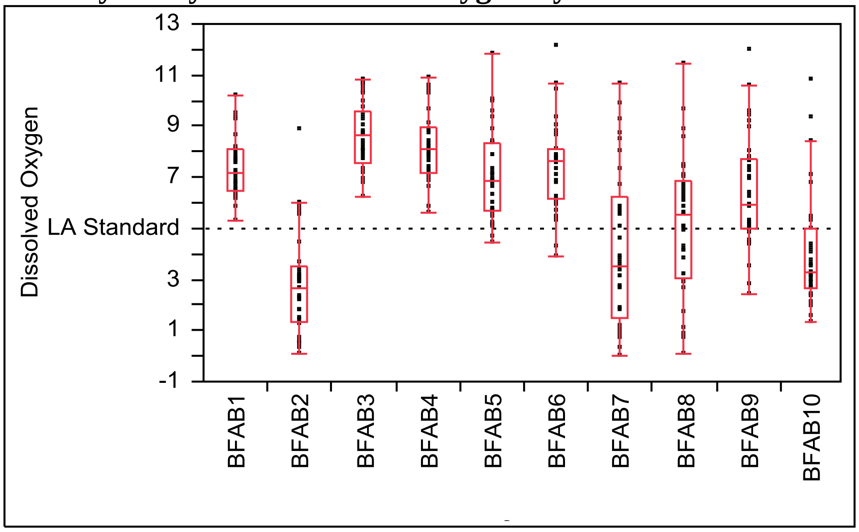


Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value	Hodges-Lehmann	Lower CL	Upper CL	Difference
BFAB10	BFAB3	-4.6165	4.667024	-0.98917	0.3226	-20.000	-60.000	25.000	
BFAB10	BFAB4	-5.2936	4.670012	-1.13352	0.2570	-20.000	-70.000	20.000	
BFAB8	BFAB7	-7.6364	4.709510	-1.62148	0.1049	-32.000	-110.000	1.000	
BFAB7	BFAB5	-7.8485	4.710401	-1.66620	0.0957	-48.000	-100.000	0.000	
BFAB6	BFAB3	-7.9091	4.703071	-1.68169	0.0926	-27.000	-80.000	0.000	
BFAB2	BFAB1	-8.0000	4.706441	-1.69980	0.0892	-30.000	-57.000	0.000	
BFAB6	BFAB4	-8.5152	4.703815	-1.81027	0.0703	-30.000	-80.000	0.000	
BFAB8	BFAB1	-8.7879	4.696326	-1.87122	0.0613	-30.000	-57.000	0.000	
BFAB10	BFAB5	-10.7102	4.668158	-2.29432	0.0218*	-50.000	-125.000	0.000	
BFAB8	BFAB3	-11.2424	4.704855	-2.38954	0.0169*	-48.000	-80.000	-6.000	
BFAB8	BFAB4	-11.8182	4.703914	-2.51241	0.0120*	-48.000	-90.000	-7.000	
BFAB6	BFAB5	-13.8182	4.699551	-2.94032	0.0033*	-60.000	-130.000	-20.000	
BFAB10	BFAB9	-15.3575	4.675569	-3.28462	0.0010*	-130.000	-200.000	-50.000	
BFAB8	BFAB5	-17.2424	4.699055	-3.66934	0.0002*	-80.000	-160.000	-37.000	



Fit Y by X Group

Oneway Analysis of Dissolved Oxygen By Site



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
BFAB1	5.28	6.112	6.475	7.17	8.115	9.418	10.19
BFAB2	0.06	0.474	1.335	2.63	3.5	5.78	8.86
BFAB3	6.24	7.024	7.535	8.64	9.59	10.606	10.86
BFAB4	5.63	6.59	7.135	8.13	8.985	10.512	10.87
BFAB5	4.41	5.05	5.665	6.86	8.325	9.82	11.83
BFAB6	3.9	5.284	6.14	7.67	8.125	9.968	12.16
BFAB7	0.02	0.688	1.47	3.5	6.27	9.066	10.7
BFAB8	0.06	0.968	3.07	5.52	6.86	8.734	11.44
BFAB9	2.43	3.824	5.005	5.93	7.705	9.516	12.02
BFAB10	1.36	1.638	2.67	3.24	4.99	8.168	10.8

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
BFAB1	33	6764.50	5428.50	204.985	2.585
BFAB2	33	1842.50	5428.50	55.833	-6.940
BFAB3	33	8472.50	5428.50	256.742	5.891
BFAB4	33	7921.00	5428.50	240.030	4.824
BFAB5	33	6207.00	5428.50	188.091	1.506
BFAB6	33	6850.50	5428.50	207.591	2.752
BFAB7	33	3439.00	5428.50	104.212	-3.850
BFAB8	33	4195.50	5428.50	127.136	-2.386
BFAB9	33	5441.00	5428.50	164.879	0.023
BFAB10	31	2822.50	5099.50	91.048	-4.531

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
147.4244	9	<.0001*

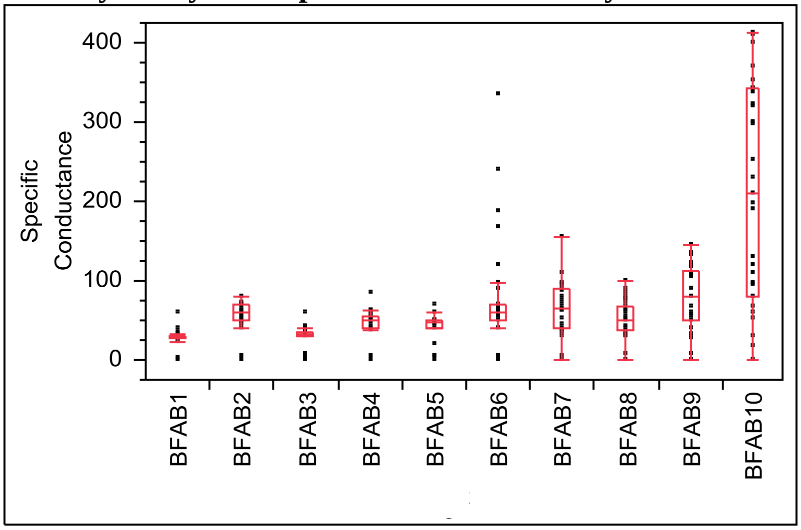
Nonparametric Comparisons For Each Pair Using Wilcoxon Method

