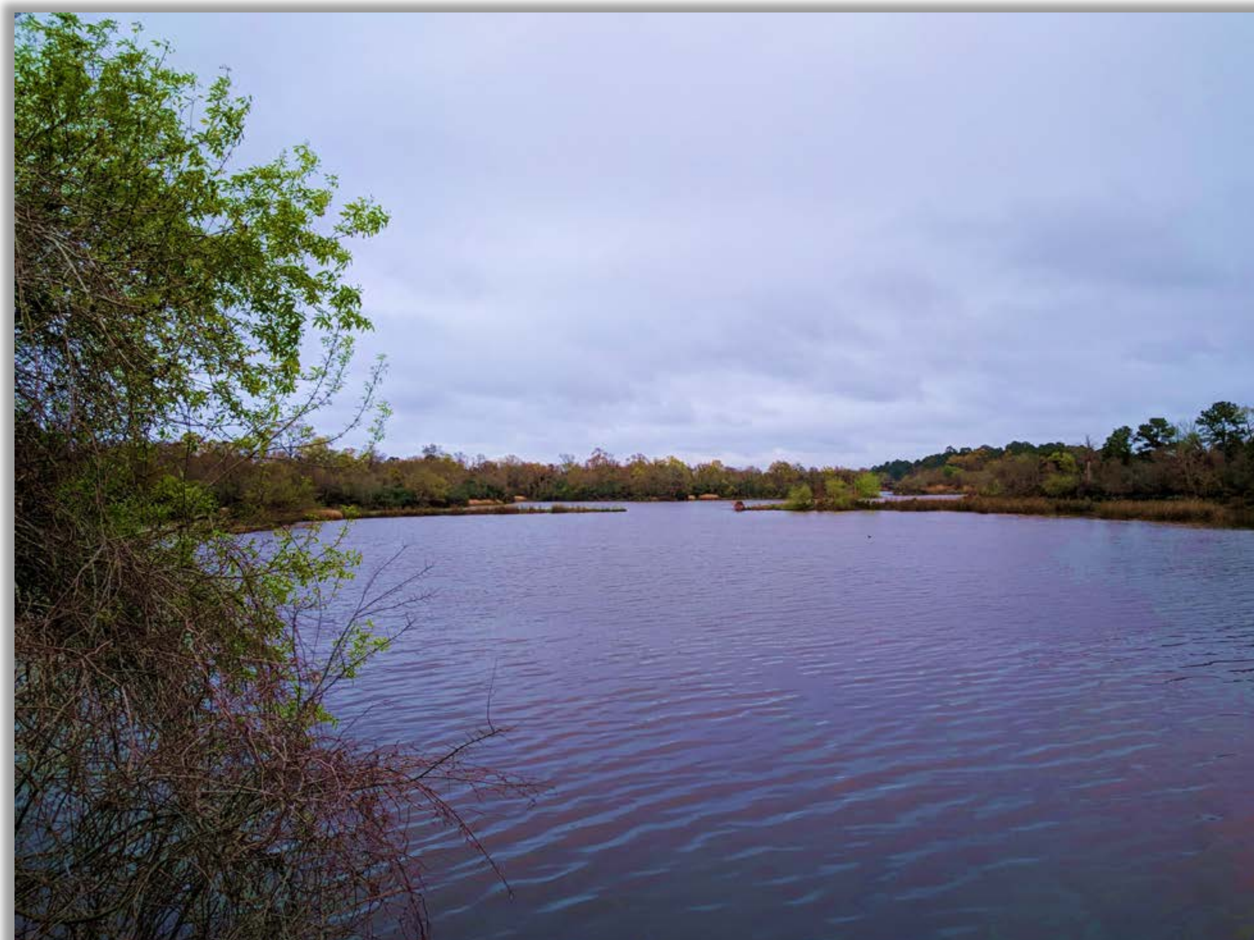
Technical Support Document for One Total Maximum Daily Load for Indicator Bacteria in Armand Bayou

Segment 1113

Assessment Unit 1113_03



View of Armand Bayou at the Bay Area Boulevard crossing.

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Segment: 1113
Assessment Unit: 1113_03

Prepared for
Total Maximum Daily Load Program
Texas Commission on Environmental Quality
MC-203
P.O. Box 13087
Austin, Texas 78711-3087

Prepared by
Stephanie Brady
Jimmy Millican
Larry Hauck
Texas Institute for Applied Environmental Research
Tarleton State University
Stephenville, Texas

PR1803

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List of Acronyms and Abbreviations

AU	assessment unit
AVMA	American Veterinary Medical Association
CFR	Code of Federal Regulations
cfs	cubic feet per second
CCN	Certificate of Convenience and Necessity
DAR	drainage-area ratio
DMU	Deer Management Unit
DMR	Discharge Monitoring Report
DSLP	days since last precipiation
E. coli	Escherichia coli
ECHO	Enforcement & Compliance History Online
ESRI	Environmental Systems Research Institute
FDA	fractional proportion of drainage area
FDC	flow duration curve
FG	future growth
FIB	fecal indicator bacteria
GIS	Geographic Information System
gpcd	gallons per capita per day
HCFCD	Harris County Flood Control District
H-GAC	Houston-Galveston Area Council
ICIS	Integrated Compliance Information System
I&I	inflow and infiltration
I-Plan	implementation plan
IRNR	Institute of Renewable Natural Resources (Texas A&M)
LA	load allocation
LDC	load duration curve
M	mean
MGD	million gallons per day
mL	milliliter
MOS	margin of safety
MPN	most probable number
MS4	municipal separate storm sewer system
MSGP	multi-sector general permit
NDEP	Nevada Department of Environmental Pollution
NEIWPCC	New England Interstate Water Pollution Control Commission
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
ODEQ	Oregon Depatment of Environmental Quality
OSSF	onsite sewage facility

