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Six Total Maximum Daily Loads for Indicator Bacteria in the Armand Bayou Watershed

Segments 1113, 1113A, 1113B, 1113C, 1113D, and 1113E

Assessment Units 1113_02, 1113A_01, 1113B_01, 1113C_01, 1113D_01, and 1113E_01

Water Quality Planning Division, Office of Water

TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

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This TMDL report is based in large part on the report titled:
"Technical Support Document: Bacteria Total Maximum Daily Loads for the Armand Bayou Watershed, Houston, Texas"
prepared by the University of Houston and CDM Smith.

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Abbreviations

AU	assessment unit
BIG	Bacteria Implementation Group
BMP	best management practice
CFR	Code of Federal Regulations
cfs	cubic feet per second
cfu	colony forming unit
E. coli	*Escherichia coli*
EPA	United States Environmental Protection Agency
FDC	flow duration curve
GIS	geographic information system
HCFCD	Harris County Flood Control District
H-GAC	Houston-Galveston Area Council
I/I	inflow and infiltration
I-Plan	Implementation Plan
JSC	Johnson Space Center
LA	load allocation
LDC	load duration curve
MGD	million gallons per day
mL	milliliter
MOS	margin of safety
MPN	most probable number
MS4	municipal separate storm sewer system
NASA	National Aeronautics and Space Administration
NPDES	National Pollution Discharge Elimination System
NPS	nonpoint source
OSSF	on-site sewage facility
SSO	sanitary sewer overflow
SWMP	Stormwater Management Program
SWPPP	Stormwater Pollution Prevention Plan
TCEQ	Texas Commission on Environmental Quality
TMDL	Total Maximum Daily Load
TPDES	Texas Pollution Discharge Elimination System
TSARP	Tropical Storm Allison Recovery Project
TWDB	Texas Water Development Board
USGS	United States Geological Survey
WLA	wasteload allocation
WQMP	Water Quality Management Plan
WWTF	wastewater treatment facility
WWTP	wastewater treatment plant

Six TMDLs for Indicator Bacteria in the Armand Bayou Watershed

Executive Summary

This document describes total maximum daily loads (TMDLs) for six segments in the Armand Bayou watershed, where concentrations of bacteria exceed the criteria used to evaluate attainment of the contact recreation use. The Texas Commission on Environmental Quality (TCEQ) first identified the impairments of the contact recreation use for these segments and assessment units (AUs) on multiple *Texas Water Quality Inventory and 303(d) Lists* published between 1998 and 2012.

The impaired segments and corresponding AUs are:

- Armand Bayou Tidal: 1113_02,
- Armand Bayou Above Tidal: 1113A_01,
- Horsepen Bayou Tidal: 1113B_01,
- Unnamed Tributary to Horsepen Bayou: 1113C_01,
- Willow Springs Bayou: 1113D_01, and
- Big Island Slough: 1113E_01.

The Armand Bayou Watershed encompasses approximately 60 square miles of land located just southeast of the City of Houston, Texas and lies within Harris County and the San Jacinto-Brazos Coastal Basin. Armand Bayou is one of the major tributaries within this basin along with Clear Creek, Dickinson Bayou, Chocolate Bayou, Bastrop Bayou, and Oyster Creek. The northern and southern portions of the watershed are heavily developed while the middle region is sparsely developed. Within the lower region of the watershed, Armand Bayou Nature Center owns and manages 2,500 acres as part of a wildlife and nature preserve.

The preferred indicator bacteria for assessing the contact recreation use is *Escherichia coli* (*E. coli*) for freshwater and Enterococci in tidal water. For this project *E. coli* data were used for data analysis and modeling to support TMDL development for Armand Bayou Above Tidal, Unnamed Tributary to Horsepen Bayou, Willow Springs Bayou, and Big Island Slough. Enterococci data were used for data analysis and modeling to support TMDL development for Armand Bayou Tidal and Horsepen Bayou.

For the *E. coli* indicator, the contact recreation use is not supported when the geometric mean of all *E. coli* samples exceeds 126 counts per 100 milliliter (mL). For the Enterococci indicator, the contact recreation use is not supported when the geometric mean of all Enterococci samples exceeds 35 counts per 100 mL.

Data the TCEQ analyzed from the assessment period of December 1, 2003, through November 20, 2010, showed 10 of the 11 sampling locations in the impaired segments exceeded the indicator bacteria concentrations for the current contact recreation standard.

The most probable sources of indicator bacteria are non-compliant wastewater treatment facility (WWTF) discharges, stormwater runoff from permitted storm sewer sources, sanitary sewer overflows (SSOs), dry weather discharges (illicit discharges) from storm sewers, failing on-site sewage facilities (OSSFs), and runoff from areas not covered by a permit.

There are two regulated WWTF outfalls that continuously discharge wastewater to surface waters addressed in these TMDLs. There are two regulated no-discharge facilities within the watershed as well.

For the freshwater segments (Armand Bayou Above Tidal, Unnamed Tributary to Horsepen Bayou, Willow Springs Bayou, and Big Island Slough), a load duration curve (LDC) analysis was used to quantify allowable pollutant loads and specific TMDL allocations for point and nonpoint sources of indicator bacteria. The mass balance (tidal prism) method was used for the tidal segments (Armand Bayou Tidal and Horsepen Bayou).

Future growth of existing or new domestic point sources was determined using population projections through 2050. The TMDL calculations in this report will guide determination of the assimilative capacity of each stream 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 impairments to the contact recreation use due to exceedances of the indicator bacteria criteria in Armand Bayou Tidal, Armand Bayou Above Tidal, Horsepen Bayou Tidal (typically referred to simply as "Horsepen Bayou" in this document), Unnamed Tributary to Horsepen Bayou, Willow Springs Bayou, and Big Island Slough. This TMDL takes a watershed approach to addressing contact recreation impairments. While TMDL allocations were developed only for the impaired AUs identified in this report, the entire project 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 United States Environmental Protection Agency (EPA) in Title 40 of the Code of Federal Regulations (CFR), Part 130 (40 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 of this report:

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

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

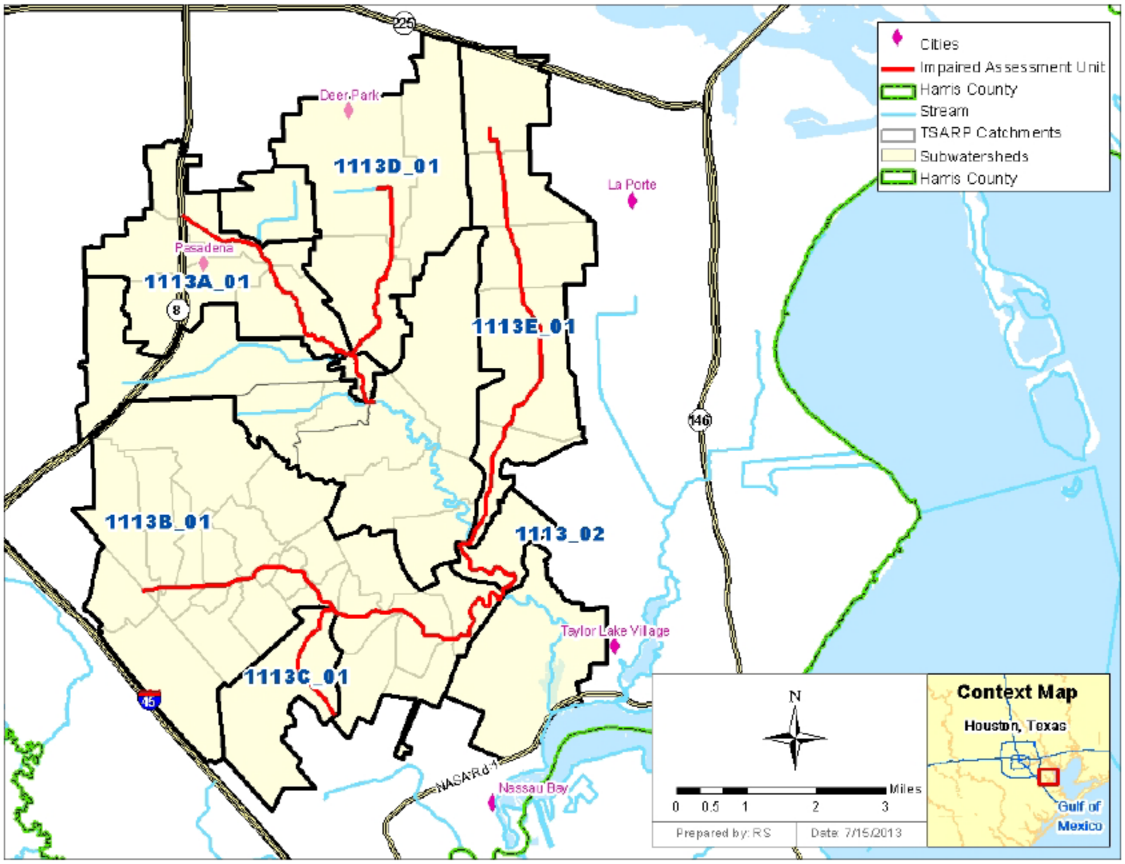

Figure 1. Armand Bayou Watershed

Problem Definition

The TCEQ first identified impairments of the contact recreation use for these segments and AUs on multiple 303(d) lists published between 1998 and 2012 (Table 1). Armand Bayou and its tributaries have both freshwater segments and tidally influenced segments. Armand Bayou is classified as two separate water bodies, Armand Bayou Tidal, and Armand Bayou Above Tidal.

Figure 1 shows the water bodies and their contributing subwatersheds that are addressed in this TMDL report. The delineation of each subwatershed 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 segments (Segment 1113). However, the use of TSARP drainage areas provides finer resolution and results in delineations that accurately represent the subwatersheds contributing to each classified and unclassified segment.

The TMDL study area includes other areas that are not addressed in this TMDL document. Segments 1113G, 1113F, and 1113H are tributaries to Armand Bayou Above Tidal. These streams have not been recently assessed for the contact recreation use and are not listed as impaired. Two portions of Armand Bayou Tidal (1113 _01 and 1113_03) have been assessed and are meeting water quality standards for contact recreation.

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

Assessment Unit	Segment Name	Type	Year First Listed
1113_02	Armand Bayou Tidal	Tidal	2006
1113A_01	Armand Bayou Above Tidal	Freshwater	1998
1113B_01	Horsepen Bayou Tidal	Tidal	2006
1113C_01	Unnamed Tributary to Horsepen Bayou	Freshwater	2010
1113D_01	Willow Springs Bayou	Freshwater	2010
1113E_01	Big Island Slough	Freshwater	2012

The standards for water quality are defined in the Texas Surface Water Quality Standards (TCEQ 2010a). The criteria for assessing attainment of the contact recreation use are expressed as the number of indicator bacteria per hundred milliliters (100 mL) of water.

As described in the TCEQ's 2010 Guidance for Assessing and Reporting Surface Water Quality in Texas (TCEQ 2010b), 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 are *E. coli* for freshwater and Enterococci for tidal water. *E. coli* data were used for analysis and modeling of Armand Bayou Above Tidal, Unnamed Tributary to Horsepen Bayou, Willow Springs Bayou, and Big Island Slough. Enterococci data were used in analysis and modeling for Armand Bayou Tidal and Horsepen Bayou.

For the *E. coli* indicator, if the minimum sample requirement is met, the contact recreation use is not supported when the geometric mean of *E. coli* samples exceeds 126 counts per 100 mL. For the Enterococci indicator, if the minimum sample requirement is met, the contact recreation use is not supported when the geometric mean of Enterococci samples exceeds 35 counts per 100 mL.

Data the TCEQ analyzed from the assessment period of December 1, 2003, through November 20, 2010, showed 10 of the 11 sampling locations in the impaired segments exceeded the indicator bacteria concentrations for the contact recreation standard (Table 2). Bacteria concentrations are expressed as either colony-forming units (cfu)/100 mL or most probable number (MPN)/100 mL 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 may also be referred to as "counts." Most of the analyses for *E. coli* and Enterococci are in MPN but some older analyses are in cfu.

Ambient Indicator Bacteria Concentrations

Table 2 summarizes indicator bacteria data for sampling locations in each segment for the period of record of 2003-2010. The data in the table are not intended to be an exact replication of the 2012 Integrated Report. Sampling locations are shown in Figure 2.

Table 2. Summary of Data (2003-2010)

Assessment Unit	Station ID	Indicator Bacteria	Geometric Mean Concentration (MPN/100ml)	Number of Samples
1113_02	11503	EC	231.7	11
		ENT	38.9	80
1113A_01	11404	EC	172.0	72
	11405	EC	56.3	5
	17488	EC	1479.5	59
1113B_01	11409	EC	204.3	13
		ENT	55.0	77
	17317	ENT	67.2	26
1113C_01	17485	EC	192.2	69
1113D_01	17487	EC	628.3	70
1113E_01	17486	EC	646.4	67

EC: *E coli*; ENT: enterococci

Highlighted stations are tidally influenced.

