For Public Comment, February 2016

One Total Maximum Daily Load for Bacteria in Jarbo Bayou

Segment 2425B

Assessment Unit 2425B_01

Water Quality Planning Division, Office of Water

TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

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Bacteria Total Maximum Daily Loads for the Jarbo Bayou Watershed, Houston, Texas
(2425B_01),"
prepared by the University of Houston.

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ACRONYMS AND ABBREVIATIONS

AU	Assessment Unit
BIG	Bacteria Implementation Group
BMPs	best management practices
CFR	Code of Federal Regulations
cfs	cubic feet per second
cfu	colony forming unit
E. coli	Escherichia coli
EPA	U.S. Environmental Protection Agency
GIS	geographic information system
HCFCD	Harris County Flood Control District
H-GAC	Houston-Galveston Area Council
I/I	Inflow and infiltration
LA	load allocation
mL	milliliter
MPN	most probable number
MOS	margin of safety
MS4	municipal separate storm sewer system
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
OSSF	on-site sewage facility
PPP	pollution prevention plan
SSO	sanitary sewer overflow
SWMP	stormwater management plan
SWPPP	stormwater pollution prevention plan
TCEQ	Texas Commission on Environmental Quality
TMDL	Total Maximum Daily Loads
TPDES	Texas Pollutant Discharge Elimination System
TSARP	Tropical Storm Allison Recovery Project
TSSWCB	Texas State Soil and Water Conservation Board
TWDB	Texas Water Development Board
USDA	U.S. Department of Agriculture
WCID	water control and improvement district
WLA	waste load allocation
WQMP	Water Quality Management Plan
WWTF	wastewater treatment facility

One TMDL for Bacteria in Jarbo Bayou

Executive Summary

This document describes the total maximum daily load (TMDL) for Jarbo Bayou, where concentrations of bacteria exceed the criteria used to evaluate attainment of the contact recreation use. This impairment was first identified in the *Texas Water Quality Inventory and 303(d) List* in 2002.

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 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 single stream segment that feeds directly into Clear Lake. While there are two Assessment Units (AUs) on this segment, only one of them is impaired and is the focus of this study. The regions of the Jarbo Bayou watershed 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.

As described in the Texas Commission on Environmental Quality's (TCEQ) "2010 Guidance for Assessing Texas Surface and Finished Drinking Water Quality Data" (TCEQ 2010), the TCEQ requires a minimum of 10 samples in order to assess support of the contact recreation use. *Escherichia coli* (*E. coli*) for freshwater and Enterococci in tidal water are the preferred indicator bacteria for assessing the contact recreation use. For this project, Enterococci data were used for data analysis and modeling to support TMDL development for Jarbo Bayou.

For the Enterococci indicator, the contact recreation use is not supported when the geometric mean of all Enterococci samples exceeds 35 counts per 100 milliliters (mL), and/or individual samples exceed 104 counts per 100 mL more than 25 percent of the time.

Data the TCEQ analyzed from the assessment period of December 1, 2003, through November 20, 2010, showed sampling locations in the impaired segment exceeded the indicator bacteria concentrations for the current contact recreation standard.

The most probable sources of indicator bacteria are sanitary sewer overflows (SSO), leaking or illicit discharge from centralized wastewater collection lines, stormwater runoff from permitted storm sewer sources, dry weather discharges

(illicit discharges) from storm sewers, failing on-site sewage facilities (OSSF), and runoff from areas not covered by a permit.

The mass balance, tidal prism method was used to determine the load capacity, current loads, and percent reduction goals for Jarbo Bayou. The waste load allocation for wastewater treatment facilities (WWTFs) was established as the permitted flow times the geometric mean of the indicator bacteria criterion.

Compliance with this TMDL is based on keeping the indicator bacteria concentrations in this tidally-influenced (saltwater) bayou below the geometric mean criterion for Enterococci of 35 counts/100 mL.

Future growth of existing or new point sources is not limited by this TMDL as long as the sources do not cause indicator bacteria to exceed the limits. The TMDL calculations in this report will guide determination of the assimilative capacity of the bayou under changing conditions, including future growth. Wastewater discharge facilities will be evaluated case-by-case.

Introduction

Section 303(d) of the federal Clean Water Act requires all states to identify waters that do not meet, or are not expected to meet, applicable water quality standards. States must develop a TMDL for each pollutant that contributes to the impairment of a listed water body. The TCEQ is responsible for ensuring that TMDLs are developed for impaired surface waters in Texas.

A TMDL is like a budget—it determines the amount of a particular pollutant that a water body can receive and still meet its applicable water quality standards. TMDLs are the best possible estimates of the assimilative capacity of the water body for a pollutant under consideration. A TMDL is commonly expressed as a load with units of mass per period of time, but may be expressed in other ways.

The TMDL Program is a major component of Texas' overall process for managing the quality of its surface waters. The program addresses impaired or threatened streams, reservoirs, lakes, bays, and estuaries (water bodies) in, or bordering on, the state of Texas. The primary objective of the TMDL Program is to restore and maintain the beneficial uses—such as drinking water supply, recreation, support of aquatic life, or fishing—of impaired or threatened water bodies.

This TMDL addresses impairment to the contact recreation use due to exceedances of Enterococci criteria in Jarbo Bayou. This TMDL takes a watershed approach to addressing the bacteria impairment. While TMDL allocations were developed only for the single impaired AU (segment 2425B) identified in this report, the entire segment watershed (Figure 1) and all WWTFs that discharge within it are included within the scope of this TMDL.

Section 303(d) of the Clean Water Act and the implementing regulations of the U.S. Environmental Protection Agency (EPA) in Title 40 of the Code of Federal Regulations, Part 130 (40 Code of Federal Regulations (CFR) 130) describe the statutory and regulatory requirements for acceptable TMDLs. The EPA provides further direction in its *Guidance for Water Quality-Based Decisions: The TMDL Process* (EPA 1991). This TMDL document has been prepared in accordance with those regulations and guidelines.

The TCEQ must consider certain elements in developing a TMDL; they are described in the following sections:

- Problem Definition
- Endpoint Identification
- Source Analysis
- Linkage Analysis
- Seasonal Variation
- Margin of Safety
- Pollutant Load Allocation
- Public Participation
- Implementation and Reasonable Assurance

Upon adoption of the TMDL report by the TCEQ and subsequent EPA approval, this TMDL will become an update to the state's Water Quality Management Plan (WQMP).

Problem Definition

Jarbo Bayou is tidally influenced and is classified as two separate AUs: 2425B_01 and 2425B_02; however, only AU 2425B_01 is impaired. The TCEQ first identified impairments of the contact recreation use for this segment and AU on the 303(d) list in 2002 (Table 1).

Figure 1 shows the watershed that is addressed in this TMDL report. 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). Using the TSARP GIS file produces watershed delineations that are slightly different from the historic delineations based on TCEQ GIS files associated with classified Segment 2425. However, the use of TSARP drainage areas provides finer resolution and results in delineations that accurately represent the watershed.

Table 1. TMDL Segment and First Year on 303(d) List

AU	Segment Name	Type	Category	Year First Listed
2425B_01	Jarbo Bayou	Tidal	5a	2002

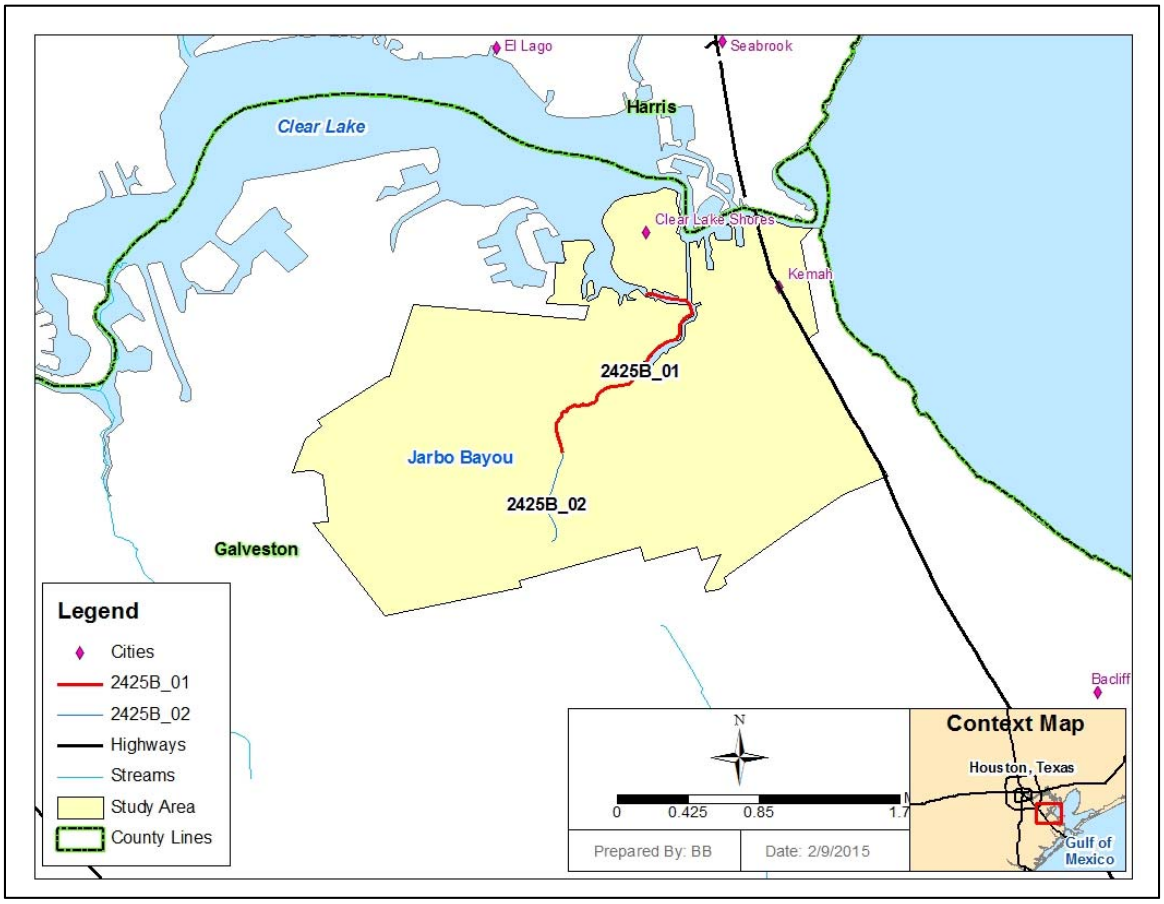

Figure 1. Jarbo Bayou Watershed

The standards for water quality are defined in the *Texas Surface Water Quality Standards* (TCEQ 2010). The specific uses assigned to Jarbo Bayou are contact recreation, aquatic life, general, and fish consumption. The criteria for assessing attainment of the contact recreation use are expressed as the number of indicator bacteria per 100 mL of water. The number of colony-forming units (cfu) may not exceed certain concentrations in a single sample, nor as a geometric mean of all samples.