PCS	Permit Compliance System
QAPP	Quality Assurance Project Plan
SD	standard deviation
SEGID	segment identification number
SSO	sanitary sewer overflow
SWMP	Stormwater Management Program
SWQM	surface water quality monitoring
SWQMIS	Surface Water Quality Monitoring Information System
TAC	Texas Administrative Code
TCEQ	Texas Commission on Environmental Quality
TIAER	Texas Institute for Applied Environmental Research
TMDL	total maximum daily load
TNRIS	Texas Natural Resources Information System
TPDES	Texas Pollutant Discharge Elimination System
TPWD	Texas Parks and Wildlife Department
TSSWCB	Texas State Soil and Water Conservation Board
TWDB	Texas Water Development Board
USCB	U.S. Census Bureau
USDA-NASS	U.S. Department of Agriculture – National Agricultural Statistics Service
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WCID	Water Control and Improvement District
WLA	wasteload allocation
WUG	water user group
WWTF	wastewater treatment facility

Section 1
INTRODUCTION

1.1 Background

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 total maximum daily load (TMDL) for each pollutant that contributes to the impairment of a listed water body. The Texas Commission on Environmental Quality (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. In addition to the TMDL, an implementation plan (I-Plan) is developed, which is a description of the regulatory and voluntary management measures necessary to improve water quality and restore full use of the water body.

The TCEQ's 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.

The TCEQ first identified the bacteria impairments within Armand Bayou Tidal (Segment 1113) AU 1113_03 in the 2014 Texas Integrated Report of Surface Water Quality for the Clean Water Act Sections 305(b) and 303(d) (TCEQ, 2015a).

This document will, therefore, consider bacteria impairments in a single assessment unit (AU). The water body and it's identifying AU number is shown below:

- Armand Bayou Tidal 1113_03

1.2 Water Quality Standards

To protect public health, aquatic life, and development of industries and economies throughout Texas, water quality standards were established by the TCEQ. The water quality standards describe the limits for indicators which are monitored in an effort to assess the quality of available water for specific users. The TCEQ is charged with monitoring and assessing water bodies based on these water quality standards, and publishes the Texas Water Quality Integrated Report list biennially.

The Texas Surface Water Quality Standards (TCEQ, 2010) are rules that:

- designate the uses, or purposes, for which the state's water bodies should be suitable;
- establish numerical and narrative goals for water quality throughout the state; and
- provide a basis on which TCEQ regulatory programs can establish reasonable methods to implement and attain the state's goals for water quality.

Standards are established to protect designated uses assigned to water bodies of which the primary uses assigned in the Texas Surface Water Quality Standards to water bodies are:

- aquatic life use
- contact recreation
- domestic water supply
- general use

Fecal indicator bacteria (FIB) are used to assess the risk of illness during contact recreation (e.g., swimming) from ingestion of water. FIBs such as *Escherichia coli* (*E. coli*) and *Enterococcus* spp. (enterococci) are present in the intestinal tracts of humans and other warm-blooded animals. The presence of these bacteria in water indicates that associated pathogens from the wastes that may be reaching water bodies as a result of such sources as inadequately treated sewage, improperly managed animal waste from livestock, pets, aquatic birds, wildlife, and failing septic systems (TCEQ, 2006). Within the State of Texas, *E. coli* is used as the FIB in freshwater, and Enterococci is used as the FIB in saltwater. Enterococci are the relevant indicator for Armand Bayou Tidal (1113_03).

On June 30, 2010, the TCEQ adopted revisions to the Texas Surface Water Quality Standards (TCEQ, 2010) and on June 29, 2011, the U.S. Environmental Protection Agency (USEPA) approved the categorical levels of recreational use and their associated criteria.

For freshwater, recreational use consists of four categories:

- Primary contact recreation is that with a significant risk of ingestion of water (such as swimming), and has a geometric mean criterion for *E. coli* of 126 most probable number (MPN) per 100 mL and an additional single sample criterion of 399 MPN per 100 mL;
- Secondary contact recreation 1 covers activities with limited body contact and a less significant risk of ingestion of water (such as fishing), and has a geometric mean criterion for *E. coli* of 630 MPN per 100 mL;
- Secondary contact recreation 2 is similar to secondary contact 1, but activities occur less frequently. It has a geometric mean criterion for *E. coli* of 1,030 MPN per 100 mL; and

- Noncontact recreation is that with no significant risk of ingestion of water, where contact recreation should not occur due to unsafe conditions. It has a geometric mean criterion for *E. coli* of 2,060 MPN per 100 mL (TCEQ, 2010).

For saltwater, recreational use consists of three categories:

- Primary contact recreation is that with a significant risk of ingestion of water (such as swimming), and has a geometric mean criterion for Enterococci of 35 most probable number (MPN) per 100 mL and a single sample criterion of 104 MPN per 100 mL;
- Secondary contact recreation 1 covers activities with limited body contact and a less significant risk of ingestion of water (such as fishing), and has a geometric mean criterion for Enterococci of 175 per 100 mL;
- Noncontact recreation is that with no significant risk of ingestion of water, where contact recreation should not occur due to unsafe conditions. It has a geometric mean criterion for Enterococci of 350 per 100 mL.

In the Armand Bayou watershed, the impaired assessment unit (1113_03) is approved for primary contact recreation. Since the impaired assessment unit is considered a saltwater water body, the associated Enterococci geometric mean criterion of a 35 MPN per 100 mL and single sample of 104 MPN per 100 mL is applied.

1.3 Report Purpose and Organization

The TMDL project for the selected watershed within Armand Bayou was initiated through a contract between the TCEQ and Texas Institute for Applied Environmental Research (TIAER). This project is considered to be an addendum to the existing bacteria TMDLs for the Armand Bayou Watershed (TCEQ, 2015b) that was adopted by the TCEQ Commission on August 5, 2015 and approved by the USEPA on October 2, 2015. The previous TMDL included the following AU's: 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 watershed for Armand Bayou Tidal AU 1103_03 (the subject of this effort) along with the greater Armand Bayou watershed is shown in Figure 1, below.