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

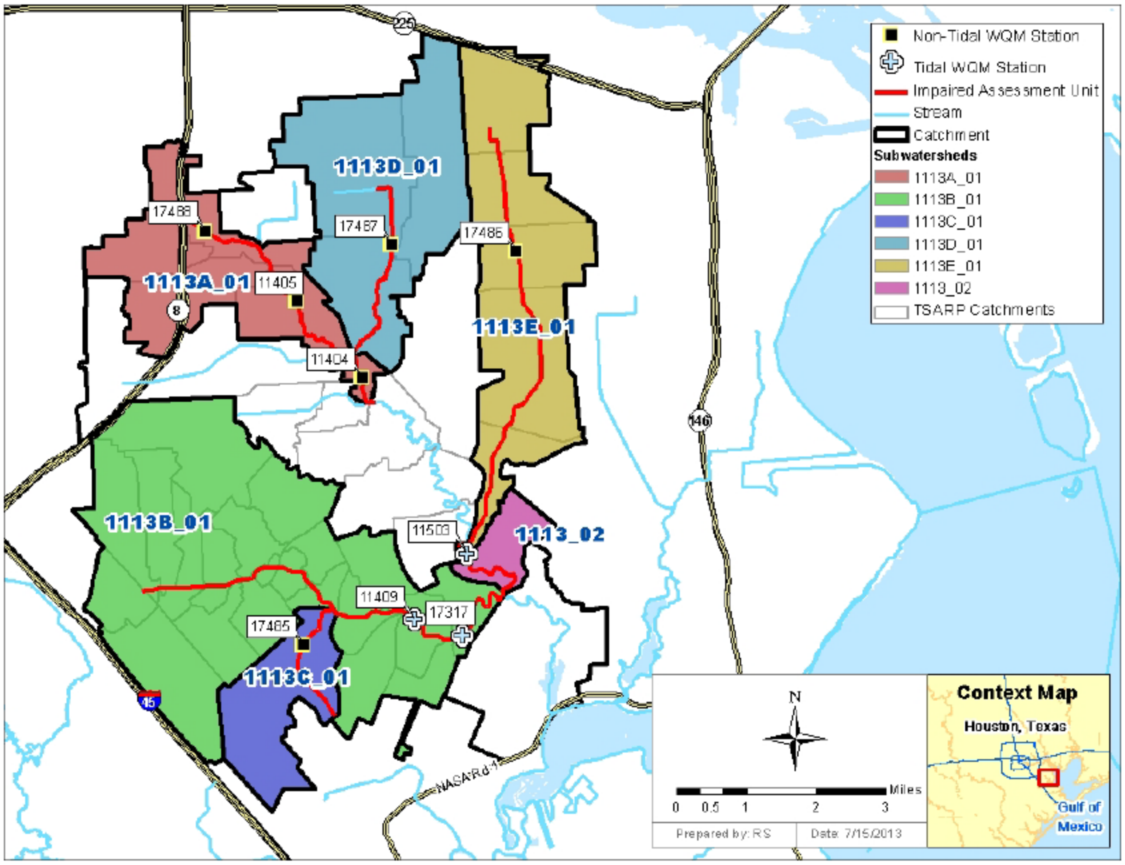

Figure 2. Armand Bayou Watershed Sampling Locations

Watershed Overview

The 2012 Texas Integrated Report of Surface Water Quality for Clean Water Act Sections 305(b) and 303(d) (TCEQ 2012) provides the segment and AU descriptions for the water bodies considered in this document.

- Segment 1113 - Armand Bayou Tidal; From the Clear Lake confluence (at NASA Road 1 bridge) in Harris County to a point 0.8 km (0.5 miles) downstream of Genoa-Red Bluff Road in Pasadena in Harris County (includes Mud Lake/Pasadena Lake)(segment consists of three AUs)
  - 1113_02 - From the Horsepen Bayou confluence to the Big Island Slough confluence
- Segment 1113A - Armand Bayou Above Tidal (unclassified water body); From the upper segment boundary of Armand Bayou Tidal, 0.8 km (0.5 miles) downstream of Genoa-Red Bluff Road, upstream to Beltway 8 in Harris County (segment consists of only one AU)

- Segment 1113B - Horsepen Bayou Tidal (unclassified water body); From the Armand Bayou confluence to the State Highway 3 (segment consists of only one AU)
- Segment 1113C - Unnamed Tributary to Horsepen Bayou (unclassified water body); From the Horsepen Bayou confluence to Reseda Road (segment consists of only one AU)
- Segment 1113D - Willow Springs Bayou (unclassified water body); From the Armand Bayou confluence to a point 2.8 km (1.8 mi) upstream to an unnamed tributary (segment consists of only one AU)
- Segment 1113E - Big Island Slough (unclassified water body); From the Armand Bayou confluence upstream to a point 2.4 km (1.5 mi) north of Spencer Hwy (segment consists of only one AU)

Armand Bayou Tidal and Horsepen Bayou are perennial tidal water bodies. Armand Bayou Tidal terminates at Clear Lake, while Horsepen Bayou drains into Armand Bayou Tidal at the downstream boundary of AU 1113_02. The remaining four water bodies are freshwater. Armand Bayou Above Tidal (1113A_01) is the perennial freshwater part of Armand Bayou that extends from Armand Bayou Tidal through the City of Pasadena. Willow Springs Bayou and Big Island Slough are perennial tributaries of Armand Bayou Tidal (1113). Unnamed Tributary to Horsepen Bayou is a tributary of Horsepen Bayou Tidal.

All of the water bodies addressed by these TMDLs are within the Armand Bayou watershed. The Armand Bayou watershed encompasses approximately 60 square miles of land located just southeast of the City of Houston, Texas and lies entirely within Harris County. The Armand Bayou watershed is part of the San Jacinto-Brazos Coastal Basin. The watershed feeds into Clear Lake (Segment 2425) which, in turn, feeds into Upper Galveston Bay (Segment 2421). The northern and southern portions of the watershed are heavily developed while the lower region is sparsely developed. Within the lower region of the watershed, Armand Bayou Nature Center owns and manages 2,500 acres as part of a wildlife and nature preserve. The watershed is expected to continue to develop based on its proximity to the Johnson Space Center, Houston Ship Channel, and Clear Lake.

The climate of the region is subtropical humid, with very hot and humid summers and mild winters (USACE 1985). The average maximum daytime temperature in the summer is 34 degrees Celsius (93 degrees Fahrenheit) while the temperature averages between 4 and 16 degrees Celsius (39 to 61 degrees Fahrenheit) during the winter. Rainfall in the summer months is dominated by subtropical convection, winter months 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 Group (PRISM Group 2010), is summarized in Table 3. Annual rainfall averages range from 54.7

inches in the Armand Bayou Above Tidal subwatershed to 55.8 inches in the Armand Bayou Tidal and Unnamed Tributary to Horsepen Bayou subwatersheds.

Table 3. PRISM Annual Average Precipitation, 1981-2010

Segment Name	Assessment Unit	Average Annual (Inches)
Armand Bayou Tidal	1113_02	55.8
Armand Bayou Above Tidal	1113A_01	54.7
Horsepen Bayou Tidal	1113B_01	55.4
Unnamed Tributary to Horsepen Bayou	1113C_01	55.8
Willow Springs Bayou	1113D_01	54.8
Big Island Slough	1113E_01	55.2

Table 4 summarizes the percentages of the land cover categories for the contributing subwatershed associated with each respective AU in the Armand Bayou watershed. 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 these subwatersheds is developed land (between 10% and 100%), followed by woody wetlands (between 0% and 66%) and hay/pasture (between 0% and 11%). Open water and bare/transitional land account for 10 percent or less of the AUs.

The Armand Bayou Above Tidal, Horsepen Bayou, Unnamed Tributary to Horsepen Bayou, Willow Springs Bayou, and Big Island Slough subwatersheds are primarily urban with 67 percent to 100 percent developed land. Armand Bayou Tidal is less urbanized with 10 percent developed land.

The study area has six incorporated cities within its watershed. The six cities within the Armand Bayou watershed are expected to increase in population by an average of 24 percent from 2010 to 2050, according to the Texas Water Development Board (TWDB) (Montgomery Watson America, Inc. 2010). Table 5 lists TWDB population growth estimates for these six cities from 2010 to 2050.

Table 4. Summary of Watershed Characteristics

Aggregated Land Cover Category	Armand Bayou Tidal	Armand Bayou Above Tidal	Horsepen Bayou Tidal	Unnamed Tributary to Horsepen Bayou	Willow Springs Bayou	Big Island Slough
Assessment Unit	**1113_02**	**1113A_01**	**1113B_01**	**1113C_01**	**1113D_01**	**1113E_01**
Watershed Area (acres)	673	3,688	10,667	1,776	4,870	5,105
Land Cover Category (percent)						
Open Water	10%	1%	1%	0%	1%	1%
Developed, Open Space	4%	17%	28%	12%	22%	17%
Developed, Low Intensity	2%	22%	13%	19%	16%	15%
Developed, Medium Intensity	2%	32%	24%	58%	33%	25%
Developed, High Intensity	2%	14%	6%	11%	8%	10%
Barren Land	2%	0%	0%	0%	1%	1%
Deciduous Forest	1%	1%	3%	0%	1%	2%
Evergreen Forest	4%	0%	0%	0%	0%	0%
Mixed Forest	1%	0%	0%	0%	0%	1%
Shrub/Scrub	0%	1%	3%	0%	1%	1%
Herbaceous	3%	3%	5%	0%	6%	6%
Hay/Pasture	0%	5%	11%	0%	10%	5%
Cultivated Crops	0%	0%	0%	0%	0%	0%
Woody Wetlands	66%	4%	6%	0%	1%	16%
Emergent Herbaceous Wetlands	3%	0%	0%	0%	0%	0%

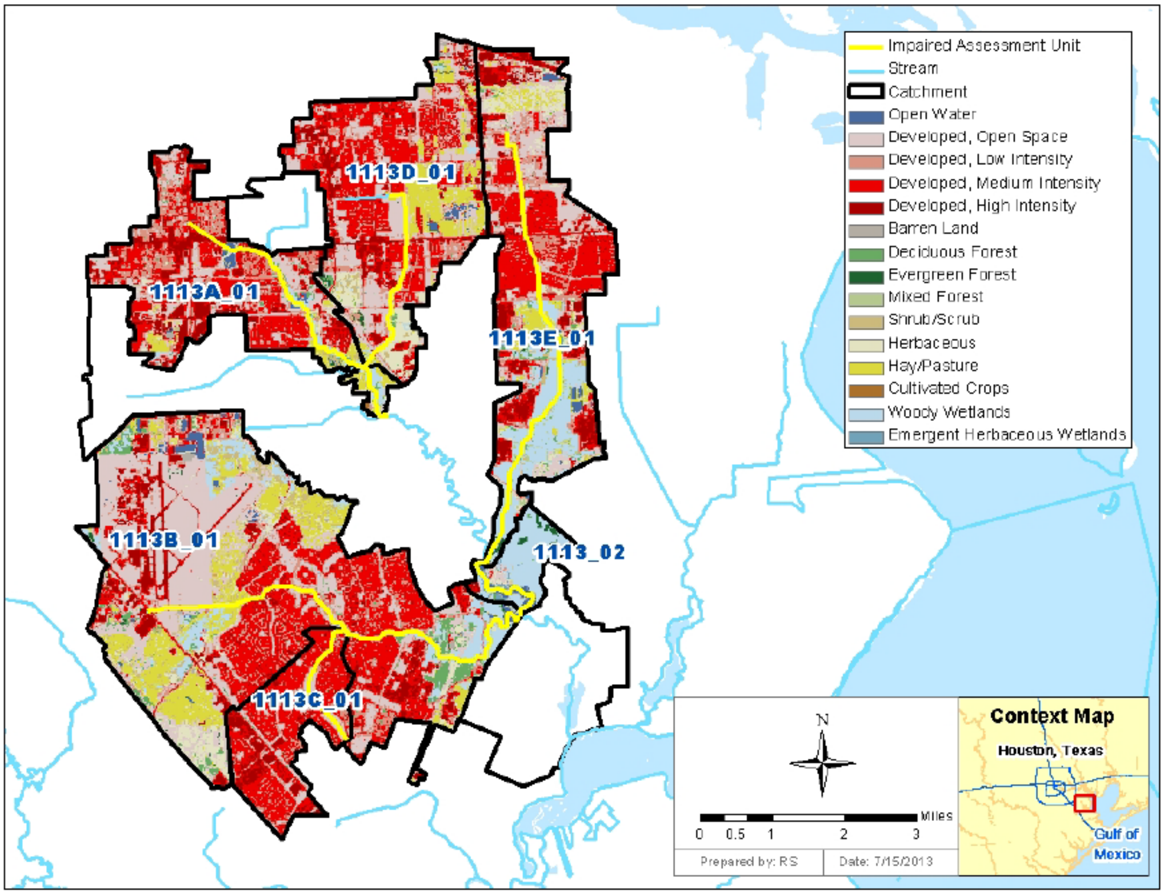

Figure 3. Armand Bayou Watershed Land Cover

Table 5. Armand Bayou Watershed Population Increases by City, 2010-2050

City	2010 Census Population	2020 Population Estimate	2050 Population Estimate	Growth Rate (2010-2050)
Deer Park	32,010	34,255	38,853	21%
Houston	2,058,056	2,201,986	2,724,216	32%
La Porte	33,800	34,345	35,785	6%
Pasadena	149,043	154,441	167,450	12%
Taylor Lake Village	3,544	3,557	3,690	4%
Webster	10,400	15,071	17,776	71%

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 the TMDLs for freshwater segments is to maintain concentrations of *E. coli* below the geometric mean criterion of 126 counts/100 mL. The freshwater segments are Armand Bayou Above Tidal, Unnamed Tributary to Horsepen Bayou, Willow Springs Bayou, and Big Island Slough. The endpoint for the TMDLs for tidal (saltwater) segments is to achieve concentrations of Enterococci below the geometric mean criterion of 35 counts/100 mL. The tidal segments are Armand Bayou Tidal and Horsepen Bayou.

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 stormwater 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 surface waters. Nonpoint sources are not regulated by permit.

With the exception of WWTFs, which receive individual wasteload allocations (WLAs; 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

Permitted sources are regulated by permit under the TPDES and the National Pollution Discharge Elimination System (NPDES) programs. The permitted sources in the TMDL watershed include WWTF outfalls and stormwater discharges from industries, construction, and municipal separate storm sewer system (MS4s). Two of the six segments in the study area have TPDES-permitted sources. A significant portion of the study area (over 95 percent) is regulated under the TPDES permit for stormwater discharge held jointly by Harris County, Harris County Flood Control District, City of Houston, and Texas Department of Transportation. There are no NPDES-permitted concentrated animal feeding operations within the study area.

Domestic and Industrial Wastewater Treatment Facilities

There are four permitted wastewater facilities in the Armand Bayou watershed. The locations of the two domestic TPDES-permitted facilities that continuously discharge wastewater to surface waters addressed in these TMDLs are listed in Table 6 and displayed in Figure 4. One facility with an intermittent and variable industrial stormwater discharge is found in Big Island Slough, and a no-discharge sludge disposal facility is located in Horsepen Bayou. These are also in Table 6.

