TECHNICAL SUPPORT DOCUMENT: BACTERIA TOTAL MAXIMUM DAILY LOADS FOR THE JARBO BAYOU WATERSHED, HOUSTON, TEXAS
(2425B_01)

Prepared for:

TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

TCEQ

Prepared by:

University of Houston

August 2016

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS AND ABBREVIATIONS

ASAE	American Society of Agricultural Engineers
AU	Assessment Unit
C-CAP	Coastal Change Analysis Program
CAFO	concentrated animal feeding operation
CFR	Code of Federal Regulations
cfs	cubic feet per second
counts	colony forming unit
CN	curve number
dL	deciliter
DMR	discharge monitoring report
E coli	Escherichia coli
FDC	flow duration curve
GCHD	Galveston County Health District
GIS	geographic information system
HCFCD	Harris County Flood Control District
HCOEM	Harris County Office of Emergency Management
H-GAC	Houston-Galveston Area Council
LA	load allocation
LDC	load duration curve
mL	milliliter
MOS	margin of safety
MS4	municipal separate storm sewer system
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollution Discharge Elimination System
NRCS	National Resources Conservation Service
OSSF	on-site sewage facility
RMSE	root mean square error
SSO	sanitary sewer overflow
SWQS	surface water quality standards
SWQMIS	Surface Water Quality Monitoring Information System
TAC	Texas Administrative Code
TCEQ	Texas Commission on Environmental Quality
TCOON	Texas Coastal Ocean Observation Network
TMDL	Total Maximum Daily Loads
TPDES	Texas Pollution Discharge Elimination System
TSARP	Tropical Storm Allison Recovery Project

TWDB	Texas Water Development Board
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WCID	water control and improvement district
WLA	waste load allocation
WQM	water quality monitoring
WQS	water quality standard
WWTF	wastewater treatment facility

CHAPTER 1
INTRODUCTION

1.1 Watershed Description

The Jarbo Bayou Watershed encompasses approximately 4.8 square miles of land located on the southeast border of Clear Lake and lies entirely within Galveston County. The Jarbo Bayou Watershed is part of the San Jacinto-Brazos Coastal Basin, which covers the coastal portions of Galveston, Harris and Brazoria counties located between the San Jacinto River and the Brazos River. Jarbo Bayou is an unclassified tributary within this basin, consisting of a singular stream segment that feeds directly into Clear Lake. Major tributaries within the San Jacinto-Brazos Coastal Basin include Clear Creek, Dickinson Bayou, Chocolate Bayou, Bastrop Bayou and Oyster Creek. Jarbo Bayou flows into Clear Lake (Segment 2425) which, in turn, feeds into Upper Galveston Bay (Segment 2421) which eventually discharges to the Gulf of Mexico (Segment 2501).

Jarbo Bayou lies wholly within the Northern Humid Gulf Coastal Prairies ecoregion, characterized by original vegetation consisting of “grasslands with a few clusters of oaks, known as oak mottes or maritime woodlands.” As noted by Griffith et al. (2007), “almost all of the coastal prairies have been converted to cropland, rangeland, pasture or urban land uses” and the Jarbo Bayou watershed is no different: the regions bordering Clear Lake as well as the western section of the watershed are thoroughly developed while the central and southeastern regions are less developed and include pasture land as well as pockets of wooded wetlands. The watershed is expected to continue to develop based on its proximity to the Johnson Space Center, Kemah Boardwalk, and Clear Lake.

The Texas Commission on Environmental Quality (TCEQ) lists the entirety of Jarbo Bayou as a single segment (Jarbo Bayou, segment 2425B), all of which is tidally influenced. The Jarbo Bayou segment is made up of two assessment units (AU):

- AU 2425B_01: from Clear Lake confluence upstream to Lawrence Rd. and,
- AU 2425B_02: from Lawrence Rd. to the headwaters 0.67 miles upstream of FM518.

Background of Watershed

This report focuses on the Jarbo Bayou waterbody because it is classified as Category 5 on the TCEQ 303(d) list (2012 Integrated Report). Assessment unit 2425B_01 has been listed as non-supportive of contact recreation since 2002 due to elevated levels of bacteria. AU 2425B_02 is not on the 303(d) list as non-supportive; however, the reason is largely due to insufficient data to meet the minimum requirement, and will be included with AU 2425B_01 so that the entire Jarbo Bayou section is considered.

Figure 1-1 is a location map showing Jarbo Bayou and its watershed. The delineation of the watershed is derived from 2005 geographic information system (GIS) data files created for the Tropical Storm Allison Recovery Project (TSARP) provided by Harris County Flood Control District (HCFCD). The Jarbo Bayou waterbody and its surrounding watersheds are hereinafter referred to as the Study Area.

The climate of the region is subtropical humid, with very hot and humid summers and mild winters. The average maximum daytime temperature is 33 degrees Celsius (91.5 degrees Fahrenheit) while the temperature averages between 6 and 18 degrees Celsius (43 to 64.5 degrees Fahrenheit) during the winter. Summer rainfall is dominated by sub-tropical convection, winter rainfall by frontal storms, and fall and spring months by combinations of these two (Burian 2005).

Table 1-1, derived from the 2000 and 2010 U.S. Census, demonstrates that the county in which the watershed is located is very densely populated. Table 1-1 also shows population growth for Galveston County (U.S. Census Bureau 2010).

Table 1-1: County Population and Density

County Name	2000 U.S. Census	2000 Population Density (per square mile)	2010 U.S. Census	2010 Population Density (per square mile)
Galveston	250,158	629	291,309	732

Source: U.S. Census 2000 and 2010

The three cities that limits fall inside the Study Area are expected to increase in population by an average of 113 percent from 2010 to 2030, according to the Texas Water Development Board (TWDB) (TWDB 2013). Table 1-2 lists TWDB population growth estimates for these three cities from 2010 to 2030. The city limit of League City makes up the largest portion of the Study Area and is anticipated to grow by 44% between 2010 and 2030. Kemah has the greatest population increase, at just under 250%, and a significant amount of undeveloped land that is within the Study area. For this reason Kemah that has the greatest potential to increase both the population and urbanization within the Study Area. Additionally, the population within the Study Area was estimated using the populations reported for each Census Block Group within the Study Area as reported in the 2010 U.S. Census. Table 1-3 lists the population, occupied households, and resulting household density for the Study Area.

Table 1-2: Jarbo Bayou Watershed Population Increases by City, 2010 to 2030

City	2010 Census Population	2020 Population Estimate	2030 Population Estimate	Growth Rate (2010-2030)
Clear Lake Shores	1,063	1,525	1,579	49%
Kemah	1,773	4,685	6,166	248%
League City	83,560	106,764	120,273	44%

Source: Region H - Draft Population and Municipal Demand Projections for 2016 Regional and 2017 State Water Plan
http://www.twdb.state.tx.us/waterplanning/data/projections/2017/demandproj.asp

Table 1-3: Estimated Population and Occupied Households for the Study Area

Segment Name	Total Population	Occupied Households	Household Density
Jarbo Bayou	13,725	5,171	2.65

Source: U.S. Census 2010

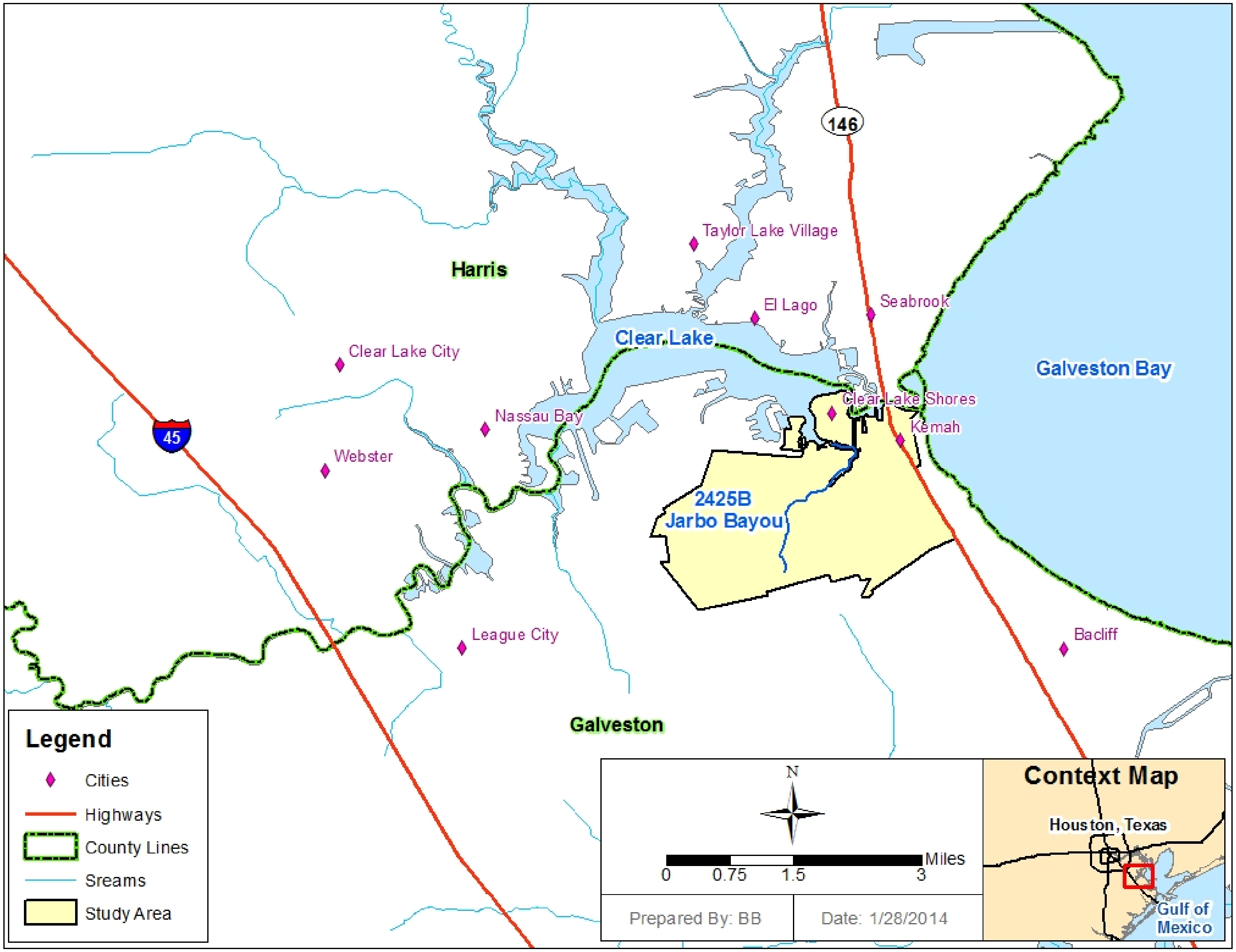

Figure 1-1: Location Map for Jarbo Bayou Watershed

1.2 Summary of Existing Data

The following subsections summarize existing data relevant to soil, land cover, and precipitation throughout the Study Area as well as the chemical and physical characteristics of the waterbody using ambient water quality, stream flow, tide, and conductivity data.

1.2.1 Soil

The geology of the Jarbo Bayou Watershed is comprised of moderately to very clayey soils which combined with the flat topography in the area, results in the large amount of natural wetlands in the area (Coastal Coordination Council, 2006). The soil has a low water-bearing capacity, high moisture content, low permeability, and a high shrink-swell potential. The Soil Survey Geographic (SSURGO) Database National Resources Conservation Service (NRCS) 2012 information was used to characterize soil in the Study Area. As shown in Figure 1-2, the soil types that dominate the watershed are the Bernard, Montery-Leton, and Verland soil series. Table 1-4 provides the soil distribution in the Study Area; Table 1-5 lists the attributes of the soil series found in the Study Area.

Table 1-4: Soil Type Distribution in Jarbo Bayou Watershed

Soil Series Name	Study Area
Bacliff clay	2%
Bernard clay loam	25%
Ijam clay, 0 to 2 percent slopes	1%
Francitas-Urban land complex	>1%
Kemah silt loam, 0 to 1 percent slopes	4%
Lake Charles clay, 0 to 1 percent slopes	6%
Leton loam	>1%
Leton-Aris complex	4%
Mocarey loam	7%
Mocarey-Algoa complex	10%
Mocarey-Leton complex	19%
Morey silt loam	1%
Verland silty clay loam	16%
Veston loam, slightly saline-strongly saline complex	2%

All information derived from SSURGO data: http://datagateway.nrcs.usda.gov/

Table 1-5: Characteristics of Soil Types of Jarbo Bayou Watershed

NRCS Soil Type	Surface Texture	Soil Series Name	Hydrologic Soil Group	Soil Drainage Class	Average Available Water Storage (cm)
TX167	Clay	Bacliff clay	D	Poorly Drained	27.0
TX167	Clay loam	Bernard clay loam	D	Somewhat Poorly Drained	23.3
TX167	Clay	Ijam clay, 0 to 2 percent slopes	D	Poorly Drained	16.6
TX167	Clay	Francitas-Urban land complex	D	Poorly Drained	16.5
TX167	Silt loam	Kemah silt loam, 0 to 1 percent slopes	D	Somewhat Poorly Drained	23.6
TX167	Clay	Lake Charles clay, 0 to 1 percent slopes	D	Poorly Drained	27.0
TX167	Loam	Leton loam	C/D	Poorly Drained	27.0
TX167	Fine sandy loam	Leton-Aris complex	C/D	Poorly Drained	24.2
TX167	Loam	Mocarey loam	C/D	Poorly Drained	26.8
TX167	Silty clay loam	Mocarey-Algoa complex	C/D	Somewhat Poorly Drained	27.2
TX167	Loam	Mocarey-Leton complex	C/D	Poorly Drained	26.9
TX167	Silt loam	Morey silt loam	D	Somewhat Poorly Drained	30.0
TX167	Silty clay loam	Verland silty clay loam	D	Somewhat Poorly Drained	26.1
TX167	Loam	Veston loam, slight-strongly saline complex	C/D	Poorly Drained	9.4

All information derived from SSURGO data: http://datagateway.nrcs.usda.gov/
http://websoilsurvey.nrcs.usda.gov/app/

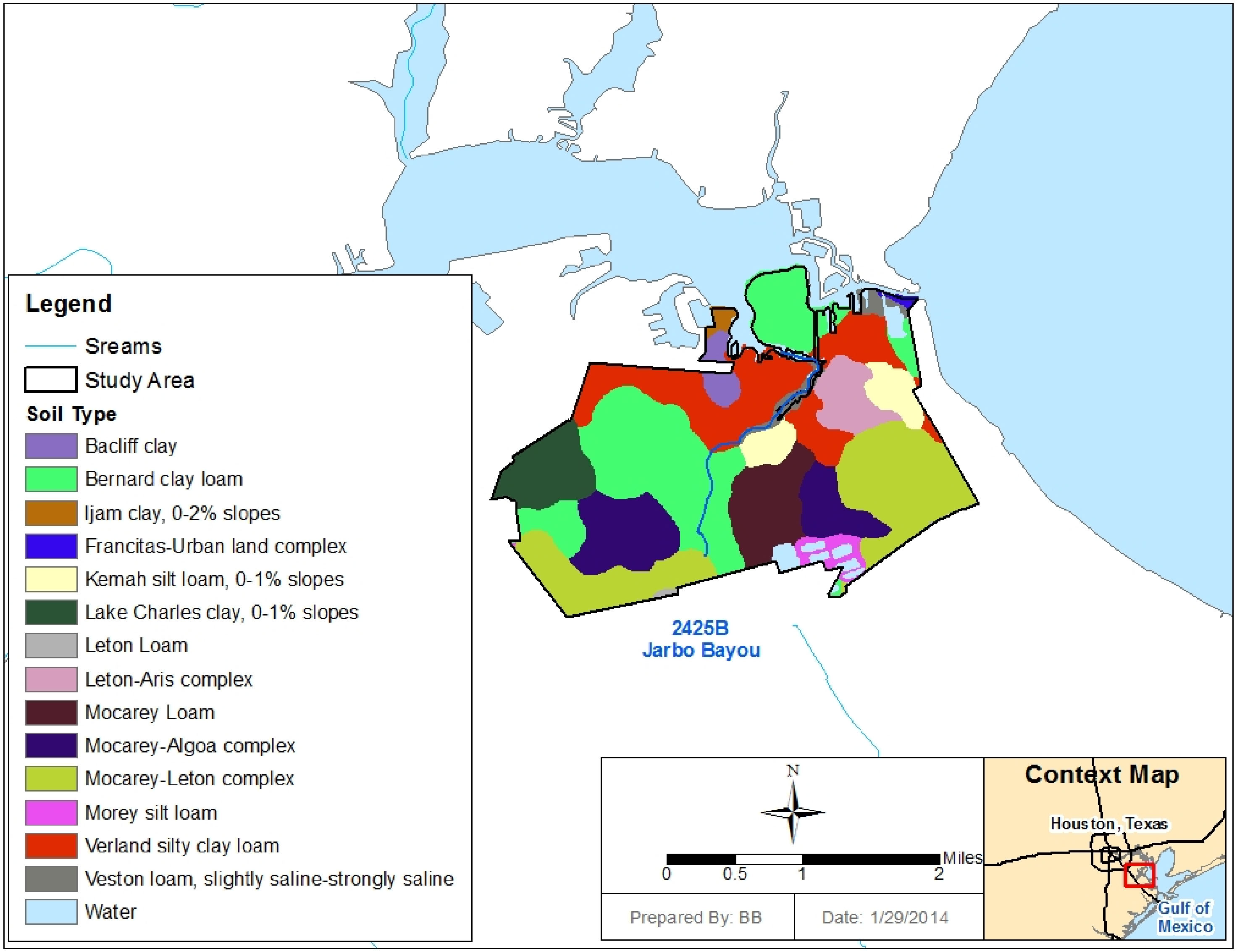

Figure 1-2: Jarbo Bayou Region Soil Types

1.2.2 Land Cover

As previously noted, the regions bordering Clear Lake as well as the western section of the watershed are thoroughly developed while the central and southeastern regions are less developed and include pasture land as well as pockets of wooded wetlands. Table 1-6 summarizes the acreages and the corresponding percentages of the land cover categories for the Study Area. The land cover data was retrieved from the National Oceanic and Atmospheric Administration (NOAA) 2011 land cover database obtained from Houston-Galveston Area Council. The total acreage of each land cover category in Table 1-6 corresponds to the watershed delineation in Figure 1-3. The predominant land cover category in this watershed is developed land (79%), followed by small amounts of woody wetlands (5%) and hay/pasture (4%).