As described in the TCEQ's "2010 Guidance for Assessing Texas Surface and Finished Drinking Water Quality Data," the TCEQ requires a minimum of 10 samples in order to assess support of the contact recreation use. The preferred bacteria for indicating attainment of the contact recreation use is Enterococci for

tidal water, so Enterococci data were used in analysis and modeling for Jarbo Bayou.

For the Enterococci indicator, if the minimum sample requirement is met, the contact recreation use is not supported when:

- the geometric mean of all Enterococci samples exceeds 35 counts per 100 mL;
- and/or individual samples exceed 104 counts per 100 mL more than 25 percent of the time.

Ambient Indicator Bacteria Concentrations

Data the TCEQ analyzed from the assessment period of December 1, 2003, through November 20, 2010, showed the sampling location in the impaired AU exceeded the indicator bacteria concentrations for the contact recreation standard (Table 2). Bacteria concentrations are expressed as either cfu or most probable number (MPN) depending on the type of indicator bacteria and the type of test used to analyze the sample. The MPN is a statistical estimate of the actual number of cfu in a water sample. Throughout this document, indicator bacteria concentrations will be referred to as "counts" rather than using the two different units. Most of the analyses for Enterococci are in MPN but some older analyses are in cfu.

Table 2. Summary of Criteria and Assessment Data- 2003-2010

AU	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%

ENT: enterococci

Geometric mean concentrations were calculated assuming one-half the value of any concentration reported as less than the detection limit

Summary of Analysis

The project team collected numerous samples in the impaired AU. These samples were analyzed to determine the extent of the bacteria impairment and the appropriate load allocation. Sampling location is shown in Figure 2.

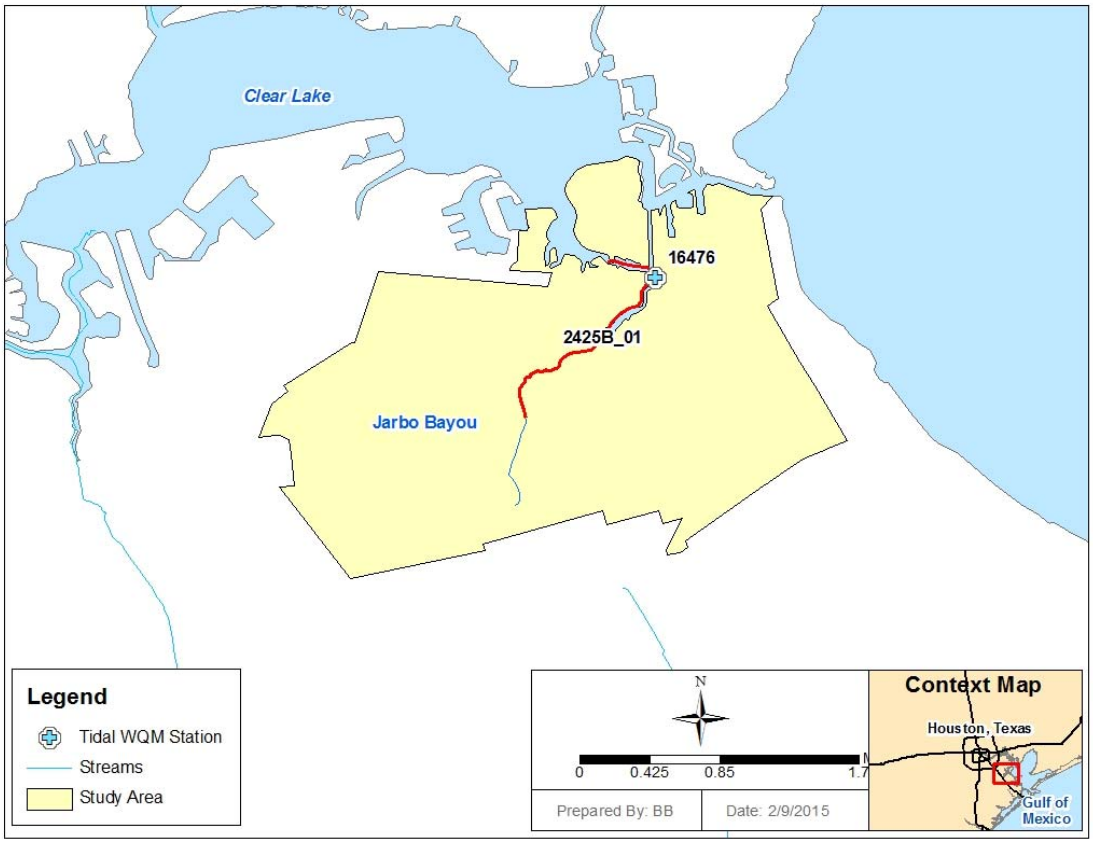

Figure 2. Jarbo Bayou Watershed Sampling Location

The project team used the results of 34 Enterococcus samples collected near the downstream boundary of Jarbo Bayou AU 2425B_01 for its analysis. The geometric mean for Enterococci was 62.14 counts/100mL; individual sample concentrations exceeded the criterion in 41 percent of the samples. This indicates elevated levels of indicator bacteria that result in nonsupport of contact recreation use.

Watershed Overview

Jarbo Bayou is a perennial tidal water body that terminates at Clear Lake. 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 single stream segment that feeds directly into Clear Lake. 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). The regions of Jarbo Bayou bordering Clear Lake and 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 climate of the region is subtropical humid, with very hot and humid summers and mild winters. The average maximum daytime temperature is 91.5 degrees Fahrenheit during the summer, while the temperature averages between 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).

Average annual rainfall from 1981 to 2010, based on the national data set from PRISM Climate Group (PRISM Climate Group 2013), is summarized in Table 3. Annual rainfall average is 57.3 inches.

Table 3. PRISM Annual Average Precipitation, 1981-2010

Segment Name	AU	Average Annual (Inches)
Jarbo Bayou	2425B_01	57.3

Table 4 summarizes the percentages of the land cover categories for the watershed associated with Jarbo Bayou. The specific land use/land cover data files were derived from the National Oceanic and Atmospheric Administration (NOAA 2011). The land cover categories are displayed in Figure 3.

The predominant land cover category in this watershed is medium intensity developed land (37%), followed by low intensity developed (21%) and open space developed (14%). High intensity developed, woody wetlands, hay/pasture, deciduous forest, herbaceous, and open water each comprise between 6% and 2% of land cover. The western and northeastern portions of the Jarbo Bayou watershed are heavily developed, while the southeastern regions have heterogeneous land cover. Population growth in the southeastern portion of the watershed is expected to result in land cover change from what used to be woody wetland and hay/pasture (which is now just undeveloped) to developed classes.

The watershed has three incorporated cities within its boundaries—Clear Lake Shores, Kemah, and League City. These three cities are expected to see increases in population between 44 and 248 percent from 2010 to 2030, according to the Texas Water Development Board (TWDB) (Montgomery Watson America, Inc. 2010). Table 5 lists TWDB population growth estimates for these three cities from 2010 to 2030.

Table 4. Summary of Watershed Characteristics

Aggregated Land Cover Category	Acres	Percent
Open Water	66	2%
Developed, Open Space	423	14%
Developed, Low Intensity	647	21%
Developed, Medium Intensity	1,150	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	**3,068**	**100%**

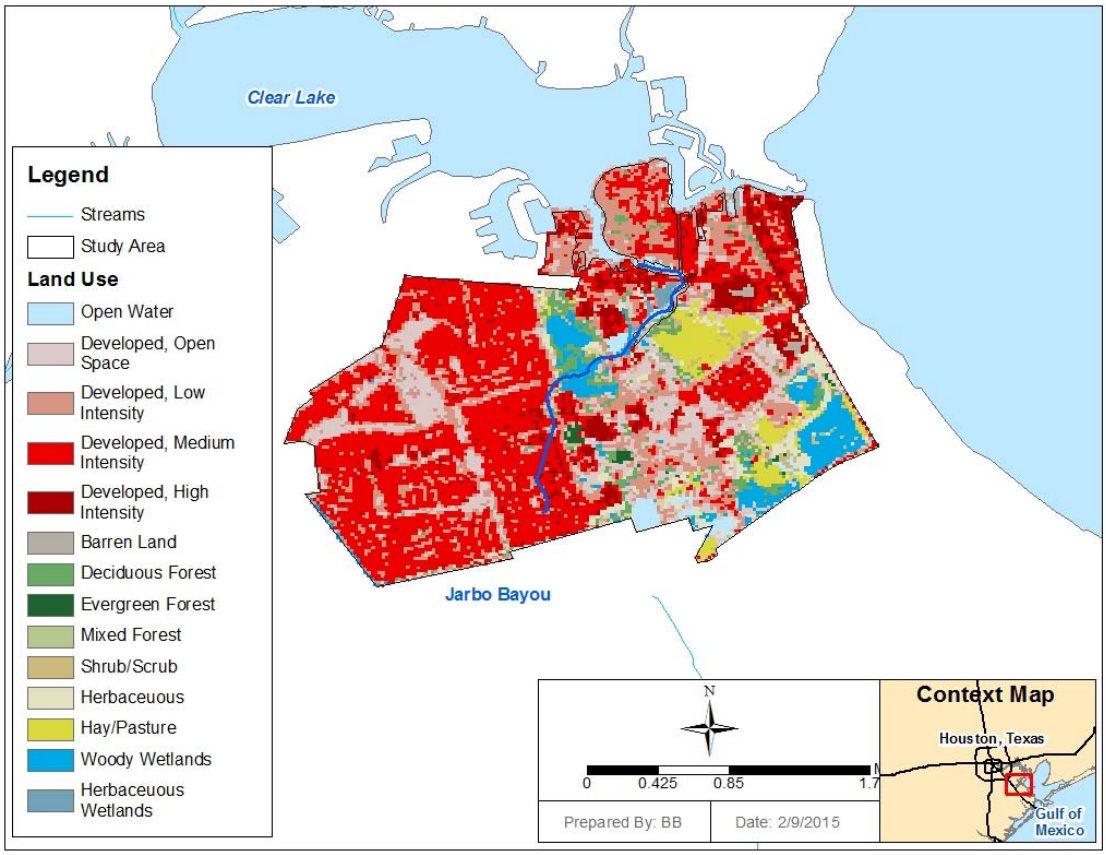

Figure 3. Jarbo Bayou Watershed Land Cover

Table 5. Jarbo Bayou Watershed Population Increases by City, 2010-2030

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 <www.twdb.state.tx.us/waterplanning/data/projections/2017/demandproj.asp>

Endpoint Identification

All TMDLs must identify a quantifiable water quality target that indicates the desired water quality condition and provides a measurable goal for the TMDL. The TMDL endpoint also serves to focus the technical work to be accomplished and as a criterion against which to evaluate future conditions.