Both of the continuously discharging WWTFs are in the Horsepen Bayou (1113B) subwatershed, with a combined total permitted flow of 15 million gallons per day (MGD). These WWTFs include the Clear Lake City Water Authority (Robert T. Savely Wastewater Treatment Plant (WWTP); 10539-001) and City of Houston (Metro Central WWTP; 10495-152). There are no WWTFs located in the Armand Bayou Tidal, Armand Bayou Above Tidal, Unnamed Tributary to Horsepen Bayou, Willow Springs Bayou, or Big Island Slough subwatersheds.

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 Armand Bayou watershed. The locations and magnitudes of all reported SSOs, and WWTF service area boundaries are displayed in Figure 5 and summarized in Table 7.

As shown by the data, there have been approximately 119 SSOs reported in the Armand Bayou watershed since August 2003. The reported SSOs averaged 3,905 gallons per event.

Table 6. Permitted Wastewater Facilities in the Armand Bayou Watershed

AU	Receiving Water	TPDES Number	NPDES Number	Facility Name	Facility Type	Dis-charge TYPE	Permitted Flow (MGD)	Average Monthly Flow (MGD)[c]
1113B_01	Horsepen Bayou Tidal	10495-152	TX 0069736	Metro Central WWTP	Sewerage Systems	W	5	1.44
1113B_01	Horsepen Bayou Tidal	10539-001	TX 0022543	Robert T Savely Water Reclamation Facility	Sewerage Systems	W	10	5.58
1113B_01	Horsepen Bayou Tidal	03523-000	TX L005000	City of Houston Sludge Plant[a]	Sludge Disposal	*n/a*	*n/a*	*n/a*
1113E_01	Big Island Slough	03029-000	TX 0103900	Equistar Chemicals Bayport Complex	Industrial Stormwater	*SW*	*n/a*[b]	*n/a*

Source: TCEQ Wastewater Outfall Shapefile, August 2013, EPA, ICIS monitoring data search August 2013
MGD = Millions of Gallons per Day; n/a = Not Applicable
TYPE: D = Domestic < 1 MGD; W=Domestic >= 1 MGD; SW=Stormwater
[a] Permit does not contain a discharge provision
[b] Flow is permitted as intermittent and variable with a requirement to measure and report
[c] November 2003 - May 2013

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 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.

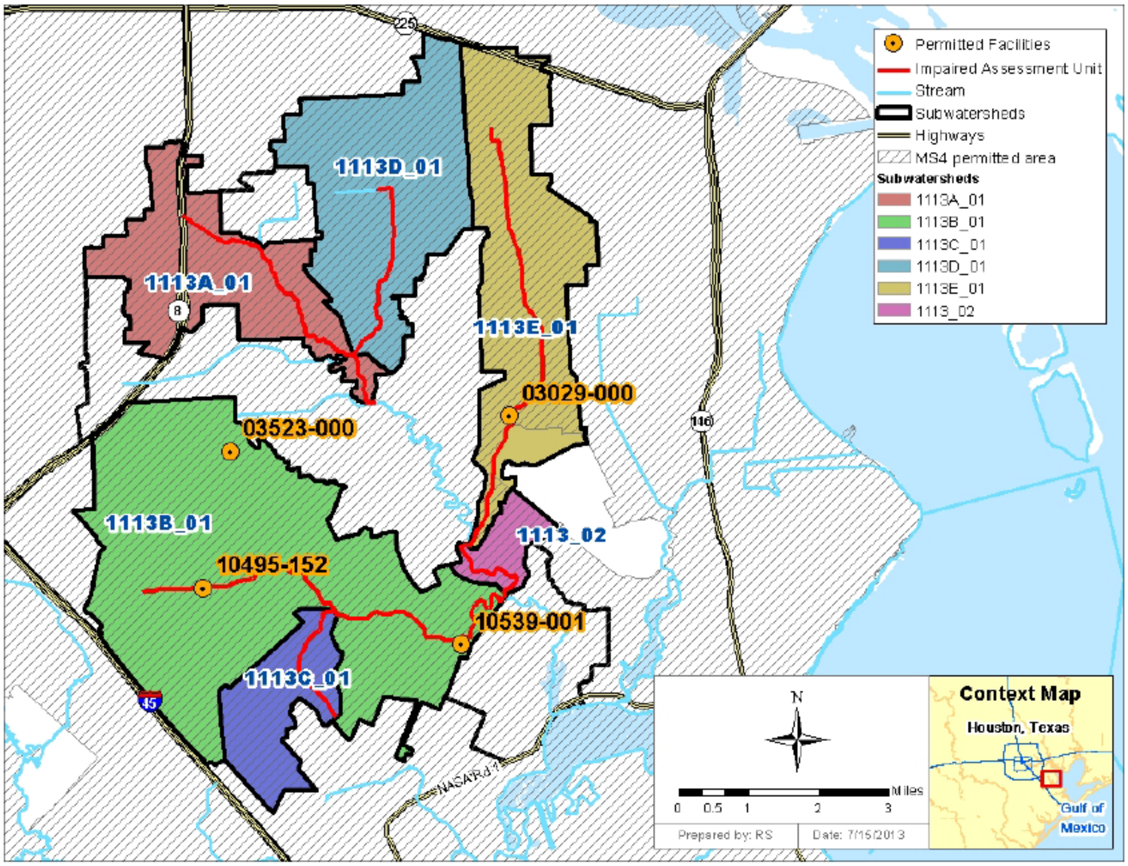

Figure 4. TPDES-Permitted Facilities in the Armand Bayou Watershed

The geographic region of the Armand Bayou watershed covered by MS4 [and/or industrial/construction] permits is designated as that portion of the watershed defined by the 2010 Census as being an urbanized area. Figure 4 displays the portion of the watershed that potentially contributes indicator bacteria loads to the receiving waters from regulated and unregulated stormwater. Table 8 lists the percentage of each subwatershed within the 2010 urbanized area (and therefore expected to have coverage under an appropriate stormwater permit).

Within the Armand Bayou watershed, there are six individual Phase I and 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 Pasadena (Phase II permit); City of Webster (Phase II permit); City of Deer Park (Phase II permit); National Aeronautics and Space Administration – Johnson Space Center (NASA - JSC; Phase II permit); and City of La Porte (Phase II permit).

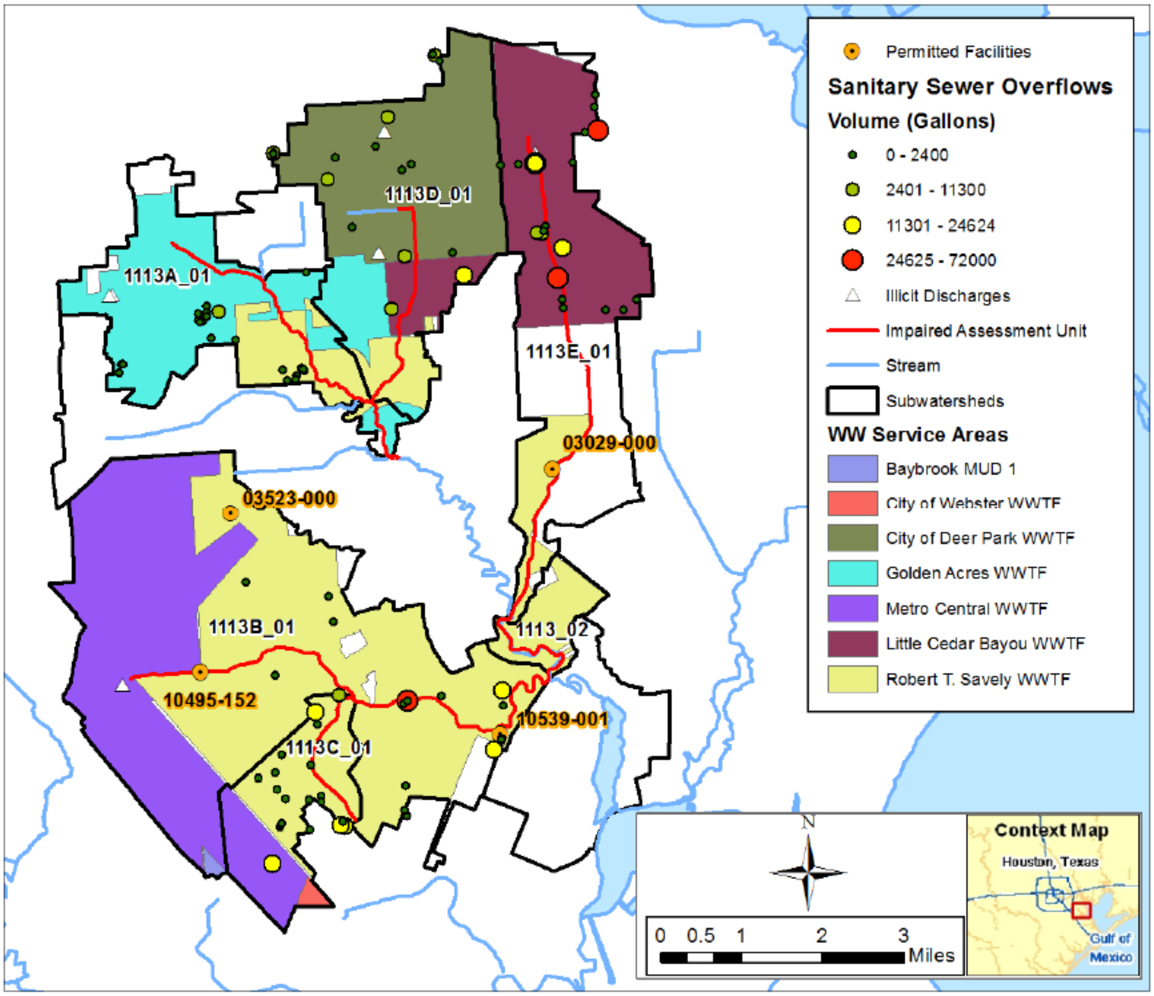

Figure 5. Sanitary Sewer Overflow Locations

Table 7. Sanitary Sewer Overflow Summary

Facility Name	NPDES Permit No.	TPDES Number	Number of Occurrences	Date Range	Amount in Gallons (Min / Max)
Robert T. Savely WWTF	TX0022543	10539-001	58	8/22/03 - 5/14/13	6 / 19,200
Metro Central WWTF	TX0069736	10495-152	2	4/18/12 - 5/12/12	200 / 1000
City of Deer Park WWTF	TX0025321	10519-002	21	9/26/03 - 6/26/13	50 / 10,000
Little Cedar Bayou WWTF	TX0022799	10206-001	23	6/11/06 - 4/27/13	15 / 72,000
Golden Acres WWTF	TX0134813	10053-011	15	3/20/04 – 5/2/10	150 / 3,955

3)

Table 8. Percentage of Permitted Stormwater in each Subwatershed

Segment	Receiving Stream	Regulated Entity Name	TPDES Number	Total Area (acres)	Area under MS4 Permit (Acres)	Percent of Subwatershed under MS4 Jurisdiction*
1113_02	Armand Bayou Tidal	City of Houston/ Harris County	WQ0004685000	673	673	100%
		City of Pasadena	WQ0004524000			
1113A_01	Armand Bayou Above Tidal	City of Houston/ Harris County	WQ0004685000	3,688	3,688	100%
		City of Pasadena	WQ0004524000			
1113B_01	Horsepen Bayou	City of Houston/ Harris County	WQ0004685000	10,667	10,667	100%
		NASA - JSC	TXR040214			
		City of Pasadena	WQ0004524000			
1113C_01	Unnamed Tributary to Horsepen Bayou	City of Houston/ Harris County	WQ0004685000	1,776	1,776	100%
		City of Webster	TXR040070			
1113D_01	Willow Springs Bayou	City of Houston/ Harris County	WQ0004685000	4,870	4,870	100%
		City of Deer Park	TXR040058			
		City of La Porte	TXR040117			
		City of Pasadena	WQ0004524000			
1113E_01	Big Island Slough	City of Houston/ Harris County	WQ0004685000	5,106	5,106	93%
		City of La Porte	TXR040117			
		City of Pasadena	WQ0004524000			

*Defined as the area designated as urbanized area in the 2010 US Census

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 identified in the *Illicit*

Discharge Detection and Elimination Manual: A Handbook for Municipalities (NEIWPCC, 2003) include:

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.

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 (NPS) loading enters the impaired segment through distributed, nonspecific locations, which may include urban runoff not covered by a permit, failing OSSFs, agricultural practices, pet, and wildlife waste and other natural sources.

Failing 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. 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 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 (local governmental agency) agents; therefore, it is difficult to estimate the exact number of OSSFs that are in use in the study area. Figure 6 displays the locations of OSSFs as well as unsewered areas that did not fall under the wastewater service areas. Table 9 lists the OSSF totals for each segment based on comprehensive studies conducted by the Houston-Galveston Area Council (H-GAC).