Table 1-6: Aggregated Land Cover Summaries by Assessment Unit

Aggregated Land Cover Category	Jarbo Bayou (2425B)	
	Acres	Percent %
Open Water	66	2%
Developed, Open Space	423	14%
Developed, Low Intensity	647	21%
Developed, Medium Intensity	1150	37%
Developed, High Intensity	198	6%
Barren Land	24	1%
Deciduous Forest	120	4%
Evergreen Forest	12	1%
Mixed Forest	2	>1%
Shrub/Scrub	34	1%
Herbaceous	102	3%
Hay/Pasture	128	4%
Cultivated Crops	0	0%
Woody Wetlands	151	5%
Emergent Herbaceous Wetlands	11	1%
Total	**3068**	**100%**

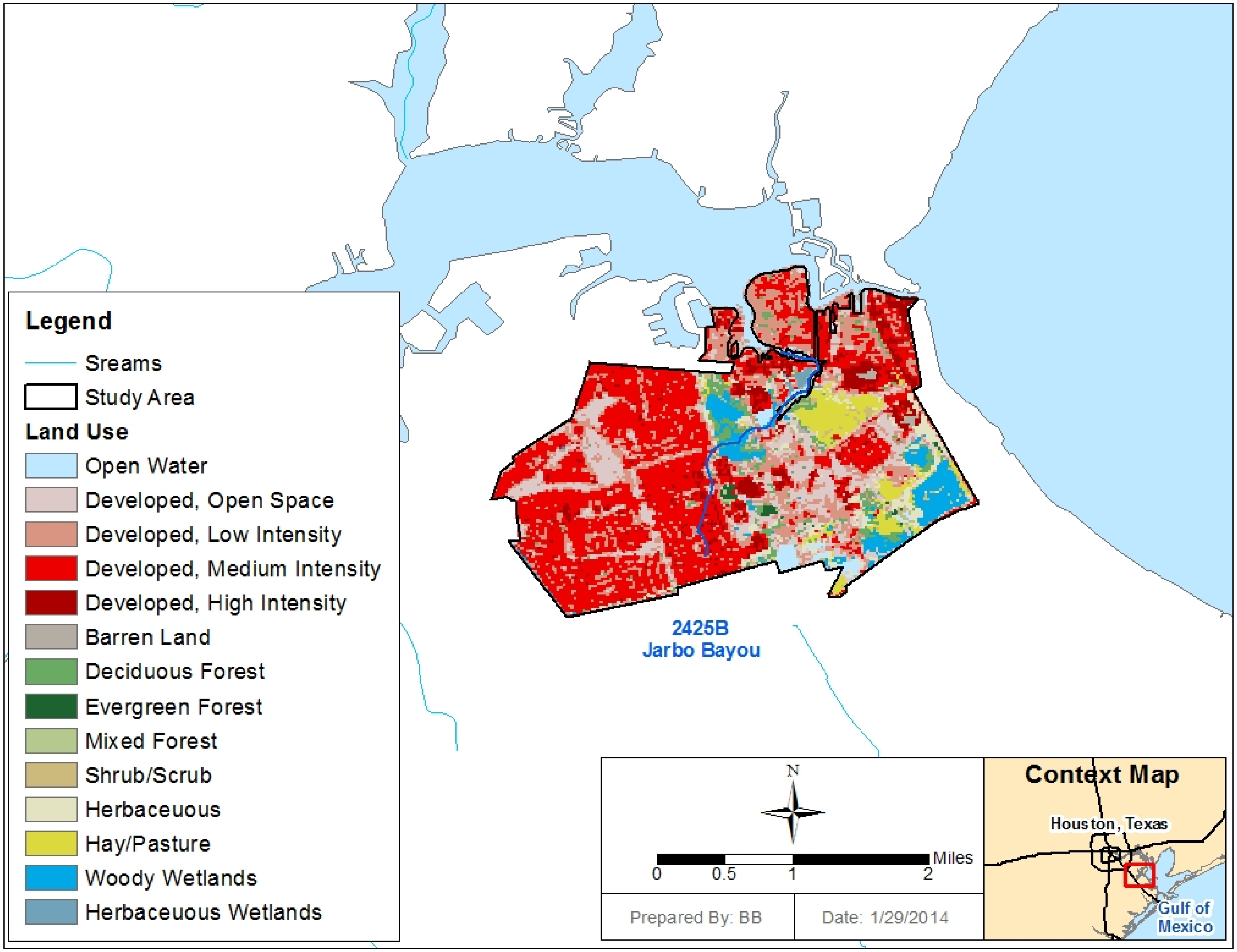

Figure 1-3: Land Cover Map

1.2.3 Precipitation

Unfortunately, there are no rain gauges currently in operation within the Study Area; however, two gauges (Figure 1-4) are within reasonable distance to be used. The gauges are maintained by the Harris County Office of Homeland Security and Emergency Management (HCOEM). Table 1-7 summarizes total annual rainfall for the two gauges for a 12-year period. The region has high levels of humidity and receives annual precipitation ranging between 43.0 and 51.5 inches per year as shown in the table. Based on data for the period 2000 to 2012, the watershed average is around 47.3 inches per year.

To evaluate the distribution of rainfall across the Study Area, Thiessen polygons were developed for the two rainfall gauges as shown in Figure 1-4. Interestingly, the area closer to Galveston Bay (gauge 100) reported less rainfall than the gauge further inland (gauge 170). The average annual rainfall for the Study Area was calculated based on the weighted average of the two gauges.

To supplement the HCOEM rainfall data, average annual precipitation data was also compiled for the time period 1981 to 2010 based on the national data set from PRISM Group (PRISM Group 2006). The average annual precipitation value derived from PRISM for the Study Area is 57.3 inches per year. Table 1-8 compares the average annual precipitation values calculated from the HCOEM and PRISM datasets. The PRISM data represents a significantly higher average annual precipitation for the Study Area than the rainfall gauges of the HCOEM. One possible explanation to the observed difference could be the drought events that occurred during the past decade (especially 2011), which reduce the annual averages for the HCOEM data more than the PRISM. Compared to regional numbers, an annual rainfall average of 44.4 inches appears to be low, while on the other end of the spectrum, an average of 57.3 appears high for the region. With no rainfall gauge within the Study Area it is impossible to determine with great accuracy the annual average of rainfall, however, it is safe to assume that the rainfall within the Study Area is within the range of the data gathered from both HCOEM and PRISM.

Table 1-7: Annual Totals at HCOEM Rainfall Gauges near Jarbo Bayou Watershed

Gauge Number	Year													Average
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	
Gauge 100	43.7	56.4	56.4	38.0	49.0	32.6	43.1	46.4	42.0	36.2	44.9	23.8	46.4	43.0
Gauge 170	38.7	60.9	61.6	54.3	57.7	36.0	58.9	59.1	67.6	50.6	48.3	24.6	51.6	51.5

Table 1-8: Average Annual HCOEM and PRISM Precipitation in Jarbo Bayou Watershed

Segment Name	Assessment Unit	Average Annual (inches) HCOEM 2000-2012	Average Annual (inches) PRISM 1981-2010
Jarbo Bayou	2425B	44.4	57.3

Source: PRISM Group 2006

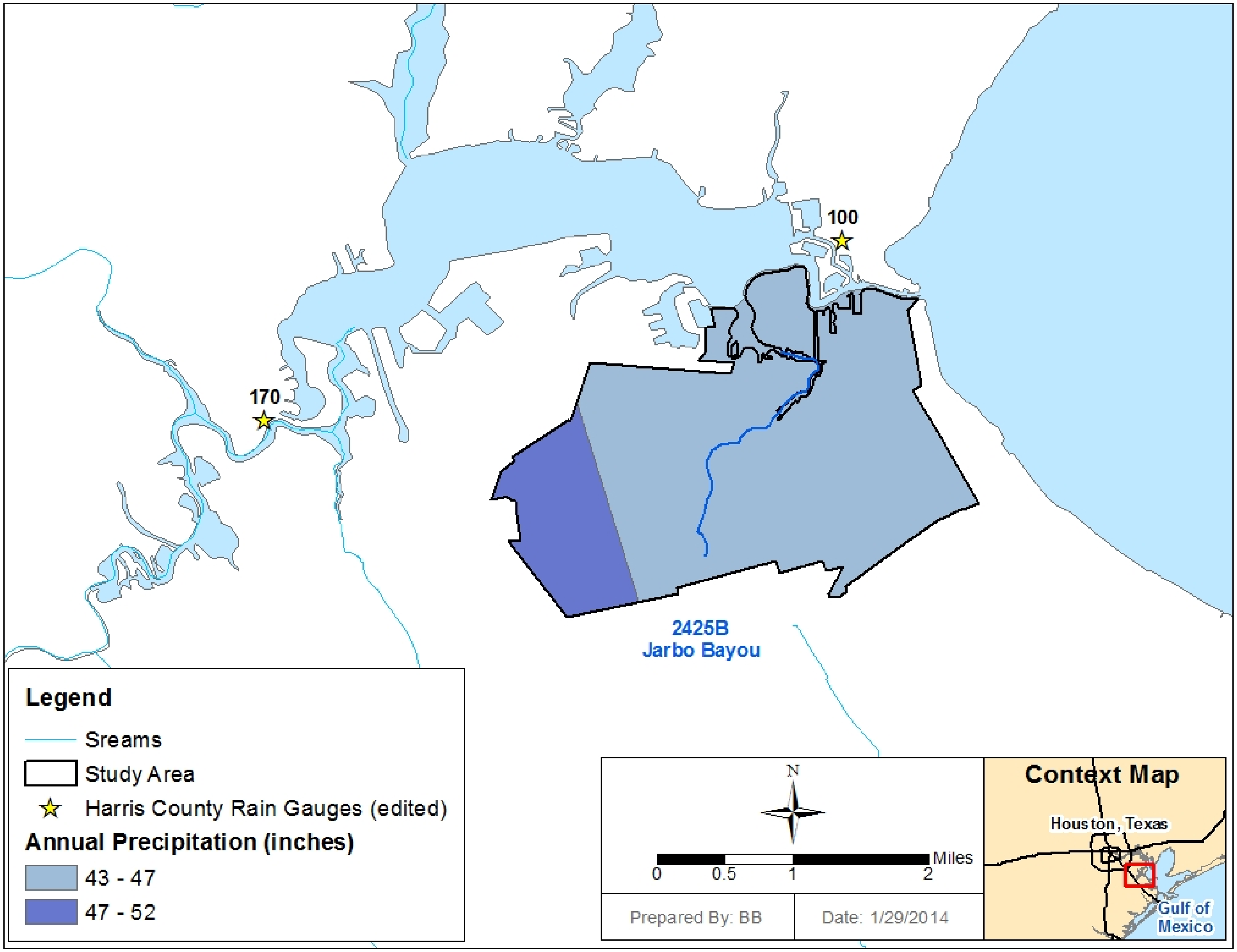

Figure 1-4: HCOEM Precipitation Map

1.2.4 Ambient Water Quality

Historical water quality data, including indicator bacteria data, was obtained for the period 2004 to 2010 from the TCEQ Surface Water Quality Monitoring Information System (SWQMIS) database. Figure 1-5 illustrates the location of the two water quality monitoring (WQM) stations along Jarbo Bayou for which the data was gathered. Only station 16476 has more than the 20 sample minimum of bacteria (TCEQ, 2012) to be used for consideration in the TMDL process. Because Jarbo Bayou is a tidal stream, all of the bacteria data collected are from the Enterococci species.

Table 1-9 summarizes the historical ambient water quality data for indicator bacteria (2004-2010) for both of the TCEQ WQM stations along Jarbo Bayou. As previously noted, station 16485 does not meet the minimum requirement of 20 bacteria samples, and is therefore not included in discussion or calculations beyond this point. The complete ambient water quality data set for bacteria used to prepare Table 1-9 is provided in Appendix A. Table 1-9 presents the number of indicator bacteria samples, as well as the geometric mean of the concentrations for each indicator, and the number and percentage of single sample exceedances of the Texas SWQS. A more in-depth discussion of the analysis of this data set is provided in Subsections 2.3 and 2.4.

Table 1-9: Historical Water Quality Data for TCEQ Stations from 2004 to 2010

Assessment Unit	Station ID	Indicator Bacteria	Geometric Mean Concentration (MPN/100ml)	Number of Samples	Number of Samples Exceeding Single Sample Criterion	% of Samples Exceeding
2425B_01	16476	ENT	62.14	34	14	41%
2425B_02	16485	ENT	69.88	8	3	38%

ENT: enterococci
Geometric Mean Criteria: 35 MPN/100 ml for ENT.
Single Sample Criteria: 104 MPN/100 ml for ENT.

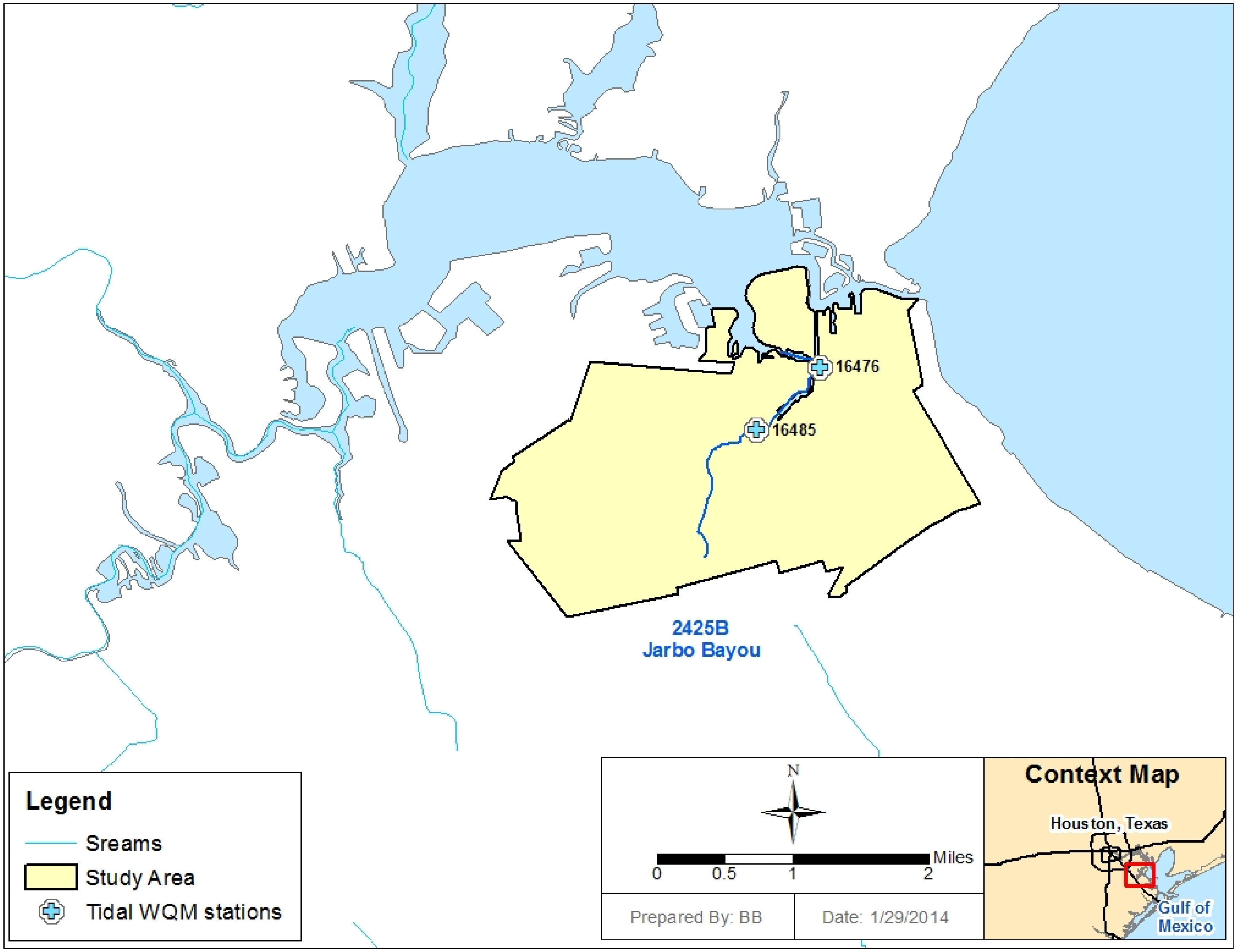

Figure 1-5: WQM Station Locations

1.2.5 Stream Flow Data

Jarbo Bayou is classified entirely as a tidal stream; therefore, flows cannot be measured by a typical flow gauge. To determine the water movement in Jarbo Bayou, a mass balance model is used which incorporates tidal action along with fresh water inputs from runoff during storm events. A detailed description of the model setup and results is given in Chapter 4.