The endpoint for TMDLs for tidal segments is to achieve concentrations of Enterococci below the geometric mean criterion of 35 counts/100 mL.

Source Analysis

Pollutants may come from several sources, both regulated and unregulated. Regulated pollutants, referred to as "point sources," come from a single definable point, such as a pipe, and are regulated by permit under the Texas Pollutant Discharge Elimination System (TPDES). WWTFs, and storm water discharges from industries, construction, and the separate storm sewer systems of cities are considered point sources of pollution.

Unregulated sources are typically nonpoint source in origin, meaning the pollutants originate from multiple locations and rainfall runoff washes them into to surface waters. Nonpoint sources are not regulated by permit.

With the exception of WWTFs, which receive individual WLA (see the "Wasteload Allocation" section), the regulated and unregulated sources in this section are presented to give a general account of the different sources of bacteria expected in the watershed. These are not meant to be used for allocating bacteria loads or interpreted as precise inventories and loadings.

Regulated Sources

No TPDES-permitted outfalls discharge to Jarbo Bayou. However, 100 percent of the watershed is regulated under the TPDES permit for stormwater discharge held jointly by Harris County, HCFCD, City of Houston, and Texas Department of Transportation, as well as the cities of League City, Kemah, and Clear Lake Shores. This means that all stormwater sources are covered under a municipal separate storm sewer system (MS4) permit, and therefore become a regulated source.

WWTFs

There are no permitted outfalls in the Jarbo Bayou watershed.

Sanitary Sewer Overflows

SSOs are unauthorized discharges that must be addressed by the responsible party: either the TPDES permittee or the owner of the collection system that is connected to a permitted system. SSOs in dry weather most often result from blockages in the sewer collection pipes caused by tree roots, grease, and other debris. Inflow and infiltration (I/I) are typical causes of SSOs under conditions of high flow in the WWTF system. Blockages in the line may exacerbate the I/I problem. Other causes, such as a collapsed sewer line, may occur under any condition.

The TCEQ maintains a database of SSO data collected from wastewater operators in the Jarbo Bayou watershed. The locations and magnitudes of all reported SSOs and WWTF service area boundaries are displayed in Figure 4 and summarized in Table 6. It is important to note that the WWTFs that serve the Jarbo Bayou watershed are outside the watershed boundary.

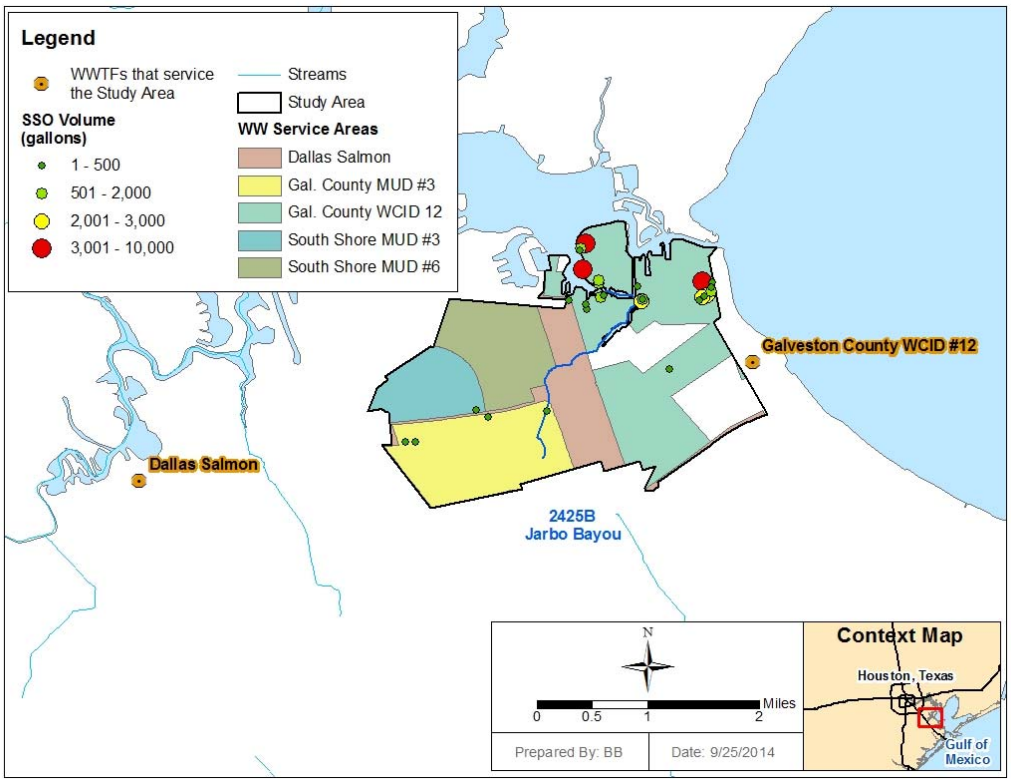

Figure 4. Sanitary Sewer Overflow Locations and WWTF Service Areas

Table 6. Sanitary Sewer Overflow Summary

Amounts in gallons

Facility Name	NPDES Permit No.	Facility ID	Number of Occurrences	Date From	Date To	Min Amount	Max Amount
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

As shown by the data, there have been approximately 30 sanitary sewer overflows reported in the Jarbo Bayou watershed between 2002 and 2013. Overflow volumes range between 30 and 10,000 gallons.

TPDES Regulated Stormwater

When evaluating stormwater for a TMDL allocation, a distinction must be made between stormwater originating from an area under a TPDES or National Pollution Discharge Elimination System (NPDES)-regulated discharge permit and stormwater originating from areas not under a TPDES or NPDES-regulated discharge permit. Stormwater discharges fall into two categories:

1) Stormwater subject to regulation, which is any stormwater originating from TPDES-regulated MS4 system, industrial facilities, and regulated construction activities.
2) Stormwater runoff not subject to regulation.

The geographic region of the Jarbo Bayou watershed covered by MS4 permits is that portion of the watershed defined by the 2000 Census as being an Urbanized Area. Considerable portions of the Jarbo Bayou watershed are covered under the City of Houston/Harris County discharge 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 EPA Web site: <http://www2.census.gov/geo/maps/dc10map/UAUC_RefMap/ua/ua40429_houston_tx/DC10UA40429.pdf>. Individual cities may also hold MS4 boundaries that pertain to their city limits.

Under the City of Houston/Harris County permit for stormwater discharge, Harris County, Harris County Flood Control District, City of Houston, and Texas Department of Transportation are designated as co-permittees. These agencies do not have any monitoring points located on water bodies that drain into the Jarbo Bayou watershed (Martin 2005). Therefore, there are no monitoring data available to characterize bacteria concentrations or loads from regulated stormwater discharged to receiving waters in the Jarbo Bayou watershed.

Figure 5 displays the portion of the watershed that contributes indicator bacteria loads to the receiving waters from permitted sources. Table 7 lists the regulated entities and the percentage of the watershed covered under an MS4 permit.

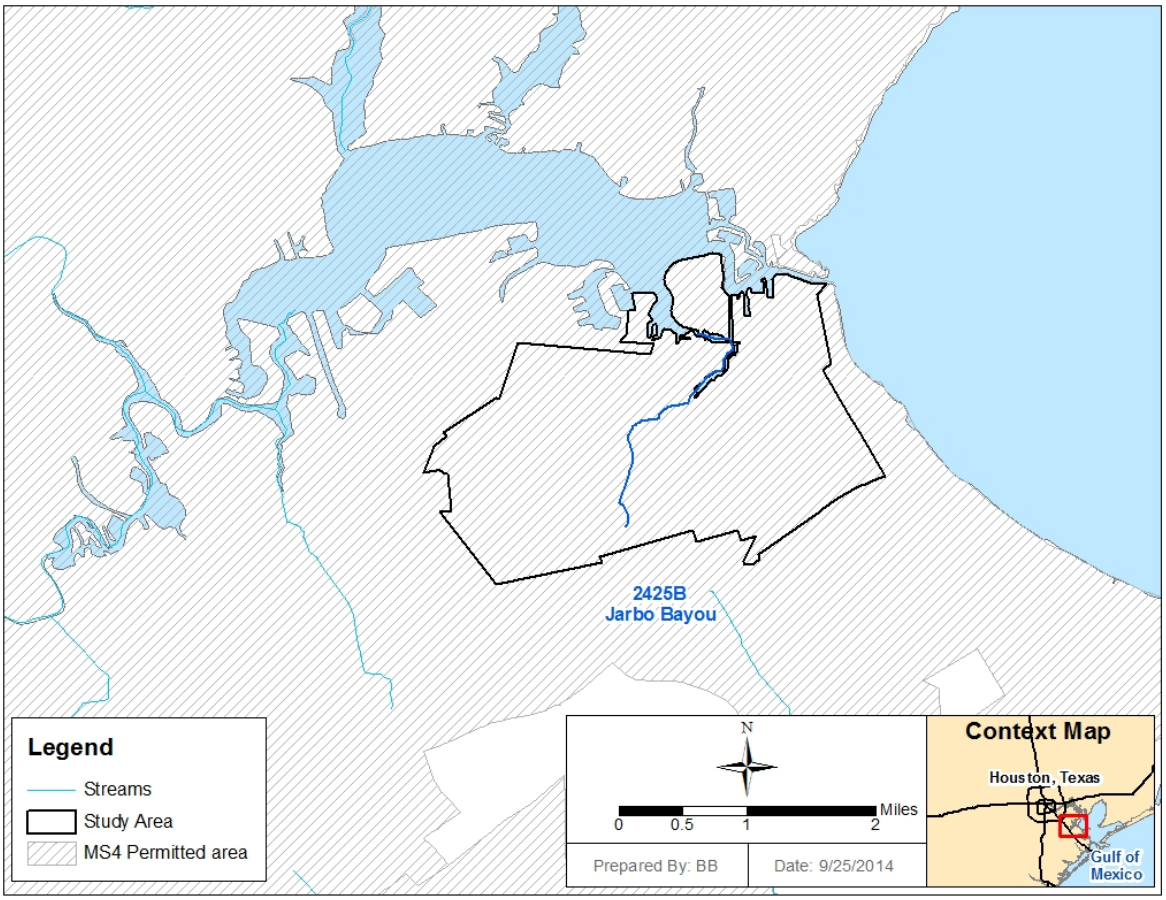

Figure 5. TPDES-Permitted Facilities in the Jarbo Bayou Watershed

Table 7. Regulated Stormwater Discharges in the Watershed

Regulated Entity Name	TPDES or Reference Numbers	Total Area (acres)	Area under MS4 Permit (Acres)	Percent of Watershed under MS4 Jurisdiction
City of Houston	WQ0004685000	3,068	3,068	100%
City of League City	RN105569735			
City of Kemah	RN105498216			
City of Clear Lake Shores	RN105551337			
City of La Porte	RN105510440			
City of Pasadena	WQ0004685000			

Dry Weather Discharges/Illicit Discharges

Pollutant loads can enter streams from MS4 outfalls that carry authorized sources as well as illicit discharges under both dry and wet weather conditions. The term "illicit discharge" is defined in TPDES General Permit No. TXR040000 for Phase II MS4s as "Any discharge to a municipal separate storm sewer that is not entirely composed of stormwater, except discharges pursuant to this general permit or a separate authorization and discharges resulting from emergency firefighting activities." Illicit discharges can be categorized as either direct or indirect contributions. Examples of illicit discharges, as identified in the Illicit Discharge Detection and Elimination Manual: A Handbook for Municipalities (NEIWPCC, 2003), are provided following.