Fecal coliform loads were estimated using the following equation (USEPA 2001), modified to use 60 gallons per person per day (TCEQ standard) instead of 70 gallons per person per day (original EPA equation):

$$\#\frac{counts}{day} = (\#Failing\_systems) \times \left(\frac{10^6\, counts}{100ml}\right) \times \left(\frac{60gal}{person/\,day}\right) \times \left(\#\frac{person}{household}\right) \times \left(3785.2\frac{ml}{gal}\right)$$

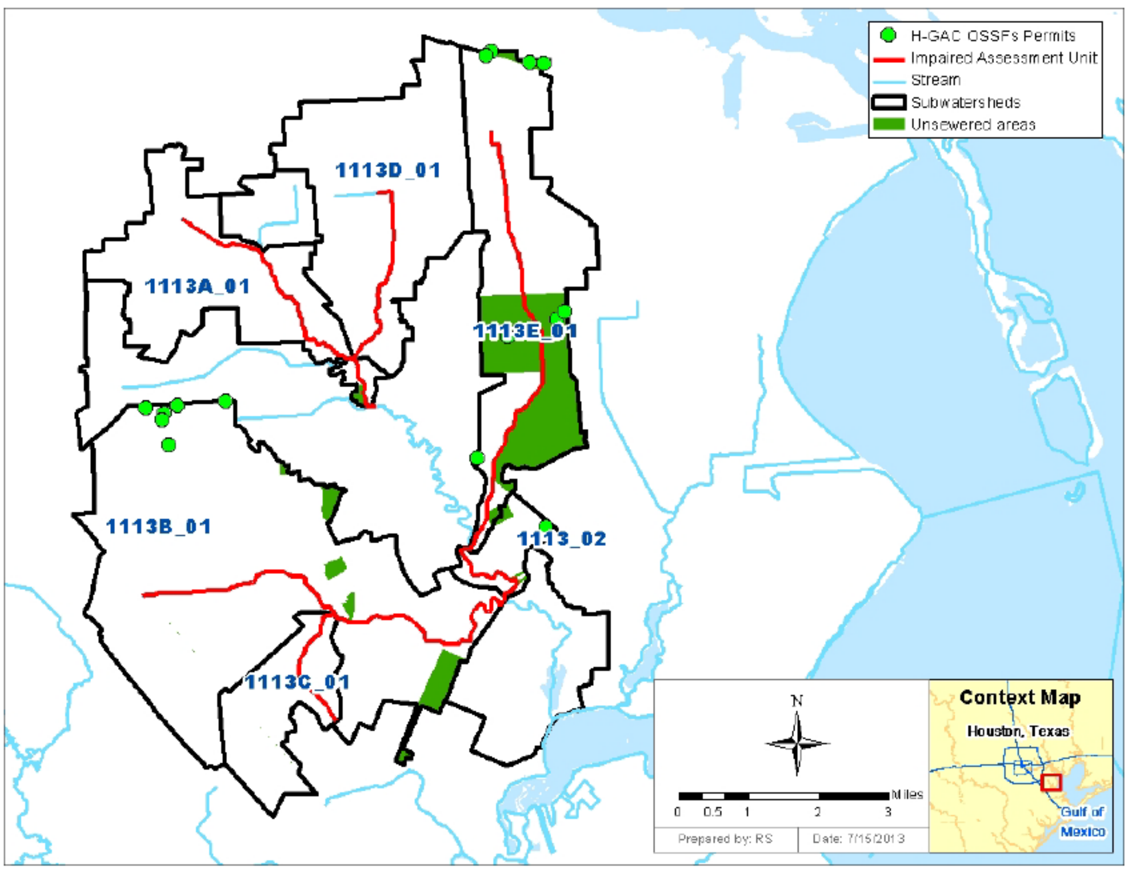

Figure 6. Areas with OSSFs*

*A portion of the large area shaded as unsewered in the Big Island Slough (1113E_01) subwatershed is within the Bayport Industrial Complex. Gulf Coast Waste Disposal Authority (01054-000; TX0005380) treats the wastewater (including some sanitary waste) for most of the industrial facilities within this complex at a facility located outside of the Armand Bayou watershed, and discharges to the Bayport Ship Channel (Segment 2438), which is also outside of the Armand Bayou watershed.

The average of number of people per household was calculated to be 2.77 for the Study Area (U.S. Census Bureau 2010) based on an average household density for Houston, La Porte, Deer Park, and Pasadena. Approximately 60 gallons of wastewater were estimated to be produced on average per person per day. 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 each subwatershed was calculated and is summarized in Table 9. Based on this data, it was determined that the estimated fecal coliform loading from OSSFs in the study area were found to be negligible.

Table 9. Number of OSSF Permits Issued by Authorized Agent

Segment	Stream Name	# of OSSFs*	# of Failing OSSFs	Estimated Fecal Coliform Loads from OSSFs (Billion counts/day)
1113_02	Armand Bayou Tidal	1	0.12	0.75
1113A_01	Armand Bayou Above Tidal	0	0	0
1113B_01	Horsepen Bayou	9	1.08	6.79
1113C_01	Unnamed Tributary to Horsepen Bayou	0	0	0
1113D_01	Willow Springs Bayou	0	0	0
1113E_01	Big Island Slough	10	1.2	7.55

*Data from H-GAC

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 10 provides estimated numbers of selected livestock by watershed based on the 2007 Census of Agriculture conducted by U.S. Department of Agriculture (USDA 2007). The county-level estimated livestock populations were distributed among subwatersheds based on GIS calculations of pastureland per subwatershed, based on the Texas 2011 Land Cover Data (NOAA 2011). Because the subwatersheds are generally much smaller than the counties, and livestock are not evenly distributed across counties or constant with time, these are rough estimates only. Cattle are the most abundant species of livestock in the study area, and often have direct access to the water bodies or their tributaries. The livestock numbers in Table 10 are provided to demonstrate that livestock are a potential source of bacteria in the watershed. These livestock numbers, however, are not used to develop an allocation of allowable bacteria loading to livestock.

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

Table 10. Livestock Estimates by Subwatershed

Type of Animal	1113_02	1113A_01	1113B_01	1113C_01	1113D_01	1113E_01
Cattle and Calves	0	41	291	0	130	69
Horses and Ponies	0	8	53	0	24	13
Goats	0	3	21	0	10	5
Hogs and Pigs	0	1	6	0	2	1
Sheep and Lambs	0	1	6	0	3	1
Bison	0	0	0	0	0	0
Captive Deer	0	1	7	0	3	2
Donkey	0	1	4	0	2	1
Rabbits	0	1	4	0	2	1
Llamas	0	0	2	0	1	0
Pullets	0	1	4	0	2	1
Broilers	0	1	8	0	4	2
Layers	0	6	43	0	19	10
Turkeys	0	0	2	0	1	1
Ducks	0	0	4	0	2	1
Geese	0	0	2	0	1	0
Other Poultry	0	1	7	0	3	2

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 by watershed. 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 it may be washed into nearby streams by rainfall runoff. Typical of coastal watersheds, there is a significant population of avian species that frequent the watershed and the riparian corridors. However, currently there are insufficient data available to estimate populations and spatial distribution of wildlife and avian species by 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 2000), dog and cat populations can be estimated for each subwatershed. Table 11 summarizes the estimated number of dogs and cats for the subwatersheds of the study area.

Table 11. Estimated Number of Pets in Each Subwatershed

Segment	Stream Name	Estimated Number of Households	Dogs	Cats
1113_02	Armand Bayou Tidal	207	120	137
1113A_01	Armand Bayou Above Tidal	5,277	3,061	3,483
1113B_01	Horsepen Bayou	11,076	6,424	7,310
1113C_01	Unnamed Tributary to Horsepen Bayou	8,041	4,664	5,307
1113D_01	Willow Springs Bayou	8,163	4,735	5,388
1113E_01	Big Island Slough	5,177	3,003	3,417

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. The relationship may be established through a variety of techniques.

Generally, if high bacteria concentrations are measured in a water body at low to median flow in the absence of runoff events, the main contributing sources are likely point sources. 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.

Two methods of analysis were used for analyzing indicator bacteria loads and instream water quality. LDC analyses were used for the four freshwater segments. A mass balance analysis was used for the two tidal segments.

Load Duration Curve Analysis

LDCs are graphs of the frequency distribution of loads of pollutants in a stream. In the case of the TMDLs for the freshwater segments, the loads shown are of *E. coli* bacteria in MPN/day. LDCs are derived from Flow Duration Curves (FDC). A detailed description of the LDC method is found in the technical support document (UH and CDM Smith 2014). The LDCs shown in the following figures represent the maximum acceptable load in the stream that will result in achievement of the TMDL water quality target. (The figures include curves for both the geometric mean and single sample criteria. While the geometric mean is used in assessing the use, the curve based on the single sample criterion is useful for making comparisons to the individual data points.) The basic steps to generate LDCs involve:

- preparing FDCs for gauged and un-gauged sampling locations;
- estimating existing bacteria loading in the receiving water using ambient water quality data;
- using LDCs to identify the critical condition that will define loading reductions necessary to attain the contact recreation standard; and
- interpreting LDCs to derive TMDL elements—WLA, load allocation (LA), margin of safety (MOS), and overall percent reduction goals.

The result of these steps is expressed in the following formula, which is displayed on the LDC as the TMDL curve.

TMDL (counts/day) = criterion * flow in cubic feet per second (cfs) * unit conversion factor

Where:

criterion = 399 counts/100 mL (*E. coli*; single sample) or
criterion = 126 counts/100 mL (*E. coli*; geometric mean)

unit conversion factor = 24,465,755 100 mL/ft^3 * seconds/day

The flow exceedance frequency (x-value of each point) is obtained by determining the percent of historical observations that equal or exceed the measured or estimated flow. The lack of current, long-term flow data from within the study area necessitated that flows be estimated for Armand Bayou Above Tidal, Unnamed Tributary to Horsepen Bayou, Willow Springs Bayou, and Big Island Slough. Therefore, United States Geological Survey (USGS) gauge stations 08075400 (Sims Bayou at Hiram Clarke Street, Houston, Texas) and 08075730 (Vince Bayou at Pasadena, TX), which are located outside the watershed, were chosen to conduct flow projections to establish estimated flows for each of these freshwater segments.

The period of record for flow data used from these stations was 2002 through 2012. Historical measurements of bacteria concentration are paired with flow data and are plotted on the LDC. The indicator bacteria load (or the y-value of each point) is calculated by multiplying the indicator bacteria concentration (counts or counts/100mL) by the instantaneous flow in cfs at the same site and time, with appropriate volumetric and time unit conversions. Indicator bacteria loads that exceed the geometric mean criterion fall above the line that represents the criterion on the graph.

LDCs display the maximum allowable load over the complete range of flow conditions by a line using the calculation of flow multiplied by the single-sample criterion. Using LDCs, a TMDL can be expressed as a continuous function of flow, equal to the line, or as a discrete value derived from a specific flow condition. LDCs do not simulate the fate of contaminants; rather, they calculate allowable loading for a given flow. Since LDCs do not link the loading to specific sources, processes affecting the fate of bacteria are not included.

Load Duration Curve Results

Armand Bayou Above Tidal

There are no permitted WWTF discharges in Armand Bayou Above Tidal so no additions to the naturalized projected flow were necessary. The LDC for Armand Bayou Above Tidal segment 1113A_01 (Figure 7) is based on *E. coli* bacteria measurements at sampling location 11404 (Armand Bayou at Genoa-Red Bluff Rd). The LDC indicates that *E. coli* levels exceed the single sample quality criterion during high flow conditions. This analysis also indicates that the *E. coli* observations in the highest flow range may be wet weather influenced.

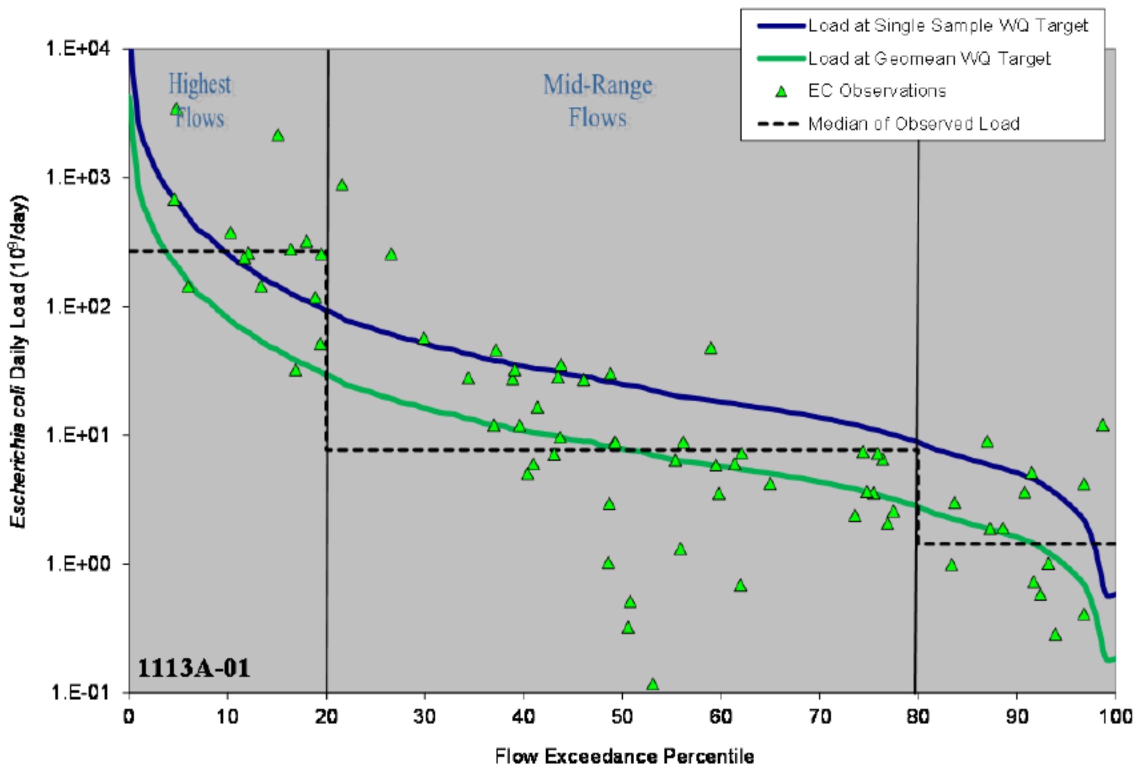

Figure 7. Load Duration Curve for *E. coli* in Armand Bayou Above Tidal (1113A_01)

Unnamed Tributary to Horsepen Bayou

There are no permitted WWTF discharges in Unnamed Tributary to Horsepen Bayou so no additions to the naturalized projected flow were necessary. The LDC for Unnamed Tributary to Horsepen Bayou segment 1113C_01 (Figure 8) is based on *E. coli* bacteria measurements at sampling location 17485 (Unnamed Tributary of Horsepen Bayou Tidal at Penn Hills). The LDC indicates that *E. coli* levels exceed the single sample criterion under all three flow conditions.