1.2.6 Tide Data

Tide data were compiled to support the assessment and modeling of bacteria loading in the tidal segments of Jarbo Bayou. There are no tide gauges currently located along Jarbo Bayou; however, there is significant historical tide data within the surrounding Clear Lake region. The closest gauges that provide data regarding tides are as follows:

- The Texas Coastal Ocean Observation Network (TCOON) operated Station 502 near the mouth of Armand Bayou at Clear Lake Park. This gauge had been in operation since 1991 but was damaged in Hurricane Ike and is no longer active as of September 13, 2008. (http://lighthouse.tamucc.edu/overview/502).
- The U.S. Geological survey (USGS) operates Gauge 08077637 at the mouth of Clear Lake into Galveston Bay. This gauge is the next closest tide gauge for the area. This gauge has been in operation since 2007 and continues to operate at this time.

To confirm that there was no significant difference between the two gauges, located approximately 3 miles apart within Clear Lake, the data from the gauges were statistically compared for the entire time period at which they were both in operation. There was only a 8.4mm difference between the mean values (n=8202, R^2=0.985), indicating that there is almost no difference between the gauges that are positioned on either side of the confluence point of Jarbo Bayou with Clear Lake. Figure 1-6 visually illustrates the close correlation between the two tidal gauges for a 24 day period. TCOON gauge 502 tidal data was used up until it was destroyed during Hurricane Ike, after which the USGS gauge 08077637 was used. In total, tidal data from the two gauges was collected for the time period between 2000 and early 2013. A spreadsheet of the tidal data is provided in Appendix B.

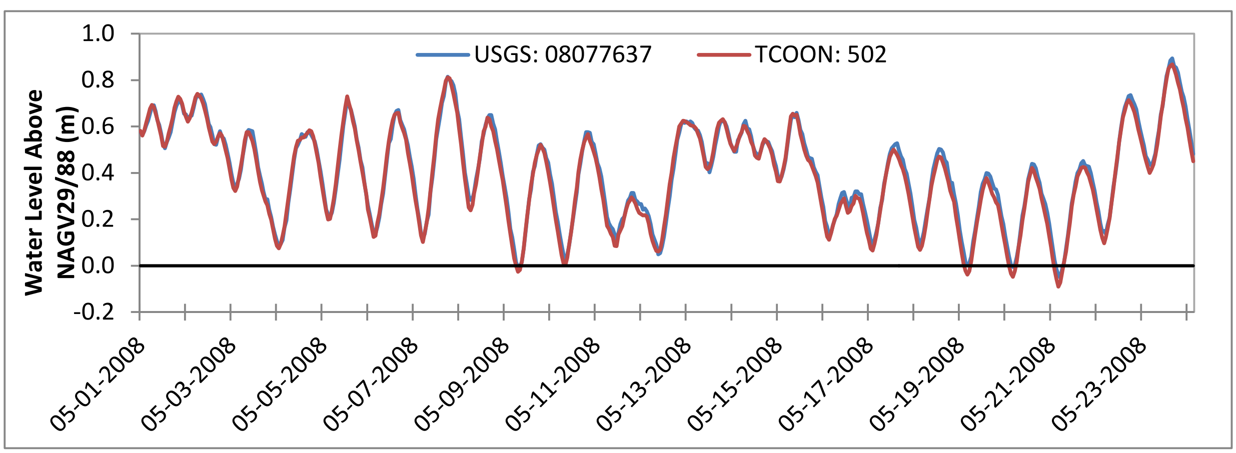

Figure 1-6: Tide Data Near Jarbo Bayou Watershed (TCOON Station 502 and USGS Gauge 08077637)

1.3 Jarbo Bayou Seasonality

Seasonal differences in indicator bacteria concentrations were assessed by comparing historical bacteria concentrations collected in the warmer months versus those collected during the cooler months. The monthly average temperatures for Houston obtained from NOAA (Table 1-10) and were used to divide the data sets into warmer (24 – 28˚C) and cooler months (11 – 18˚C). Based on these temperature ranges, November, December, January, February, and March were considered the cooler months; June, July, August, and September were warmer months.

Table 1-10: Average Monthly Temperatures at the Houston National Weather Service Office, TX (1981-2010)

Month	Daily Max (ºC)	Daily Min (ºC)	Daily Mean (ºC)	Classification
Jan	16.6	6.3	11.4	Cool
Feb	18.5	8.3	13.4	Cool
Mar	21.7	11.4	16.6	Cool
Apr	24.9	14.8	19.8	
May	28.4	19.4	23.9	
Jun	31.2	22.3	26.8	Warm
Jul	32.6	23.0	27.8	Warm
Aug	32.6	23.0	27.8	Warm
Sep	30.5	20.6	25.5	Warm
Oct	26.6	15.4	21.0	
Nov	22.0	11.0	16.5	Cool
Dec	17.8	7.1	12.4	Cool

Note: Temperature values from NOAA Houston National Weather Service Office (degrees Fahrenheit) have been converted to degrees Celsius.
http://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets/climate-normals/1981-2010-normals-data

To determine if there was a statistically significant difference between cool and warm months, a *t*-test was conducted on log transformed data between the warmer months and cooler months for the 16476 WQM station. Table 1-11 contains the results from the t-test as well as geometric means that were also calculated for the warmer and cooler months. The geomean of the cool months was more than twice that of the warm month; however, there were no statistically significant differences at the 95% confidence interval between the warmer and cooler months.

Table 1-11: Seasonal Differences for enterococci Concentrations at WQM station 16476

Assessment Unit	Station ID	Indicator	Warm Months		Cool Months		*p*-value
			n	Geomean (MPN/100 ml)	n	Geomean (MPN/100 ml)	
2425B_01	16476	ENT	13	56.6	8	120.7	0.43

ENT: enterococci; n = number of samples

Highlighted rows correspond to stations for which the warm and cold datasets are significantly different at a 95% confidence interval.

p-value is based on a t-test conducted at each station using log transformed single sample concentrations.

CHAPTER 2
PROBLEM IDENTIFICATION AND WATER QUALITY TARGET

2.1 Pollutant of Concern: Characteristics of Bacterial Indicators

The contact recreation use is assigned to almost every designated water body in the State of Texas, although full support of the contact recreation use is not a guarantee that the water is completely safe of disease-causing organisms. The evolution of the contact recreation criteria currently used by Texas began with criteria first published in 1968 based on general studies done on lakes in the Midwest and New York using fecal coliform bacteria as an indicator of the potential presence of fecal contamination (USEPA 1986). The USEPA-recommended criteria for recreational waters in 1976 included a geometric mean criterion: no more than 200 counts/dL based on five samples collected over a 30-day period; and an instantaneous criterion: no more than 10 percent of the individual grab samples could exceed 400 counts/dL (USEPA 1986). Shortly thereafter, these recommended criteria were adopted by the State of Texas in its SWQS. The fecal coliform criteria, and the studies on which they were based, were heavily criticized by the USEPA in 1986 (USEPA 1986) following an extensive program of epidemiology testing. During that decade, USEPA studies found that fecal coliform was not a good predictor of the risk of disease and recommended new tests and criteria. The USEPA recommended new criteria for swimming areas, using *E coli* and enterococci as new fecal indicator organisms, and incorporating the idea of varying criteria with the level of swimming use.

In Texas, three indicator bacteria have been analyzed in water samples collected to determine support of the contact recreation use: fecal coliform and *E coli* in freshwater and fecal coliform and enterococci in marine waters. Currently, *E coli* and enterococci bacteria are measured to determine the relative risk of contact recreation, depending on whether the water body is fresh or marine. The presence of these bacteria indicates that associated pathogens from the fecal waste of warm-blooded species (human or animal) may be reaching a body of water. High concentrations of certain bacteria in water indicate there may be an increased risk of becoming ill from recreational activities.

Texas water quality standards (WQS) for contact recreation allow exemptions for waterbodies where elevated bacteria concentrations frequently occur due to sources of pollution that cannot be reasonably controlled by the existing regulations, or where recreation is considered unsafe for other reasons, such as barge or ship traffic (e.g., the Houston Ship Channel), unrelated to water quality. This exemption and reclassification to less strict “noncontact recreation” standards has been applied to only a few waterbodies in Texas.

2.2 TCEQ Water Quality Standards for Contact Recreation

The TCEQ is responsible for administering provisions of the constitution and laws of the State of Texas to promote judicious use of and protection of the quality of waters in the state. Included in this responsibility is the continuous monitoring and assessment of water quality to evaluate compliance with SWQSs established within Texas Water Code, §26.023 and Title 30 Texas Administrative Code (TAC), §§307.1-307.10. Texas SWQS, 30 TAC 307.4, specify the designated uses and general criteria for all surface waters in the state.

The present report focuses on the Jarbo Bayou Watershed which is on the federal Clean Water Act §303(d) list because it does not support contact recreation use. Table 2-1 summarizes the designated uses and the applicable bacteria indicators used to assess the contact recreation use of each waterbody addressed in this report. Table 2-1 also identifies the year Jarbo Bayou was placed on the Texas' Clean Water Act §303(d) List for nonsupport of contact recreation use, the stream length in miles, and other designated uses. The TMDLs in this report only address the contact recreation use.

Table 2-1: Synopsis of Texas Integrated Report for the Jarbo Bayou Watershed

Assessment Unit	Segment Name	Parameter	Designated Use*				Year Impaired	Stream Length (miles)
			CR	AL	GU	FC		
2425B_01	Jarbo Bayou	ENT	NS	FS	NA	NS	2002	1.55

** CR: Contact recreation; AL: Aquatic Life; GU: General Use; F: Fish Consumption; ENT: enterococci,*
NS = Not Supporting; FS = Fully Supporting; NA= Not Assessed

The excerpts below from Chapter 307, Texas SWQS stipulate how water quality data were assessed to determine support of contact recreation use as well as how the water quality targets are defined for each bacterial indicator. In addition to the specific requirements of §307.7 outlined below, the TMDLs for the Jarbo Bayou Watershed will also adhere to §307.5 of the SWQS which defines the antidegradation policy and procedures that apply to authorized wastewater discharges, TMDLs, waste load evaluations, and any other miscellaneous actions, such as those related to man-induced nonpoint sources of pollution, which may impact the water in the state.

Excerpted from 30 Texas Administrative Code (TAC) §307.7. Site-specific Uses and Criteria.

(a) Uses and numerical criteria are established on a site-specific basis in Appendices A,B,D,E,F and G of §307.10 of this title (relating to Appendices A - G). Site-specific uses and numerical criteria may also be applied to unclassified waters in accordance with §307.4(h) of this title (relating to General Criteria) and §307.5(c) of this title (relating to Antidegradation). Site-specific criteria apply specifically to substances attributed to waste discharges or human activities. Site-specific criteria do not apply to those instances in which surface waters exceed criteria due to natural phenomena. The application of site-specific uses and criteria is described in §307.8 of this title (relating to the Application of Standards) and §307.9 of this title (relating to the Determination of Standards Attainment).

(b) Appropriate uses and criteria for site-specific standards are defined as follows.

(1) Recreation. Recreational use consists of four categories – primary contact recreation, secondary contact recreation 1, secondary contact recreation 2, and noncontact recreation waters. Classified segments are designated for primary contact recreation unless sufficient site-specific information demonstrates that elevated concentrations of indicator bacteria frequently occur due to sources of pollution which cannot be reasonably controlled by existing regulations, wildlife sources of bacteria are unavoidably high and there is limited aquatic recreational potential, or primary or secondary contact recreation is considered unsafe for other reasons such as ship or barge traffic. In a classified segment where contact recreation is considered unsafe for reasons unrelated to water quality, a designated use of noncontact recreation may be assigned criteria normally associated with contact recreation. A designation of primary or secondary contact recreation is not a guarantee that the water so designated is completely free of disease-causing organisms. Indicator bacteria, although not generally pathogenic, are indicative of potential contamination by feces of warm blooded animals. The criteria for contact recreation are based on these indicator bacteria, rather than direct measurements of pathogens. Criteria are expressed as the number of bacteria per 100 milliliters (ml) of water (in terms of colony forming units, most probable number, or other applicable reporting measures). Even where the concentration of indicator bacteria is less than the criteria for primary or secondary contact recreation, there is still some risk of contracting waterborne diseases. Additional guidelines on minimum data requirements and procedures for evaluating standards attainment are specified in the TCEQ Guidance for Assessing and Reporting Surface Water Quality Data in Texas, as amended.

(A) Freshwater

(i) Primary contact recreation. The geometric mean criterion for E coli is 126 per 100 mL. In addition, the single samples criterion for E coli is 399 per 100 mL.

(ii) Secondary contact recreation 1. The geometric mean criterion for E coli is 630 per 100 mL.

(iii) Secondary contact recreation 2. The geometric mean criterion for E coli is 1,030 per 100 mL.

(iv) Noncontact recreation. The geometric mean criterion for E coli is 2,060 per 100 mL.

(v) For high saline inland water bodies where enterococci is the recreational indicator for instream bacteria sampling at all times for the classified water body and for the unclassified water bodies that are within the watershed of that

classified segment, unless it is demonstrated that an unclassified water body is not high saline. E coli is the applicable recreational indicator for instream bacteria sampling at all times for unclassified water bodies where conductivity values indicate that the water bodies are not high saline. For high saline water bodies with primary contact recreation, the geometric mean criterion for enterococci is 33 per 100 ml and the single sample criterion is 78 per 100 ml. For high saline inland waters with secondary contact recreation 1, the geometric mean criterion for enterococci is 165 per 100 ml. For high saline inland waters with secondary contact recreation 2, the geometric mean criterion for enterococci is 270 per 100 ml. For high saline inland water bodies with noncontact recreation, the geometric mean criterion for enterococci is 540 per 100 ml.

(B) Saltwater

(i) Primary contact recreation. The geometric mean criterion for enterococci is 35 per 100 mL. In addition, the single sample criterion for enterococci is 104 per 100 mL.

(ii) Secondary contact recreation 1. A secondary contact recreation 1 use for tidal streams and rivers can be established on a site-specific basis in §307.10 of this title if justified by a use-attainability analysis and the water body is not a coastal recreation water as defined in the Beaches Environmental Assessment and Coastal Health Act of 2000 (BEACH Act). The geometric mean criterion for enterococci is 175 per 100 mL.

(iii) Noncontact recreation. A noncontact recreation use for tidal streams and rivers can be established on a site-specific basis in §307.10 of this title if justified by a use-attainability analysis and the water body is not a coastal recreation water as defined in the BEACH Act. The geometric mean criterion for enterococci is 350 per 100 mL.

(C) Fecal coliform bacteria. Fecal coliform bacteria can be used as an alternative instream indicator of recreational suitability in high saline inland water bodies where enterococci is the designated recreational indicator in Appendix A of §307.10 of this title for two years after the adoption of this title to allow time to collect sufficient data for enterococci. Fecal coliform criteria for high saline inland water bodies are as follows:

(i) Primary contact recreation. The geometric mean criterion for fecal coliform is 200 per 100 mL. In addition, single sample criterion for fecal coliform is 400 per 100 mL.