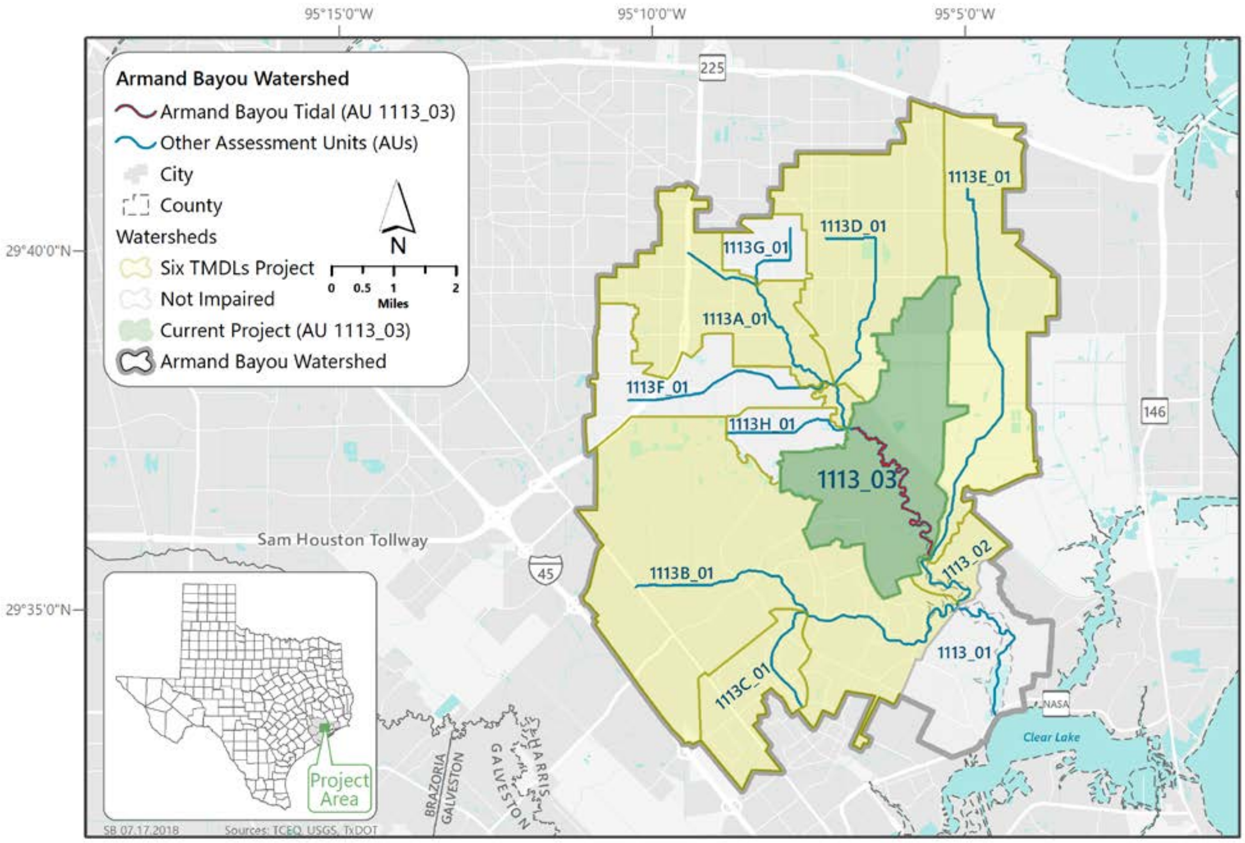

Figure 1. Map showing the greater Armand Bayou watershed and the Armand Bayou Tidal watershed considered in this addendum (1113_03)

The tasks of this project were to (1) administer the project; (2) develop, have approved, and adhere to a quality assurance project plan; (3) assist the TCEQ with public participation; (4) and develop a technical support document for the impaired watershed. The purpose of this report is to provide technical documentation and supporting information for developing a bacteria TMDL for the impaired watershed within Armand Bayou. This report contains:

- information on historical data,
- watershed properties and characteristics,
- summary of historical bacteria data that confirm the State of Texas 303(d) listings of impairment due to the presence of indicator bacteria (Enterococci),
- development of load duration curve (LDC), and
- application of the LDC approach for the pollutant load allocation process.

Section 2
HISTORICAL DATA REVIEW AND WATERSHED PROPERTIES

2.1 Description of the Study Area

Armand Bayou Tidal (Assessment Unit 1113_03) is a classified, saltwater tidal stream (TCEQ, 2015a). A classified stream segment refers to water bodies that are protected by site-specific criteria; the designation includes most rivers and major tributaries within the state (TCEQ, 2016). This study incorporates a watershed approach where the drainage area for the assessment unit is considered.