q*	Alpha
1.95996	0.05

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value	Hodges-Lehmann	Lower CL	Upper CL	Difference
BFAB3	BFAB2	31.6364	4.725668	6.69458	<.0001*	5.97000	5.16000	6.85000	
BFAB4	BFAB2	31.2424	4.725569	6.61136	<.0001*	5.57000	4.81000	6.42000	
BFAB6	BFAB2	29.7273	4.725717	6.29053	<.0001*	4.83000	4.02000	5.62000	
BFAB5	BFAB2	29.0000	4.725618	6.13676	<.0001*	4.30000	3.50000	5.21000	
BFAB9	BFAB2	26.1212	4.725816	5.52734	<.0001*	3.65000	2.71000	4.62000	
BFAB8	BFAB2	17.6667	4.725717	3.73841	0.0002*	2.65000	1.27000	3.74000	
BFAB3	BFAB1	17.4848	4.725618	3.70001	0.0002*	1.21000	0.61000	1.86000	
BFAB9	BFAB7	15.2727	4.725816	3.23177	0.0012*	2.42000	1.19000	3.83000	
BFAB4	BFAB1	12.1212	4.725421	2.56511	0.0103*	0.83000	0.19000	1.45000	
BFAB10	BFAB2	11.5425	4.656915	2.47858	0.0132*	1.10000	0.18000	2.05000	
BFAB7	BFAB2	9.5758	4.725816	2.02627	0.0427*	1.08000	0.04000	2.60000	
BFAB9	BFAB8	8.4848	4.725668	1.79548	0.0726	1.04000	-0.12000	2.39000	
BFAB8	BFAB7	7.1515	4.725766	1.51330	0.1302	1.20000	-0.41000	2.73000	
BFAB6	BFAB5	5.7576	4.725520	1.21840	0.2231	0.60000	-0.37000	1.31000	
BFAB6	BFAB1	1.4848	4.725618	0.31421	0.7534	0.09000	-0.63000	0.87000	
BFAB10	BFAB7	0.1251	4.656861	0.02687	0.9786	0.02000	-1.31000	1.29000	
BFAB4	BFAB3	-5.3939	4.725224	-1.14152	0.2537	-0.39000	-1.12000	0.23000	
BFAB5	BFAB1	-5.7576	4.725668	-1.21836	0.2231	-0.48000	-1.18000	0.28000	
BFAB9	BFAB5	-6.6061	4.725520	-1.39795	0.1621	-0.70000	-1.63000	0.24000	
BFAB10	BFAB8	-9.1339	4.656915	-1.96137	0.0498*	-1.42000	-2.69000	0.01000	
BFAB6	BFAB4	-9.5152	4.725470	-2.01359	0.0441*	-0.71000	-1.47000	-0.01000	
BFAB9	BFAB6	-11.0606	4.725717	-2.34051	0.0193*	-1.18000	-2.16000	-0.15000	
BFAB9	BFAB1	-12.3939	4.725668	-2.62269	0.0087*	-1.21000	-1.90000	-0.30000	
BFAB5	BFAB4	-14.0000	4.725470	-2.96267	0.0030*	-1.27000	-2.05000	-0.51000	
BFAB8	BFAB5	-14.0000	4.725618	-2.96258	0.0031*	-1.76000	-2.96000	-0.57000	
BFAB6	BFAB3	-14.1818	4.725026	-3.00143	0.0027*	-1.09000	-1.90000	-0.40000	
BFAB9	BFAB4	-17.4242	4.725569	-3.68723	0.0002*	-1.97000	-2.85000	-1.05000	
BFAB8	BFAB6	-18.0000	4.725569	-3.80907	0.0001*	-2.10000	-3.40000	-1.11000	
BFAB5	BFAB3	-18.4242	4.725322	-3.89904	<.0001*	-1.70000	-2.42000	-0.93000	
BFAB8	BFAB1	-18.7879	4.725766	-3.97563	<.0001*	-2.08000	-3.21000	-1.02000	
BFAB7	BFAB5	-18.8788	4.725618	-3.99499	<.0001*	-3.24000	-4.37000	-1.82000	

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value	Hodges-Lehmann	Lower CL	Upper CL	Difference
BFAB10	BFAB9	-19.4252	4.656915	-4.17126	<.0001*	-2.47000	-3.47000	-1.58000	
BFAB7	BFAB6	-20.2121	4.725717	-4.27705	<.0001*	-3.69000	-4.75000	-2.21000	
BFAB7	BFAB1	-20.3939	4.725766	-4.31548	<.0001*	-3.59000	-4.77000	-2.43000	
BFAB9	BFAB3	-20.4242	4.725668	-4.32198	<.0001*	-2.35000	-3.19000	-1.42000	
BFAB7	BFAB4	-23.1515	4.725618	-4.89915	<.0001*	-4.46000	-5.53000	-3.12000	
BFAB10	BFAB5	-23.3353	4.656808	-5.01101	<.0001*	-3.16000	-4.06000	-2.37000	
BFAB8	BFAB4	-23.4545	4.725569	-4.96333	<.0001*	-2.91000	-4.04000	-1.81000	
BFAB10	BFAB6	-24.2424	4.656861	-5.20574	<.0001*	-3.80000	-4.64000	-2.78000	
BFAB10	BFAB1	-24.4927	4.656915	-5.25942	<.0001*	-3.73000	-4.43000	-2.97000	
BFAB7	BFAB3	-24.7576	4.725618	-5.23901	<.0001*	-4.84000	-5.99000	-3.56000	
BFAB8	BFAB3	-25.5758	4.725470	-5.41232	<.0001*	-3.30000	-4.46000	-2.24000	
BFAB10	BFAB4	-26.1505	4.656755	-5.61561	<.0001*	-4.53000	-5.26000	-3.71000	
BFAB10	BFAB3	-27.1828	4.656755	-5.83728	<.0001*	-4.98000	-5.71000	-4.17000	
BFAB2	BFAB1	-30.9091	4.725816	-6.54048	<.0001*	-4.79000	-5.62000	-3.99000	

Oneway Analysis of Specific Conductance By Site



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
BFAB1	0	10.192	26.55	30	30	35.04	60
BFAB2	0.07	41.52	50	60	69.15	72.682	80
BFAB3	0.03	17.07	30	32.5	34.4	40	60
BFAB4	0.06	38.14	40	49.2	54.85	61.02	85
BFAB5	0	5.022	40	47.7	50	50.66	70
BFAB6	0.06	40	50	60	70	178.82	334.8
BFAB7	0.05	32.3	40	66	88.75	95.68	154
BFAB8	0.05	29.88	37.25	50	67.2	87.96	100
BFAB9	0.07	15.416	50	80	113.7	134.14	144.3
BFAB10	0.13	18.904	80	210	341.3	399.8	412.9

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
BFAB1	33	1693.50	5428.50	51.318	-7.234
BFAB2	33	6426.50	5428.50	194.742	1.932
BFAB3	33	2434.00	5428.50	73.758	-5.800
BFAB4	33	4978.50	5428.50	150.864	-0.871
BFAB5	33	4307.50	5428.50	130.530	-2.171
BFAB6	33	6864.00	5428.50	208.000	2.780
BFAB7	33	6620.00	5428.50	200.606	2.307
BFAB8	33	5365.00	5428.50	162.576	-0.122
BFAB9	33	7071.00	5428.50	214.273	3.181
BFAB10	31	8196.00	5099.50	264.387	6.167

1-way Test, ChiSquare Approximation

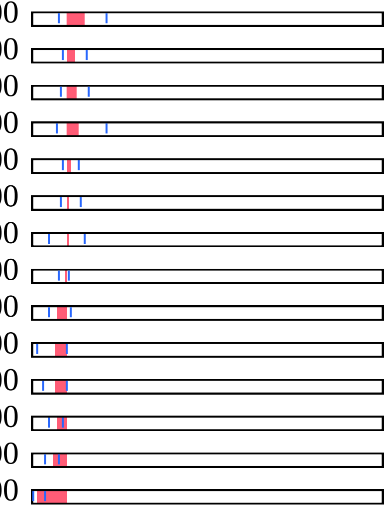
ChiSquare	DF	Prob>ChiSq
140.9400	9	<.0001*