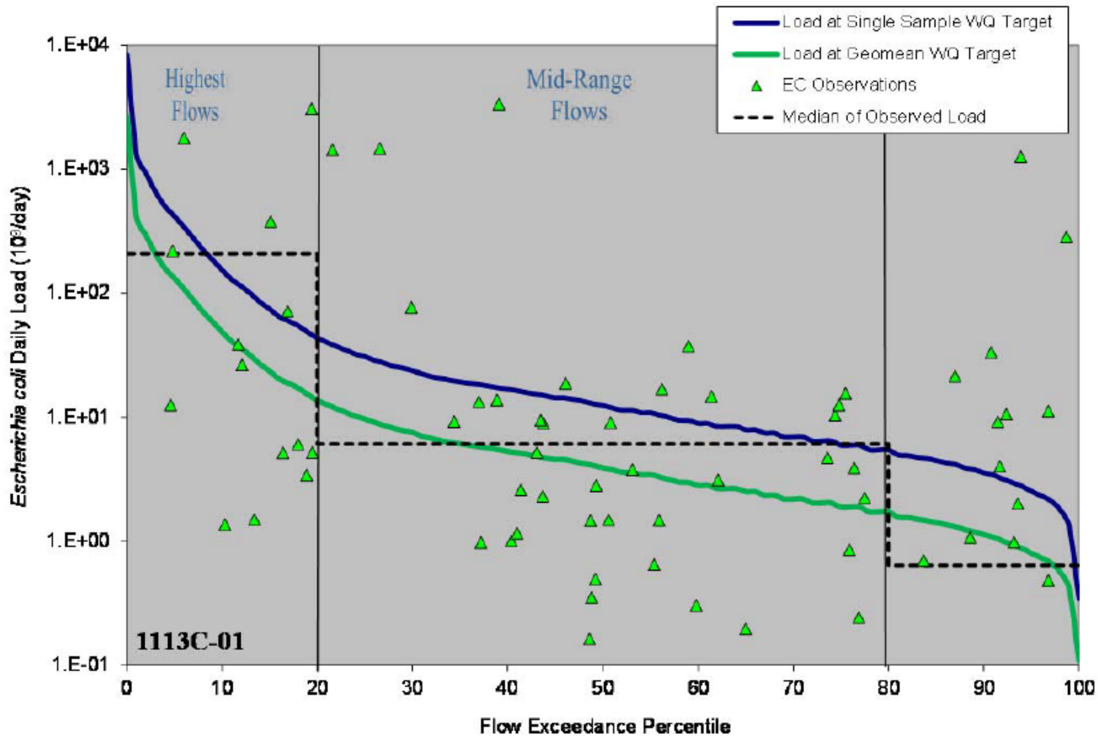

Figure 8. Load Duration Curve for *E. coli* in Unnamed Tributary to Horsepen Bayou (1113C_01)

Willow Springs Bayou

There are no permitted WWTF discharges in Willow Springs Bayou so no additions to the naturalized projected flow were necessary. The LDC for Willow Springs Bayou segment 1113D_01 (Figure 9) is based on *E. coli* bacteria measurements at sampling location 17487 (Willow Spring at Bandridge Rd in southeast Houston). The LDC indicates that *E. coli* levels exceed the single sample criterion under all three flow conditions.

Big Island Slough

There are no permitted WWTF discharges in Big Island Slough so no additions to the naturalized projected flow were necessary. The LDC for Big Island Slough segment 1113E_01 (Figure 10) is based on *E. coli* bacteria measurements at sampling location 17486 (Big Island Slough at Hillridge Rd). The LDC indicates that *E. coli* levels exceed the single sample criterion under all three flow conditions.

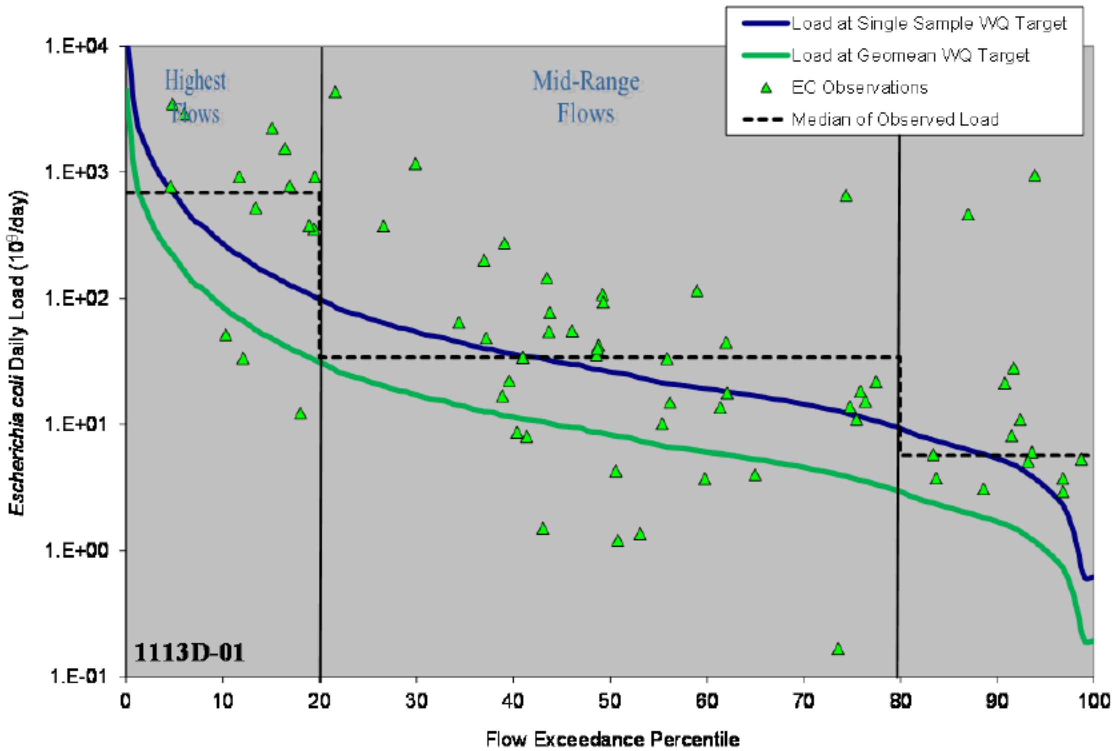

Figure 9. Load Duration Curve for *E. coli* in Willow Springs Bayou (1113D_01)

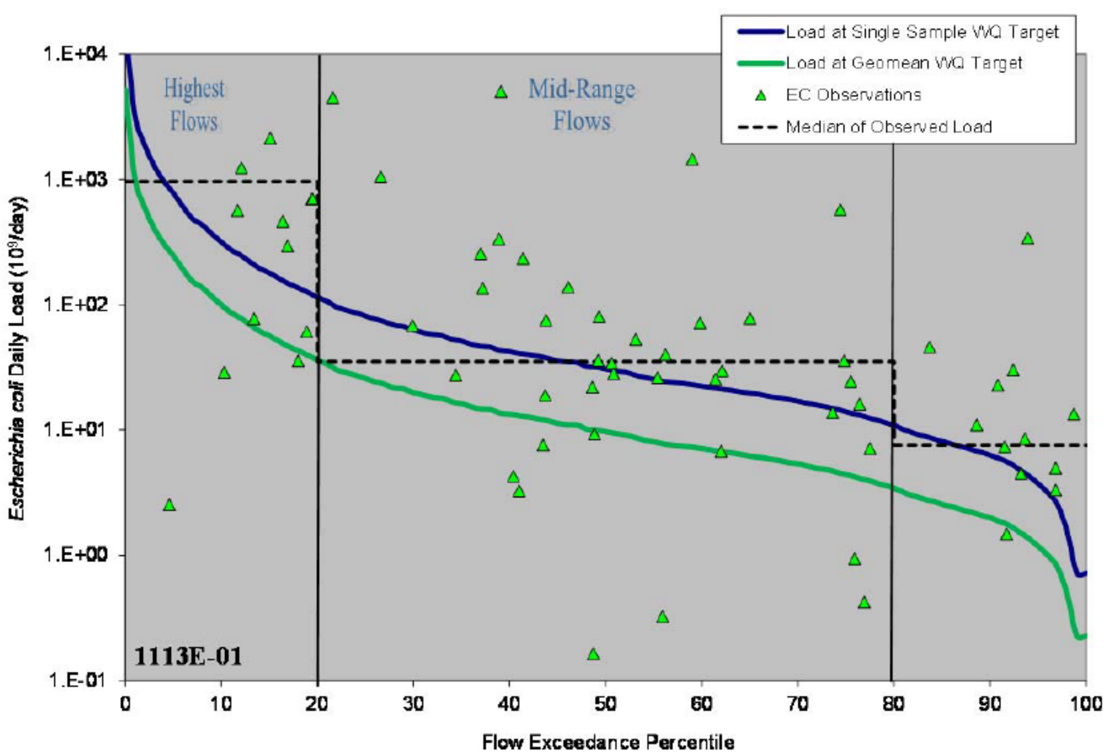

Figure 10. Load Duration Curve for *E. coli* in Big Island Slough (1113E_01)

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 segments of the Armand Bayou watershed. 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 a series of reaches within Armand Bayou Tidal and Horsepen Bayou.

The model incorporates the three mechanisms through which Enterococci loadings enter the impaired systems:

1) rain-induced freshwater inputs (i.e. runoff),
2) direct point source discharges, and
3) 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 out from the tidal system and via biodegradation and die-off. It is also assumed that biodegradation and die-off exceed potential bacteria contributions from re-growth. A generalized schematic of the source and sink terms for the tidally influenced impaired water bodies is presented in Figure 11.

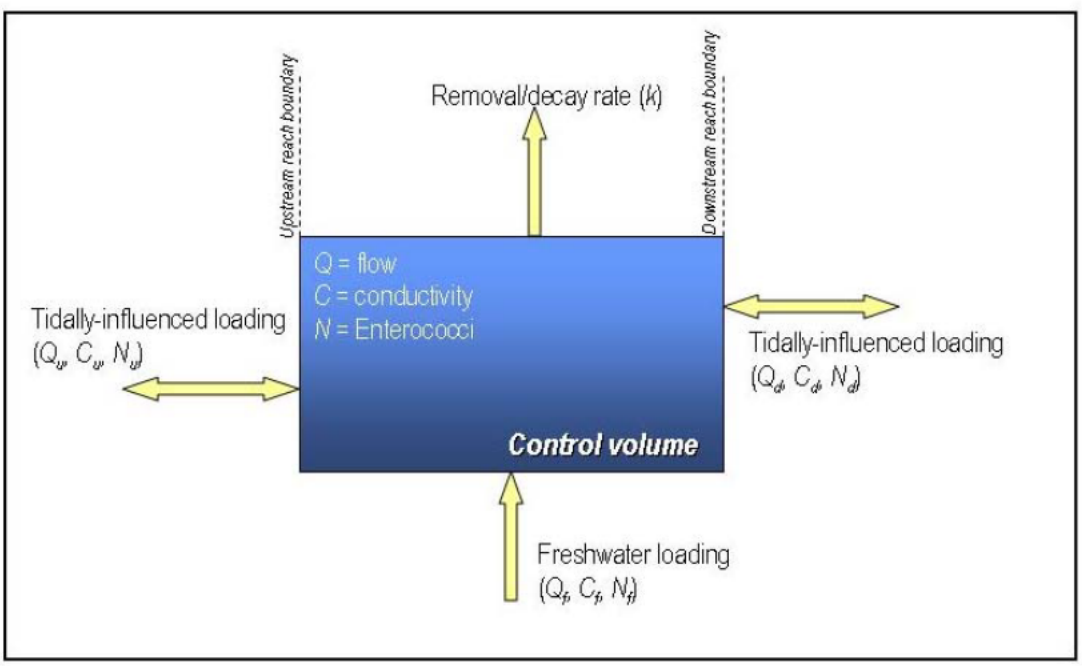

Figure 11. Conceptual Model for Sources and Sinks of Enterococci

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

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

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 average Enterococci concentrations measured at each of the water quality monitoring stations along Armand Bayou Tidal and Horsepen Bayou were used to define the initial conditions in each model reach. The geometric mean of Enterococci concentrations measured in Armand Bayou Tidal station 15455 (18 counts/100 mL; downstream of the impaired AUs) was used to set the downstream boundary concentration of Enterococci. Enterococci levels in runoff, tributaries, and WWTFs were estimated using the tidal prism method.

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 0.5 to 1.2 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.

Figure 12 presents a comparison of measured and modeled Enterococci concentrations along the main stem of Armand and Horsepen Bayous. 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 2010 through 2012 for a given station were used to compare to modeled values. Fecal coliform and *E. coli* data were converted to Enterococci concentrations using calculated Enterococci/fecal coliform and Enterococci /*E. coli* ratios (0.27 and 0.34, respectively). A detailed description of the tidal prism method is included in the technical support document (UH and CDM Smith 2014).