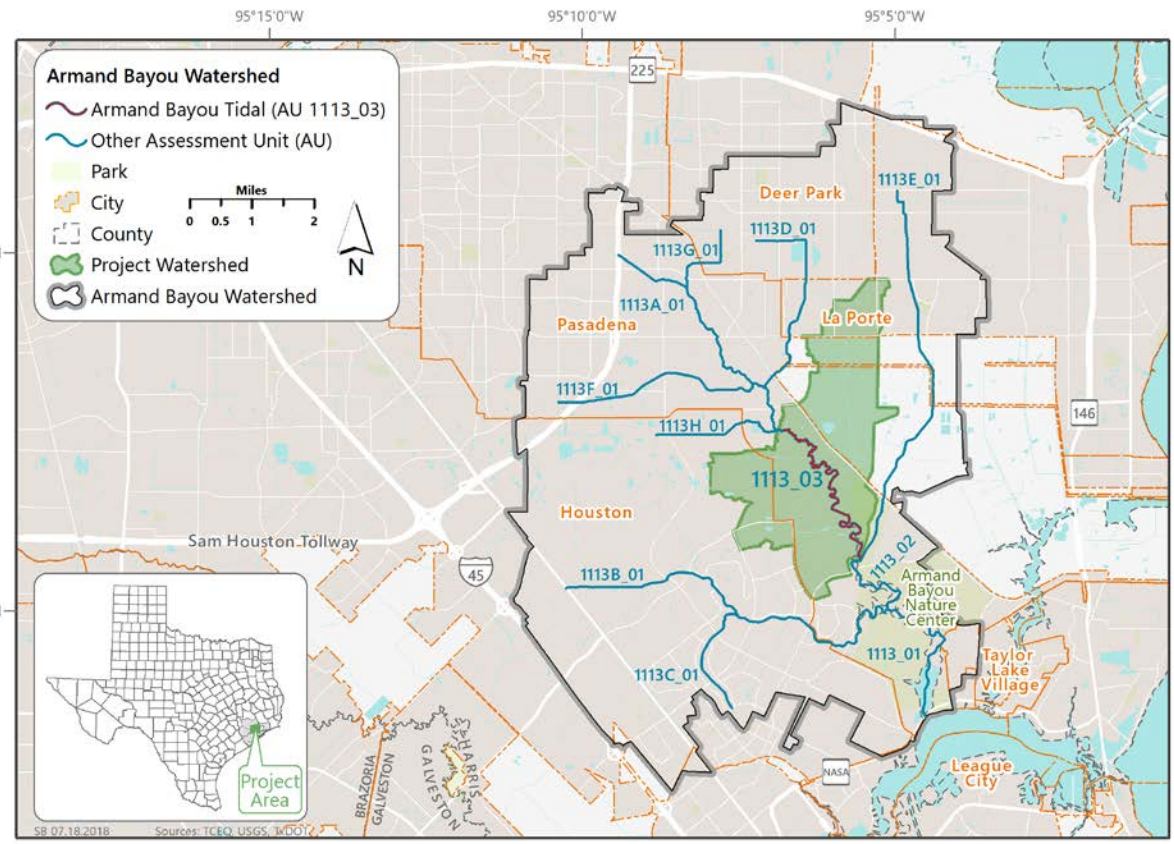

Figure 2. Overview map showing the study watershed for AU 1113_03.

Armand Bayou Tidal (Segment 1113) debouches into Clear Lake (Segment 2425), which connects to the Upper Galveston Bay (Segment 2421) and thence to the Gulf of Mexico. The entire Armand Bayou segment is composed of three assessment units (AUs); the subject AU (1113_03) is the farthest upstream AU. Armand Bayou Tidal 1113_03 is approximately 4.82 miles in length and drains an area of 7.16 square miles (4,580.85 acres). At the outlet of the most downstream AU (1113_01), an area of 59.13 square miles (37,840.40 acres) is drained. The project watershed makes up 12.11% of the entire Armand Bayou watershed.

The segment and AU descriptions for the water body considered in this document is as follows:

- SEGID: 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)
    - AU_ID: 1113_03 - From the Big Island Slough confluence upstream to a point 0.8 km (0.5 mi) downstream of Genoa-Red Bluff Road (TCEQ, 2018a)

2.2 Watershed Climate

The Armand Bayou watershed is located in the eastern portion of the state of Texas, where the climate is classified as “Subtropical Humid” (Larkin & Bomar, 1983). The region’s subtropical climate is caused by the “predominant onshore flow of tropical maritime air from the Gulf of Mexico,” while the increasing moisture content (from west to east) reflects variations in “intermittent seasonal intrusions of continental air” (Larkin & Bomar, 1983). Occasional anomalous climatic events, including floods and droughts, are a feature of the climate.

For the period from 1981 – 2010, average annual precipitation in the project watershed was calculated to be 55.13 inches, which is slightly higher than the average annual total precipitation for the entire Armand Bayou watershed of 55.05 inches (PRISM Climate Group at Oregon State University, 2012). As shown in Figure 3, average precipitation totals tend to increase from west to east across the project area, which is consistent with the statewide trend.