Nonparametric Comparisons For Each Pair Using Wilcoxon Method

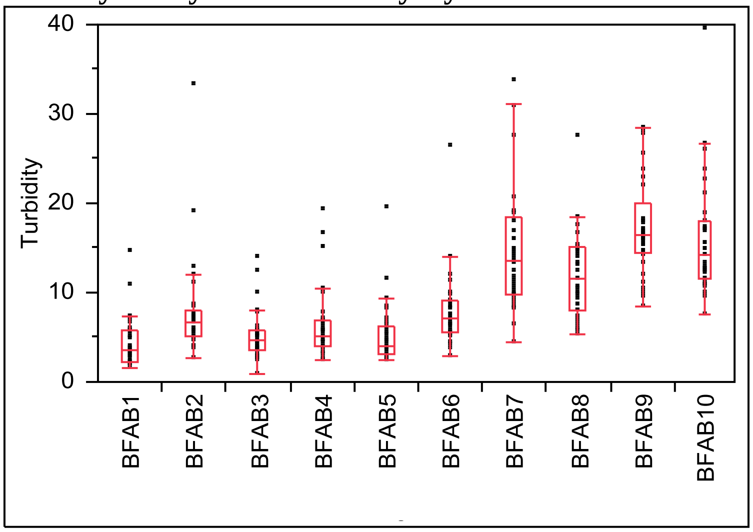
q*	Alpha
1.95996	0.05

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value	Hodges-Lehmann	Lower CL	Upper CL	Difference
BFAB2	BFAB1	28.3030	4.714853	6.00295	<.0001*	30.000	23.8000	34.900	
BFAB6	BFAB1	28.3030	4.715397	6.00226	<.0001*	31.100	26.1000	38.500	
BFAB6	BFAB3	28.0000	4.717176	5.93575	<.0001*	27.700	22.0000	34.300	
BFAB7	BFAB1	27.9697	4.715644	5.93126	<.0001*	39.000	24.0000	49.000	
BFAB4	BFAB1	27.3030	4.712776	5.79341	<.0001*	19.800	14.9000	23.300	
BFAB4	BFAB3	26.2424	4.713073	5.56801	<.0001*	15.900	10.0000	19.300	
BFAB7	BFAB3	26.2424	4.716682	5.56375	<.0001*	35.100	20.0000	45.100	
BFAB8	BFAB1	25.9091	4.716089	5.49377	<.0001*	22.100	12.3000	31.200	
BFAB9	BFAB1	25.1818	4.716830	5.33872	<.0001*	50.600	28.6000	75.400	
BFAB10	BFAB1	24.8680	4.648110	5.35014	<.0001*	182.800	90.0000	281.300	
BFAB10	BFAB5	24.2737	4.654035	5.21563	<.0001*	170.000	73.0000	270.000	
BFAB10	BFAB3	24.1173	4.650299	5.18618	<.0001*	180.000	85.7000	278.700	
BFAB10	BFAB4	23.1476	4.653288	4.97446	<.0001*	163.800	70.0000	261.000	
BFAB9	BFAB3	22.8788	4.718707	4.84853	<.0001*	47.800	25.0000	71.800	
BFAB8	BFAB3	22.4242	4.717472	4.75344	<.0001*	18.000	8.0000	27.800	
BFAB6	BFAB5	22.1515	4.711391	4.70169	<.0001*	14.600	10.0000	23.000	
BFAB5	BFAB1	21.8788	4.714062	4.64118	<.0001*	18.100	14.3000	20.000	
BFAB10	BFAB8	21.5836	4.655848	4.63580	<.0001*	161.000	67.5000	255.600	
BFAB5	BFAB3	21.1818	4.715100	4.49234	<.0001*	14.100	10.0000	16.200	
BFAB10	BFAB2	21.1457	4.654035	4.54351	<.0001*	154.800	60.0000	251.000	
BFAB10	BFAB7	19.3939	4.655582	4.16574	<.0001*	150.000	56.3000	240.000	
BFAB9	BFAB5	18.7576	4.715644	3.97773	<.0001*	40.000	12.2000	59.200	
BFAB10	BFAB6	18.1427	4.654782	3.89765	<.0001*	136.500	46.9000	231.000	
BFAB6	BFAB4	17.3636	4.712133	3.68488	0.0002*	12.000	6.6000	20.000	
BFAB3	BFAB1	17.1515	4.668698	3.67373	0.0002*	3.700	2.2000	5.200	
BFAB10	BFAB9	16.7664	4.655688	3.60127	0.0003*	139.500	51.6000	217.600	
BFAB9	BFAB4	15.4848	4.717225	3.28262	0.0010*	32.500	10.0000	54.000	
BFAB7	BFAB5	14.5455	4.715446	3.08464	0.0020*	23.700	11.8000	34.950	
BFAB9	BFAB8	12.8182	4.721226	2.71501	0.0066*	26.900	8.3000	47.600	
BFAB7	BFAB4	12.6667	4.710846	2.68883	0.0072*	19.200	3.4000	30.000	
BFAB9	BFAB2	9.7273	4.718263	2.06162	0.0392*	23.000	0.0000	44.300	

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value	Hodges-Lehmann	Lower CL	Upper CL	Difference
BFAB9	BFAB7	6.8182	4.722362	1.44381	0.1488	15.000	-6.8000	36.000	
BFAB8	BFAB5	6.2424	4.713666	1.32432	0.1854	5.900	-4.3000	18.300	
BFAB7	BFAB2	6.1515	4.721621	1.30284	0.1926	9.000	-5.5000	20.000	
BFAB9	BFAB6	3.9091	4.718856	0.82840	0.4074	10.000	-10.0000	36.000	
BFAB6	BFAB2	3.1212	4.711242	0.66250	0.5076	2.400	-4.2000	10.000	
BFAB8	BFAB4	2.0000	4.711589	0.42449	0.6712	0.900	-6.5000	12.300	
BFAB7	BFAB6	0.6970	4.720831	0.14764	0.8826	0.700	-16.1000	16.000	
BFAB5	BFAB4	-5.0303	4.703270	-1.06953	0.2848	-1.600	-8.0000	1.200	
BFAB8	BFAB2	-7.1212	4.717719	-1.50946	0.1312	-8.670	-16.7000	2.500	
BFAB8	BFAB7	-9.3939	4.718164	-1.99102	0.0465*	-11.800	-27.7000	0.000	
BFAB8	BFAB6	-10.1515	4.717917	-2.15169	0.0314*	-11.700	-21.7000	0.000	
BFAB4	BFAB2	-15.8182	4.712924	-3.35634	0.0008*	-10.000	-16.1000	-4.000	
BFAB5	BFAB2	-20.6061	4.712133	-4.37298	<.0001*	-12.700	-20.0000	-8.200	
BFAB3	BFAB2	-28.0909	4.716781	-5.95553	<.0001*	-26.300	-30.3000	-20.000	



Oneway Analysis of Turbidity By Site



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
BFAB1	1.65	1.988	2.305	3.5	5.675	7.248	14.6
BFAB2	2.6	3.776	5.03	6.57	8.035	12.52	33.3
BFAB3	0.95	2.74	3.47	4.68	5.715	9.09	14.1
BFAB4	2.46	2.826	4.03	5.1	6.945	13.22	19.4
BFAB5	2.35	2.682	3.1	3.92	6.31	8.998	19.5
BFAB6	2.96	4.202	5.475	7.14	9.12	11.86	26.4
BFAB7	4.41	8.252	9.685	13.6	18.4	29.6	33.7
BFAB8	5.29	6.2	7.95	11.6	15.1	23.96	48.8
BFAB9	8.34	10.146	14.4	16.5	20.05	28.04	53.7
BFAB10	7.52	9.648	11.5	14.2	18.1	25.46	39.5

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
BFAB1	33	2228.00	5428.50	67.515	-6.194
BFAB2	33	4647.50	5428.50	140.833	-1.511
BFAB3	33	3050.00	5428.50	92.424	-4.603
BFAB4	33	3754.50	5428.50	113.773	-3.239
BFAB5	33	2889.50	5428.50	87.561	-4.914
BFAB6	33	5092.50	5428.50	154.318	-0.649
BFAB7	33	8018.00	5428.50	242.970	5.011
BFAB8	33	7322.00	5428.50	221.879	3.664
BFAB9	33	9001.00	5428.50	272.758	6.914
BFAB10	31	7953.00	5099.50	256.548	5.679