Examples of Direct illicit discharges:

- sanitary wastewater piping that is directly connected from a home to the storm sewer;
- materials that have been dumped illegally into a storm drain catch basin;
- a shop floor drain that is connected to the storm sewer; and
- a cross-connection between the sanitary sewer and storm sewer systems.

Examples of Indirect illicit discharges:

- an old and damaged sanitary sewer line that is leaking fluids into a cracked storm sewer line; and
- a failing septic system that is leaking into a cracked storm sewer line or causing surface discharge into the storm sewer.

Unregulated Sources

Unregulated sources of bacteria are generally nonpoint. Nonpoint source loading enters the impaired segment through distributed, non-specific locations and is usually not regulated. Nonpoint sources of indicator bacteria can emanate from wildlife, various agricultural activities and animals, land application fields, urban runoff not covered by a permit, failing OSSFs, and domestic pets. With the entirety of the watershed falling within an MS4 permit, what are often unregulated sources fall under regulation for this project.

On-site Sewage Facilities

Failing 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. Bacteria-contaminated groundwater can also be discharged to creeks through springs and seeps.

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 OSSF failure 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 failure problems (Canter and Knox 1985).

Only permitted OSSF systems are recorded by authorized agents; therefore, it is difficult to estimate the exact number of OSSFs that are in use in the watershed. The average number of people per household in the watershed was calculated to be 2.65 (U.S. Census Bureau 2010). 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 106 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 and data from the Houston-Galveston Area Council (H-GAC), the estimated load from failing septic systems within the Jarbo Bayou watershed was calculated and is summarized in Table 8. Based on this data, the estimated fecal coliform loading from OSSFs in the watershed is negligible. Figure 6 displays the locations of OSSFs as well as unsewered areas that did not fall within the wastewater service areas.

Table 8. Number of OSSF Permits Issued by Authorized County or City Agent

AU	Stream Name	OSSF data from H-GAC	# of Failing OSSFs	Estimated Loads from OSSFs (x 10^9 counts/day)
2425B_01	Jarbo Bayou	8	0.96	6.74

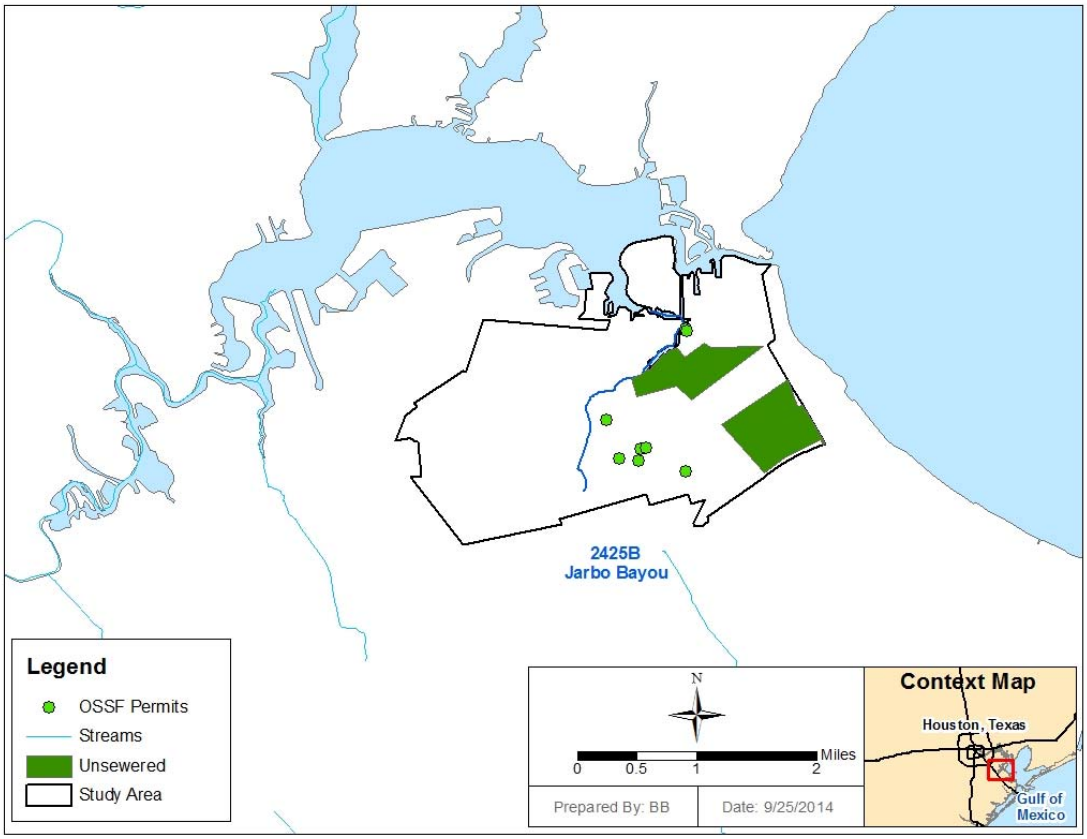

Figure 6. Unsewered Areas with OSSFs

Unregulated Agricultural Activities and Domesticated Animals

A number of agricultural activities that do not require permits can be potential sources of fecal bacteria loading. Livestock are present throughout the more rural portions of the project watershed.

Table 9 provides estimated numbers of selected livestock in the watershed based on the 2007 Census of Agriculture conducted by U.S. Department of Agriculture (USDA 2007). The county-level estimated livestock populations were verified by the Texas State Soil and Water Conservation Board (TSSWCB) and were distributed based on GIS calculations of pastureland in the watershed, based on the Texas 2011 Land Cover Data (National Oceanic AA 2011). These livestock numbers, however, were not used to develop an allocation of allowable bacteria loading to livestock.

Livestock numbers and their contributions to bacteria loadings in the Jarbo Bayou watershed are expected to decrease over time as more land is converted from grazing to developed, urban uses.

Table 9. Livestock Estimates in the Watershed

Type of Animal	2425B
Cattle and Calves	50
Horses and Ponies	7
Llamas	0
Donkey	1
Goats	6
Hogs and Pigs	1
Sheep and Lambs	1
Bison	0
Captive Deer	0
Rabbits	1
Layers	10
Pullets	3
Broilers	0
Turkeys	1
Ducks	1
Geese	0
Other Poultry	3
Total Animals	85

Source: <www.agcensus.usda.gov/Publications/2007/Full_Report/Volume_1,_Chapter_2_County_Level/Texas/>

Wildlife and Unmanaged Animal Contributions

Indicator 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. Wildlife is 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 indicator bacteria loading to a water body. Indicator bacteria from wildlife are also deposited onto land surfaces, where they may be washed into nearby streams by rainfall runoff.

As is typical of coastal watersheds, a significant population of avian species frequents the Jarbo Bayou watershed and its riparian corridors. However, currently there are insufficient data available to estimate populations and spatial distribution of wildlife and avian species within the watershed. Consequently, it is difficult to assess the magnitude of indicator bacteria contributions from wildlife species as a general category.

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 indicator 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 the watershed. Table 10 summarizes the estimated number of dogs and cats for the Jarbo Bayou watershed.

Table 10. Estimated Number of Pets in Each Watershed

AU	Stream Name	Dogs	Cats
2425B_01	Jarbo Bayou	3,000	3,413

Linkage Analysis

Establishing the relationship between instream water quality and the source of loadings is an important component in developing a TMDL. It allows for the evaluation of management options that will achieve the desired endpoint. This relationship may be established through a variety of techniques.

Generally, if high bacteria concentrations are measured in a water body at low to medium flow in the absence of runoff events, point sources are likely the main contributors. During ambient flows, these constant inputs to the system will increase pollutant concentrations depending on the magnitude and concentration of the sources. As flows increase in magnitude, the impact of point sources is typically diluted, and would therefore be a smaller part of the overall concentrations.

Bacteria contributions from nonpoint sources are greatest during runoff events. Rainfall runoff, depending upon the severity of the storm, has the capacity to carry indicator bacteria from the land surface into the receiving stream. Generally, this loading follows a pattern of low concentration in the water body just before the rain event, followed by a rapid increase in bacteria concentrations in the water body as the first flush of storm runoff enters the receiving stream. Over time, the

concentrations reduce because the sources of indicator bacteria are attenuated as runoff washes them from the land surface and the volume of runoff decreases following the rain event.

A mass balance analysis was used to analyze the linkage between indicator bacteria loads and instream water quality in Jarbo Bayou.

Mass Balance Analysis—Tidal Prism Method

A time-varying tidal prism modeling approach with a moderate level of spatial resolution was used to simulate the tidal segment Jarbo Bayou. The tidal prism is the volume of water between low and high tide levels or between the high tide elevation and the bottom of the tidal waterway. Load calculations were developed for two model reaches within Jarbo Bayou, shown in Figure 7. A detailed description of the modeling effort is provided in Appendix A. Based on the critical flow identified by the model, all of the sources described in the watershed characterization are potential contributors.