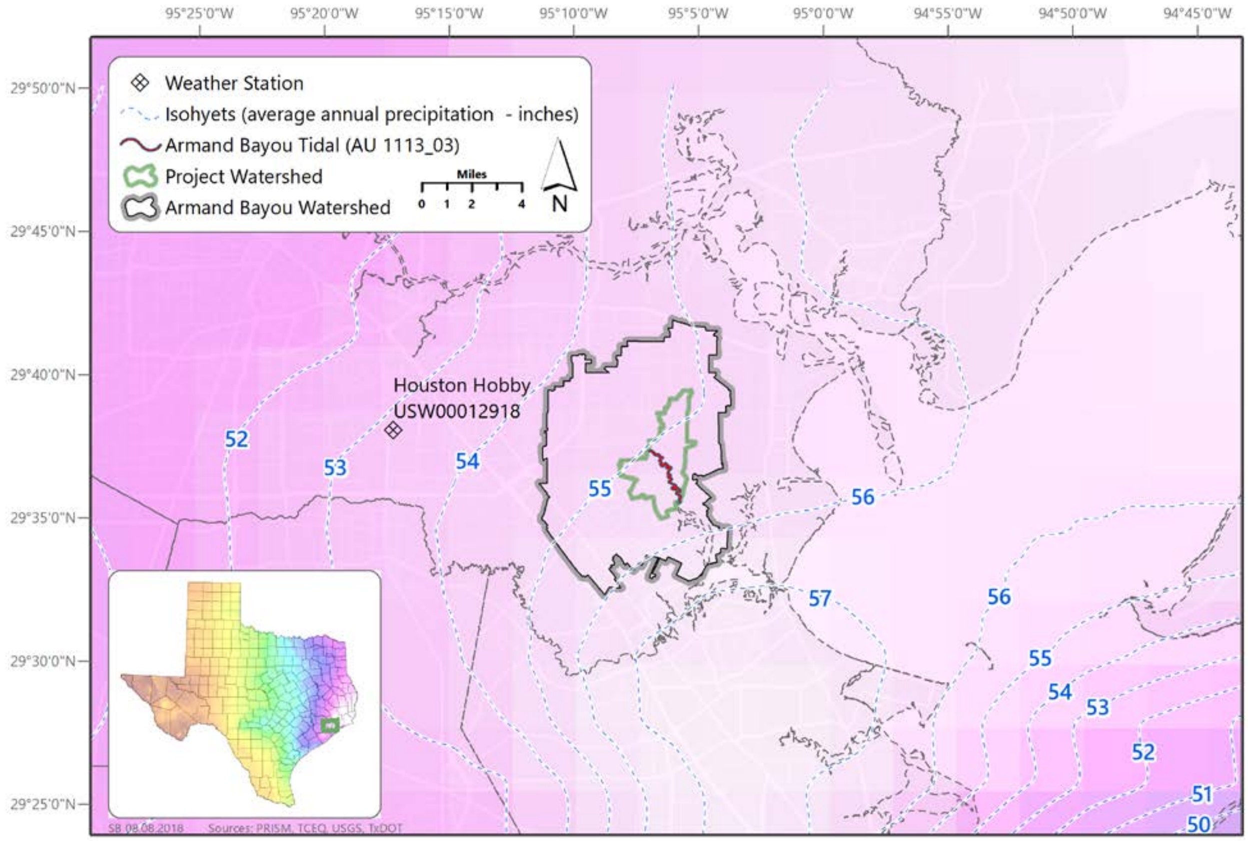

Figure 3. Annual average precipitation map showing isohyets (in inches) for areas in the vicinity of the Armand Bayou watershed (1981-2010).

Source: (PRISM Climate Group at Oregon State University, 2012)

Climate normals obtained from the National Oceanic and Atmospheric Administration (NOAA) for the nearby Houston William P Hobby Airport weather station (USW00012918, shown in Figure 3) reveal that average annual precipitation totals can vary greatly; over the 1981- 2010 period, annual precipitation totals ranged from a low of 25.39 inches in 2011 to a high of 82.14 inches in 1981 (Arguez, et al., 2010b). Climate normals also indicate a bimodal precipitation pattern (Figure 4) (Arguez, et al., 2010c). The wettest months are typically June (7.1 inches) and October (6.0 inches), while February and March (both at 3.2 inches) are normally the driest months.

In the project area, average high temperatures generally reach their peak of 93 °F in August (Figure 4), and highs above 100 °F have occurred from June through September (Arguez, et al., 2010c). Fair skies generally accompany the highest temperatures of summer when nightly average lows drop to about 76 °F (Arguez et al., 2010a). During winter, the average daily low temperature bottoms out at 45 °F in January, although below-freezing temperatures have occurred from November through April (Arguez, et al., 2010c). The frost-free period in the project area generally lasts for about 320 days, with the average last frost occurring February 3rd and the average first frost occurring on December 20th (Arguez, et al., 2010a).

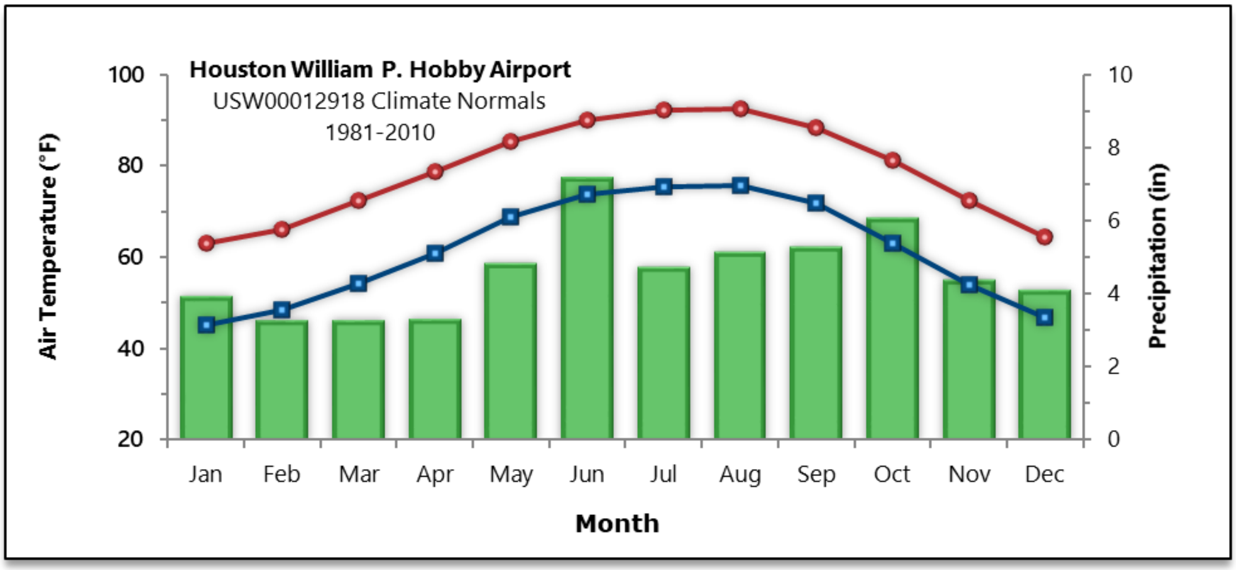

Figure 4. Chart showing the average minimum and maximum air temperature and total precipitation by month from 1981-2010 for the Hobby Airport weather station.

Source: (Arguez, et al., 2010c)

2.3 Watershed Population and Population Projections

According to the 2010 Census (USCB & TNRIS, 2011), there are an estimated 8,071 people in the project watershed (Armand Bayou Tidal 1113_03), indicating a population density of 1,127 people/ square mile. The entire population of the project watershed lives within either Pasadena (3,242), Houston (2,776) or La Porte (2,053), as shown in Figure 5. Approximately 45 percent of the area of the watershed is included within the Pasadena city limits, 17 percent is within the Houston city limits, 9 percent is within the La Porte city limits, and 28 percent is located outside of any city limits.