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
194.0785	9	<.0001*

Nonparametric Comparisons For Each Pair Using Wilcoxon Method

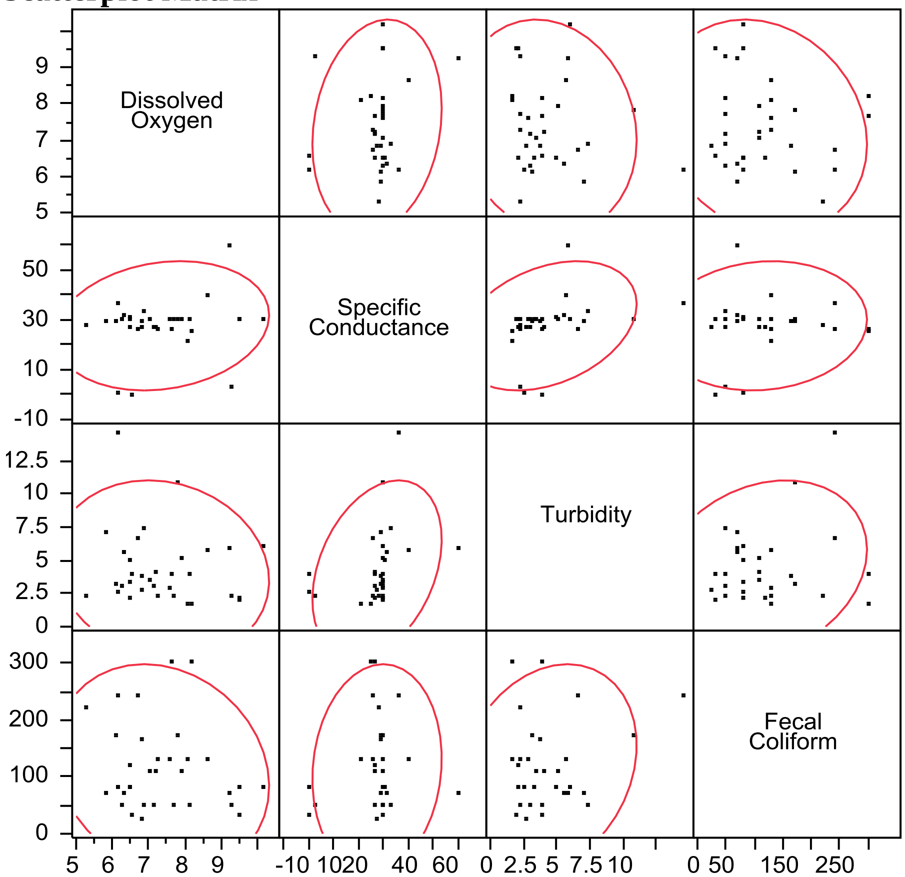
q*	Alpha
1.95996	0.05

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value	Hodges-Lehmann	Lower CL	Upper CL	Difference
BFAB9	BFAB1	32.2121	4.725618	6.81649	<.0001*	12.6500	11.0000	14.1500	
BFAB9	BFAB3	32.0606	4.725618	6.78443	<.0001*	11.7700	10.2500	13.1900	
BFAB9	BFAB5	31.0303	4.725668	6.56633	<.0001*	11.9600	10.2100	13.4400	
BFAB10	BFAB1	30.6549	4.656915	6.58267	<.0001*	10.2300	8.6000	12.2400	
BFAB7	BFAB1	30.3636	4.725816	6.42506	<.0001*	9.2700	7.1700	11.8700	
BFAB10	BFAB3	30.0293	4.656861	6.44840	<.0001*	9.3100	7.6100	11.5000	
BFAB10	BFAB5	29.7478	4.656861	6.38795	<.0001*	9.4600	7.9000	11.6000	
BFAB7	BFAB3	29.4545	4.725668	6.23289	<.0001*	8.4500	6.2200	10.9600	
BFAB9	BFAB4	29.3939	4.725520	6.22026	<.0001*	11.1000	9.2400	12.6300	
BFAB9	BFAB6	29.2727	4.725668	6.19441	<.0001*	9.1400	7.2200	11.0600	
BFAB8	BFAB1	29.2121	4.725816	6.18139	<.0001*	7.4800	5.4900	9.8000	
BFAB7	BFAB5	29.0000	4.725766	6.13657	<.0001*	8.5700	6.4000	11.0400	
BFAB9	BFAB2	28.3939	4.725569	6.00858	<.0001*	9.8700	8.1300	11.5600	
BFAB8	BFAB3	28.0909	4.725618	5.94439	<.0001*	6.6400	4.5200	9.0100	
BFAB10	BFAB4	27.5269	4.656915	5.91097	<.0001*	8.5300	6.9400	10.7000	
BFAB8	BFAB5	27.4545	4.725816	5.80948	<.0001*	6.6800	4.7400	9.1700	
BFAB10	BFAB6	26.7761	4.656915	5.74976	<.0001*	6.9200	5.1300	9.1000	
BFAB10	BFAB2	26.5572	4.656808	5.70287	<.0001*	7.5000	5.7600	9.7800	
BFAB7	BFAB4	26.3030	4.725816	5.56582	<.0001*	7.6600	5.5300	10.3100	
BFAB7	BFAB2	24.6061	4.725766	5.20679	<.0001*	6.6100	4.4700	9.2100	
BFAB8	BFAB4	24.2424	4.725717	5.12989	<.0001*	5.7700	3.6800	8.2200	
BFAB7	BFAB6	23.6364	4.725618	5.00175	<.0001*	5.9300	3.8400	8.5200	
BFAB6	BFAB1	22.3030	4.725816	4.71940	<.0001*	3.2900	2.2400	4.5300	
BFAB8	BFAB2	21.2121	4.725766	4.48861	<.0001*	4.7600	2.7000	7.2500	
BFAB2	BFAB1	19.4848	4.725717	4.12315	<.0001*	2.6600	1.5400	3.6700	
BFAB8	BFAB6	18.5455	4.725717	3.92437	<.0001*	4.1500	2.0200	6.3500	
BFAB6	BFAB5	18.5152	4.725766	3.91792	<.0001*	2.6300	1.5300	3.8600	
BFAB6	BFAB3	18.3030	4.725668	3.87311	0.0001*	2.4600	1.2700	3.6700	
BFAB9	BFAB8	17.2121	4.725421	3.64245	0.0003*	4.9000	2.3000	7.7900	
BFAB4	BFAB1	13.9091	4.725766	2.94325	0.0032*	1.5100	0.5000	2.5000	
BFAB6	BFAB4	12.8485	4.725816	2.71879	0.0066*	1.7700	0.5300	3.0800	

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value	Hodges-Lehmann	Lower CL	Upper CL	Difference
BFAB10	BFAB8	10.3539	4.656755	2.22341	0.0262*	2.9900	0.3000	5.4300	
BFAB9	BFAB7	9.6970	4.725569	2.05202	0.0402*	3.1000	0.2000	5.9500	
BFAB3	BFAB1	9.0606	4.725470	1.91740	0.0552	0.9300	-0.0300	1.8600	
BFAB5	BFAB1	7.4545	4.725618	1.57748	0.1147	0.7000	-0.1700	1.5300	
BFAB4	BFAB3	5.3030	4.725618	1.12219	0.2618	0.5900	-0.4100	1.6400	
BFAB6	BFAB2	5.0303	4.725766	1.06444	0.2871	0.7500	-0.5700	2.1400	
BFAB10	BFAB7	3.8475	4.656755	0.82622	0.4087	1.1000	-1.8000	3.7000	
BFAB5	BFAB3	-3.2121	4.725668	-0.67972	0.4967	-0.2900	-1.2100	0.6800	
BFAB8	BFAB7	-6.8485	4.725520	-1.44926	0.1473	-1.9500	-4.5000	0.7500	
BFAB10	BFAB9	-7.1945	4.656541	-1.54504	0.1223	-2.2000	-4.5000	0.5000	
BFAB5	BFAB4	-7.9394	4.725717	-1.68004	0.0929	-0.8200	-1.7900	0.1400	
BFAB4	BFAB2	-9.0606	4.725618	-1.91734	0.0552	-1.1300	-2.2600	0.0500	
BFAB3	BFAB2	-13.9697	4.725668	-2.95613	0.0031*	-1.6900	-2.8300	-0.6300	
BFAB5	BFAB2	-15.1515	4.725766	-3.20615	0.0013*	-1.9900	-3.0400	-0.8000	