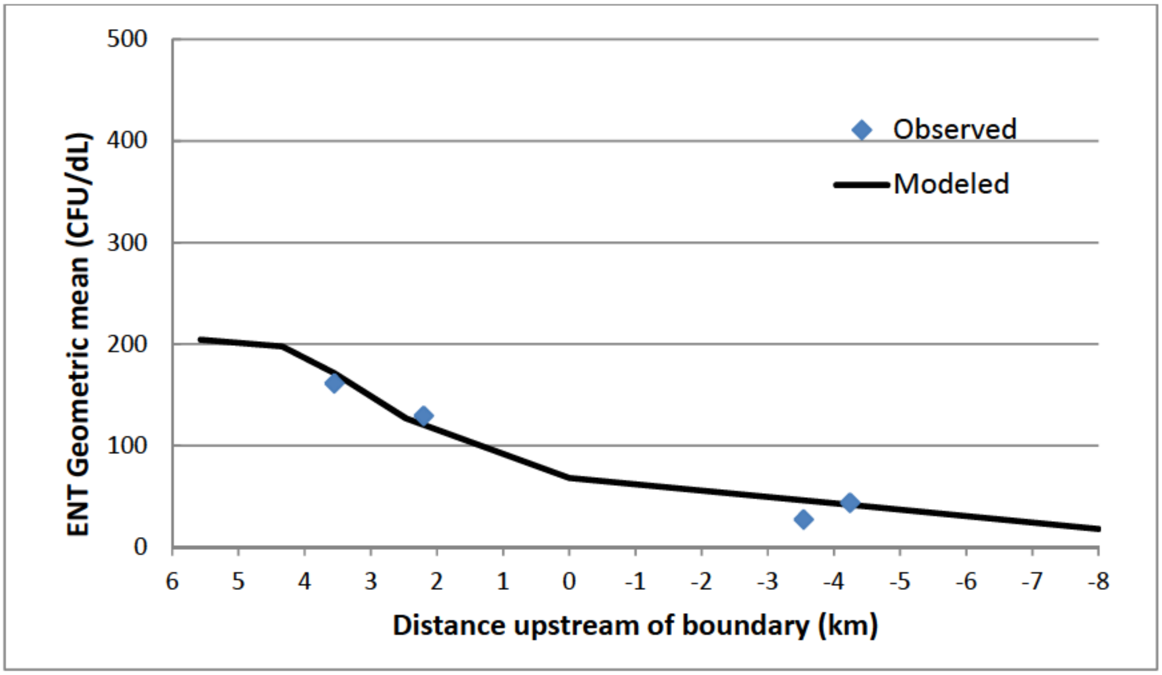

Figure 12. Longitudinal Profile of Enterococci Concentrations

Margin of Safety

The MOS is used to 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:

1) Implicitly incorporating the MOS using conservative model assumptions to develop allocations; or
2) 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.

The TMDLs for freshwater segments incorporate an explicit MOS by setting a more stringent target for indicator bacteria loads that is 5 percent lower than the geometric mean criterion. The explicit MOS was used because of the limited amount of data for some of the sampling locations. For contact recreation, this equates to a geometric mean of 120 counts/100 mL for *E. coli*. The net effect of the TMDL with a MOS is that the assimilative capacity or allowable pollutant loading of each water body is slightly reduced. The TMDLs for the freshwater streams in this report incorporate an explicit MOS by using an LDC developed using 95 percent of the geometric mean 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.

Pollutant Load Allocation

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

$$TMDL = \Sigma WLA + \Sigma LA + \Sigma FG + MOS$$

Where:

WLA = wasteload allocation, the amount of pollutant allowed by regulated dischargers

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

FG = loadings associated with future growth from potential permitted facilities

MOS = margin of safety load

As stated in 40 CFR 130.2(1), 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 counts per day and represent the maximum one day load the stream can assimilate while still attaining the standards for surface water quality.

For the Armand Bayou watershed, two different methods were used to quantify allowable pollutant loads and specific TMDL allocations for point and nonpoint sources:

2) the load duration curve method for freshwater streams, and
3) a mass balance method using a tidal prism for tidal streams.

To establish the watershed targets, TMDL calculations and associated allocations are established for the most-downstream sampling locations in each subwatershed. This establishes a distinct TMDL for each 303(d) listed water body. The most-downstream sampling locations for each freshwater body are listed in Table 12.

To calculate the bacteria load at the criteria for non-tidal segments, the flow rate at each flow exceedance percentile is multiplied by a unit conversion factor (24,465,755 100 mL/ft^3 * seconds/day) and the criterion specific to each indicator bacteria. This calculation produces the maximum bacteria load in the stream without exceeding the instantaneous criterion over the range of flow conditions. In the case of fecal coliform or *E. coli* for freshwater streams, the allowable geometric mean concentrations in the Standards are equivalent to the TMDL. Fecal coliform and *E. coli* are plotted in relation to flow exceedance percentiles as an LDC. The x-axis indicates the flow exceedance percentile, while the y-axis is expressed in terms of a bacteria load.

To estimate existing loading, bacteria concentrations from 2002 to 2012 are paired with the flows measured or estimated in that segment on the same date. Pollutant loads are then calculated by multiplying the measured bacteria concentration by the flow rate and the unit conversion factor. The associated flow exceedance percentile is then matched with the measured flow. The observed bacteria loads are then added to the LDC plot as points.

These points represent individual ambient water quality samples of bacteria. Points above the LDC indicate the bacteria instantaneous criterion was exceeded at the time of sampling. Conversely, points under the LDC indicate the sample were below the criterion.

Table 12. Sampling Locations Used to Establish TMDL

Segment	Sampling Location	Description
Armand Bayou Above Tidal	11404	Armand Bayou at Genoa-Red Bluff Rd
Unnamed Tributary to Horsepen Bayou	17485	Unnamed Tributary of Horsepen Bayou Tidal at Penn Hills
Willow Springs Bayou	17487	Willow Spring at Bandridge Rd in southeast Houston
Big Island Slough	17486	Big Island Slough at Hillridge Rd

The LDC approach recognizes that the assimilative capacity of a water body depends on the flow, and that maximum allowable loading varies with flow condition. The existing loading required to meet the TMDL water quality target can also be calculated under different flow conditions. For the tidal segments, existing loading is calculated as the average daily input load (permitted and non-permitted runoff and WWTFs) for the simulation period (1/01/2010 to 12/31/2012).

Selecting the most-downstream sampling location for each 303(d) listed water body as the location for establishing a TMDL is the most logical approach since TMDLs are most effective when established at the watershed scale.

Wasteload Allocation

The WLA is the sum of loads from regulated sources.

WWTFs

TPDES-permitted facilities listed in Table 6 (with a domestic sewage component to their discharge) are allocated a daily wasteload based on their permitted discharge flow rate. The coordination committee for this project decided to join the implementation efforts of the Bacteria Implementation Group (BIG), which has an approved Implementation Plan (I-Plan) in a large area adjacent to the Armand Bayou watershed. The BIG area calls for reduced bacteria limits for WWTFs. For discharges to tidally influenced water bodies (such as the two facilities currently discharging in this watershed), the limit for WWTFs is 23 counts/100 mL for the geometric mean of Enterococci. The stakeholders on the coordination committee formed for this project have agreed to this reduced limit. See the Public Participation section for more information about the decision to join the BIG. The facilities are required to meet instream criteria at their points of discharge. Table 13 summarizes the WLA for the TPDES-permitted facilities within the study area at the time of this analysis. The allocated loads are calculated for Enterococci. All TPDES-permitted WWTF dischargers added in the Armand Bayou watersheds will be assigned from the future growth allocation. Any additional flow for these facilities is accounted for in the development of the future growth allocation.

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

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

Where:

criterion = 23 counts/100 mL for the geometric mean of Enterococci flow (MGD) = permitted flow

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

When multiple TPDES facilities occur within an AU subwatershed, 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 AU. When there are no TPDES WWTFs discharging into an AU subwatershed, then WLA_{WWTF} is not applicable. The assimilative capacity of streams increases as the amount of flow increases so future WWTF discharges will be required to conform to the WLA_{WWTF} equation. Increases in flow allow for increased loadings. Compliance with the WLA_{WWTF} will be achieved by adhering to the indicator bacteria discharge limits and disinfection requirements of TPDES permits, as well as changes to domestic TPDES WWTF permits to include water quality-based effluent limitations, representative monitoring requirements for bacteria, or other requirements established in the implementation plan.

Table 13. Wasteload Allocations for TPDES-Permitted WWTF

TPDES Number	NPDES NUMBER	Facility Name	Final Permitted Flow (MGD)	Enterococci (Billion MPN/Day)
10495-152	TX0069736	Metro Central WWTP	5	4.35
10539-001	TX0022543	Robert Savely Water Reclamation Facility	10	8.71
03523-000	TXL005000	City of Houston Sludge Plant	n/a [a]	n/a
03029-000	TX0103900	Equistar Chemicals Bayport Complex	n/a [b]	n/a

[a] Permit does not contain a discharge provision; facility receives no individual WLA

[b] Flow is permitted as intermittent and variable with a requirement to measure and report; facility receives no individual WLA

Stormwater

Stormwater discharges from MS4, industrial, and construction areas are considered regulated point sources. Therefore, the WLA calculations must also 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 these TMDLs due to the limited amount of data available, the complexities associated with simulating rainfall runoff, and the variability of stormwater loading.

The percentage of each subwatershed that is under the jurisdiction of stormwater permits (i.e., defined as the area designated as urbanized area in the 2010 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. 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}.

For the freshwater streams, the flow-dependent calculations for the stormwater portion of the WLA were derived using LDC and the MS4 percentages found in Table 8. The flow-dependent calculations for the portion of the WLA assigned to permitted stormwater are discussed in greater detail in the technical support document (UH and CDM Smith 2014). For the tidal segments, any runoff occurring within the boundaries of an MS4 permit was considered a point source contribution and was included in the WLA calculation. The allowable load from all stormwater runoff was calculated as the maximum allowable load (TMDL) minus the MOS minus the load allocated to WWTFs (WLA_{WWTF}). The resulting load was split into WLA_{SW} component (regulated) and LA component (unregulated) using the percent of the drainage areas within the tidal prism model covered by MS4 permits provided in Table 8.

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). 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 best management practices (BMPs) as specified in 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.

Implementation of WLAs

The TMDLs 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 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. WWTFs discharging to the TMDL Segments will be assigned an effluent limit based on the TMDL. Monitoring requirements are based on permitted flow rates and are listed in Section 319.9.

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 Water Quality Management Plan. Regardless, all 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 22, 2002, memorandum from EPA relating to establishing WLAs for stormwater sources states:

> "The Interim Permitting Approach Policy recognizes the need for an iterative approach to control pollutants in stormwater discharges. Specifically, the policy anticipates that a suite of BMPs will be used in the initial rounds of permits and that these BMPs will be tailored in subsequent rounds."

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 Water Quality Management Plan. Any future changes to effluent limitations will be addressed through the permitting process and by updating the WQMP.

Load Allocation

The LA is the sum of loads from unregulated sources. LAs for freshwater segments can be calculated under different flow conditions as the water quality target load (TMDL) minus the WLA. The LA is represented by the area under the LDC but above the WLA. The LA at any particular flow exceedance is calculated as shown in the following equation.

$$LA = TMDL - MOS - \Sigma WLA_{WWTF} - \Sigma WLA_{Stormwater}$$

Where:

LA = allowable load from non-permitted sources

TMDL= total allowable load

ΣWLA_{WWTF} = sum of all WWTF loads

$\Sigma WLA_{Stormwater}$ = sum of all permitted stormwater loads

MOS = margin of safety

For tidally influenced segments, the load allocation is also calculated using the same equation.

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. The future growth for these TMDLs is calculated as follows.

To account for new additional flows from WWTF that may occur in some 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 TWDB. A detailed description of the methodology used to predict waste water flow capacity based on population growth is found in the technical support document (UH and CDM Smith 2014). For the freshwater segments, only Big Island Slough (1113E_01) has an area that is not completely serviced by WWTF(s) outside of the AU subwatershed. An estimated future flow increase of 0.5 MGD was applied to determine the future growth load in Big Island Slough (1113E_01). For the tidally influenced segments, only Horsepen Bayou (1113B_01) contains WWTFs, while the area in Armand Bayou Tidal (1113_02) is completely serviced by a WWTF outside the AU subwatershed boundary. Loads were calculated using the projected flows and a 23 counts/100 mL concentration were input in the tidal prism model along with all the other existing loads. The loads were then reduced by different percentages until the contact recreation criterion was met in all the reaches. The reduced loads were then added to calculate the assimilative capacity or $TMDL_{Future}$. In both cases, the WLA_{WWTF} for future population growth is the difference between the $TMDL_{Future}$ and the TMDL calculated using current conditions.

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 subwatershed can be accommodated by shifting allotments between the WLA and the LA. This can be done without the need to reserve future-capacity WLAs 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 covered by an MS4 permit, development and/or redevelopment of land in urbanized areas must implement the control measures/programs outlined in an approved Stormwater Pollution Prevention Plan (SWPPP).

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 SWPPP. Currently, it is envisioned that an iterative, adaptive management BMP approach be used to address stormwater discharges. This approach encourages the implementation of controls (i.e. structural or nonstructural), implementation of mechanisms to evaluate the performance of the controls, and finally, allowance to make adjustments (i.e., more stringent controls or specific BMPs) as necessary to protect water quality.

Compliance with these TMDLs is based on keeping the 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 bacteria to exceed the limits. The assimilative capacity of streams increases as the amount of flow increases. Consequently, increases in flow allow for increased loadings. The LDC and tables in this TMDL will guide determination of the assimilative capacity of the stream under changing conditions, including future growth.

TMDL Calculations

TMDL allocations for the subwatersheds were calculated for the most downstream sampling locations listed in Table 12. Table 14 summarizes the estimated maximum allowable loads of *E. coli* for the segment subwatersheds currently listed as freshwater. For the tidal stream segment subwatersheds, Table 15 summarizes the estimated maximum allowable loads of Enterococci that will ensure the contact recreation standard is met.

The final TMDL allocations needed to comply with the requirements of 40 CFR 130.7 are provided in Tables 16 and 17. The WLA_{WWTF} component of the final TMDL allocations includes potential future growth loadings.

In the event that the criterion changes due to future revisions in the state's surface water quality standards, Appendix A provides guidance for recalculating the allocations in Tables 16 and 17. The six figures (Figures 13-18) of Appendix A were developed to demonstrate how assimilative capacity, TMDL calculations, and pollutant load allocations change in relation to a number of proposed water quality criteria for *E. coli* or Enterococci. The equations provided, along with the figures allow calculation of new TMDLs and pollutant load allocations based on any potential new water quality criterion.