(ii) Secondary contact recreation 1 and 2. The geometric mean criterion for fecal coliform is 1,000 per 100 mL.

(iii) Noncontact recreation. The geometric mean criterion for fecal coliform is 2,000 per 100 mL.

(D) Swimming advisory programs. For areas where local jurisdictions or private property owners voluntarily provide public notice or closure based on water quality, the use of any single sample or short-term indicators of recreational suitability are selected at the discretion of the local managers of aquatic recreation. Guidance for single-sample bacterial indicators is available in the USEPA document entitled Ambient Water Quality Criteria for

Bacteria - 1986. Other short-term indicators to assess water quality suitability for recreation -- such as measures of streamflow, turbidity, or rainfall -- may also be appropriate.

As stipulated in 2012 *Guidance for Assessing and Reporting Surface Water Quality in Texas* (TCEQ 2012), utilization of the geometric mean to determine compliance for any of the bacterial indicators depends on the collection of a *minimum of 10 (20 for bacteria) samples from the last seven years or the most recently collected 10 samples (20 for bacteria) for up to ten years are used to determine use support*. The 2012 *Guidance for Assessing and Reporting Surface Water Quality in Texas* (TCEQ 2012) specifically states the following*:*

- *All assessment methods based on the average will require 10 samples (20 for bacteria) for listing and delisting, although in rare instances the assessor will make the use attainment decision with fewer samples and indicate this by reporting a data set qualifier of JQ (based on judgment of the assessor).*
- *The 2012 assessment period of record for the last seven years is December 1, 2003 through November 30, 2010. Samples from these seven years are evaluated when available, and if necessary, the most recent samples collected in the preceding three years (December 1, 2000 through November 30, 2003) can also be included to meet the requirements for minimum sample number.*

2.3 Problem Identification

Pursuant to §303(d) of the federal Clean Water Act, states must establish TMDLs for pollutants contributing to violations of WQS. Table 2-2 identifies Jarbo Bayou as requiring a TMDL through identification as Category 5 of the 2012 Texas Water Quality Inventory and §303(d) List (TCEQ 2012b). Table 2-2 lists the TCEQ WQM stations from which ambient water quality data were summarized to support the decision to place Jarbo Bayou on the TCEQ 303(d) List. The locations of these WQM stations are displayed in Figure 1-5 from the previous chapter.

Table 2-2: Water Quality Monitoring Stations Used for 303(d) Listing Decision

Assessment Unit	Water Body	Description	Monitoring Station IDs	Year impaired
2425B_01	Jarbo Bayou Tidal	From the Clear Lake confluence upstream to Lawrence Road	16476	2002

A number of changes have occurred over the past decade that warrant refinements in how indicator bacteria data are used to support water quality assessments and TMDL development in Texas. Some key factors that influence which indicator bacteria to use for water quality assessment and TMDL development and the period of record to use include:

- Changes in land cover and locations of Texas Pollution Discharge Elimination System (TPDES)-permitted facilities
- Changing the indicator bacteria in the 2000 TCEQ SWQS from fecal coliform to *E coli* for fresh water, and enterococci for marine waters
- Refinements in the TCEQ surface water quality monitoring procedures

- Changes in the TCEQ guidance, *Assessing and Reporting Surface Water Quality in Texas*

As a result of these evolving factors in the water quality management arena associated with the protection and maintenance of contact recreation use, the historical data set used to support the TMDLs in this report have been narrowed, wherever possible, to utilize only *E coli* and enterococci data from 2003 through 2011.

2.4 Water Quality Targets for Contact Recreation

The Code of Federal Regulations (40 CFR §130.7(c)(1)) states that, "TMDLs shall be established at levels necessary to attain and maintain the applicable narrative and numerical water quality standards." The Texas SWQS (TCEQ 2010) provide numeric and narrative criteria to evaluate attainment of designated uses. The basis for water quality targets for all TMDLs developed in this report will be the numeric criteria for bacterial indicators from the 2010 Texas SWQS as described in Subsection 2.2 above. Jarbo Bayou is a tidally influence stream with saline water, making enterococci the preferred indicator bacteria and the only bacterial indicator species considered for this report.

Several studies have been performed by the USEPA that show a stronger link between the concentrations of *E coli* and enterococci and the concentrations of fecal pathogens than the previous standard, fecal coliform. The TCEQ adopted a limit of 104 per dL for enterococci in any single sample, and a limit of 35 per dL for the geomean of all samples at any location for enterococci concentrations within a tidal stream designated for contact recreation uses (TCEQ 2010). The water quality target for the TMDLs for tidal (saltwater) segments is to achieve concentrations of enterococci below the geometric mean criterion of 35 counts per dL. Maintaining the geometric mean criterion for indicator bacteria is expected to be protective of the single sample criterion also and therefore will ultimately result in the attainment of the contact recreation use. TMDLs will be based on a percent reduction goal required to meet the geometric mean criterion.

For example, if *E coli* is utilized to establish the TMDL, then the water quality target would be 379 counts/dL, 5 percent lower than the single sample water quality criterion (399 counts/dL) and the geometric mean water quality target would be 120 counts/dL, 5 percent lower than the criterion value (126 counts/dL). For enterococci, the single sample water quality target would be 99 counts/dL and the geometric mean water quality target would be 33 counts/dL, both 5 percent lower than the criterion values.

For non-tidal segments, each water quality target will be used to determine the allowable bacteria load that is derived by using the actual or estimated flow record multiplied by the instream criteria minus a 5 percent MOS. For tidal segments, a mass-balance model will be used to determine the maximum amount of loading discharged to the water bodies that result in meeting the geometric mean criteria throughout the length of the segment.

CHAPTER 3
POLLUTANT SOURCE ASSESSMENT

To support TMDL development, a pollutant source assessment attempts to characterize known and suspected sources of pollutant loading to the impaired waterbody. Pollutant sources within a watershed are categorized and quantified to the extent that information is available. Fecal bacteria such as *E coli* and Enterococcus originate in the intestines of warm-blooded species (human and animal), and sources of bacteria may be point (permitted) or nonpoint (unregulated) in nature. For example, in the case of stormwater, runoff that is conveyed and discharged at a specific point may be permitted through National Pollution Discharge Elimination System (NPDES) as municipal separate storm sewer systems (MS4), while other sources of stormwater runoff that cannot be identified as entering a waterbody through a discrete conveyance at a single location are often referred to as nonpoint sources and therefore unregulated.

Point sources are permitted through the NPDES and TPDES programs. For the TMDLs presented in this report, all sources of pollutant loading not regulated by a NPDES/TPDES permit are considered nonpoint sources. The following discussion describes what is known regarding permitted and unregulated sources of bacteria in Jarbo Bayou watershed.

3.1 Point Sources: NPDES/TPDES-Permitted Sources

Under 40 CFR, §122.2, a point source is described as a discernible, confined, and discrete conveyance from which pollutants are or may be discharged to surface waters. Under the Texas Water Code, TCEQ has adopted rules and procedures to issue permits to control the quantity and quality of discharges into or adjacent to waters of the state through the TPDES program. NPDES/TPDES-permitted facilities classified as point sources that may contribute bacteria loading to surface waters include:

- TPDES municipal wastewater treatment facilities (WWTF)
- TPDES industrial WWTF (stormwater and/or wastewater)
- TPDES municipal no-discharge WWTF
- TPDES regulated stormwater (MS4s)
- TPDES Concentrated Animal Feeding Operation (CAFO)

Point source discharges such as WWTFs could result in discharge of elevated concentrations of fecal bacteria if the plant is not properly maintained, is of poor design, or if flow rates exceed the treatment capability of the plant. Industrial WWTFs may contain fecal bacteria in their effluent. While no-discharge facilities do not discharge wastewater directly to a waterbody, it is possible that collection systems associated with these types of facilities may be a source of bacteria loading to surface waters. Permitted stormwater runoff from TPDES regulated discharge areas, MS4s, may also contain high fecal bacteria concentrations. Finally, CAFOs are recognized by USEPA as significant potential source of pollution, and may have the potential to seriously impact water quality if not properly managed.

3.1.1 Permitted Sources: NPDES/TPDES Wastewater Facility Point Source Discharges

There are no TPDES-permitted facilities discharging into the Study Area. The residents in the Study Area are serviced by two WWTPs: Dallas Salmon in League City, and Galveston County Water Control and Improvement District (WCID) #12 in Kemah, which discharge into Clear Creek Tidal and Upper Galveston Bay, respectively. The service area boundaries of these two WWTF are shown in Figure 3-1. Three Municipal Utility Districts (MUDs) are within the Study area: Galveston County MUD #3, South Shores MUD #3, and South Shores MUD #6. The wastewater from these three MUDs is conveyed to the Dallas Salmon WWTF for treatment.

3.1.2 Permitted Sources: Sanitary Sewer Overflows

Sanitary sewer overflows (SSO) are overflows from sanitary sewers that most often result from blockages in the sewer collection pipes caused by tree roots, grease and other debris. Occurrences of SSOs are permit violations that must be addressed by the responsible TPDES permittee.

The TCEQ maintains a database of SSO data collected from the wastewater facilities that service the Jarbo Bayou Watershed. TCEQ Region 12-Houston provided a database for SSO data for the two WWTF that service the Jarbo Bayou watershed (Laird 2014). The data in Table 3-1 includes the SSO details for occurrences within the Study Area. There have been approximately 30 SSOs reported in the Jarbo Bayou watershed since March 2002. The reported SSOs averaged 1,768 gallons per event.

The locations and magnitudes of all reported SSOs within the Study Area are displayed in Figure 3-1. Most SSOs occurred in the northern portion of the watershed where Jarbo Bayou feeds into Clear Lake. Only a small number SSOs of minimal volume occurred in the League City residential area that contributes to the headwaters of Jarbo Bayou.

Table 3-1: Sanitary Sewer Overflow (SSO) Summary

Facility Name	NPDES Permit No.	Facility ID	Number of Occurrences	Date Range		Amount (Gallons)	
				From	To	Min	Max
Dallas Salmon WWTF	TX0085618	10568-005	24	4/22/2002	12/10/2013	30	10,000
Galveston County WCID #12	TX0078441	12039-001	6	11/3/2003	2/2/2012	100	1,200

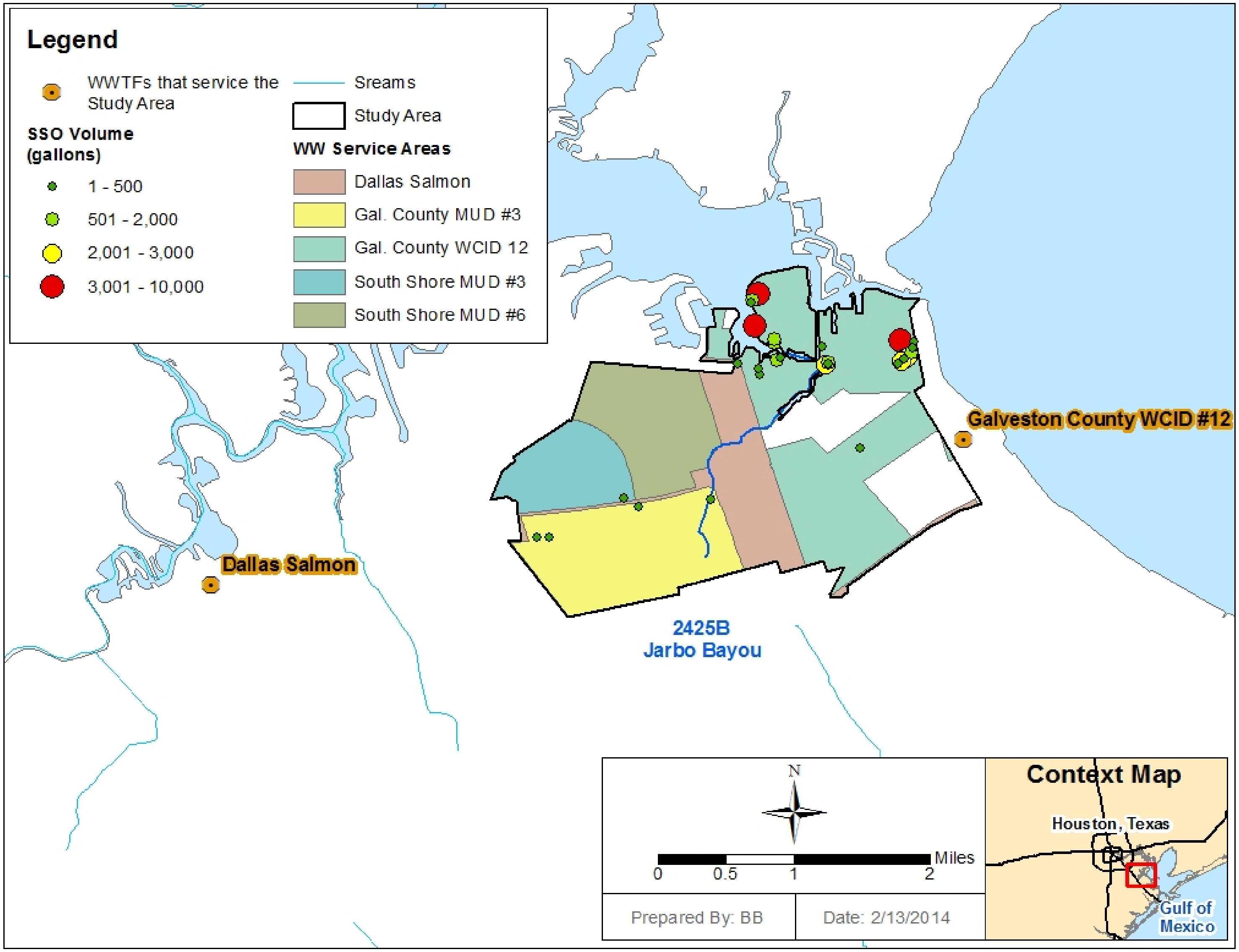

Figure 3-1: WWTF and associated SSO incidences

3.1.3 Permitted Sources: TPDES Regulated Stormwater

In 1990, the USEPA established Phase I of the NPDES Stormwater Program, designed to prevent nonpoint source pollutants from being washed by stormwater runoff into municipal separate storm sewer systems and then discharged into local waterbodies (USEPA 2005). Phase I of the program required medium and large permitted dischargers (those generally serving populations of 100,000 or greater) to implement a stormwater management program as a means to control polluted discharges. Approved stormwater management programs for medium and large permitted discharges are required to address a variety of water quality-related issues, including roadway runoff management, municipal-owned operations, and hazardous waste treatment.

Phase II of the rule extended coverage of the NPDES Stormwater program in 2000 to certain small MS4s. Small MS4s are defined as any MS4 in an urbanized area as defined by the U.S. Census Bureau that was not already covered by a Phase I NPDES Stormwater Permit. The Phase II MS4 program requires operators of regulated small MS4s to obtain NPDES permits and develop a stormwater management program. Programs are designed to reduce discharges of pollutants to the "maximum extent practicable," protect water quality, and satisfy appropriate water quality requirements of the CWA. Small MS4 stormwater programs must address the following minimum control measures including Public Education and Outreach; Public Participation/Involvement; Illicit Discharge Detection and Elimination; Construction Site Runoff Control; Post- Construction Runoff Control; and Pollution Prevention/Good Housekeeping.

When evaluating pollutant loads originating from stormwater runoff, a critical distinction must be made between stormwater originating from an area under an NPDES/TPDES regulated discharge permit and stormwater originating from areas not under an NPDES/TPDES regulated discharge permit. To characterize pollutant loads from stormwater runoff, it is necessary to segregate stormwater into two categories:

1) permitted stormwater, which is stormwater originating from an NPDES/TPDES-permitted Phase I or Phase II urbanized area; and
2) unregulated stormwater, which is stormwater originating from any area outside an NPDES/TPDES-permitted Phase I or Phase II urbanized area.

Within the Jarbo Bayou watershed, there are four collective Phase I or Phase II MS4 programs that are currently permitted by TCEQ. These programs are operated by:

- City of Houston/Harris County (Phase I permit);
- City of Clear Lake Shores (Phase II permit);
- City of Kemah (Phase II permit); and
- City of League City (Phase II permit);

The coverage areas for these permits are shown in Figure 3-2. As shown in the figure, the entire Study Area is covered under a MS4 permit, either from one of the local municipalities, or the City of Houston permit (TPDES Permit No. WQ0004685000). The jurisdictional boundary of the Houston MS4 permit is derived from *Urbanized Area Map Results for Texas* which is based on the 2010 U.S. Census and can be found at the USEPA website http://cfpub.epa.gov/npdes/stormwater/urbanmaps.cfm. Table 3-2 is a summary of the MS4 permit holders for the Jarbo Bayou watershed. As demonstrated in the table and Figure 3-2, 100% of the Study Area is covered by MS4 permits.