Multivariate Site=BFAB1

Scatterplot Matrix

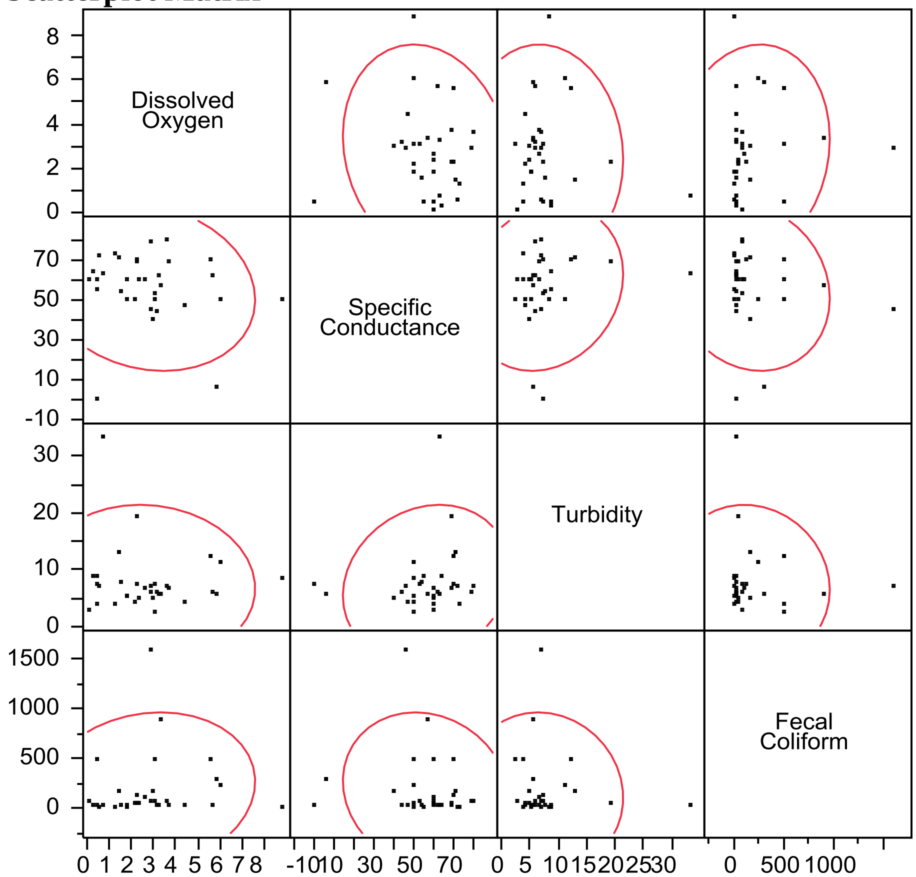


Nonparametric: Spearman's ρ

Variable	by Variable	Spearman ρ	Prob>|ρ|	Plot
Specific Cond.	Dissolved Oxygen	0.0566	0.7544	
Turbidity	Dissolved Oxygen	-0.1534	0.3940	
Turbidity	Specific Cond.	0.4961	0.0033*	
Fecal Coliform	Dissolved Oxygen	-0.1134	0.5299	
Fecal Coliform	Specific Cond.	-0.1467	0.4153	
Fecal Coliform	Turbidity	0.0737	0.6837	

Multivariate Site=BFAB2

Scatterplot Matrix

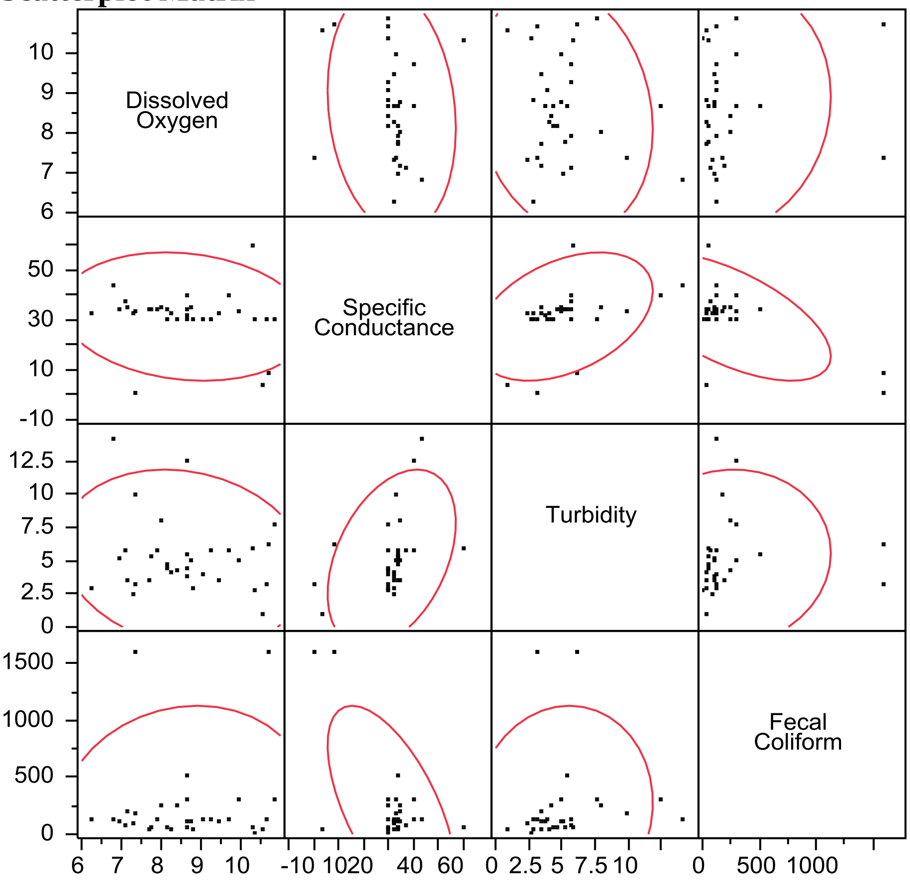


Nonparametric: Spearman's ρ

Variable	by Variable	Spearman ρ	Prob>|ρ|	Plot
Specific Cond.	Dissolved Oxygen	-0.2052	0.2519	
Turbidity	Dissolved Oxygen	0.0182	0.9199	
Turbidity	Specific Cond.	0.2336	0.1908	
Fecal Coliform	Dissolved Oxygen	0.2372	0.1839	
Fecal Coliform	Specific Cond.	-0.1591	0.3765	
Fecal Coliform	Turbidity	-0.0667	0.7123	