Table 14. *E. coli* TMDL Calculations for Freshwater Segments

All loads expressed as billion MPN/day

AU	Stream Name	Indicator Bacteria	TMDL[a]	WLA_{WWTF}[b]	$WLA_{Stormwater}$[c]	LA[d]	MOS[e]	Future Growth[f]
1113A_01	Armand Bayou Above Tidal	*E coli*	85.3	0	81.0	0	4.26	0
1113C_01	Unnamed Tributary to Horsepen Bayou	*E coli*	51.1	0	48.6	0	2.56	0
1113D_01	Willow Springs Bayou	*E coli*	90.1	0	85.6	0	4.50	0
1113E_01	Big Island Slough	*E coli*	106.2	0	93.2	6.57	5.25	1.19

[a] Maximum allowable load for the high flow range
[b] Sum of loads from the WWTF discharging upstream of the TMDL station
[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*126/2*conversion factor

Table 15. Enterococci TMDL Calculations for Tidal Segments

All loads expressed as billion MPN/day

AU	Stream Name	Indicator Bacteria	TMDL[a]	WLA_{WWTF}[b]	$WLA_{Stormwater}$[c]	LA[d]	MOS[e]	Future Growth[f]
1113_02	Armand Bayou Tidal	Enterococci	1,260	0	1,197	0	63.0	0
1113B_01	Horsepen Bayou	Enterococci	783	13.1	727	0	38.9	4.23

[a] Maximum allowable load for the high flow range
[b] Sum of loads from the WWTF discharging upstream of the TMDL station
[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

Table 16. Final *E. coli* TMDL Calculations for Freshwater Segments

All loads expressed as billion MPN/day

AU	Stream Name	Indicator Bacteria	TMDL	WLA_{WWTF} [a]	$WLA_{Stormwater}$	LA	MOS
1113A_01	Armand Bayou Above Tidal	*E coli*	85.3	0	81.0	0	4.26
1113C_01	Unnamed Tributary to Horsepen Bayou	*E coli*	51.1	0	48.6	0	2.56
1113D_01	Willow Springs Bayou	*E coli*	90.1	0	85.6	0	4.50
1113E_01	Big Island Slough	*E coli*	106.2	1.19	93.2	6.57	5.25

[a] WLA_{WWTF} includes the future potential allocation to wastewater treatment facilities

Table 17. Final Enterococci TMDL Calculations for Tidal Segments

All loads expressed as billion MPN/day

AU	Stream Name	Indicator Bacteria	TMDL	WLA_{WWTF} [a]	$WLA_{Stormwater}$	LA	MOS
1113_02	Armand Bayou Tidal	Enterococci	1,260	0	1,197	0	63.0
1113B_01	Horsepen Bayou	Enterococci	783	17.3	727	0	38.9

[a] WLA_{WWTF} includes the future potential allocation to wastewater treatment facilities

Seasonal Variation

Federal regulations (40 CFR 30.7(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 five years of water quality data and by using the longest period of USGS flow records when estimating flows to develop flow exceedance percentiles.

For *E. coli,* two of the four stations with six or more samples exhibited higher geometric mean concentrations for the cooler months (defined as November through March) than the warmer months (defined as May through September). No station showed statistically significant differences at the 95% confidence interval between the warmer and cooler months. For Enterococci, both stations have slightly higher geometric mean concentrations during the cooler months, but neither difference was 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 Armand Bayou Bacteria TMDL and the implementation phase, a coordination committee was formed. The group has balanced representation within the watershed and commitment was formalized. The group has ground rules and H-GAC maintains a membership roster and has a web page dedicated to the Armand Bayou Bacteria TMDL project: <www.h-gac.com/community/water/tmdl/armand-bayou.aspx>. The TCEQ also maintains a project page where technical reports and project summary information can be found at <www.tceq.texas.gov/waterquality/tmdl/89-armandbacteria.html>.

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. TCEQ solicits stakeholder comment at each project milestone and assists stakeholders with communications. H-GAC has assisted TCEQ with the public participation. As contractors to TCEQ, the University of Houston and CDM Smith provide technical support and presentations at stakeholder meetings.

The first public meeting for the Armand Bayou Bacteria TMDL was held on January 24, 2013. The meeting introduced the TMDL process, identified the impaired segments and the reason for the impairment, a review of historical data, described potential sources of indicator bacteria within the watershed, and formed the coordination committee.

Coordination committee meetings were held on a bimonthly basis for most of 2013. The technical team presented the status of the project on August 13, 2013, by reviewing historical data, the characteristics of the watershed, future population projections, potential sources of indicator bacteria within the watershed, and explained TMDL determination methods. The committee discussed work group efforts and voted to join the BIG. The TCEQ had formally approved the BIG's I-Plan on January 30, 2013.

At the September 18, 2013, meeting, the coordination committee decided to continue to meet as a separate entity from the BIG, although less frequently. On

February 5, 2014, the coordination committee submitted letters to TCEQ expressing their formal request to join the BIG. This information was presented at the biannual BIG meeting on May 27, 2014, and the BIG members voted unanimously to accept the addition of the Armand Bayou bacteria TMDL watershed to the area covered by the BIG I-Plan. This acceptance is considered provisional until the adoption of the TMDL document. After that takes place, the BIG will revise its I-Plan, maps, and other materials to include the Armand Bayou watershed.

Implementation and Reasonable Assurance

The issuance of TPDES permits consistent with TMDLs provides reasonable assurance that wasteload allocations in this TMDL report will be achieved. Per federal requirements, each TMDL is included in an update to the Texas WQMP as a plan element.

The WQMP coordinates and directs the state's efforts to manage water quality and maintain or restore designated uses throughout Texas. The WQMP is continually updated with new, more specifically focused plan elements, as identified in federal regulations (40 CFR Sec. 130.6(c)). Commission adoption of a TMDL is the state's certification of the associated WQMP update.

Because the TMDL does not reflect or direct specific implementation by any single pollutant discharger, the TCEQ certifies additional elements to the WQMP after the I-Plan is approved by the commission. (In this case, an I-Plan has already been approved, but will be revised to reflect the addition of the Armand Bayou watershed.) Based on the TMDL and I-Plan, the TCEQ will propose and certify WQMP updates to establish required water-quality-based effluent limitations necessary for specific TPDES wastewater discharge permits.

For MS4 permits, the TCEQ will normally establish best management practices, which are a substitute for effluent limitations, as allowed by federal rules, where numeric effluent limitations are infeasible. When such practices are established in an MS4 permit, the TCEQ will not identify specific implementation requirements applicable to a specific TPDES stormwater permit through an effluent limitation update. Rather, the TCEQ might revise a stormwater permit, require a revised SWMP or SWPPP, or implement other specific revisions affecting stormwater dischargers in accordance with an adopted I-Plan.

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

I-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. I-Plans will be adapted as necessary to reflect needs identified in evaluations of progress.

Key Elements of an I-Plan

An I-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. I-Plans also identify the organizations responsible for carrying out management measures, and a plan for periodic evaluation of progress. As noted in the Public Participation section, the implementation of the TMDLs for bacteria in the Armand Bayou watershed will be conducted through the ongoing work of the I-Plan for the BIG area, approved by the TCEQ on January 30, 2013.

Strategies to optimize compliance and oversight are identified in an I-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 an impairment.

The TCEQ works with stakeholders and interested governmental agencies to develop and support I-Plans and track their progress. For this project, the I-Plan has already been developed and approved, and will be revised to include the Armand Bayou watershed. Because these TMDLs address agricultural sources of pollution, the TCEQ will worked in close partnership with the TSSWCB when developing the I-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 I-Plan is a cornerstone for the shared responsibility necessary to carry it out.

Ultimately, the I-Plan identifies the commitments and requirements to be implemented through specific permit actions and other means. For these reasons, the I-Plan that has been approved may not approximate the predicted loadings identified category-by-category in the TMDL and its underlying assessment. The I-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.

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Appendix A. Equations for Calculating TMDL Allocations for Changed Contact Recreation Standard

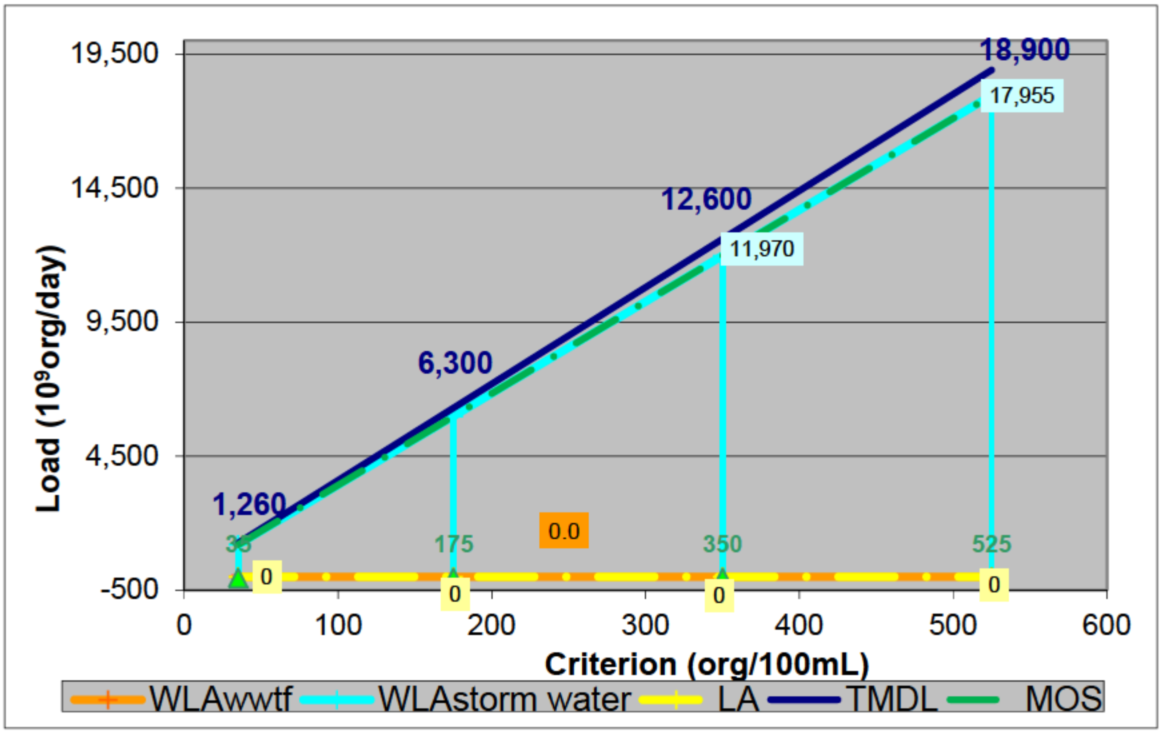

Figure 13. Allocation loads for Armand Bayou Tidal (1113_02) as a function of water quality criteria

Equations for Calculations New TMDL and Allocations

TMDL = 36.00 * Std + 0.0

MOS = 0.05 * TMDL

LA = 0.0 * Std + 0.0

$WLA_{Stormwater}$ = 34.20 * Std - 0.0

WLA_{WWTF} = 0.0

Where:

Std = Revised Contact Recreation criteria

LA = load allocation (unregulated source contributions)

$WLA_{Stormwater}$ = wasteload allocation (permitted stormwater)

WLA_{WWTF} = wasteload allocation (permitted WWTF)

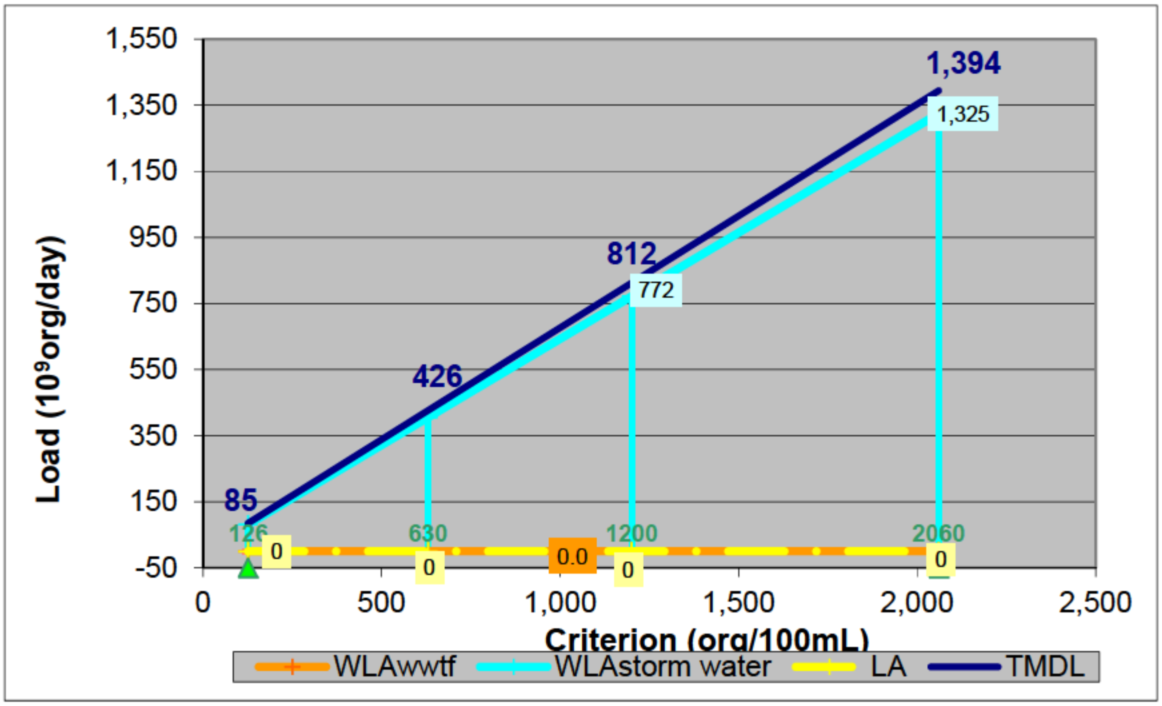

Figure 14. Allocation loads for Armand Bayou Above Tidal (1113A_01) as a function of water quality criteria