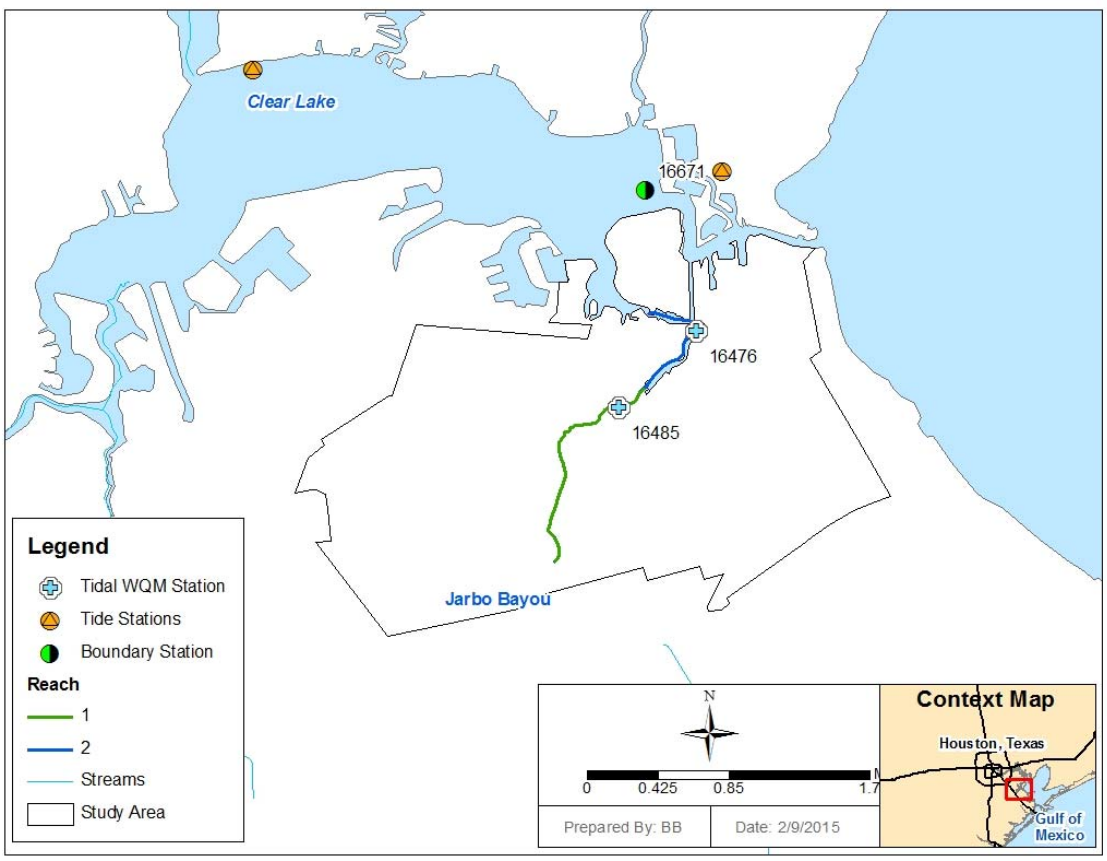

Figure 7. Jarbo Bayou Tidal Model Reaches

Figure 8 presents a comparison of measured and modeled Enterococci concentrations in Jarbo Bayou. As can be seen, the model reasonably predicts the spatial distribution of Enterococci along the segment. For the tidal prism model, indicator bacteria data (including fecal coliform and *E. coli*), from 2004 through 2010 for a given station were used to compare to modeled values. Fecal coliform(FC) and *E. coli* (EC) data were converted to Enterococci (ENT) concentrations using calculated ENT/FC and ENT/EC ratios (0.27 and 0.34, respectively), as described in Appendix A. A detailed description of the tidal prism method is also included in Appendix A.

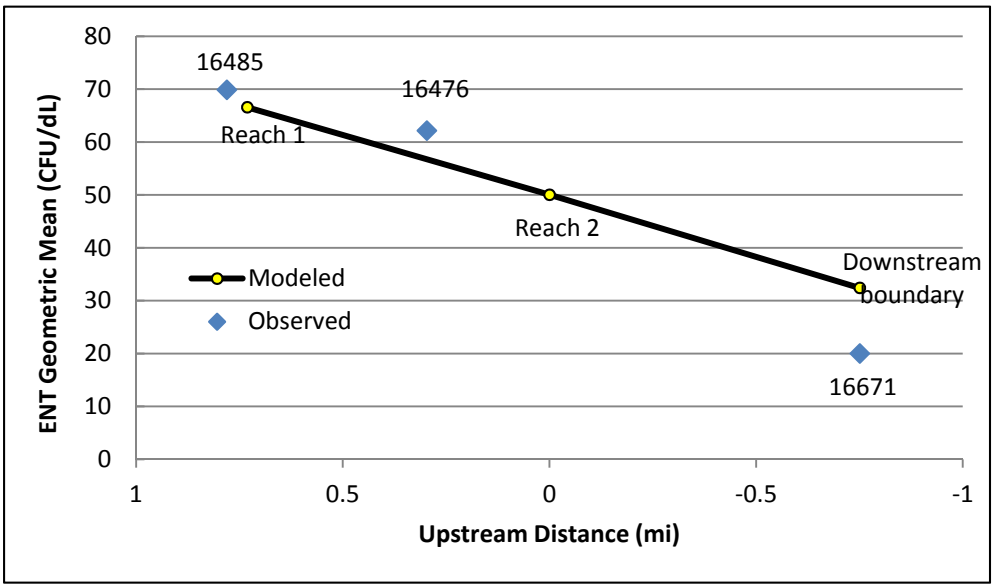

Figure 8. Longitudinal Profile of Enterococci Concentrations

Margin of Safety

The margin of safety (MOS) should account for uncertainty in the analysis used to develop the TMDL and thus provide a higher level of assurance that the goal of the TMDL will be met. According to EPA guidance (EPA 1991), the MOS can be incorporated into the TMDL using two methods:

- Implicitly incorporating the MOS using conservative model assumptions to develop allocations; or
- Explicitly specifying a portion of the TMDL as the MOS and using the remainder for allocations.

The MOS is designed to account for any uncertainty that may arise in specifying water quality control strategies for the complex environmental processes that affect water quality. Quantification of this uncertainty, to the extent possible, is the basis for assigning a MOS.

An explicit MOS was used because of the limited amount of data for the two sampling locations. 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. This MOS was based on allowable loading not concentration. The net effect of the TMDL with a MOS is that the assimilative capacity or allowable pollutant loading is slightly reduced.

Pollutant Load Allocation

The TMDL represents the maximum amount of a pollutant that the stream can receive in a single day without exceeding the water quality standard. The pollutant load allocations for this TMDL are calculated using the following equation:

Equation 1

$$TMDL = \sum WLA + \sum LA + MOS$$

Where:

WLA = wasteload allocation (point source contributions)

LA = load allocation (nonpoint source contributions)

MOS = margin of safety

As stated in 40 CFR, §130.2(1), TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures. For Enterococci bacteria, TMDLs are expressed as colony-forming units per day, and represent the maximum one-day load the stream can assimilate while still attaining the standards for surface water quality.

For the Jarbo Bayou watershed, a mass balance method using a tidal prism was used to quantify allowable pollutant loads and specific TMDL allocations for point and nonpoint sources.

To establish the watershed targets, TMDL calculations and associated allocations are established for the most-downstream sampling locations in the watershed. This defines a distinct TMDL for the 303(d) listed water body.

Waste Load Allocation

There are no TPDES-permitted WWTFs in the watershed. If added, TPDES-permitted WWTF dischargers will be assigned from the future capacity allocation and will be subject to the effluent limitations. Any additional flow for these facilities is accounted for in the development of the future capacity allocation.

The WLA for a facility (WLA_{WWTF}) is derived from the following equation.

Equation 2

$$WLA_{WWTF} = \text{criterion} * \text{flow} * \text{unit conversion factor}$$

Where:

criterion = 35 counts/100mL for the geometric mean of Enterococci

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

unit conversion factor = 37,854,120 100ml/10^6gal

Stormwater Discharges

Stormwater discharges from MS4, industrial, and construction areas are also considered permitted or regulated point sources. Therefore, the WLA calculations must include an allocation for regulated stormwater discharges (WLA_{SW}). A simplified approach for estimating the WLA for these areas was used in the development of this TMDL due to the limited amount of data available, the complexities associated with simulating rainfall runoff, and the variability of stormwater loading.

The percentage of the watershed that is under the jurisdiction of stormwater permits (i.e., defined as the area designated as urbanized in the 2000 US Census) is used to estimate the amount of the overall runoff load to be allocated as the regulated stormwater contribution in the WLA_{SW} component of the TMDL (Figure 5). The LA component of the TMDL corresponds to direct nonpoint runoff and is the difference between the total load from stormwater runoff and the portion allocated to WLA_{SW}.

Thus, WLA_{SW} is the sum of loads from regulated stormwater sources and is calculated as follows:

$$\Sigma WLA_{SW} = (TMDL - \Sigma WLA_{WWTF} - LA - \Sigma FG - MOS) * FDA_{SWP}$$

Where:

ΣWLA_{SW} = sum of all permitted or regulated stormwater loads

TMDL = total maximum daily load

ΣWLA_{WWTF} = sum of all WWTF loads

LA = load allocation, the amount of pollutant allowed by unregulated or unregulated sources.

ΣFG = sum of future growth loads from potential permitted facilities

MOS = margin of safety load

FDA_{SWP} = fractional proportion of drainage area under jurisdiction of stormwater permits

In urbanized areas currently regulated by an MS4 permit, development and/or re-development of land in urbanized areas must implement the control measures/programs outlined in an approved Stormwater Management Program (SWMP) or Pollution Prevention Plan (PPP). Although additional flow may occur from development or re-development, loading of the pollutant of concern should be controlled and/or reduced through the implementation of best management practices (BMPs) as specified in both the NPDES or TPDES permit and the SWMP.

An iterative, adaptive management approach will be used to address stormwater discharges. This approach encourages the implementation of structural or non-structural controls, implementation of mechanisms to evaluate the performance of the controls, and finally, allowance to make adjustments (e.g., more stringent controls or specific BMPs) as necessary to protect water quality.

The flow-dependent calculations for the portion of the WLA assigned to permitted stormwater are provided in Appendix A. Runoff occurring in this watershed area was within the boundaries of an MS4 permit, and therefore was considered a point source contribution and included in the WLA calculation. The allowable load from all stormwater runoff (LA_{SW}) was calculated as the maximum allowable load (TMDL) minus the MOS the load allocated to WWTFs (WLA_{WWTF}). The resulting load (LA_{SW}) was allocated to the WLA_{SW} component (permitted) since the entire watershed area is covered by MS4 permits, as shown in Table 7.

Implementation of WLAs

The TMDL in this document will result in protection of existing beneficial uses and conform to Texas's Antidegradation Policy. The three-tiered Antidegradation Policy in the Texas Water Quality Standards prohibits an increase in loading that would cause or contribute to degradation of an existing use. The Antidegradation

Policy applies to point source pollutant discharges. In general, antidegradation procedures establish a process for reviewing individual proposed actions to determine if the activity will degrade water quality.

The TCEQ intends to implement the individual WLAs through the permitting process as monitoring requirements and/or effluent limitations as required by the amendment of 30 Texas Administrative Code Chapter 319 which became effective November 26, 2009. Future WWTFs discharging to Jarbo Bayou will be assigned effluent limits based on the TMDL. Monitoring requirements are based on permitted flow rates.

If any discharges are added in the future, then the permit requirements will be implemented during the routine permit renewal process. However, there may be a more economical or technically feasible means of achieving the goal of improved water quality and circumstances may warrant changes in individual WLAs after this TMDL is adopted. Therefore, the individual WLAs, as well as the WLAs for stormwater, are non-binding until implemented via a separate TPDES permitting action, which may involve preparation of an update to the state's WQMP. Regardless, any future permitting actions will demonstrate compliance with the TMDL.