Multivariate Site=BFAB3

Scatterplot Matrix

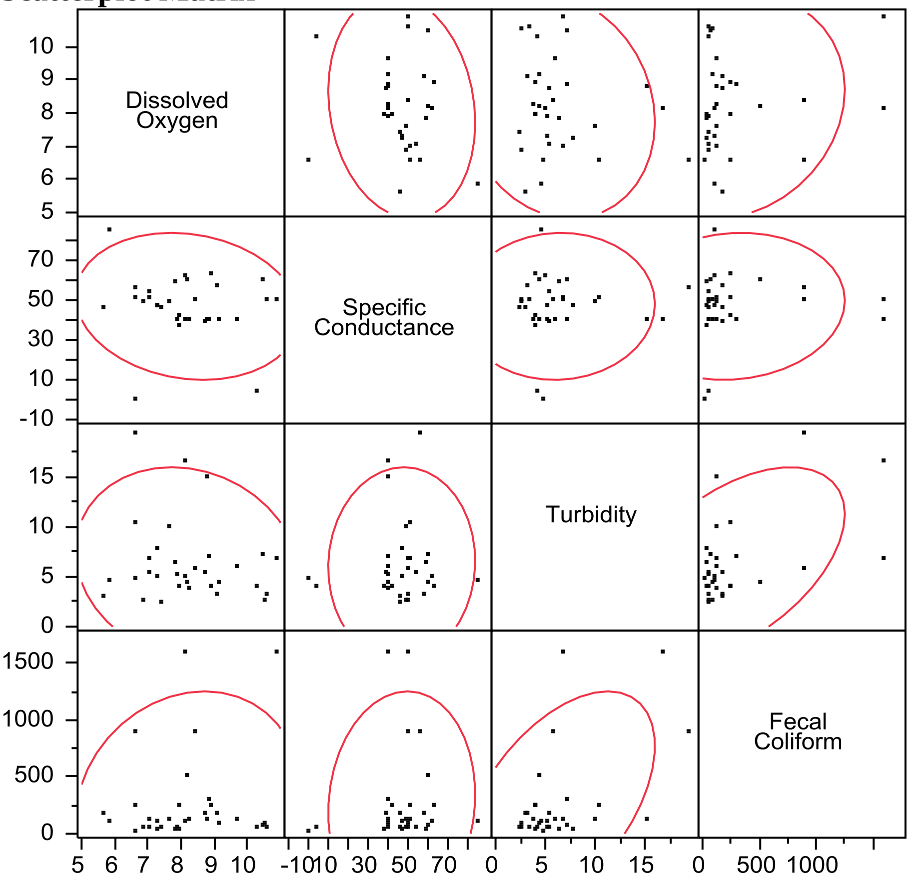


Nonparametric: Spearman's ρ

Variable	by Variable	Spearman ρ	Prob>|ρ|	Plot
Specific Cond.	Dissolved Oxygen	-0.3791	0.0296*	
Turbidity	Dissolved Oxygen	-0.0503	0.7809	
Turbidity	Specific Cond.	0.5287	0.0016*	
Fecal Coliform	Dissolved Oxygen	0.0250	0.8900	
Fecal Coliform	Specific Cond.	0.0263	0.8844	
Fecal Coliform	Turbidity	0.4338	0.0117*	

Multivariate Site=BFAB4

Scatterplot Matrix

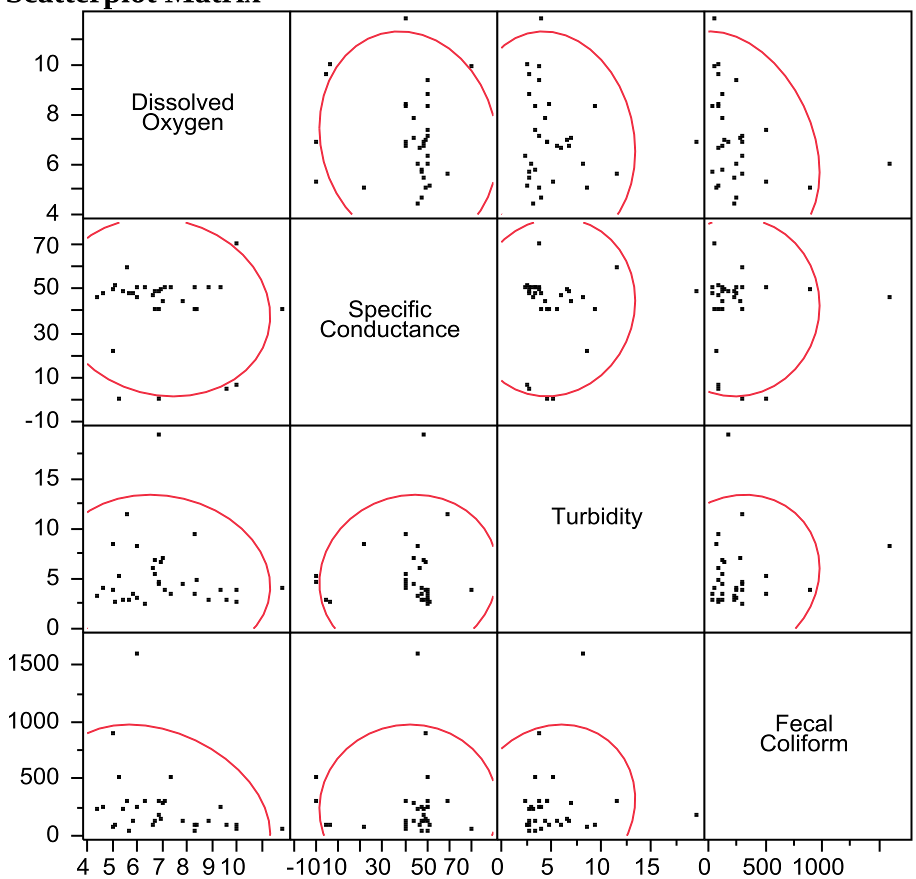


Nonparametric: Spearman's ρ

Variable	by Variable	Spearman ρ	Prob>|ρ|	Plot
Specific Cond.	Dissolved Oxygen	-0.0965	0.5932	
Turbidity	Dissolved Oxygen	-0.0960	0.5953	
Turbidity	Specific Cond.	0.0393	0.8280	
Fecal Coliform	Dissolved Oxygen	0.1498	0.4053	
Fecal Coliform	Specific Cond.	0.1773	0.3235	
Fecal Coliform	Turbidity	0.3033	0.0862	