Equations for Calculations New TMDL and Allocations

TMDL = 0.6769 * Std + 0.0

MOS = 0.05 * TMDL

LA = 0.0 * Std + 0.0

$WLA_{Stormwater}$ = 0.6430 * Std - 0.0

WLA_{WWTF} = 0.0

Where:

Std = Revised Contact Recreation criteria

LA = load allocation (unregulated source contributions)

$WLA_{Stormwater}$ = wasteload allocation (permitted stormwater)

WLA_{WWTF} = wasteload allocation (permitted WWTF)

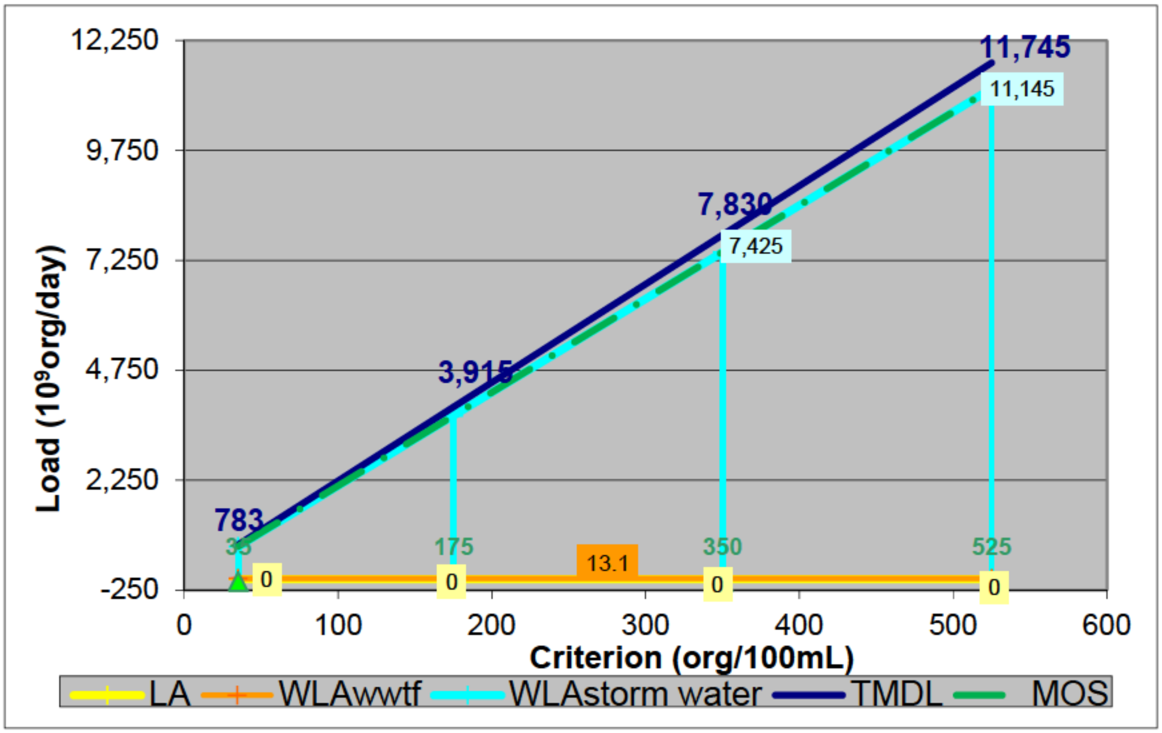

Figure 15. Allocation loads for Horsepen Bayou Tidal (1113B_01) as a function of water quality criteria

Equations for Calculations New TMDL and Allocations

$$TMDL = 22.3714 * Std + 0.0$$

$$MOS = 0.05 * TMDL$$

$$LA = 0.0 * Std + 0.0$$

$$WLA_{Stormwater} = 21.144 * Std - 13.1$$

$$WLA_{WWTF} = 13.1$$

Where:

Std = Revised Contact Recreation criteria

LA = load allocation (unregulated source contributions)

$WLA_{Stormwater}$ = wasteload allocation (permitted stormwater)

WLA_{WWTF} = wasteload allocation (permitted WWTF)

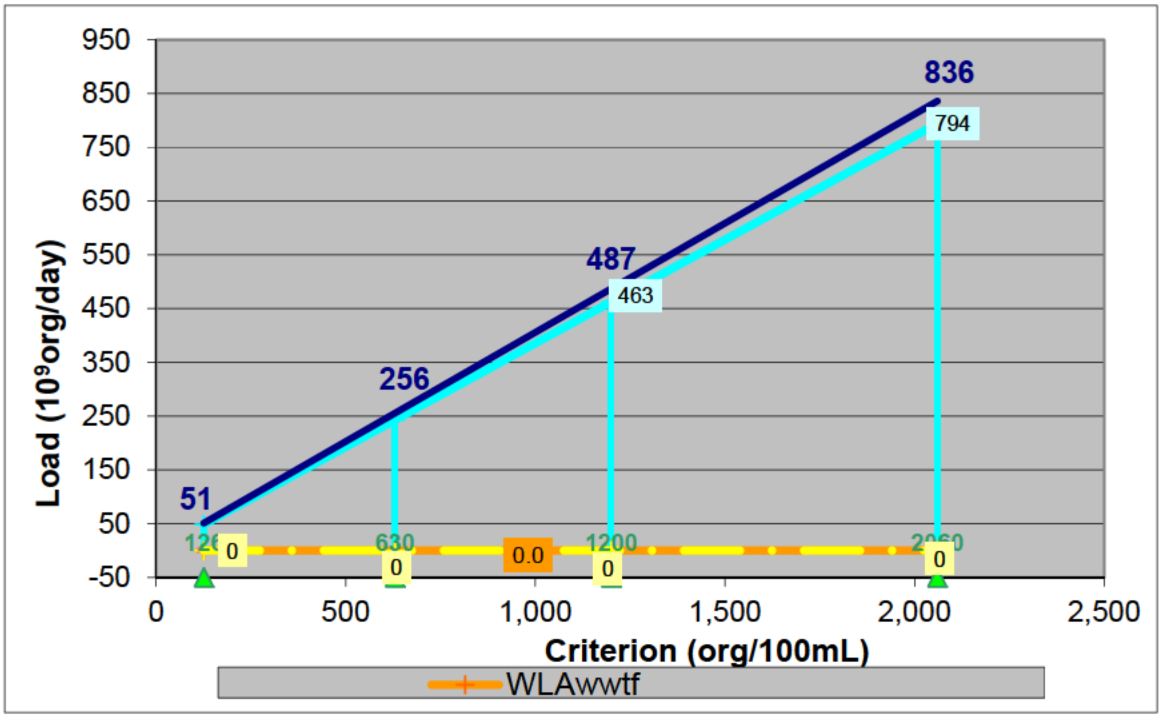

Figure 16. Allocation loads for Unnamed Tributary to Horsepen Bayou (1113C_01) as a function of water quality criteria

Equations for Calculations New TMDL and Allocations

$TMDL = 0.4058 * Std + 0.0$

$MOS = 0.05 * TMDL$

$LA = 0.0 * Std + 0.0$

$WLA_{Stormwater} = 0.3855 * Std - 0.0$

$WLA_{WWTF} = 0.0$

Where:

Std = Revised Contact Recreation criteria

LA = load allocation (unregulated source contributions)

$WLA_{Stormwater}$ = wasteload allocation (permitted stormwater)

WLA_{WWTF} = wasteload allocation (permitted WWTF)

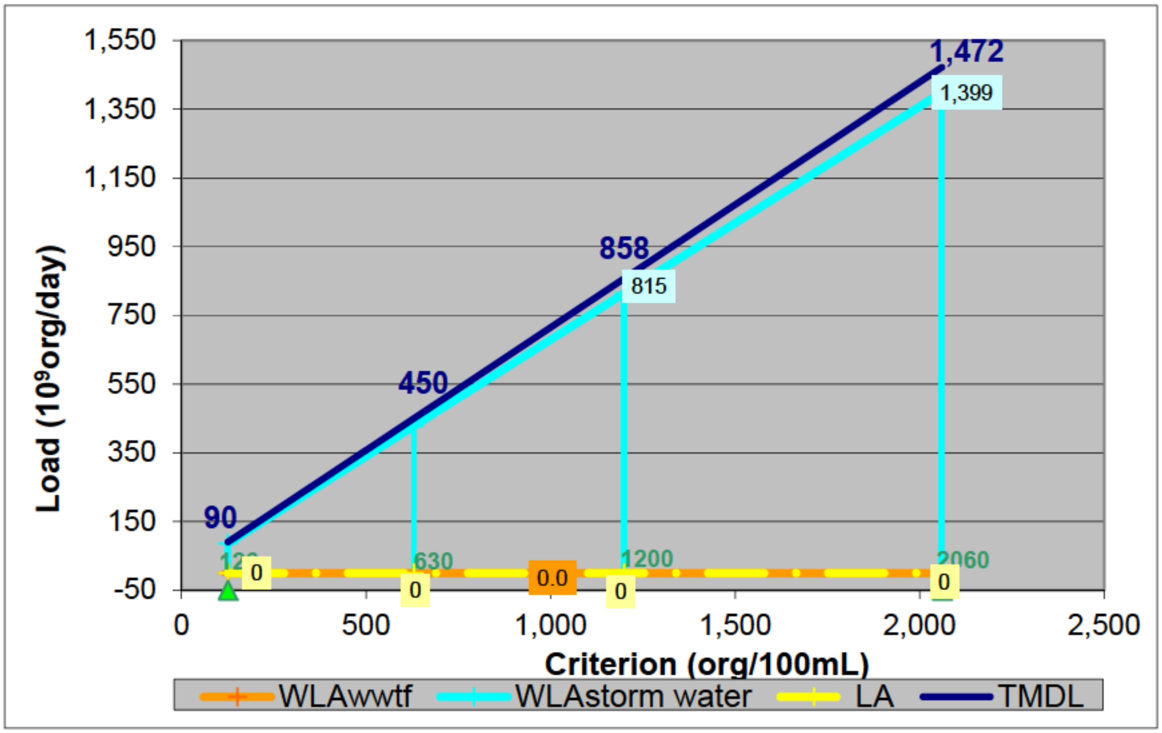

Figure 17. Allocation loads for Willow Springs Bayou (1113D_01) as a function of water quality criteria

Equations for Calculations New TMDL and Allocations

$$TMDL = 0.7147 * Std + 0.0$$

$$MOS = 0.05 * TMDL$$

$$LA = 0.0 * Std + 0.0$$

$$WLA_{Stormwater} = 0.6790 * Std - 0.0$$

$$WLA_{WWTF} = 0.0$$

Where:

Std = Revised Contact Recreation criteria

LA = load allocation (unregulated source contributions)

$WLA_{Stormwater}$ = wasteload allocation (permitted stormwater)

WLA_{WWTF} = wasteload allocation (permitted WWTF)

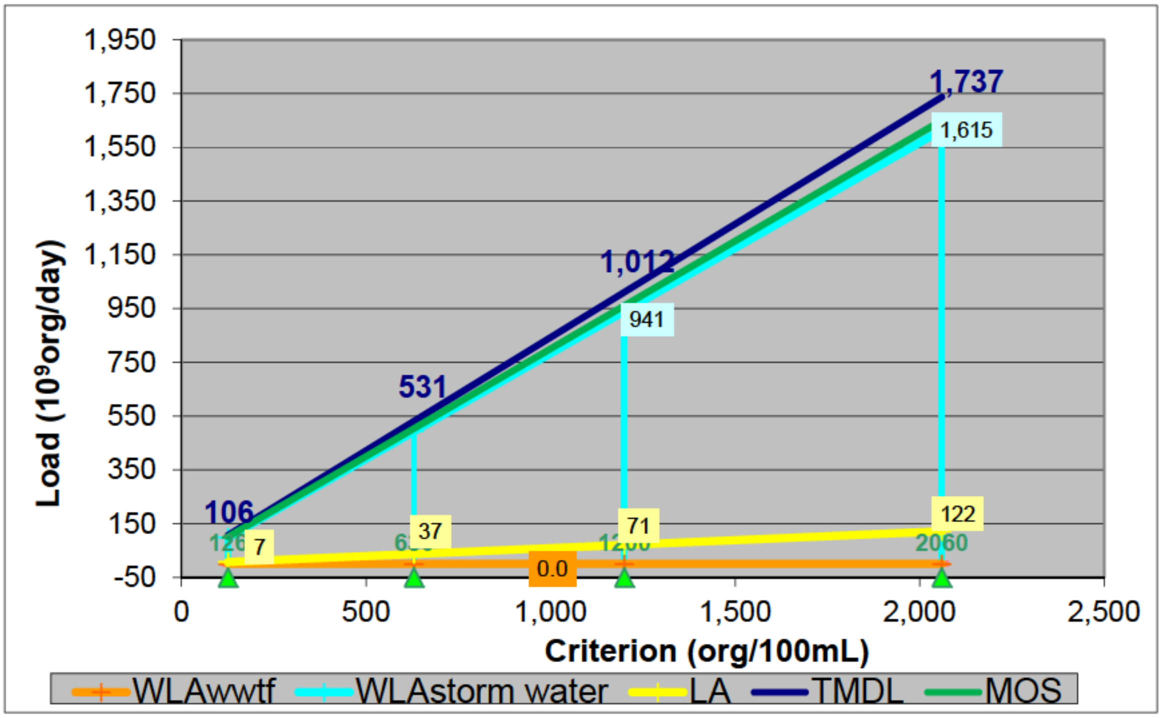

Figure 18. Allocation loads for Big Island Slough (1113E_01) as a function of water quality criteria

Equations for Calculations New TMDL and Allocations

$$TMDL = 0.8431 * Std + 0.0$$

$$MOS = 0.05 * TMDL$$

$$LA = 0.0521 * Std + 0.0$$

$$WLA_{Stormwater} = 0.7398 * Std - 0.0$$

$$WLA_{WWTF} = 0.0$$

Where:

Std = Revised Contact Recreation criteria

LA = load allocation (unregulated source contributions)

$WLA_{Stormwater}$ = wasteload allocation (permitted stormwater)

WLA_{WWTF} = wasteload allocation (permitted WWTF)