Table 3-2: Percentage of Permitted Stormwater in the Study Area

Segment	Receiving Stream	Regulated Entity Name	TPDES Number	Total Area (acres)	Area under MS4 Permit (Acres)	Percent of Watershed under MS4 Jurisdiction
2425B	Jarbo Bayou	City of Houston	WQ0004685000	3,068	3,068	100%
		City of League City	RN105569735			
		City of Kemah	RN105498216			
		City of Clear Lake Shores	RN105551337			

3.1.4 Concentrated Animal Feeding Operations

There are no CAFOs located within the Study Area.

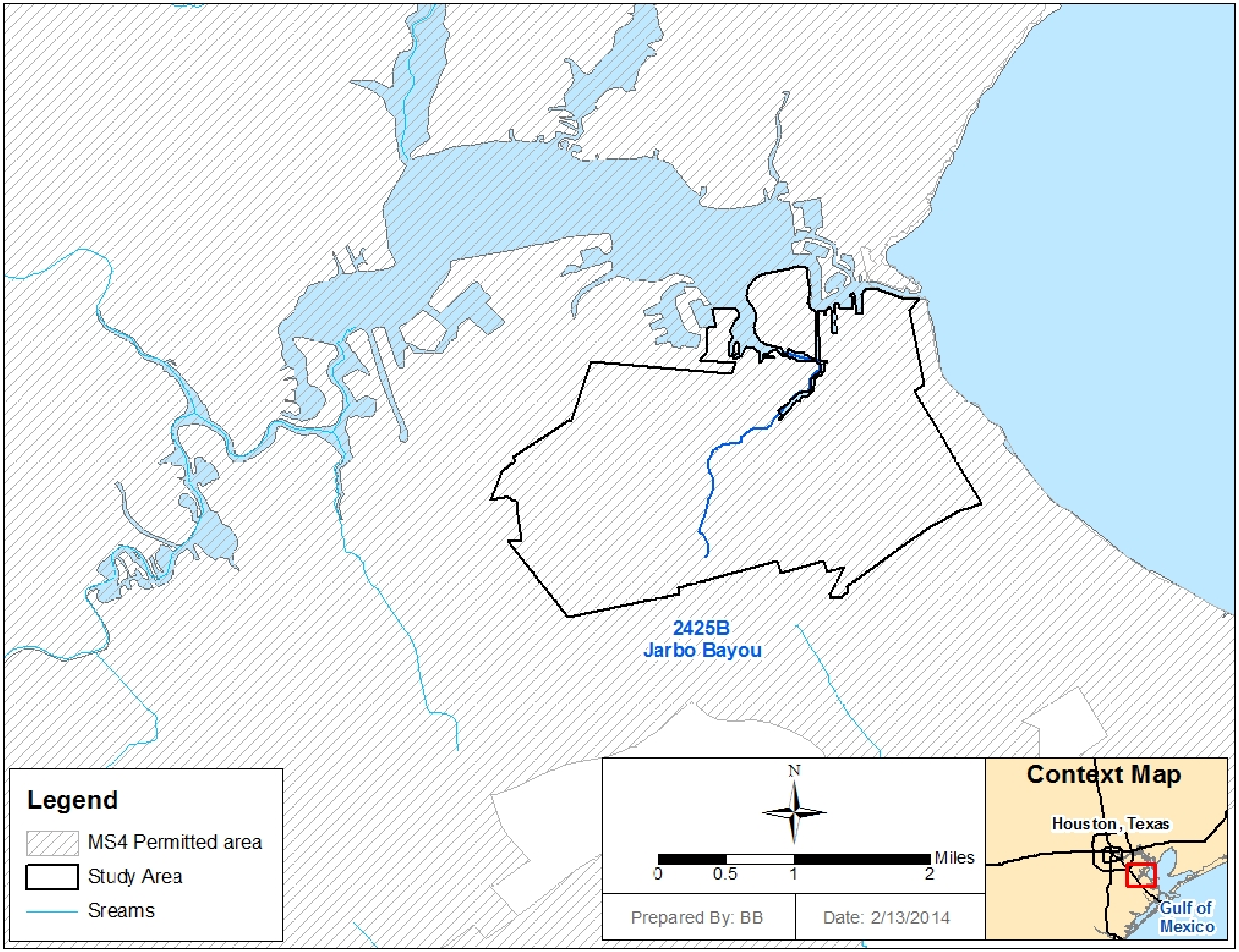

Figure 3-2: MS4 coverage based on the 2010 U.S. Census urbanized area

3.2 Unregulated Sources: Stormwater, On-site Sewage Facilities, and Direct Deposition

Unregulated sources (nonpoint sources) include those sources that cannot be identified as entering the waterbody at a specific location. The following section describes possible major unregulated sources contributing bacteria loading within the Study Area.

Nonpoint sources of bacteria can emanate from wildlife, various agricultural activities, and domesticated animals, land application fields, urban runoff, failing on-site sewage facilities (OSSF), and domestic pets. Bacteria associated with urban runoff can emanate from humans, wildlife, livestock, and domestic pets. Based on the ability of warm-blooded animals to harbor and shed human pathogens, the current USEPA policy establishes the position that it is inappropriate to conclude that livestock and wildlife sources present no risk to human health from waterborne pathogens. Consequently, states and authorized tribes should not use broad exemptions from the bacteriological criteria for waters designated for primary contact recreation based on the presumption that high levels of bacteria resulting from non-human fecal contamination present no risk to human health (USEPA 2002). Water quality data collected from streams draining urban communities often show existing concentrations of fecal coliform bacteria at levels greater than a state's instantaneous standards. A study under USEPA's National Urban Runoff Project indicated that the average fecal coliform concentration from 14 watersheds in different areas within the United States was approximately 15,000 /dL in stormwater runoff (USEPA 1983). Based on data such as these, unregulated stormwater have the potential to be a significant source of fecal bacteria.

3.2.1 Wildlife and Unmanaged Animal Contributions

E coli and enterococci bacteria are common inhabitants of the intestines of all warm-blooded animals, including wildlife such as mammals and birds. In developing bacteria TMDLs, it is important to identify the potential for bacteria contributions from wildlife by watershed. Wildlife can be naturally attracted to riparian corridors of streams and rivers. With direct access to the stream channel, the direct deposition of wildlife waste can be a concentrated source of bacteria loading to a waterbody. *E coli* and enterococci bacteria from wildlife are also deposited onto land surfaces, where it may be washed into nearby streams by rainfall runoff. Typical of coastal watersheds, many avian species frequent the watershed and the riparian corridors.

Approximately 300 acres (~10%) of the Study Area is woody wetlands and forested area which provides a habitat for many species of mammals, reptiles, and amphibians. For example, small populations of feral hogs, nutria, and feral cats are of specific concern in certain parts of the watershed.

There are currently insufficient data available to estimate populations and spatial distribution of wildlife and avian species in the watershed. Consequently, it is difficult to assess the magnitude of bacteria contributions from wildlife species as a general category. In general, due to the fact that the plots of undeveloped land providing habitat for wild animals are small and surrounded by urbanized areas, it is unlikely that there exists large quantities of wild animals that could contribute a significant source of bacteria to Jarbo Bayou.

3.2.2 Unregulated Agricultural Activities and Domesticated Animals

There are a number of unregulated agricultural activities that can also be sources of fecal bacteria loading. Agricultural activities of greatest concern are typically those associated with livestock operations (Drapcho and Hubbs 2002). The following are examples of livestock activities that can contribute to bacteria sources:

- Processed livestock manure is often applied to fields as fertilizer, and can contribute to fecal bacteria loading to waterbodies if washed into streams by runoff before incorporation.
- Livestock grazing in pastures deposit manure containing fecal bacteria onto land surfaces. These bacteria may be washed into waterbodies by runoff if inadequate buffers exist between pastures and waterbodies.
- Livestock may have direct access to waterbodies and can provide a concentrated source of fecal bacteria loading directly into streams.

The estimated numbers of selected livestock by watershed were calculated based on the 2007 USDA county agricultural census data (USDA 2007). The county-level estimated livestock populations were extrapolated to the Study Area by using the ratio of hay/pasture land in Galveston County to the Jarbo Bayou Watershed based on the National Land Cover Database (NOAA 2011). It should be noted that domesticated animals are not evenly distributed across counties or constant with time, creating the potential for high margins of error.

As shown in Table 3-3, cattle are estimated to be the most abundant species of livestock in the Study Area. Livestock numbers and their associated bacteria loading are expected to decrease over time as more land is converted from grazing to developed, urban uses in Jarbo Bayou watershed.

Table 3-3: Livestock and Domesticated Animal Estimation

Type of Animal	Galveston County	2425B
Cattle and Calves	9,909	50
Horses and Ponies	1,444	7
Llamas	19	0
Donkey	134	1
Goats	1,152	6
Hogs and Pigs	277	1
Sheep and Lambs	146	1
Bison	38	0
Captive Deer	74	0
Rabbits	193	1
Layers	2,069	10
Pullets	624	3
Broilers	84	0
Turkeys	145	1
Ducks	187	1
Geese	68	0
Other Poultry	630	3
Total Animals	**17,193**	**85**

http://www.agcensus.usda.gov/Publications/2007/Full_Report/Volume_1,_Chapter_2_County_Level/Texas/

According to a livestock study conducted by the American Society of Agricultural Engineers (ASAE) and referenced by the USEPA (2000) in their Bacteria Indicator Tool, the daily fecal coliform production rates by livestock species were estimated as follows (ASAE 1998):

- Beef cattle release approximately 1.04E+11 per animal per day
- Dairy cattle release approximately 1.01E+11 per animal per day
- Swine release approximately 1.08E+10 per animal per day
- Chickens release approximately 1.36E+08 per animal per day
- Sheep release approximately 1.20E+10 per animal per day
- Horses release approximately 4.20E+08 per animal per day
- Turkey release approximately 9.30E+07 per animal per day
- Ducks release approximately 2.43E+09 per animal per day
- Geese release approximately 4.90E+10 per animal per day

Using the estimated livestock populations and the fecal coliform production rates from ASAE, an estimate of fecal coliform production from each group of livestock was calculated in Table 3-4 for the Study Area. It should be noted that only a fraction of these fecal coliform loading estimates are expected to reach the receiving water, either washed into streams by runoff or by direct deposition from wading animals. Cattle represent the greatest potential source of fecal bacteria based on overall loading estimates.

Table 3-4: Fecal Coliform Production Estimates for Selected Livestock (x10^9 /day)

Stream Name	Cattle & Calves	Horses & Ponies	Sheep & Lambs	Hogs & Pigs	Ducks	Geese	Chickens	Total
Jarbo Bayou	5,200	3	84	11	2	0	2	5,302

3.2.3 Failing On-site Sewage Facilities

On-site sewage facilities (OSSFs) can be a source of bacteria loading to streams and rivers. Bacteria loading from failing OSSFs can be transported to streams in a variety of ways, including runoff from surface ponding or through groundwater. Indicator bacteria-contaminated groundwater can also be discharged to creeks through springs and seeps.

Over time, most OSSFs operating at full capacity will fail if not properly maintained. OSSF failures are proportional to the adequacy of a state's minimum design criteria (Hall 2002). The 1995 American Housing Survey conducted by the U.S. Census Bureau estimates that, nationwide, 10 percent of occupied homes with OSSFs experience malfunctions during the year (U.S. Census Bureau 1995). A statewide study conducted by Reed, Stowe & Yanke, LLC (2001) reported that approximately 12 percent of the OSSFs in Harris County were chronically malfunctioning. Most studies estimate that the minimum lot size necessary to ensure against contamination is roughly one-half to one acre (Hall 2002). Some studies, however, found that lot sizes in this range or even larger could still cause contamination of ground or surface water (University of Florida 1987). It is estimated that areas with more than 40 OSSFs per square mile (6.25 septic systems per 100 acres) can be considered to have potential contamination problems (Canter and Knox 1985).

Only permitted OSSF systems are recorded by authorized county or city agents; therefore, it is difficult to estimate the exact number of OSSFs in use in the Study Area. Table 3-5 lists the OSSF totals based on GIS data information provided by H-GAC. Figure 3-3 displays unsewered areas that do not fall under the wastewater service areas and may be expected to have septic systems serving households in these areas.

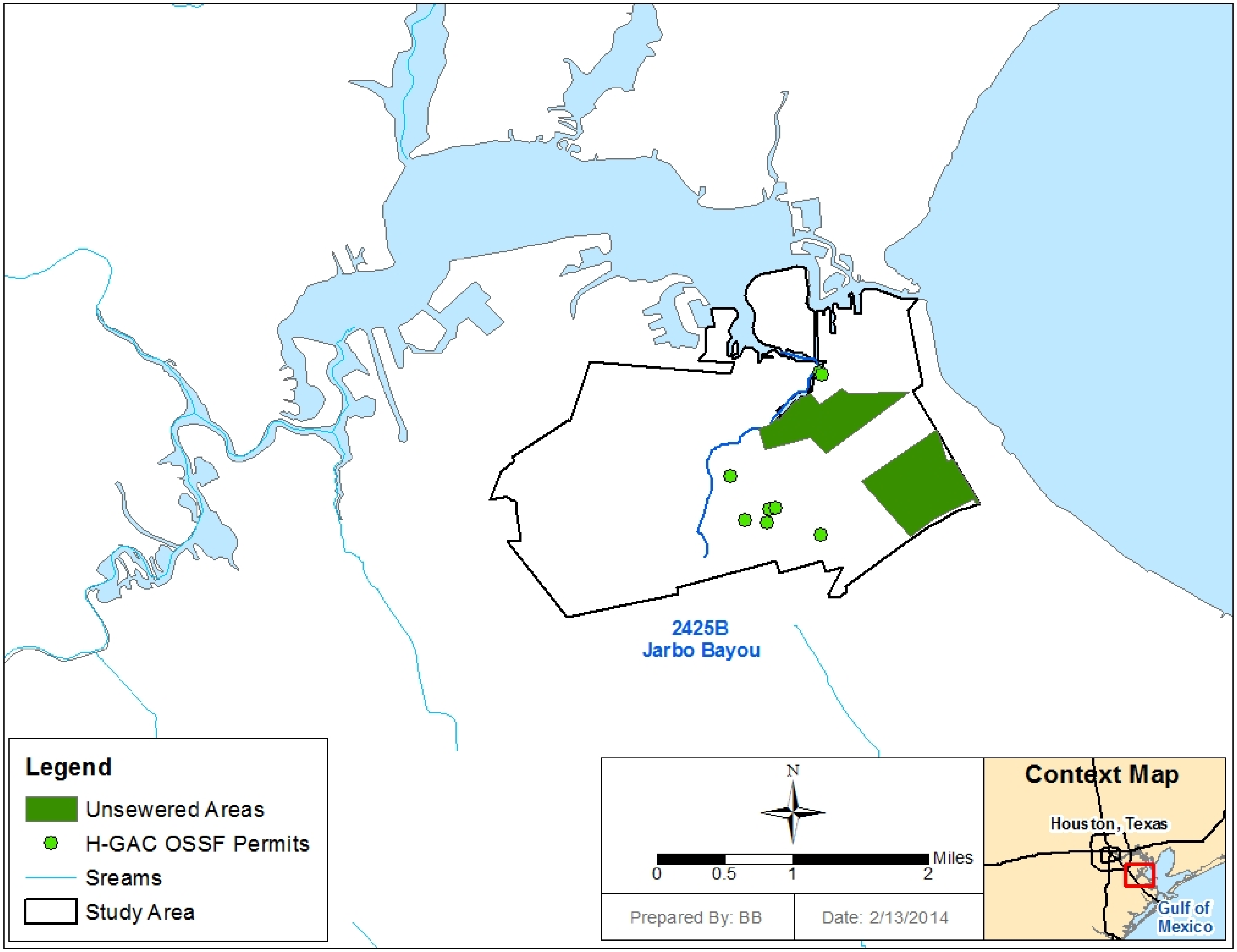

Figure 3-3: Unsewered Areas and OSSFs

For the purpose of estimating fecal coliform loading in watersheds, the OSSF failure rate of 12 percent from the Reed, Stowe & Yanke, LLC (2001) report for Texas Region 4 was used. Using this 12 percent failure rate, calculations were made to characterize fecal coliform loads in the Study Area.