The executive director or commission may establish interim effluent limits and/or monitoring-only requirements at a permit amendment or permit renewal. These interim limits will allow a permittee time to modify effluent quality in order to attain the final effluent limits necessary to meet the TCEQ and EPA approved TMDL allocations. The duration of any interim effluent limits may not be any longer than three years from the date of permit re-issuance. New permits will not contain interim effluent limits because compliance schedules are not allowed for a new permit.

Where a TMDL has been approved, domestic WWTF TPDES permits will require conditions consistent with the requirements and assumptions of the wasteload allocations. For NPDES/ TPDES-regulated municipal, construction stormwater discharges, and industrial stormwater discharges, water quality-based effluent limits that implement the WLA for stormwater may be expressed as BMPs or other similar requirements, rather than as numeric effluent limits.

The November 26, 2014 memorandum from EPA relating to establishing WLAs for stormwater sources states:

> "Incorporating greater specificity and clarity echoes the approach first advanced by EPA in the 1996 Interim Permitting Policy, which anticipated that where necessary to address water quality concerns, permits would be modified in subsequent terms to include "more specific conditions or

> limitations [which] may include an integrated suite of BMPs, performance objectives, narrative standards, monitoring triggers, numeric WQBELs, action levels, etc."

Using this iterative, adaptive BMP approach to the maximum extent practicable is appropriate to address the stormwater component of this TMDL.

Updates to WLAs

This TMDL is, by definition, the total of the sum of the WLA, the sum of the LA, and the MOS. Changes to individual WLAs may be necessary in the future in order to accommodate growth or other changing conditions. These changes to individual WLAs do not ordinarily require a revision of the TMDL document; instead, changes will be made through updates to the TCEQ's WQMP. Any future changes to effluent limitations will be addressed through the permitting process and by updating the WQMP.

Load Allocation

The load allocation is the sum of loads from unregulated sources. The load allocation includes the sum of the tributary bacteria load (LA_{TL}) entering the segment and all remaining loads in the segment from unregulated sources (LA_{SEG}):

$$LA = LA_{SEG} + LA_{TL}$$

Where:

LA = allowable load from unregulated or unregulated sources

LA_{SEG} = allowable loads from unregulated or unregulated sources within the segment

LA_{TL} = tributary load allocations entering the segment.

The study area is covered under an MS4 permit, so the LA for Jarbo Bayou is zero.

Allowance for Future Growth

The future growth component of the TMDL equation addresses the requirement to account for future loadings that may occur due to population growth, changes in community infrastructure, and development. Specifically, this TMDL component takes into account the probability that new flows from WWTF discharges may occur in the future. The assimilative capacity of streams increases as the amount of flow increases.

The allowance for future growth will result in protection of existing beneficial uses and conform to Texas's Antidegradation Policy.

To account for new additional flows from WWTFs that may occur in the watershed, 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. As shown in Figure 4, the area in the Jarbo Bayou watershed is serviced by a WWTF outside the watershed boundary. The Dallas Salmon and Galveston County WCID #12 WWTPs service wastewater in the watershed but discharge their effluents to other stream segments.

Additional dischargers represent additional flow that is not accounted for in the current allocations. Changes in MS4 jurisdiction or additional development associated with population increases in the watershed can be accommodated by shifting allotments between the WLA and the LA. This can be done without the need to reserve future-capacity waste load allocations for stormwater. In non-urbanized areas, growth can be accommodated by shifting loads between the LA and the WLA (for stormwater). In urbanized areas currently regulated by an MS4 permit, development and/or redevelopment of land in urbanized areas must implement the control measures/programs outlined in an approved SWMP or PPP.

Although additional flow may occur from development or redevelopment, loading of the pollutant of concern should be controlled and/or reduced through the implementation of BMPs as specified in both the NPDES/TPDES permit and the SWMP. Currently, it is envisioned that an iterative, adaptive management BMP approach will be used to address stormwater discharges.

TMDL Calculations

TMDL allocations for the watershed were calculated for model Reach 2and table 12 summarizes the estimated maximum allowable loads of Enterococci that will ensure the contact recreation standard is met. These are calculated from the tidal prism model based on average reductions from total existing loading (MS4s and runoff) to the water body.

Table 11. Enterococci TMDL Calculations for Jarbo Bayou Tidal

Loads are in billion MPN/day

AU	Indicator Bacteria	TMDL[a]	WLA_{WWTF}[b]	WLA_{SW}[c]	LA[d]	MOS[e]	Future Growth[f]
2425B_01	Enterococci	0.00175	0.0	0.00166	0.0	0.000087	0.0

[a] Maximum allowable load for the flow range requiring the highest percent reduction

[b] Sum of loads from the WWTF discharging upstream of the TMDL station. Individual loads are calculated as permitted flow * 35 (Enterococci) MPN/100mL*conversion factor

[c] WLA_{SW} = (TMDL – MOS –WLA_{WWTF})*(percent of drainage area covered by stormwater permits)

[d] LA = TMDL – MOS –WLA_{WWTF} –WLA_{SW}-Future growth

[e] MOS = TMDL x 0.05

[f] Projected increase in WWTF permitted flows*23*conversion factor

Seasonal Variation

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 this TMDL by using more than five years of water quality data and by using the longest period of U.S. Geological Survey flow records when estimating flows to develop flow exceedance percentiles.

For Enterococci, the geometric mean was higher during the cooler months, but the difference was not statistically significant.

Public Participation

The TCEQ maintains an inclusive public participation process. From the inception of the investigation, the project team sought to ensure that stakeholders were informed and involved. Communication and comments from the stakeholders in the watershed strengthen TMDL projects and their implementation.

To provide focused stakeholder involvement in the Jarbo Bayou Bacteria TMDL and the implementation plan, a coordination committee was formed with balanced representation within the watershed. The H-GAC coordinated public participation in the development of this TMDL. Notices of coordination committee meetings were posted on the TMDL program's Web calendar. Two weeks prior to scheduled meetings, the H-GAC initiated media releases and formally invited coordination committee members to attend. To ensure that absent members and the public were informed of past meetings and pertinent material, the H-GAC's project Web page provides meeting summaries, presentations, ground rules, and a list of coordination committee members at <www.h-gac.com/community/water/tmdl/studies/jarbo-bayou.aspx>.

The responsibility of each stakeholder on the committee is to communicate project information to others being represented and provide personal/organization perspectives on all issues; knowledge of the watershed; comments and suggestions during the project; and solicit input from others. Regular meetings were held. TCEQ solicited stakeholder comment at each project milestone and assisted stakeholders with communications. As a contractor to TCEQ, the University of Houston provided technical support and presentations at stakeholder meetings.

The first public meeting for the Jarbo Bayou Bacteria TMDL was held on December 12, 2013. The meeting introduced the TMDL process, identified the impaired segment and the reason for the impairment, reviewed historical data, described potential sources of indicator bacteria within the watershed, and formed the coordination committee.

A coordination committee meeting was held on April 10, 2014. The committee finalized their ground rules and work groups. The technical team presented the status of the project by reviewing historical data, the characteristics of the watershed, projected population increases to the year 2030, potential sources of indicator bacteria within the watershed, and explained TMDL determination methods. The committee also discussed the development of their implementation plan and the pros and cons of joining the Bacteria Implementation Group (BIG).

The technical support document was approved in May 2014 and is available on the TCEQ webpage for Jarbo Bayou <www.tceq.texas.gov/waterquality/tmdl/ 106-jarbobacteria>. On June 4 and 5, 2014, work groups for the committee met to discuss permitted sources, residential and nonpoint sources, boaters and marinas, and outreach and communications. These groups presented recommendations to the coordination committee to help determine the path to implementation.

After careful deliberation, the coordination committee decided to petition to join the BIG, a well-established project in the region, and has taken the necessary steps toward that goal. Rather than develop a separate plan, they will add their watershed into the scope of the BIG implementation plan, making sure to add components that address the specific needs of Jarbo Bayou. On September 9, 2015 the BIG members voted to accept the addition of the Jarbo Bayou bacteria TMDL watershed to the area covered by the BIG implementation plan. This acceptance is considered provisional until the adoption of the TMDL document. The TCEQ had formally approved the BIG's implementation plan on January 30, 2013.

Implementation and Reasonable Assurances

The TMDL development process involves the preparation of two documents:

1) a TMDL, which determines the amount of pollutant a water body can receive and continue to meet applicable water quality standards; and
2) an implementation plan, which is a detailed description and schedule of regulatory and voluntary management measures to achieve the pollutant reductions identified in the TMDL.

Strategies for achieving pollutant loads in TMDLs from both point and nonpoint sources are reasonably assured by the state's use of an implementation plan. The TCEQ is committed to supporting implementation of all TMDLs adopted by the commission.

Implementation plans for Texas TMDLs use an adaptive management approach that allows for refinement or addition of methods to achieve environmental goals. This adaptive approach reasonably assures that the necessary regulatory and voluntary activities to achieve pollutant reductions will be implemented. Periodic, repeated evaluations of the effectiveness of implementation methods ascertain whether progress is occurring, and may show that the original distribution of loading among sources should be modified to increase efficiency. Implementation plans will be adapted as necessary to reflect needs identified in evaluations of progress.

The TCEQ is committed to developing implementation plans (through stakeholder involvement) for all TMDLs adopted by the commission and to ensuring the plans are implemented. Implementation plans are critical to ensure water quality standards are restored and maintained. They are not subject to EPA approval.

The TCEQ works with stakeholders to develop the strategies summarized in the Implementation plan, which may use an adaptive management approach that achieves initial LAs from a subset of the source categories. Adaptive management allows for development or refinement of methods to achieve the environmental goal of the plan.

Periodic and repeated evaluations of the effectiveness of implementation methods assure that progress is occurring, and may show that the original distribution of loading among sources should be modified to increase efficiency. This adaptive approach provides reasonable assurance that the necessary regulatory and voluntary activities to achieve the pollutant reductions will be implemented.

Implementation of the TMDL

An implementation plan includes a detailed description and schedule of the regulatory and voluntary management measures to implement the WLAs and LAs of particular TMDLs within a reasonable time. Implementation plans also identify

the organizations responsible for carrying out management measures, and a plan for periodic evaluation of progress.

Strategies to optimize compliance and oversight are identified in an implementation plan when necessary. Such strategies may include additional monitoring and reporting of effluent discharge quality to evaluate and verify loading trends, adjustment of an inspection frequency or a response protocol to public complaints, and escalation of an enforcement remedy to require corrective action of a regulated entity contributing to impairment.