Multivariate Site=BFAB5

Scatterplot Matrix

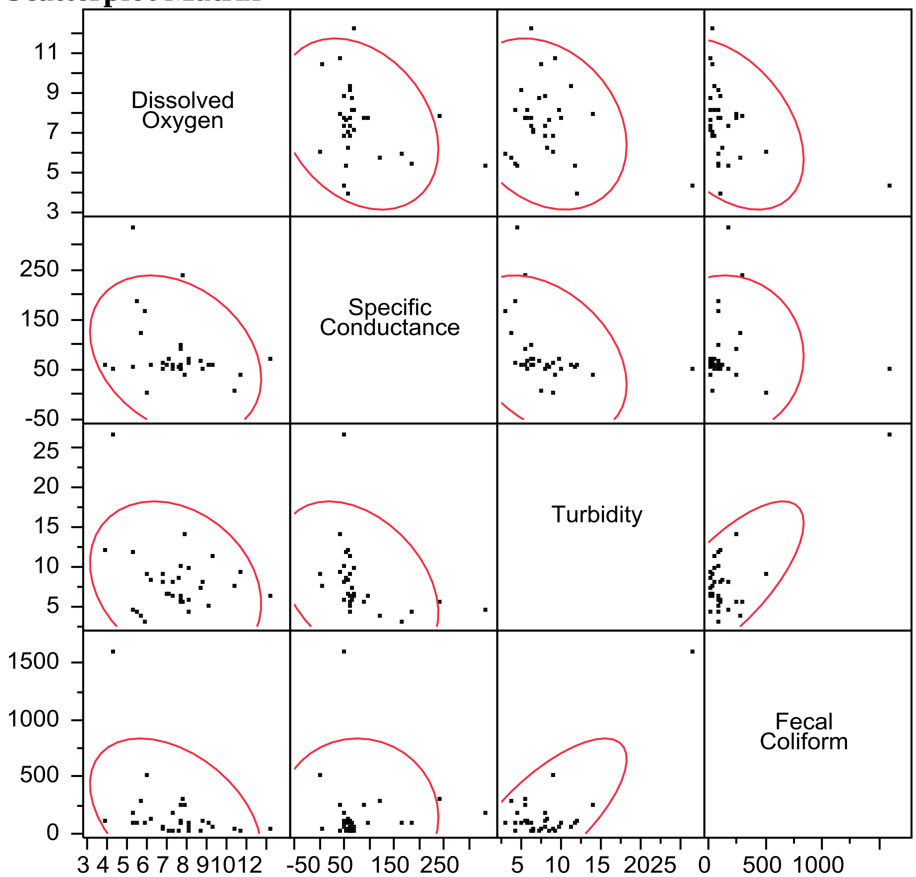


Nonparametric: Spearman's ρ

Variable	by Variable	Spearman ρ	Prob>|ρ|	Plot
Specific Cond.	Dissolved Oxygen	-0.0883	0.6249	
Turbidity	Dissolved Oxygen	-0.0336	0.8527	
Turbidity	Specific Cond.	-0.2707	0.1276	
Fecal Coliform	Dissolved Oxygen	-0.3512	0.0451*	
Fecal Coliform	Specific Cond.	0.0941	0.6026	
Fecal Coliform	Turbidity	0.1233	0.4941	

Multivariate Site=BFAB6

Scatterplot Matrix

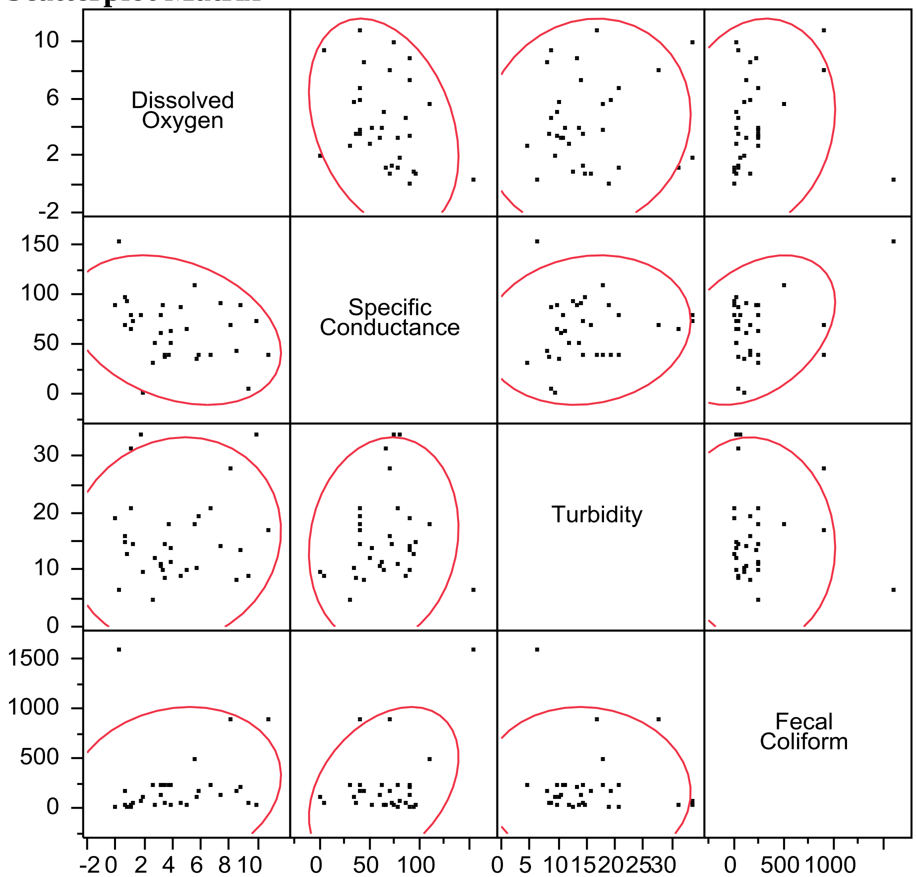


Nonparametric: Spearman's ρ

Variable	by Variable	Spearman ρ	Prob>|ρ|	Plot
Specific Cond.	Dissolved Oxygen	-0.1067	0.5544	
Turbidity	Dissolved Oxygen	-0.0480	0.7910	
Turbidity	Specific Cond.	-0.6682	<.0001*	
Fecal Coliform	Dissolved Oxygen	-0.3907	0.0246*	
Fecal Coliform	Specific Cond.	-0.0092	0.9595	
Fecal Coliform	Turbidity	-0.0187	0.9178	

Multivariate Site=BFAB7

Scatterplot Matrix

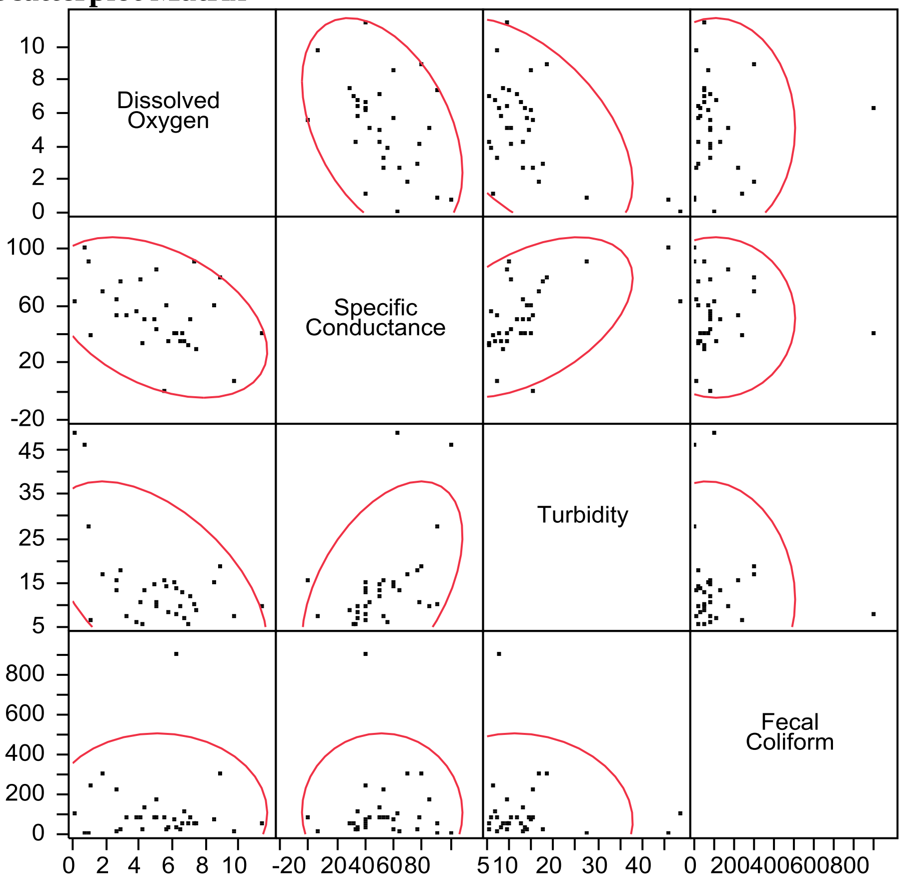


Nonparametric: Spearman's ρ

Variable	by Variable	Spearman ρ	Prob>|ρ|	Plot
Specific Cond.	Dissolved Oxygen	-0.3140	0.0752	
Turbidity	Dissolved Oxygen	0.0037	0.9838	
Turbidity	Specific Cond.	0.2194	0.2200	
Fecal Coliform	Dissolved Oxygen	0.3014	0.0882	
Fecal Coliform	Specific Cond.	-0.0881	0.6260	
Fecal Coliform	Turbidity	-0.0833	0.6450	