Fecal coliform loads were estimated using the following equation (USEPA 2001):

$$\#\frac{counts}{day} = \left(\#Failing\_systems\right) \times \left(\frac{10^6\,counts}{100ml}\right) \times \left(\frac{70gal}{personday}\right) \times \left(\#\frac{person}{household}\right) \times \left(3785.2\frac{ml}{gal}\right)$$

The average of number of people per household was calculated to be 2.65 for the Study Area (U.S. Census Bureau 2010) based on the estimated household density in the Study Area (Table 1-3). Approximately 70 gallons of wastewater were estimated to be produced on average per person per day (Metcalf and Eddy 1991). The fecal coliform concentration in failing septic tank effluent was estimated to be 10^6 per 100 mL of effluent based on reported concentrations from a number of published reports (Metcalf and Eddy 1991; Canter and Knox 1985; Cogger and Carlile 1984). Using this information, the estimated load from failing septic systems within the Jarbo Bayou watershed was calculated and is summarized in Table 3-5. Based on this data, it was determined that the estimated fecal coliform loading from OSSFs in the Study Area is negligible.

Table 3-5: Estimated Number of OSSFs per Watershed and Fecal Coliform Load

Segment	Stream Name	OSSF data from H-GAC	# of Failing OSSFs	Estimated Loads from OSSFs (x 10^9 counts/day)
2425B	Jarbo Bayou	8	0.96	6.74

3.2.4 Domestic Pets

Fecal matter from dogs and cats is transported to streams by runoff from urban and suburban areas and can be a potential source of bacteria loading. On average nationally, there are 0.58 dogs per household and 0.66 cats per household (American Veterinary Medical Association 2002). Using the U.S. Census data at the block level (U.S. Census Bureau 2010), dog and cat populations can be estimated for each watershed. Table 3-6 summarizes the estimated number of dogs and cats and their associated fecal coliform load from pets for the Study Area. These estimates are based on estimated fecal coliform production rates of 5.4×10^8 per day for cats and 3.3×10^9 per day for dogs (Schueler 2000). Only a small portion of these loads is expected to reach waterbodies, through wash-off of land surfaces and conveyance in runoff.

Table 3-6: Estimated Numbers and Fecal Coliform Daily Production (10^9) of Pets

Segment	Stream Name	Dogs		Cats		Total Load (cfu/day * 10^9)
		Count	Load	Count	Load	
1113_02	Jarbo Bayou	3,000	9,900	3,413	1,843	11,743

3.2.5 Bacteria Re-growth and Die-off

Bacteria are living organisms that grow and die. Certain enteric bacteria can regrow in organic materials if appropriate conditions prevail (*e.g.*, warm temperature). It has been shown that fecal organisms can regrow from improperly treated effluent during their transport in pipe networks, and they can regrow in organic rich materials such as compost and sludges. While the die-off of indicator bacteria has been demonstrated in natural water systems due to the presence of sunlight and predators, the potential for their regrowth is less well understood. Both processes (regrowth and die-off) are in-stream processes and are not considered in the bacteria source loading estimates of each water body.

CHAPTER 4
TECHNICAL APPROACH AND METHODS

The TMDL represents the maximum amount of a pollutant that the stream can receive in a single day without exceeding the water quality standard. A TMDL is expressed as the sum of three elements as described in the following mathematical equation:

TMDL = Σ WLA + Σ LA + MOS

The wasteload allocation (WLA) is the portion of the TMDL allocated to existing and future permitted (point) sources. The load allocation (LA) is the portion of the TMDL allocated to unregulated (nonpoint) sources, including natural background sources. The MOS is intended to account for uncertainty and ensure that standard for contact recreation will be met. Thus, the allowable pollutant load that can be allocated to point and nonpoint sources can then be defined as the TMDL minus the MOS.

40 CFR §130.2(1), states that TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures. For *E coli* or enterococci bacteria, TMDLs are expressed as numbers per day, where possible, or as a percent reduction goal, and represent the maximum one day load the stream can assimilate while still attaining the standard for contact recreation. For the Jarbo Bayou Watershed, to quantify allowable pollutant loads, percent reduction goals to achieve standard for contact recreation, and specific TMDL allocations for point and nonpoint sources a mass balance method using a tidal prism is employed for tidal streams. The tidal prism mass balance method is described in this Section.

4.1 Using Load Duration Curves to Develop TMDLs

Because Jarbo Bayou Tidal is a tidal segment, the Load Duration Curve method was not used for TMDL determination.

4.2 Development of Bacteria TMDLs for Tidal Streams Using a Mass Balance Approach

4.2.1 Modeling Approach

A time-variable tidal prism modeling approach with a moderate level of spatial resolution was used to simulate the bacterial indicator loads and establish TMDLs for the tidal segments of the Study Area. The tidal prism is the volume of water gained in a tidal stream between low and high tide levels. In addition, the model included the time period from 10/1/2004 to 10/01/2010. Load calculations were developed for two reaches within Jarbo Bayou Tidal that periodically are influenced by tidal fluctuations. The model incorporates the three primary mechanisms through which Enterococci loadings and water enter the impaired systems: i) rain-induced freshwater inputs via tributaries or direct runoff, ii) direct point source discharges, and iii) tidally influenced loadings, which are introduced during the diurnal tidal fluctuations that occur in the system. The model assumes that Enterococci are removed with the net estuarine flow from the system and via net decay. A generalized schematic of the source and sink terms for the tidally influenced impaired waterbodies is presented in Figure 4-1.

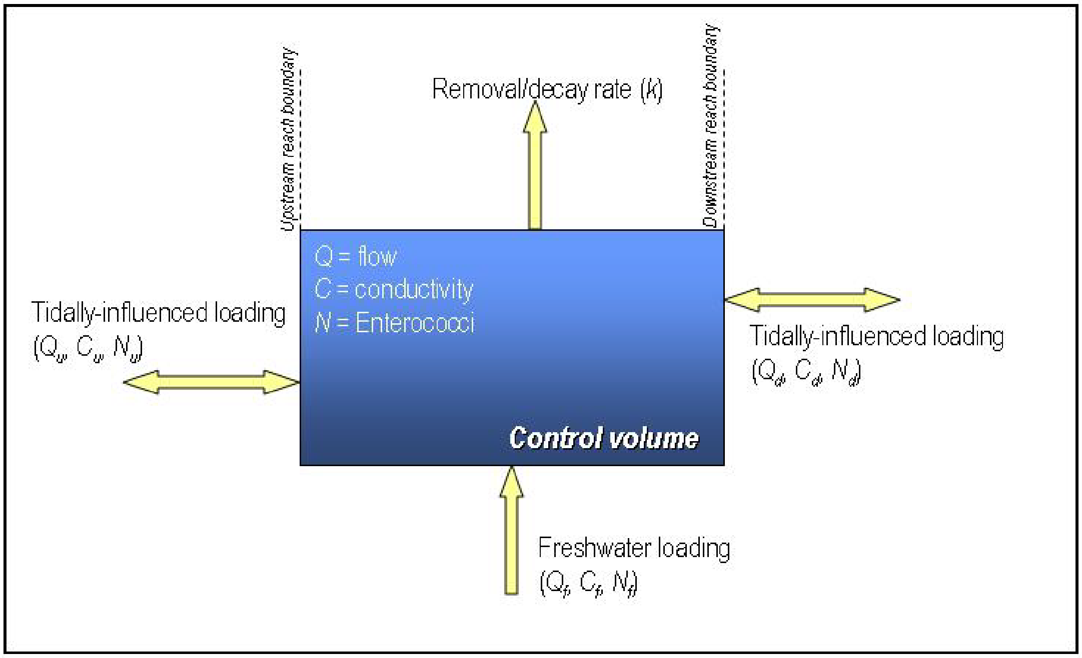

Figure 4-1: Conceptual Model for Sources and Sinks of Enterococci

The mass balance of water for a given reach at a given time step can be written as follows:

$$\frac{dV}{dt} = Q_u + Q_f - Q_d \qquad (1)$$

Where: Q_u = volume of water crossing the upstream boundary of the reach [m^3/hr]

Q_d = volume of mixed water crossing the downstream boundary of the reach [m^3/hr]

Q_f = volume of freshwater inflow (runoff, tributaries, and WWTFs) discharging along the reach [m^3/hr],

dV/dt = change in volume of the reach with time [m^3/hr]

The following paragraphs summarize the steps that were followed to complete the tidal prism model.

Step 1: Define Reaches.

Jarbo Bayou Tidal Segment 2425B_01 was divided into two reaches (Figure 4-2 & Figure 4-3). The tidal prism model does not include any tributaries as there are no streams that discharge into Jarbo Bayou.

Data from TSARP models were used to calculate cross-sectional areas for the boundaries of each main stem reach. Cross-sectional areas for small tributaries were estimated using DEM (Digital Elevation Model) profile graphs published in 2009 provided by USGS. Cross-section data for the two reaches included in the Study Area are provided in electronic format in Appendix C.

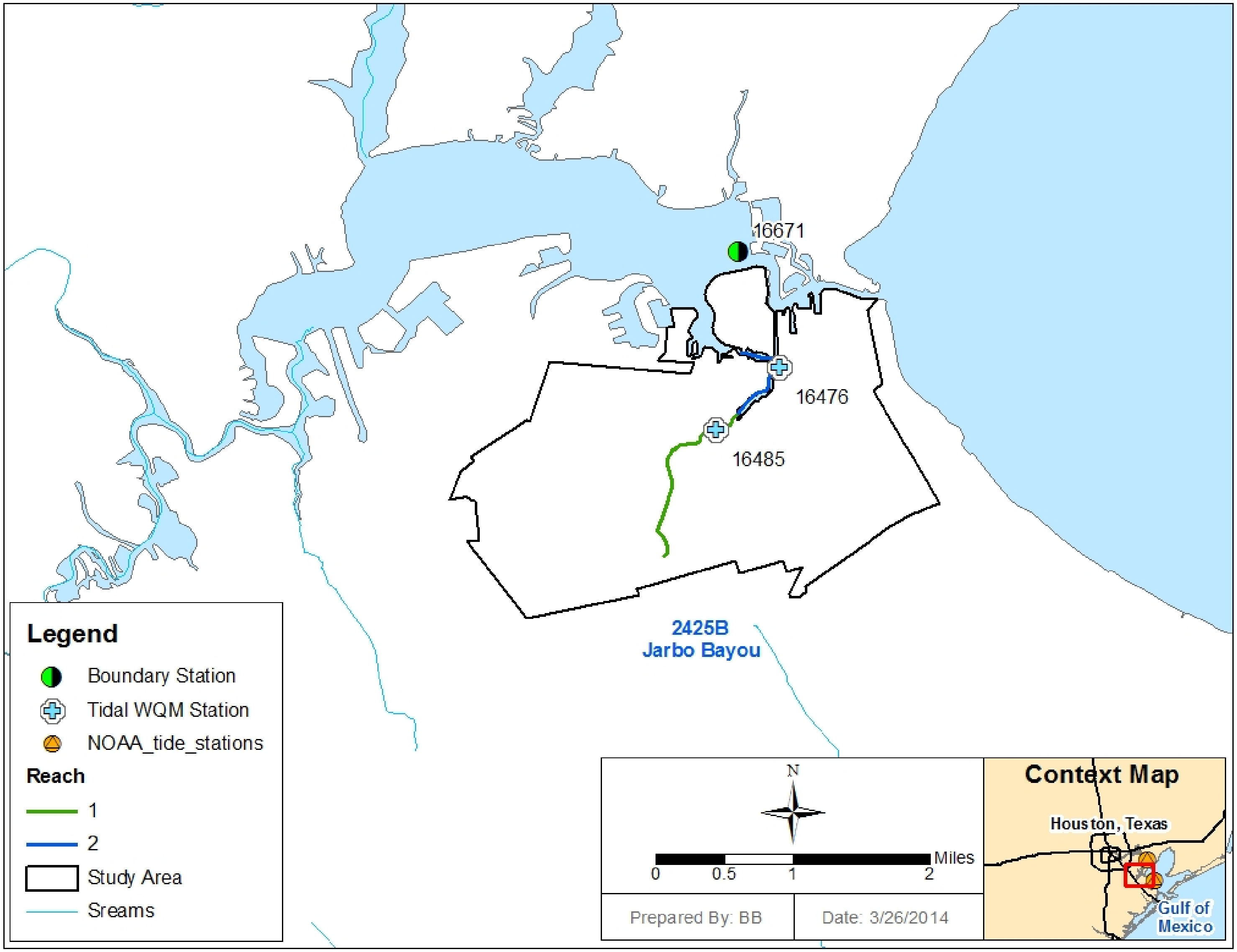

Figure 4-2: Schematic of the Modified Tidal Prism Model

Step 2: Establishing Tributary Inflows and Loads

As there are no freshwater tributaries to Jarbo Bayou Tidal, this step in the tidal prism mass balance was not needed.

Step 3: Estimating Direct (non-tributary) Point and Nonpoint Source InFlows and Loading to the System.

The key variables required for estimating loading into the model reaches are direct runoff to the tidal streams modeled, WWTF discharges to the various reaches, and indicator bacteria concentrations in runoff and WWTF effluents. The methods for estimating these tidal prism inputs are summarized below.

Permitted Sources: Continuous Point Source Dischargers (WWTFs)

There are not permitted point source discharges within Jarbo Bayou.

Permitted and Unregulated Stormwater Runoff

Stormwater runoff loads discharging directly to the model reaches were input to the model for the days on which a rain event occurred (as indicated by the closest HCOEM gage to each segment). Drainage areas were estimated using TSARP subwatersheds displayed in Figure 4-5. Daily Enterococci runoff loads were calculated using Event Mean Concentrations (EMCs), and the amounts of rainfall recorded for the simulation period.

The amount of runoff for each drainage area was calculated using the NRCS runoff curve number method (NRCS 1986). The NRCS runoff equation is:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \quad (2)$$

where Q = runoff (in);

P = rainfall (in);

S = potential maximum retention after runoff begins (in); and

I_a = initial abstraction (in).

Initial abstraction refers to all the losses before runoff begins and includes water intercepted by vegetation, infiltration, evaporation, and water retained in surface depressions. This parameter is highly variable but is correlated to land cover and soil type (NRCS 1986). Because the model was run with an hourly time step, the initial abstraction value was based on a moving sum of the five previous hours. The NRCS (1986) estimates I_a to be equal to:

$$I_a = 0.2S \quad (3)$$

thus,

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \quad (4)$$

Finally, *S* is related to the curve number (CN) by:

$$S = \frac{1000}{CN} - 10 \tag{5}$$

CN values range from 0 to 100 and are based on land cover and soil group. For this runoff calculation, all reaches were assumed to be in soil group D (silt and clay) that generally has low infiltration rates. Land coverage data developed by C-CAP were aggregated from 22 categories into the six land cover categories listed in Table 4-1. The classification system and their corresponding runoff curve numbers are included in Table 4-1.