Also according to the 2010 Census, there are an estimated 125,844 people in the entire Armand Bayou watershed, indicating a population density of 2,128 people/ square mile. The majority of the population (47,248 people, or 38 percent) live within the Houston city limits; the remaining residents with within Pasadena (27 percent), La Porte (17 percent), Deer Park (16 percent), Taylor Lake Village (2 percent), and Webster (0.3 percent), as shown in Figure 5. Approximately 10 percent of the area of the entire Armand Bayou watershed is located outside of any city limits.

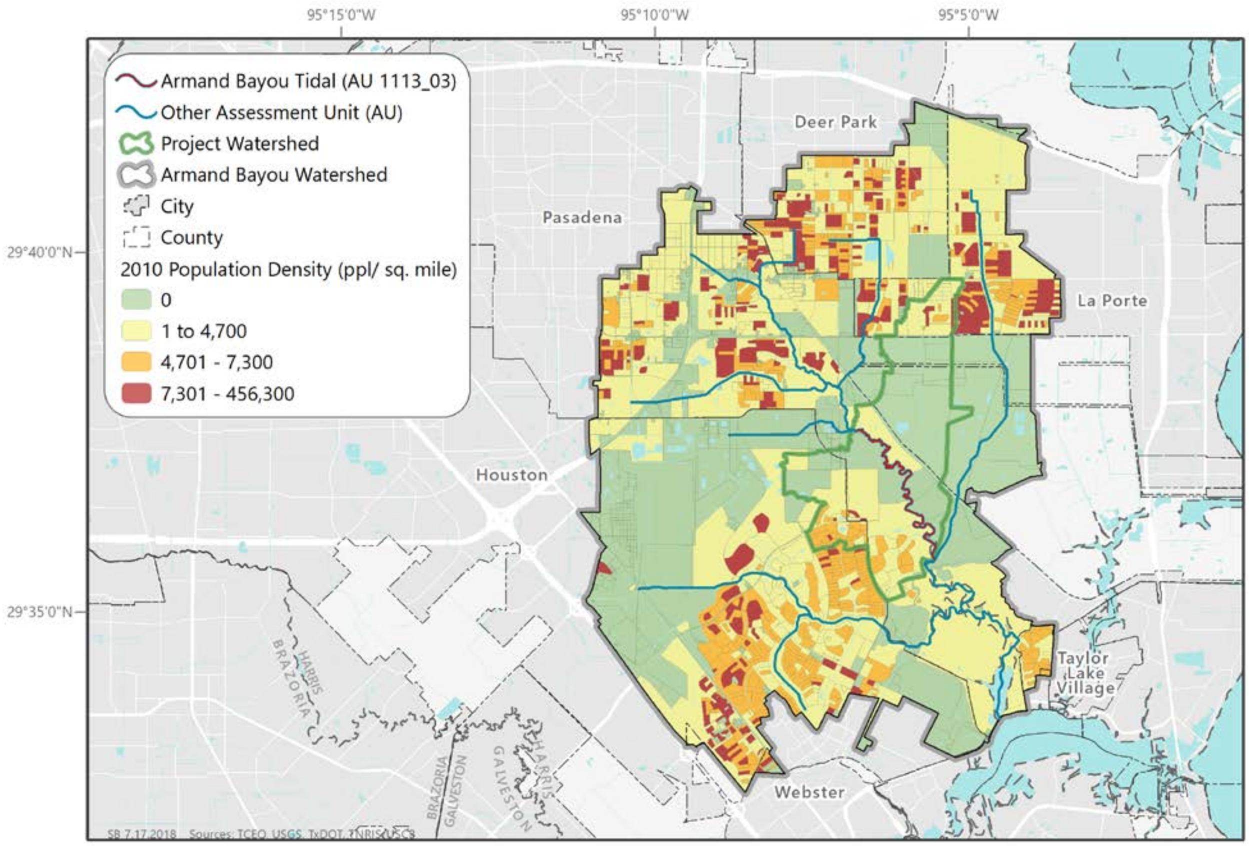

Figure 5. Population density map showing 2010 population by census block within the project watershed and the entire Armand Bayou watershed.

Source: (USCB (United States Census Bureau) & TNRIS (Texas Natural Resources Information System), 2011)

Population projection data, available through the state water planning process via the Office of the State Demographer and the Texas Water Development Board (TWDB, 2013), is based on areas known as Water User Groups (WUGs). Geospatial analysis based on WUGs, which allows a refinement of county and city-level projections, reveals that populations are predicted to increase 70.2 percent in the project watershed and 31.0 percent for the entire Armand Bayou watershed between 2010 and 2050 (Table 1).

Table 1. 2010 Population and 2020 – 2050 Population Projections for the project watershed (1113_03) and the entire Armand Bayou watershed (1113).

Sources: (USCB & TNRIS, 2017) (TWDB, 2013)

Watershed	U.S. Census	Population Projections				Population Change	Percent Increase
Based on Harris County, San Jacinto-Brazos river basin	2010	2020	2030	2040	2050	(2010-2050)	(2010-2050)
Project Watershed	8,071	11,401	12,225	12,983	13,737	+5,666	70.2%
Entire Armand Bayou Watershed	125,844	131,931	143,159	153,955	164,837	+38,993	31.0%

2.4 Land Use

The land use/land cover data for the project watershed and the entire Armand Bayou watershed were obtained from the H-GAC 2015 10 Class Land Cover Data Set and are displayed in Figure 6.