Multivariate Site=BFAB8

Scatterplot Matrix

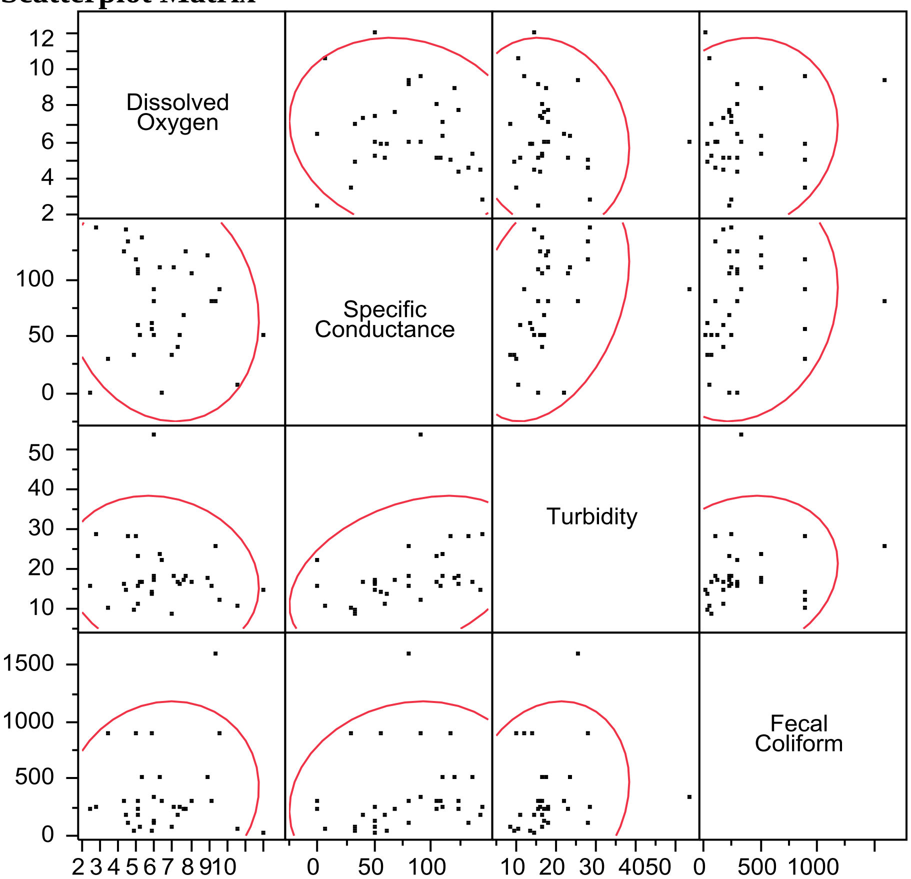


Nonparametric: Spearman's ρ

Variable	by Variable	Spearman ρ	Prob>|ρ|	Plot
Specific Cond.	Dissolved Oxygen	-0.4272	0.0132*	
Turbidity	Dissolved Oxygen	-0.3204	0.0691	
Turbidity	Specific Cond.	0.5882	0.0003*	
Fecal Coliform	Dissolved Oxygen	-0.0647	0.7205	
Fecal Coliform	Specific Cond.	0.0410	0.8206	
Fecal Coliform	Turbidity	-0.0239	0.8950	

Multivariate Site=BFAB9

Scatterplot Matrix

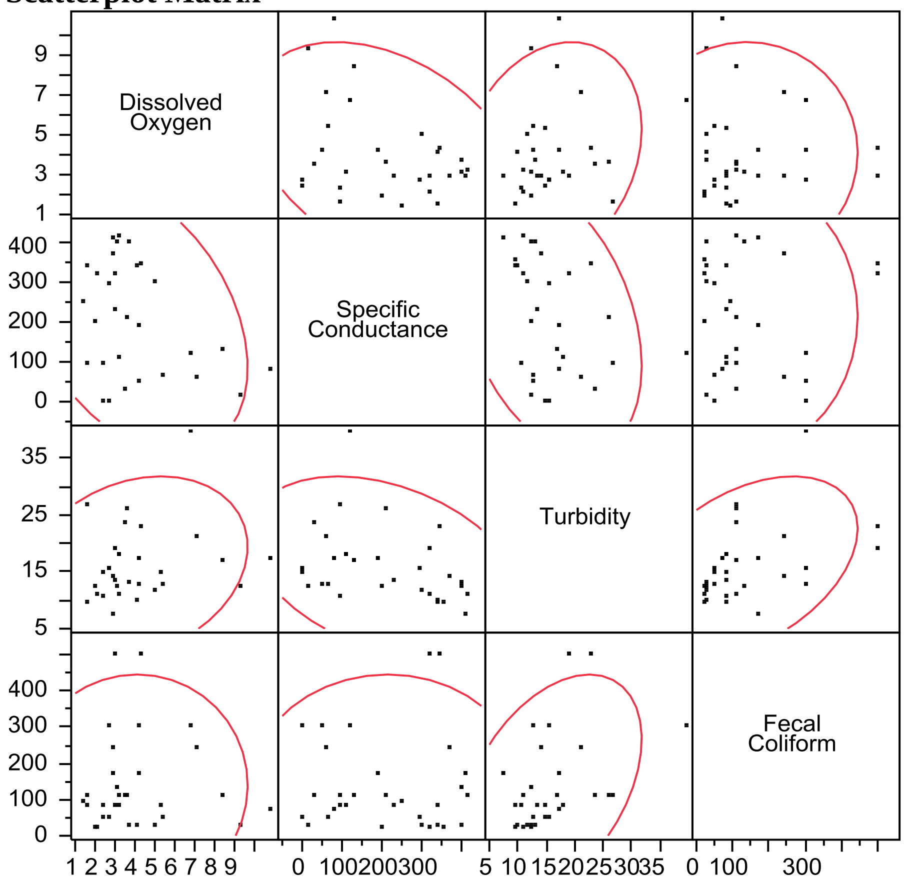


Nonparametric: Spearman's ρ

Variable	by Variable	Spearman ρ	Prob>|ρ|	Plot
Specific Cond.	Dissolved Oxygen	-0.1603	0.3729	
Turbidity	Dissolved Oxygen	-0.0119	0.9477	
Turbidity	Specific Cond.	0.5036	0.0028*	
Fecal Coliform	Dissolved Oxygen	0.0475	0.7929	
Fecal Coliform	Specific Cond.	0.3264	0.0638	
Fecal Coliform	Turbidity	0.2923	0.0988	

Multivariate Site=BFAB10

Scatterplot Matrix



Nonparametric: Spearman's ρ

Variable	by Variable	Spearman ρ	Prob>|ρ|	Plot
Specific Cond.	Dissolved Oxygen	-0.2125	0.2596	
Turbidity	Dissolved Oxygen	0.2768	0.1386	
Turbidity	Specific Cond.	-0.4337	0.0167*	
Fecal Coliform	Dissolved Oxygen	0.0993	0.5950	
Fecal Coliform	Specific Cond.	-0.0497	0.7907	
Fecal Coliform	Turbidity	0.5123	0.0032*	

VITA

Chelsea Lee Core was born in New Orleans, Louisiana. She completed her undergraduate studies in 2005 at the University of New Orleans with a Bachelor of Science degree in environmental science and policy. After being displaced to Baton Rouge from Metairie, Louisiana, because of Hurricane Katrina in August of 2005, she began her studies at Louisiana State University in the Department of Geology. In 2007, she changed course and continued her studies under Dr. Michael Leitner in the Department of Geography and Anthropology. She expects to receive her Master of Science degree in geography with a concentration in mapping science on 18 May 2012.