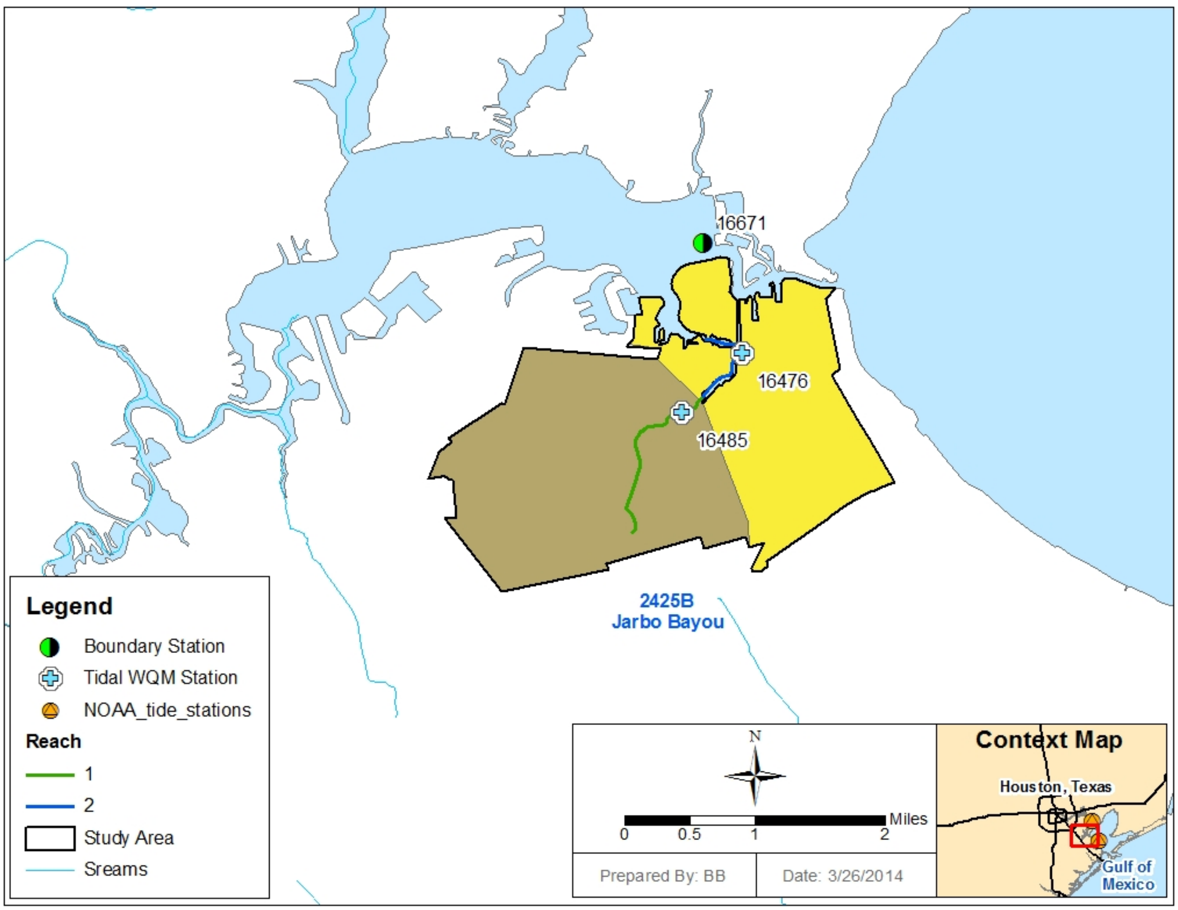

Figure 4-3: Drainage Areas for the Tidal Prism Model Reaches

Event mean concentrations (EMC) for Enterococci were estimated based on fecal coliform EMCs obtained from the Stormwater Management Joint Task Force in 2002. Enterococci concentrations were estimated from *E. coli* EMCs using Enterococci/*E. coli* (ENT/EC) conversion ratios, based on data collected by the City of Houston and H-GAC for their Alternate Indicator Study (Running 2007). The median ENT/EC ratio was 0.34. For dates with no historical water quality data available, the geometric mean of the observed values of each respective station was used. For tributaries with no WQM stations, Enterococci loads estimated from the ratio of event mean concentrations (EMC) of tributaries with WQM stations. Tributary load input datasets for Enterococci are included in electronic format in Appendix D and summarized in Table 4-2. The ENT/FC ratio (0.27) was applied to obtain Enterococci EMCs for different land cover categories. The Enterococci concentrations used for the tidal prism model are included in Table 4-1.

Table 4-1: EMCs for the Jarbo Bayou Watershed

Land Cover Description	CN	*E. coli* EMCs (cfu/dL)	Enterococci EMCs (cfu/dL)
Developed	92[a]	18,000	6120
Cultivated Land	84[b]	700	238
Grassland/Herbaceous	80[b]	700	238
Pasture/Hay	80[b]	700	238
Woodland	77[c]	400	136
Open Water	0	0	0
Wetlands	0	0	0
Transitional/Bare	89[d]	12,000	4080

Obtained from C-CAP Medium-Intensity Developed
[b] *Obtained from "Urban Hydrology for Small Watersheds." Natural Resources Conservation Service, Technical Release 55, June 1986. Cultivated agricultural land, small grain, contoured. (Good)*
[c] *Obtained from "Urban Hydrology for Small Watersheds." Natural Resources Conservation Service, Technical Release 55, June 1986. Pasture, grassland, or range- continuous forage for grazing. (Good)*
[c] *Obtained from C-CAP Mixed Forest*
[d] *Obtained from "Urban Hydrology for Small Watersheds." Natural Resources Conservation Service, Technical Release 55, June 1986. Open space (lawns, parks, golf courses, cemeteries, etc.) Poor condition (grass cover < 50%)*

Average stormwater runoff loads from the contributing subwatershed of each reach are summarized in Table 4-2. Runoff flow and Enterococci load calculations are provided in electronic format in Appendix D.

Table 4-2: Stormwater Runoff Loads to the Tidal Prism Model

Reach	Average Flow (m^3/day)	Average Flow (cfs)	Average Enterococci Load (counts/day)
1	5.70E+03	2.26E+00	3.09E+11
2	4.25E+03	1.69E+00	1.78E+11

Note: Variable daily loads were input into the model. The loads presented here are the averages over the simulation period (10/01/2004 to 10/31/2010).

Step 4: Estimate Tidal Flows. Tidal flows for each reach were computed as the tidal exchange over the course of one hour, and were estimated as the difference in volume between two consecutive time steps (Equation 1). To calculate volumes, one hour gauge data for the period of 01/01/2010 – 12/31/2012 were downloaded from the Texas Coastal Ocean Observation Network Station 507 at Eagle Point and Station 503 at Morgan's Point (http://www.cbi.tamucc.edu/obs/507). After adjusting cross-sectional areas to reflect tidal elevation, the hourly volumes for each reach were calculated as the average of the cross-sectional areas at the downstream and upstream reach boundaries times the length of the reach.

Step 5: Verify Flow Balance Using Conductivity. An important step to estimating freshwater loading is to construct a conductivity balance of the system to ensure that the model is correctly estimating freshwater inflows and tidal exchange. Electrical conductivity measures the salt content (salinity) of water, and the major salts are considered a conservative (non-reactive) tracer. To accomplish this, conductivity data from TCEQ stations was used as a conservative tracer to determine the flow balance of each reach. The conductivity balance calculation for each reach is represented as:

$$C_t V_t = C_{t-1} V_{t-1} + \sum C_{in} V_{in} - \sum C_{out} V_{out} + C_f V_f \qquad (6)$$

Where: V_t = volume of reach at time step t [m^3]

V_{t-1} = volume of reach at time step t-1 [m^3]

V_f = freshwater volume [m^3]

V_{in}, V_{out} = tidally influenced volumes for time step t [m^3]

C_t = conductivity in the reach [µS/cm]

C_f = conductivity in the freshwater inputs [µS/cm]

C_{in}, C_{out} = conductivity of the tidally influenced flows [µS/cm]

The average conductivity values for the existing water quality monitoring stations were used to define the initial conductivity levels in the model reaches. Conductivity data from station 16671 was used to determine downstream boundary conditions. Conductivity in freshwater (runoff, tributaries and effluent) was assumed equal to 500 µS/cm. Tidally influenced volumes were calculated using Equation 1 and freshwater volumes as described earlier. Using the above information Equation 6 was solved for the conductivity in the reach (C_t). The computed conductivity levels were then compared to existing measurements within the impaired waterbody to corroborate that the flows are accurately represented throughout the system. Figure 4-4 presents a comparison of observed and modeled average conductivity concentrations along Tidal Jarbo Bayou.

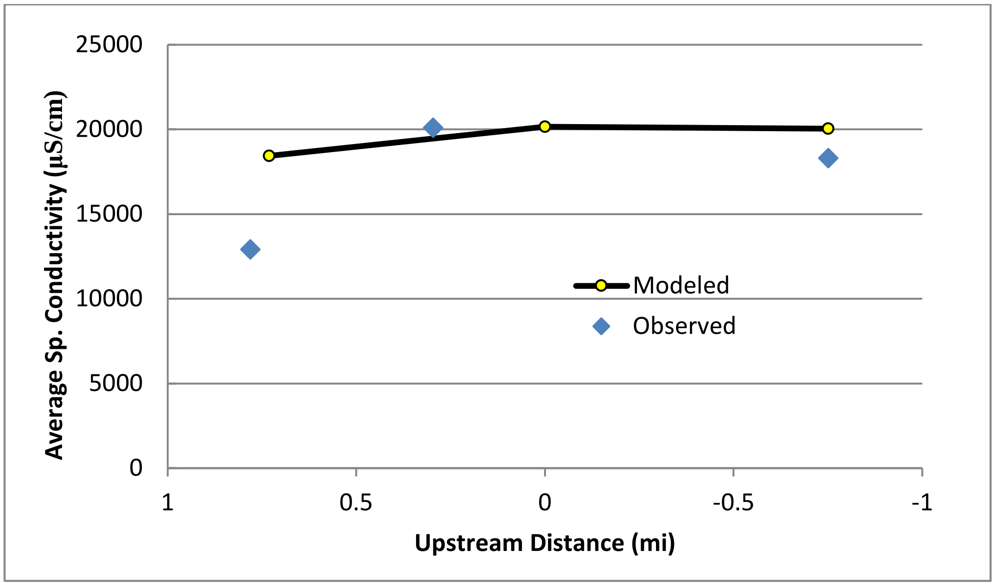

Figure 4-4: Longitudinal Profile of Average Conductivity

Step 6: Perform Mass Balance on Enterococci Levels. Upon validation of the flow balance, a mass-balance on Enterococci for each reach can be computed as follows:

$$N_t V_t = N_{t-1} V_{t-1} + \sum N_{in} V_{in} - \sum N_{out} V_{out} + N_f V_f - k N_{t-1} V_{t-1} \qquad (7)$$

Where: N_t = Enterococci level in the reach [counts/dL]

N_f = Enterococci level in the freshwater flow [counts/dL]

N_{in}, N_{out} = Enterococci level in tidally influenced flow [counts/dL]

k = Enterococci first-order decay rate [hr^{-1}]

The average Enterococci concentrations measured at each of the water quality monitoring stations along Jarbo Bayou Tidal were used to define the initial conditions in each model reach. The statistical relationships between tide height and Enterococci concentrations measured in Jarbo Bayou station 16671 (median 10 counts/dL) were used to set the downstream boundary concentration of Enterococci. Enterococci levels in runoff, tributaries and WWTFs were estimated as described in Steps 2 and 3.

The model was calibrated by varying the decay rate by reach and adjusting this decay rate within the bounds of reported rates until the model accurately reproduced the temporal and spatial distribution of observed Enterococci within the system. Sinton, *et al*. (1994) and Davies-Colley, *et al*. (1998) reported decay rates between 0.12 and 40 day^{-1}, Anderson, *et al*. (2005) reported rates between 0.73 and 2.1 day^{-1}, and Kay, *et al*. (2005) measured decay rates between 2.2 and 8.5 day^{-1}. Final decay rates applied to the model ranged from 0.2 to 0.8 day^{-1}, which is within the ranges reported in the literature. The decay rates were not varied temporally because insufficient data were available to estimate the seasonal variation in decay rates. The calibrated spreadsheet model is included in Appendix E in electronic format.

Figure 4-5 presents a comparison of measured and modeled Enterococci concentrations along the main stem of Jarbo Bayou. As can be seen, the model reasonably predicts the spatial distribution of Enterococci along the creek. For the tidal prism model, indicator bacteria data, from 2004 through 2010 for a given station were used to compare to modeled values. Fecal coliform and *E. coli* data were converted to Enterococci concentrations using calculated ENT/FC and ENT/EC ratios (0.27 and 0.34, respectively) as previously described.

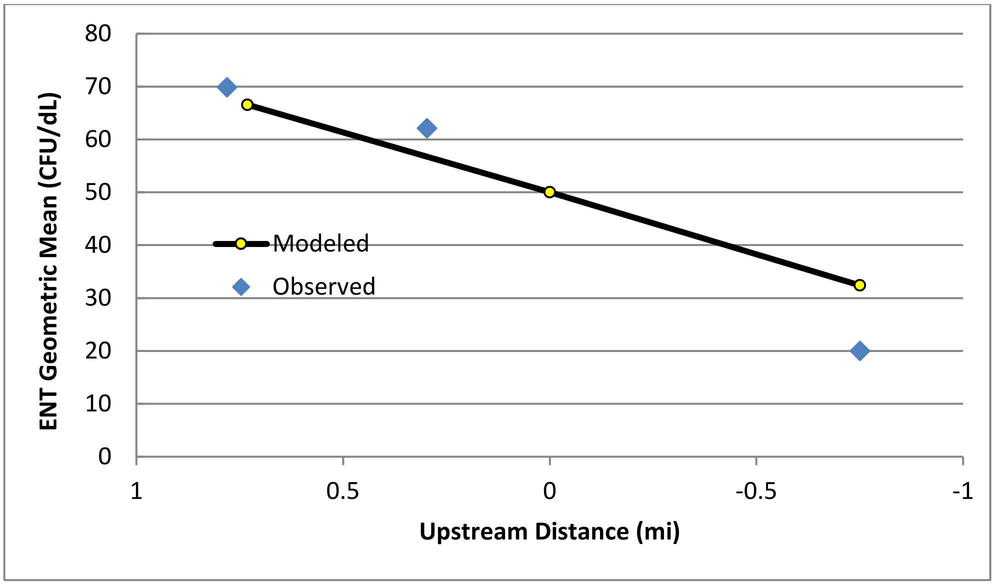

Figure 4-5: Longitudinal Profile of Enterococci Concentrations

Figures 4-6 and 4-7 show time series of Enterococci concentrations for the tidal prism results and water quality monitoring stations in Jarbo Bayou Tidal. As indicated by the figures, the model reasonably represents the temporal distribution of Enterococci concentrations for the various WQS.

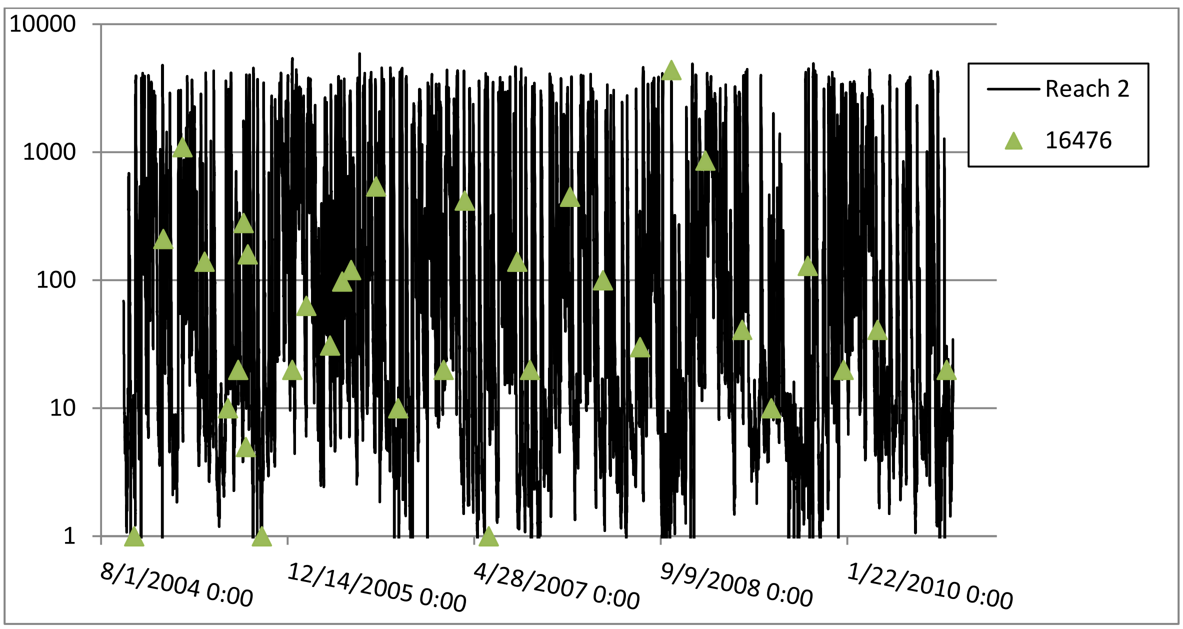

Figure 4-6: Enterococci Levels at Station 16476 (Reach 2), Jarbo Bayou (2425B_01)

Figure 4-6 Enterococci Levels at Station 16476 (Reach 2), Jarbo Bayou (2425B_01)

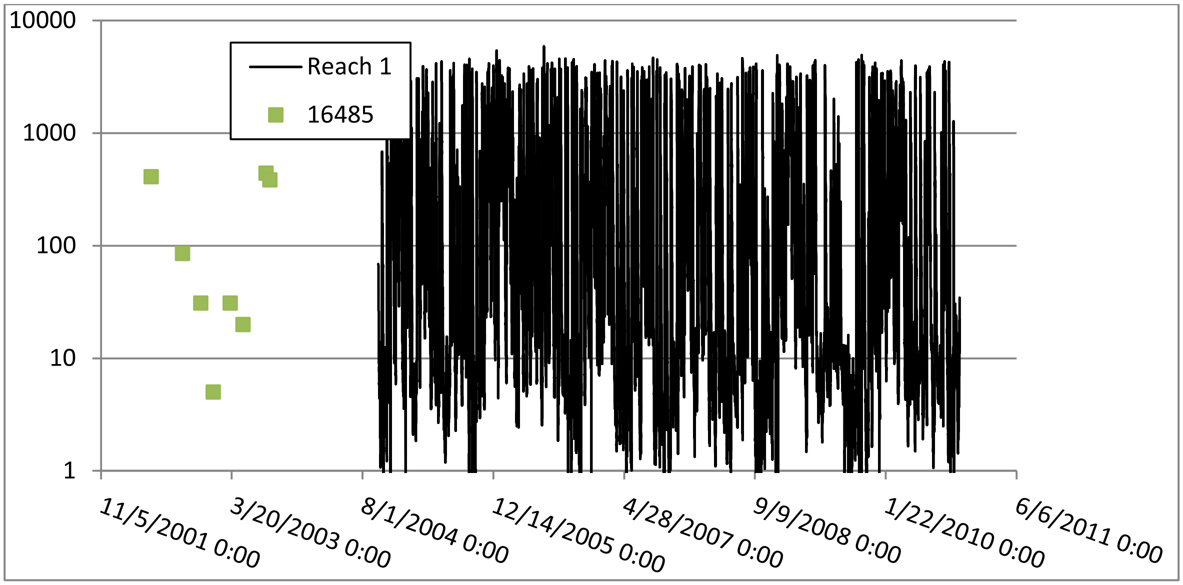

Figure 4-7: Enterococci Levels at Station 16485 (Reach 1), Jarbo Bayou (2425B_02)

4.2.2 Critical Conditions and TMDL Calculation for the Tidal Segments

To calculate the WLA and LA components of the TMDLs for the tidal streams, steps similar to those used for the LDC method are applied. As previously stated, the pollutant load allocation for permitted (point) sources is defined by the WLA. A point source can be either a wastewater (continuous) or stormwater permitted discharge. Stormwater point sources are typically associated with urban and industrialized areas, and recent USEPA guidance includes NPDES-permitted stormwater discharges as point source discharges and, therefore, part of the WLA.