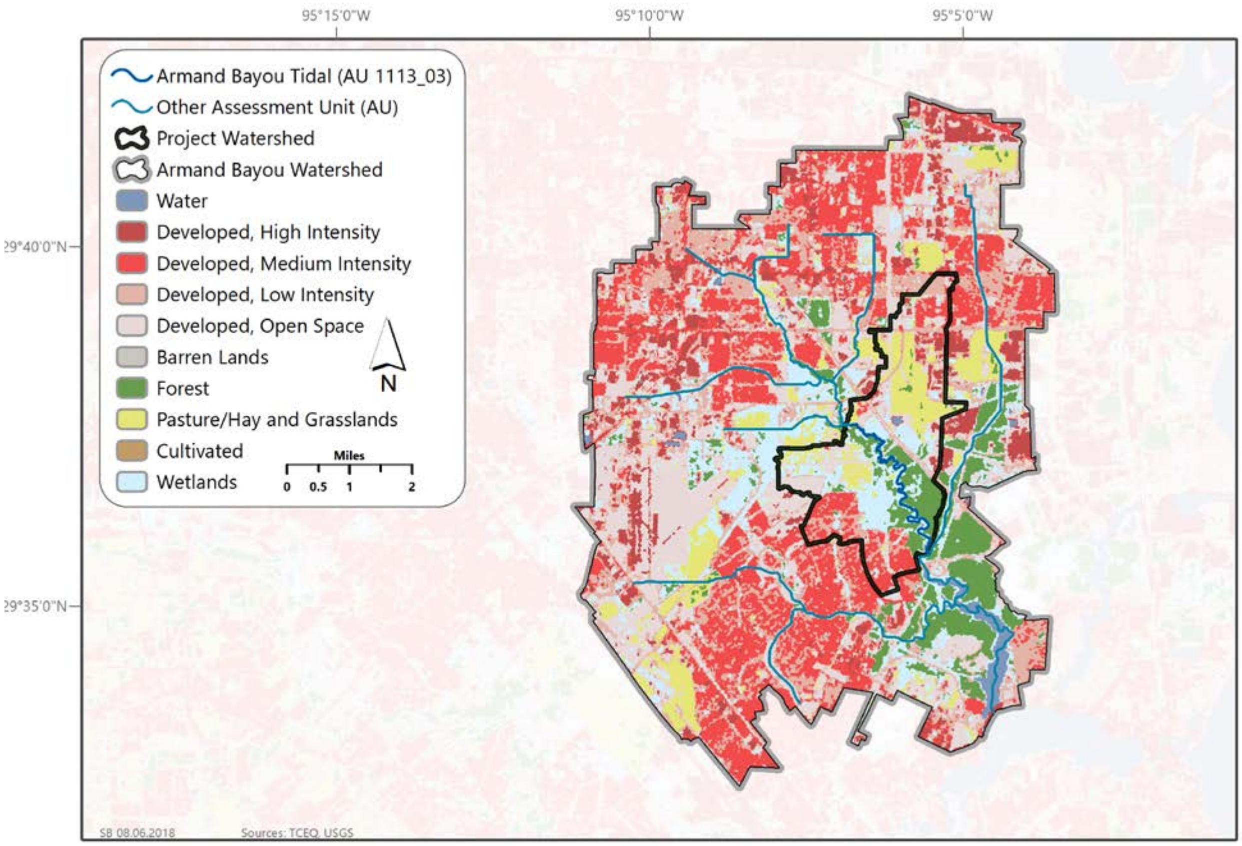

Figure 6. Land use/ land cover map showing categories within the project watershed and within the entire Armand Bayou Watershed.

Source: (H-GAC (Houston-Galveston Area Council), 2017)

The land use/land cover is represented by the following categories and definitions (as presented in (H-GAC, 2015):

- Developed, High Intensity (1) - contains significant land area is covered by concrete, asphalt, and other constructed materials. Vegetation, if present, occupies < 20 percent of the landscape. Constructed materials account for 80 to 100 percent of the total cover. This class includes heavily built-up urban centers and large constructed surfaces in suburban and rural areas with a variety of land uses.
- Developed, Medium Intensity (2) - contains area with mixture of constructed materials and vegetation or other cover. Constructed materials account for 50 to 79 percent of the total area. This class commonly includes multi- and single-family housing areas,

especially in suburban neighborhoods, but may include all types of land use. (H-GAC (Houston-Galveston Area Council), 2018b)

- Developed, Low Intensity (3) - contains areas with a mixture of constructed materials and substantial amounts of vegetation or other cover. Constructed materials account for 21 to 49 percent of total area. This subclass commonly includes single-family housing areas, especially in rural neighborhoods, but may include all types of land use.
- Developed, Open Space (4) - contains areas with a mixture of some constructed materials, but mostly managed grasses or low-lying vegetation planted in developed areas for recreation, erosion control, or aesthetic purposes. These areas are maintained by human activity such as fertilization and irrigation, are distinguished by enhanced biomass productivity, and can be recognized through vegetative indices based on spectral characteristics. Constructed surfaces account for less than 20 percent of total land cover.
- Cultivated (5) - contains areas intensely managed for the production of annual crops. Crop vegetation accounts for greater than 20 percent of total vegetation. This class also includes all land being actively tilled.
- Pasture/Hay and Grasslands (6) – This is a composite class that contains both Pasture/Hay lands and Grassland/Herbaceous.
    - Pasture/Hay - contains areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle and not tilled. Pasture/hay vegetation accounts for greater than 20 percent of total vegetation.
    - Grassland/Herbaceous - contains areas dominated by grammanoid or herbaceous vegetation, generally greater than 80 percent of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.
- Forest (7) – This is a composite class that contains all three forest land types, and shrub lands.
    - Deciduous Forest - contains areas dominated by trees generally greater than 5 meters tall and greater than 20 percent of total vegetation cover. More than 75 percent of the tree species shed foliage simultaneously in response to seasonal change.
    - Evergreen Forest - contains areas dominated by trees generally greater than 5 meters tall and greater than 20 percent of total vegetation cover. More than 75 percent of the tree species maintain their leaves all year. Canopy is never without green foliage.