The TCEQ works with stakeholders and interested governmental agencies to develop and support implementation plans and track their progress. Work on the implementation plan begins during development of TMDLs. Because these TMDLs address agricultural sources of pollution, the TCEQ will also work in close partnership with the TSSWCB when developing the implementation plan. The TSSWCB is the lead agency in Texas responsible for planning, implementing, and managing programs and practices for preventing and abating agricultural and silvicultural nonpoint sources of water pollution. The cooperation required to develop an implementation plan will become a cornerstone for the shared responsibility necessary to carry it out.

Ultimately, the implementation plan will identify the commitments and requirements to be implemented through specific permit actions and other means. For these reasons, the implementation plan that is approved may not approximate the predicted loadings identified category-by-category in the TMDL and its underlying assessment. The implementation plan is adaptive for this very reason; it allows for continuous update and improvement.

In most cases, it is not practical or feasible to approach all TMDL implementation as a one-time, short-term restoration effort. This is particularly true when a challenging wasteload reduction or load reduction is required by the TMDL, there is high uncertainty with the TMDL analysis, there is a need to reconsider or revise the established water quality standard, or the pollutant load reduction would require costly infrastructure and capital improvements.

Regulatory actions identified in the implementation plan could include:

- adjustment of an effluent limitation in a wastewater permit;
- a schedule for the elimination of a certain pollutant source;
- identification of any nonpoint source discharge that would be regulated as a point source;
- a limitation or prohibition for authorizing a point source under a general permit; or
- a required modification to a SWMP and pollution prevention plan (PPP).

Strategies to optimize compliance and oversight are identified in an implementation plan when necessary. Such strategies may include additional monitoring and reporting of effluent discharge quality to evaluate and verify loading trends, adjustment of an inspection frequency or a response protocol to public complaints, and escalation of an enforcement remedy to require corrective action of a regulated entity contributing to impairment.

In determining which sources need to accomplish what reductions, the implementation plan may consider factors such as:

- cost and/or feasibility;
- current availability or likelihood of funding;
- existing or planned pollutant reduction initiatives such as watershed-based protection plans;
- whether a source is subject to an existing regulation;
- the willingness and commitment of a regulated or unregulated source; and
- a host of additional factors.

The TCEQ maintains an overall WQMP that directs the efforts to address water quality problems and restore water quality uses throughout Texas. The WQMP is continually updated with new, more specifically focused WQMPs, or "water quality management plan elements" as identified in federal regulations (40 CFR Sec. 130.6(c)). Consistent with federal requirements, each TMDL is a plan element of a WQMP and commission adoption of a TMDL is state certification of the WQMP update.

Because the TMDL does not reflect or direct specific implementation by any one pollutant discharger, the TCEQ certifies additional "water quality management plan elements" to the WQMP after the implementation plan is approved by the commission. Based upon the TMDL and implementation plan, the TCEQ will propose and certify WQMP updates to establish required water-quality-based effluent limitations necessary for specific TPDES wastewater discharge permits. The TCEQ would normally establish BMPs, which are a substitute for effluent limitations in TPDES MS4 stormwater permits as allowed by the federal rules where numeric effluent limitations are infeasible (see November 22, 2002, memorandum from EPA relating to establishing TMDL WLAs for stormwater sources). Thus, the TCEQ would not identify specific implementation requirements applicable to a specific TPDES stormwater permit through an effluent limitation update. However, the TCEQ would revise a stormwater permit, require a revised SWMP or PPP, or implement other specific revisions affecting stormwater dischargers in accordance with an approved implementation plan.

The TCEQ plans to support the implementation of this TMDL through the efforts of the Jarbo Bayou watershed stakeholder group. This group decided to use and contribute new information to the current plan of the BIG, as described under Public Participation.

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Appendix A. Tidal Prism Method

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

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 Jarbo Bayou watershed. The tidal prism is the volume of water gained in a tidal stream between low and high tide levels. Load calculations were developed for two reaches within Jarbo Bayous. The model incorporates the three primary mechanisms through which Enterococci loadings and water enter the impaired systems:

- rain-induced freshwater inputs via upstream reaches and tributaries or direct runoff;
- direct point source discharges; and
- 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 the impaired AU is presented in Figure A-1.

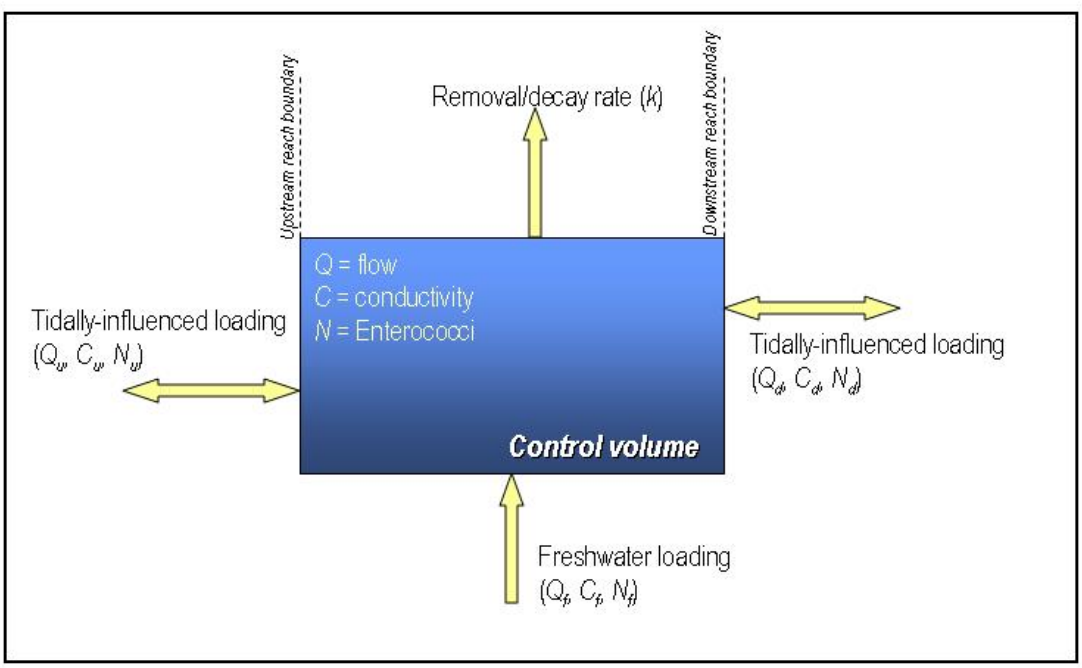

Figure A-1. Conceptual Model for Sources and Sinks of Enterococci in a Control Volume

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

Equation A-1

$$\frac{dV}{dt} = Q_u + Q_f - Q_d$$

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

Step 1: Define Reaches

Jarbo Bayou, Segment 2425B, was divided into two reaches (Figure 7) for modeling purposes. 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 LiDAR (Light Detection and Ranging) 2-foot contour elevation data collected in 2001 and provided by TSARP.

Step 2: Establishing Tributary Inflows and Loads

The model requires time series for inflow and bacterial indicator loads from the freshwater tributaries (the model headwaters) discharging to the tidal portions.

There are no upstream freshwater tributaries to the tidal prism model.

Because Jarbo Bayou's drainage area is all tidally influenced, there are no indicator bacteria loads to the tidal prism model from upstream freshwater tributaries.

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

The key variables required for estimating loading into Jarbo Bayou 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. There are no TPDES-

permitted WWTFs that continuously discharge wastewater to Jarbo Bayou Watershed. Runoff from each of the watersheds was defined using the HCFCD Hydrologic Modeling System (HMS) flow simulation model. Drainage areas were estimated using TSARP subwatersheds displayed in Figure A-2. The HCFCD model was updated to include hourly rainfall from Harris County Office of Emergency Management Rainfall Gage 100 located near the downstream outlet of Clear Lake.

Event mean concentrations (EMC) for Enterococci were estimated based on fecal coliform EMCs obtained from the Stormwater Management Joint Task Force in 2002. 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 A-1.

Table A-1. EMCs for the Jarbo Bayou Watershed

Land Cover Description	Enterococci EMCs (cfu/dL)
Developed	18,000
Cultivated Land	700
Grassland/Herbaceous	700
Pasture/Hay	700
Woodland	400
Open Water	0
Wetlands	0
Transitional/Bare	12,000

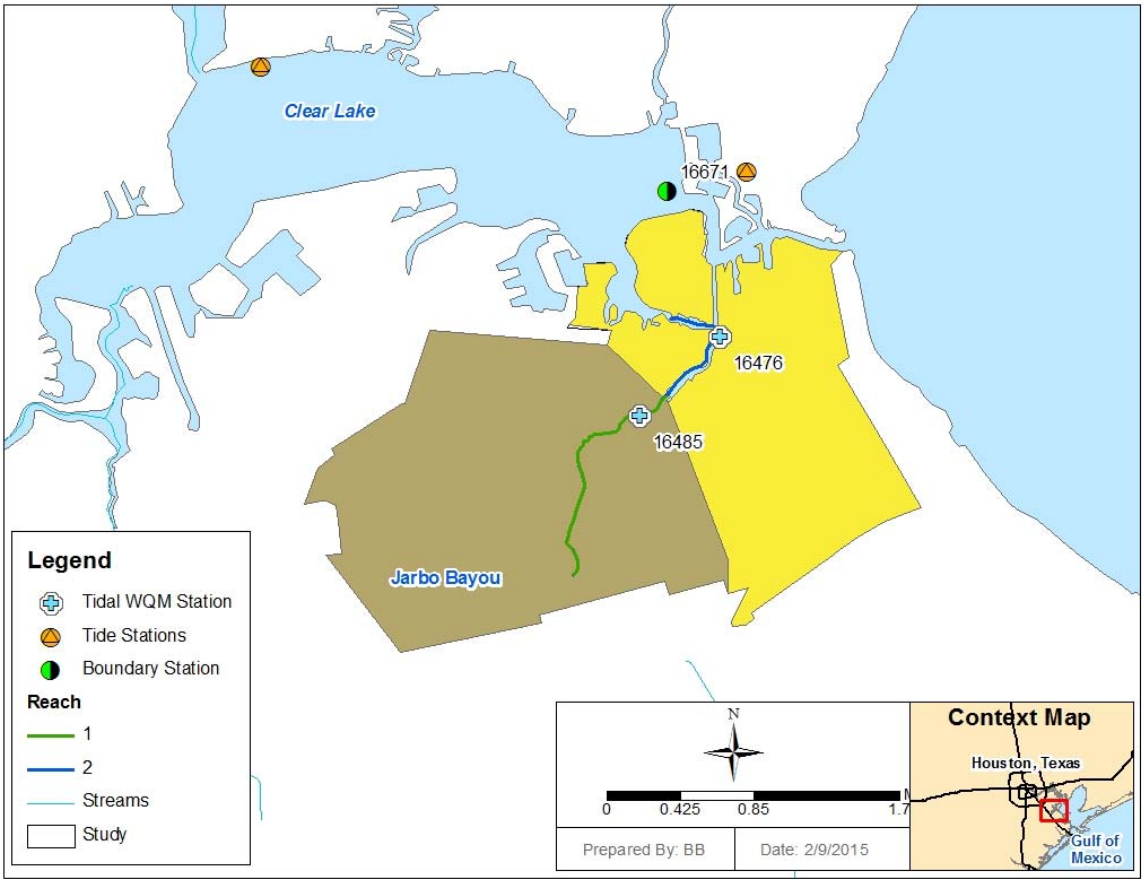

Figure A-2. Drainage Areas for the Tidal Prism Model Reaches

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

Table A-2. Stormwater Runoff Loads to the Tidal Prism Model

Reach	Average Flow (m^3/day)	Average Flow (cfs)	Average Enterococci Load (billion counts/day)
1	5,700	2.26	309
2	4,250	1.69	178