WLAs may be set to zero for watersheds with no existing or planned continuous permitted point sources. For watersheds with permitted point sources, WLAs may be derived from TPDES permit limits. A WLA may be calculated for each active TPDES wastewater discharger using a mass balance approach as shown in the equation below. The permitted flow rate used for each point source discharge and the water quality criterion concentration are used to estimate the WLA for each wastewater facility. Through TPDES permits WLAs for WWTPs are constant across all flow conditions and ensure that WQS will be attained (USEPA 2007). All WLA values for each TPDES wastewater discharger are then summed to represent the total WLA for the watershed.

*WLA = criterion * permitted flow * unit conversion factor (#/day)*

Where: criterion = 23/dL (Enterococci)

flow (mgd) = permitted flow

*unit conversion factor = 37,854,120-dL/day*mgd*

Stormwater runoff can contribute both permitted and unregulated sources of bacteria which must also be accounted for in the TMDL allocations. To be consistent with the LDC method, any stormwater runoff originating from the area of a watershed under the jurisdiction of an MS4 permit is considered a point source contribution and is therefore included as part of the WLA calculation. As such the WLA will be split into WWTP WLA and MS4 WLA. Again to be consistent with the LDC method, the estimated loading from stormwater runoff within each drainage area is separated into stormwater loading from MS4 areas and stormwater loading from unregulated areas. This is done by using the percentage of each drainage area covered by the MS4 permit. An explicit MOS of 5 percent of the criterion is also included in the TMDL calculation. The stormwater loading from unregulated areas is considered the LA. Therefore, another way of expressing the LA from unregulated stormwater runoff is calculated as the TMDL minus the margin of safety minus the WLA (sum of WWTP and MS4).

Percent reduction goals were calculated by changing the loads in the tidal prism model until all the reaches have concentrations lower than or equal to the 23 counts/dL criterion for Enterococci.

The fact that most the WQM stations on the Study Area exceed the geometric mean standard for Enterococci indicates that evaluating mean source inputs (*i.e*., under mean conditions) via a mass balance approach will be sufficient to ascribe load allocations. The daily load estimates for the simulation period were reduced by a constant such that the geometric mean standard was met (*i.e*., 33/dL). The percent reduction was computed as follows:

$$\%R = \left(1 - \frac{1}{C_R}\right) \cdot 100 \tag{8}$$

where C_R is the constant by which the daily Enterococci loadings are reduced and %R is the associated percent reduction in the Enterococci levels.

CHAPTER 5
TMDL CALCULATIONS

5.1 Results of TMDL Calculations

The calculations and results of the TMDLs for the 303(d) listed water bodies in the Study Area are provided in Section 5. The bacteria load allocations derived from the two different technical approaches used for freshwater and tidal water bodies are discussed together in each subsection of Section 5 below.

5.2 Estimated Loading and Critical Conditions

USEPA regulations at 40 CFR 130.7(c) (1) require TMDLs to take into account critical conditions for stream flow, loading, and all applicable water quality standards. To accomplish this, available instream WQM data were evaluated with respect to stream flows, tidal flux, and the magnitude of water quality criteria exceedance. TMDLs are derived for specific indicator bacteria in 303(d) listed water bodies at specific WQM stations based on mass balance calculation using a tidal prism for Jarbo Bayou Tidal (2425B_01).

As previously described in Chapter 4, a mass balance calculation was used to model the bacteria load for six years at an hourly time step for the freshwater segment over a range of flow conditions. Existing Enterococci loads to the TMDL tidal segments are summarized in Table 5-1. The estimated existing loads are calculated as the sum of runoff, tributary, and WWTF loads to model reaches in Jarbo Bayou Tidal (2425B_01).

Table 5-1: Estimated Existing Enterococci Loads to TMDL Tidal Segments

Segment	Receiving Stream	Enterococci Load (counts/day)
2425B_01	Jarbo Bayou Tidal	2.64E+11

The percent reduction goals that are required to meet the geometric mean standard for contact recreation in the TMDL tidal segments are illustrated in Figure 5-1. The required load reductions were calculated at the end of the reach containing the sampling location. Required load reductions are summarized in Table 5-2.

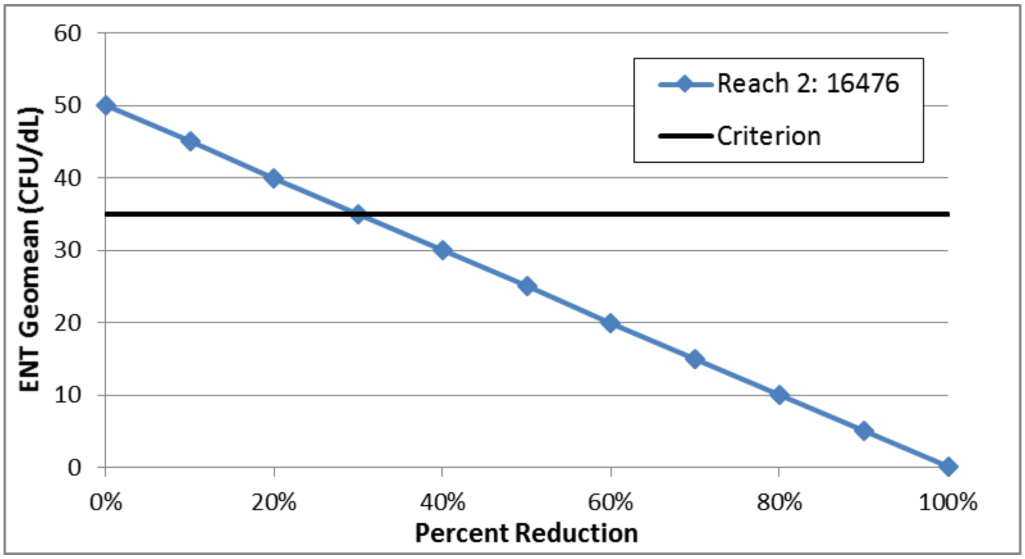

Figure 5-1: Contact Recreation Standards Attainment for Tidal Segments

Table 5-2: TMDL Percent Reductions Required to Meet Contact Recreation Standard for Tidal Segments

Segment	Sampling Location	Stream Name	Percent Reduction Required
2425B_01	16476	Jarbo Bayou Tidal	30.04%

5.3 Wasteload Allocation

TPDES-permitted facilities are allocated a daily wasteload calculated as their permitted discharge flow rate multiplied by one half of the instream geometric mean water quality criterion (or other indicated value). The WLA for each facility (WLA_{WWTF}) is derived from the following equation:

*WLA_{WWTF} = criterion * flow * unit conversion factor (#/day)*

Where:

criterion = 23 counts/dL for enterococci

flow (10^6 gal/day) = permitted flow

unit conversion factor = 37,854,120-10^6gal/day

When multiple TPDES facilities occur within a watershed, loads from individual WWTFs are summed and the total load for continuous point sources is included as part of the WLA_{WWTF} component of the TMDL calculation for the corresponding segment. When there are no TPDES WWTFs discharging into the contributing watershed of a WQM station, as is the case in Jarbo Bayou Tidal, then WWTF WLA is zero. Compliance with the WLA_{WWTF} will be achieved by adhering to the fecal coliform discharge limits and disinfection requirements of TPDES permits.

Stormwater discharges from MS4 areas are considered permitted point sources. Therefore, the WLA calculations must also include an allocation for permitted stormwater discharges. Given the limited amount of data available and the complexities associated with simulating rainfall runoff and the variability of stormwater loading a simplified approach for estimating the WLA_{MS4} areas was used in the development of these TMDLs. For both the LDC and tidal prism method the percentage of each watershed that is under a TPDES MS4 permit is used to estimate the amount of the overall runoff load that should be dedicated as the permitted stormwater contribution in the $WLA_{STORMWATER}$ component of the TMDL. The difference between the total stormwater runoff load and the portion allocated to $WLA_{STORMWATER}$ constitutes the LA component of the TMDL (direct nonpoint runoff).

5.4 Load Allocation

As discussed in Section 3, unregulated sources of bacteria loading to the receiving streams of each waterbody emanate from a number of different sources. The data analyses demonstrate that exceedances at the WQM stations are the result of a variety of nonpoint source loading. The LAs for each stream segment are calculated as the difference between the TMDL, MOS, WLA, and WLA for MS4 as follows:

$$LA = TMDL - \sum WLA_{WWTF} - \sum WLA_{STORMWATER} - MOS$$

Where:

LA = allowable load from unregulated sources
TMDL= total allowable load
ΣWLA_{WWTF} = sum of all WWTF loads
$\sum WLA_{STORMWATER}$ = sum of all Stormwater loads
MOS = margin of safety

5.5 Seasonal Variability

Federal regulations (40 CFR §130.7(c)(1)) require that TMDLs account for seasonal variation in watershed conditions and pollutant loading. Seasonal variation was accounted for in these TMDLs by using more than 5 years of water quality data and by using the longest period of USGS flow records when estimating flows to develop flow exceedance percentiles.

Analysis of the available data for enterococci in Table 1-13 showed no consistent trend among all evaluated stations for water and/or cooler months.

5.6 Allowance for Future Growth

Compliance with these TMDLs is based on keeping the indicator bacteria concentrations in the selected waters below the limits that were set as criteria for the individual sites. Future growth of existing or new point sources is not limited by these TMDLs as long as the sources do not cause indicator bacteria to exceed the limits. The assimilative capacity of streams increases as the amount of flow increases. Increases in flow allow for additional indicator bacteria loads if the concentrations are at or below the contact recreation criterion. The addition of any future wastewater discharge facilities will be evaluated on a case-by-case basis.

To account for the high probability that new additional flows from WWTF may occur in any of the segments, a provision for future growth was included in the TMDL calculations by estimating permitted flows to year 2050 using population projections completed by the Texas Water Development Board. The drainage area of Jarbo Bayou Tidal is almost entirely serviced by WWTFs whose outfall locations lie outside the watershed boundaries. An estimated future growth of 0.5 MGD is applied.

The allowance for future growth of 0.5 MGD is derived from the following equation:

*Future Growth = criterion * additional flow * unit conversion factor (#/day)*

Where:

criterion = 23 counts/dL for enterococci

flow (10^6 gal/day) = permitted flow (0.5)

unit conversion factor = 37,854,120-10^6gal/day

5.7 Margin of Safety

Federal regulations (40 CFR §130.7(c)(1)) require that TMDLs include an MOS. The MOS is a conservative measure incorporated into the TMDL equation that accounts for the uncertainty associated with calculating the allowable pollutant loading to ensure geometric mean criterion are attained. USEPA guidance allows for use of implicit or explicit expressions of the MOS, or both. When conservative assumptions are used in development of the TMDL, or conservative factors are used in the calculations, the MOS is implicit. When a specific percentage of the TMDL is set aside to account for uncertainty, then the MOS is considered explicit.

The TMDL for the freshwater segment incorporates an explicit MOS by setting a more stringent target for indicator bacteria loads that is 5 percent lower than the single sample criterion. The explicit margin of safety was used because of the limited amount of data. For contact recreation, this equates to a single sample target of 379 MPN/100mL for *E coli* and a geometric mean target of 120 MPN/100mL. The net effect of the TMDL with MOS is that the assimilative capacity or allowable pollutant loading of each waterbody is slightly reduced. The TMDL for the freshwater stream in this report incorporate an explicit MOS in the LDC by using 95 percent of the single sample criterion. For the tidal segments, the MOS was also explicit. But in this case, the MOS was based on allowable loading, not concentration. After the tidal prism model calculated the total assimilative capacity for enterococci (the TMDL), 5 percent of the allowable load was computed as the MOS.

5.8 TMDL Calculations

The bacteria TMDLs for the 303(d)-listed WQM stations covered in this report were derived using LDCs and the tidal prism model. A TMDL is expressed as the sum of all WLAs (point source loads), LAs (nonpoint source loads), and an appropriate MOS, which attempts to account for uncertainty concerning the relationship between effluent limitations and water quality.

This definition can be expressed by the following equation:

$$TMDL = \Sigma\, WLA + \Sigma\, LA + MOS + Future\ Growth$$

Table 5-3 summarizes the estimated maximum allowable load of Enterococci for the tidal assessment unit included in this project. These are calculated from the tidal prism model based on average percent reductions from total existing loading (WWTFs, runoff and tributaries) to the water body (Table 5-2).

Table 5-3: TMDL Calculations for Jarbo Bayou Tidal

Assess-ment Unit	Stream Name	Indicator Bacteria	TMDL[a] (MPN/day)	WLA_{WWTF}[b] (MPN/day)	$WLA_{STORMWATER}$[c] (MPN/day)	LA[d] (MPN/day)	MOS[e] (MPN/day)	Future Growth[f] (MPN/day)
2425B_01	Jarbo Bayou Tidal	Enterococci	1.85E+11	0.00E+00	1.75E+11	0.00E+00	9.23E+09	4.35E+08

[a] *Maximum allowable load for the flow range requiring the highest percent reduction (Table 5-2)*
[b] *Sum of loads from the WWTF discharging upstream of the TMDL station. Individual loads are calculated as permitted flow * 23 (Enterococci) MPN/100mL*conversion factor*
[c] *$WLA_{STORMWATER}$ = (TMDL – MOS –WLA_{WWTF})*(percent of drainage area covered by stormwater permits)*
[d] *LA = TMDL – MOS –WLA_{WWTF} –$WLA_{STORMWATER}$-Future growth*
[e] *MOS = TMDL x 0.05*
[f] *Projected increase in WWTF permitted flows*23*conversion factor*

CHAPTER 6
PUBLIC PARTICIPATION

To provide focused stakeholder involvement in the Jarbo Bayou Bacteria TMDL and the implementation phase, a 24 member steering committee was formed. In accordance with House Bill 2912, the group has balanced representation within the watershed and commitment was formalized. TCEQ project manager approved the formation of a Jarbo Bayou stakeholder group and approved the membership. The group has ground rules and H-GAC maintains a membership roster and has a web page dedicated to the Jarbo Bayou Bacteria TMDL project: (http://www.h-gac.com/HGAC/Programs/Water+Resources/Total+Maximum+Daily+Loads+TMDL+/default.htm).

The responsibility of each stakeholder on the committee is to communicate project information to others being represented and provide personal/organization perspective on all issues; knowledge of the watershed; comments and suggestions during the project; and solicit input from others. Regular meetings have been held and TCEQ solicits stakeholder comments at each project milestone, as well as assists stakeholders with communications. The committee is in the beginning stages of developing an Implementation Plan for this TMDL project. H-GAC has assisted TCEQ with the public participation and with a facilitator (M.J. Naquin). As contractors to TCEQ, the University of Houston and Parsons provide technical support and presentations at stakeholder meetings.

CHAPTER 7
REFERENCES

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APPENDIX A
AMBIENT WATER QUALITY BACTERIA DATA*

**** See attached CD***

APPENDIX B
TIDE DATA*

**** See attached CD***

APPENDIX C
TIDAL MODEL CROSS SECTIONS*

**** See attached CD***

APPENDIX D
RUNOFF INFLOWS AND LOADS*

**** See attached CD***

APPENDIX E
TIDAL PRISM MASS BALANCE MODEL*

***** See attached CD***