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 A-1). To calculate volumes, one hour gage data for the period of 10/01/2004 – 10/31/2010 were downloaded from the Texas Coastal Ocean Observation Network Station 507 at Eagle Point and Station 503 at Morgan's Point <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 WQM stations and from the NOAA gage (tide stations) were used as a conservative tracer to determine the flow balance of each reach. The conductivity balance calculation for each reach is represented as:

Equation A-2

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

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 [microSiemens/centimeter (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 16476 was used to determine the downstream boundary conditions. Conductivity in freshwater (runoff, tributaries and effluent)

was assumed equal to 500 µS/cm. Tidally influenced volumes were calculated using Equation A-1 and freshwater volumes as described earlier. Using the above information Equation A-2 was solved for the conductivity in the reach (C_t). The computed conductivity levels were then compared to existing measurements within the impaired water body to corroborate that the flows are accurately represented throughout the system. Figure A-3 presents a comparison of observed and modeled average conductivity concentrations along tidal Jarbo Bayou (Reach 2).

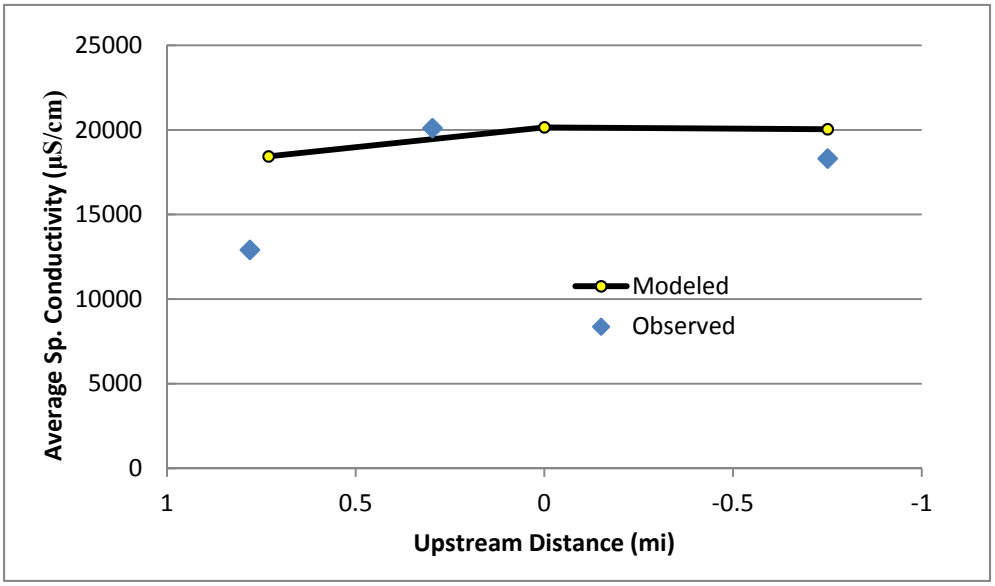

Figure A-3. Longitudinal Profile of Average Conductivity

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:

Equation A-3:

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

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 were used to define the initial conditions in each model reach. Statistical relationships between tide height and Enterococci concentrations measured in Jarbo Bayou station 16476 (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 of the technical support document.

Figure A-4 presents a comparison of measured and modeled Enterococci concentrations along 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 (including fecal coliform and E. coli), 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.

As mentioned earlier, there are no TPDES-permitted WWTFs that discharge to Jarbo Bayou. Stormwater runoff can contribute both permitted and non-permitted sources of bacteria which must also be accounted for in the TMDL allocations. 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 the WLASW. The WLA will be split into the WLAWWTF and WLASW components. To be consistent with the Load Duration Curve method, the estimated loading from stormwater runoff within each drainage area is separated into stormwater loading from permitted sources and stormwater loading from non-permitted 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 non-permitted areas is considered the LA. Therefore, another way of expressing the LA from non-permitted stormwater runoff is calculating the TMDL minus the MOS minus the WLA (sum of WWTF and stormwater).

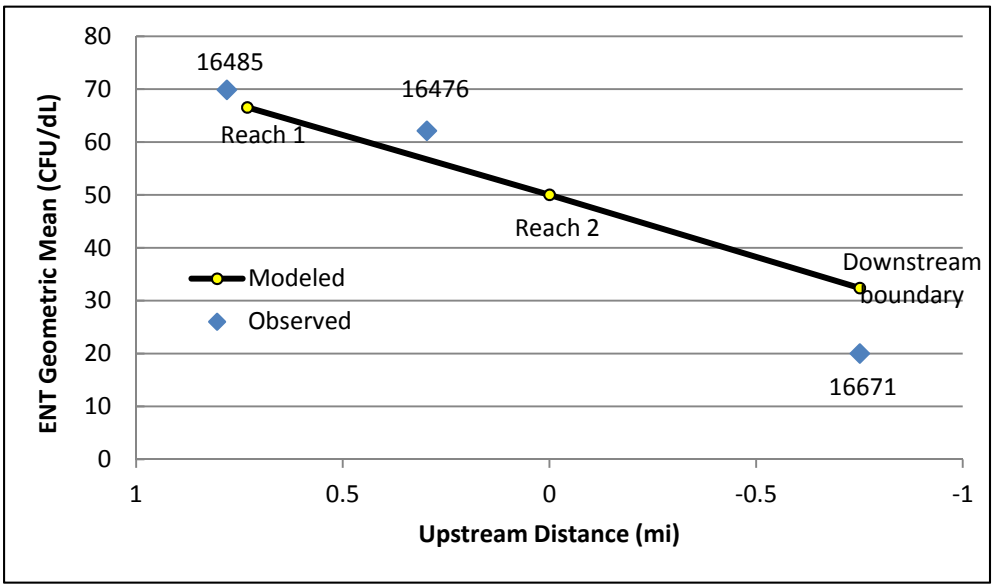

Figure A-4. Longitudinal Profile of Enterococci Concentrations (Geometric Means)

Appendix B. Method for Calculating TMDL Allocations for Revised Contact Recreation Standards

Method for Calculating TMDL Allocations for Revised Contact Recreation Standards

The method described below details the equations and procedure that will be used for revising the TMDLs and associated wasteload allocations described in this document, should the water quality standards change in the future. Provisions for revising TMDL and TMDL allocations to reflect changes in criteria in the assessment units of Jarbo Bayou (2425B) have been developed although there are currently no contact recreation standard revisions under consideration for tidal segments in Texas.

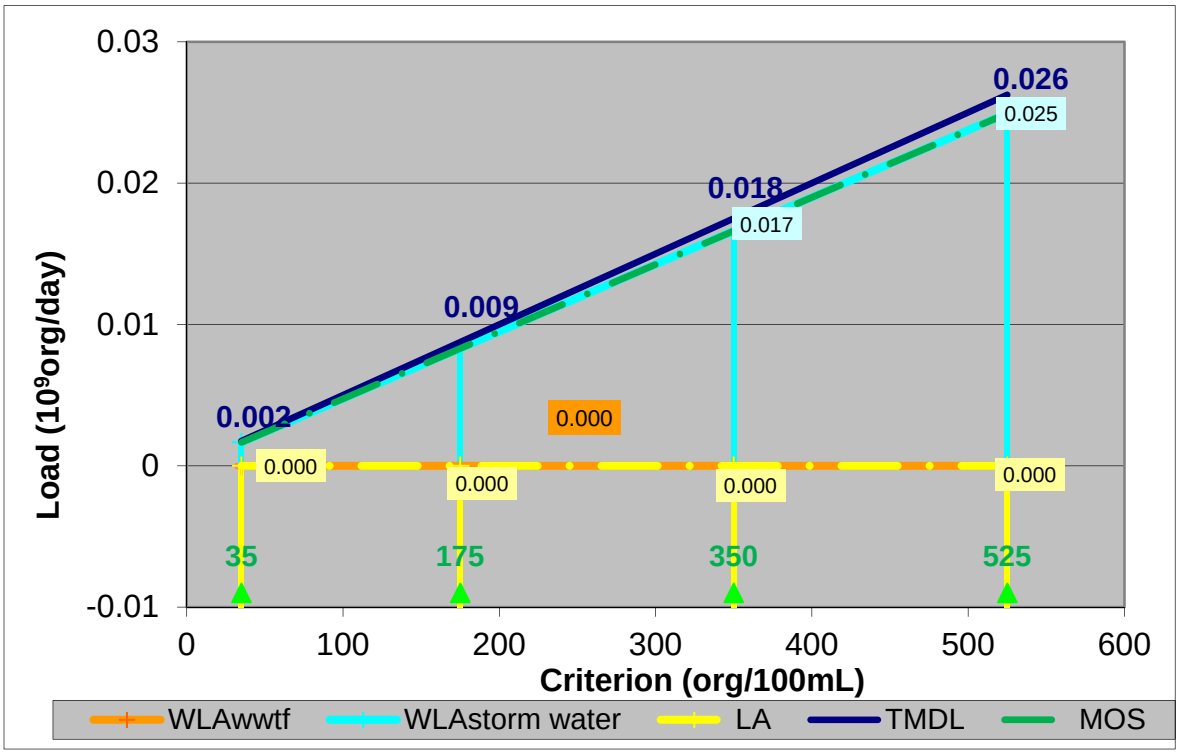

Figure B-1. Assessment Unit 2425B_01 TMDL for Revised Standards

Equations for Calculations New TMDL and Allocations

$$\text{TMDL} = 0.00005 * \text{Std} + 0.0$$

$$\text{MOS} = 0.05 * \text{TMDL}$$

$$\text{LA} = 0.0 * \text{Std} + 0.0$$

$$\text{WLA}_{\text{SW}} = 0.0000475 * \text{Std} - 0.0$$

$$\text{WLA}_{\text{WWTF}} = 0.0$$

Where:

Std = Revised contact recreation criteria

LA = load allocation (unregulated source contributions)

WLA_{SW} = wasteload allocation (permitted stormwater);

WLA_{WWTF} = wasteload allocation (permitted WWTF)