    - Mixed Forest - contains areas dominated by trees generally greater than 5 meters tall, and greater than 20 percent of total vegetation cover. Neither deciduous nor evergreen species are greater than 75 percent of total tree cover. Both coniferous and broad-leaved evergreens are included in this category.
    - Scrub/Shrub - contains areas dominated by shrubs less than 5 meters tall with shrub canopy typically greater than 20 percent of total vegetation. This class includes tree shrubs, young trees in an early successional stage, or trees stunted from environmental conditions.
- Barren Lands (8) – This class contains both barren lands and unconsolidated shore land areas
    - Barren Land - contains areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits, and other accumulations of earth material. Generally, vegetation accounts for less than 10 percent of total cover.
    - Unconsolidated Shore - includes material such as silt, sand, or gravel that is subject to inundation and redistribution due to the action of water. Substrates lack vegetation except for pioneering plants that become established during brief periods when growing conditions are favorable.
- Wetlands (9) – this is a composite class that contains all the palustrine and estuarine wetland land types
    - Palustrine Forested Wetland - includes tidal and non-tidal wetlands dominated by woody vegetation greater than or equal to 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent. Total vegetation coverage is greater than 20 percent.
    - Palustrine Scrub/Shrub Wetland - includes tidal and non-tidal wetlands dominated by woody vegetation less than 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent. Total vegetation coverage is greater than 20 percent. Species present could be true shrubs, young trees and shrubs, or trees that are small or stunted due to environmental conditions.
    - Palustrine Emergent Wetland (Persistent) - includes tidal and non-tidal wetlands dominated by persistent emergent vascular plants, emergent mosses or lichens, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent. Total vegetation cover is greater than 80 percent. Plants generally remain standing until the next growing season.

- Estuarine Forested Wetland - includes tidal wetlands dominated by woody vegetation greater than or equal to 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent. Total vegetation coverage is greater than 20 percent.
- Estuarine Scrub / Shrub Wetland - includes tidal wetlands dominated by woody vegetation less than 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent. Total vegetation coverage is greater than 20 percent.
- Estuarine Emergent Wetland - Includes all tidal wetlands dominated by erect, rooted, herbaceous hydrophytes (excluding mosses and lichens). Wetlands that occur in tidal areas in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent and that are present for most of the growing season in most years. Total vegetation cover is greater than 80 percent. Perennial plants usually dominate these wetlands.

- Water (10) – This is a composite class that contains open water, and both palustrine and estuarine aquatic beds
    - Open Water - include areas of open water, generally with less than 25 percent cover of vegetation or soil.
    - Palustrine Aquatic Bed - includes tidal and non-tidal wetlands and deep water habitats in which salinity due to ocean-derived salts is below 0.5 percent and which are dominated by plants that grow and form a continuous cover principally on or at the surface of the water. These include algal mats, detached floating mats, and rooted vascular plant assemblages. Total vegetation cover is greater than 80 percent.
    - Estuarine Aquatic Bed - includes tidal wetlands and deep water habitats in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent and which are dominated by plants that grow and form a continuous cover principally on or at the surface of the water. These include algal mats, kelp beds, and rooted vascular plant assemblages. Total vegetation cover is greater than 80 percent.

As shown in Table 2, the watershed area encompassing Assessment Unit 1113_03 (the project watershed) is approximately 4,581 acres. Dominant land uses in the project watershed include Wetlands (22%) and Pasture/Grasslands (17%).

The watershed area encompassing Segment 1113 (the entire Armand Bayou watershed) is about 37,840 acres and is by Developed Medium Intensity (23%) and Developed Low Intensity (22%).

While the project watershed is mostly rural (53%), the entire Armand Bayou watershed is mostly urban, with 72% of the area classified as Developed.

Table 2. Land Use/ Land Cover within the project watershed and within the entire Armand Bayou Watershed.

Sources: (H-GAC, 2017)

2011 NLCD Classification	Project Watershed (1113_03)		Entire Armand Bayou Watershed	
	Acres	% of Total	Acres	% of Total
Open Water	16.9	0.4%	450.3	1.2%
Developed High Intensity	143.8	3.1%	2,660.2	7.0%
Developed Medium Intensity	652.3	14.2%	8,544.4	22.6%
Developed Low Intensity	671.1	14.7%	8,290.8	21.9%
Developed Open Space	697.2	15.2%	7,674.0	20.3%
Barren Lands	7.8	0.2%	177.8	0.5%
Forest/Shrubs	609.7	13.3%	2,686.7	7.1%
Pasture/Grasslands	787.0	17.2%	2,838.0	7.5%
Cultivated Crops	0.9	0.0%	7.6	0.0%
Wetlands	994.0	21.7%	4,510.6	11.9%
Total	4,580.9	100.0%	37,840.4	100.0%

2.5 Soils

Soils within the project watershed as well as the entire Armand Bayou watershed were categorized by their Hydrologic Soil Group (NRCS & ESRI, 2017) as shown in Figure 7. The Hydrologic Soil Groups are represented by the following categories and definitions:

- Group A soils consist of deep, well-drained sands or gravelly sands with high infiltration and low runoff rates.
- Group B soils consist of deep, well-drained soils with a moderately fine to moderately coarse texture and a moderate rate of infiltration and runoff.
- Group C consists of soils with a layer that impedes the downward movement of water or fine-textured soils and a slow rate of infiltration.
- Group D consists of soils with a very slow infiltration rate and high runoff potential. This group is composed of clays that have a high shrink-swell potential, soils with a high water table, soils that have a clay pan or clay layer at or near the surface.

Geospatial analysis reveals that both the project watershed and the entire Armand Bayou watershed are primarily comprised of Group D soils, a category of soils that generally have very slow infiltration rates and high runoff potentials. For the project watershed (AU 1113_03), Group D soils comprise 92 percent of the area of the watershed. For the entire Armand Bayou, Group D soils comprise 87 percent of the area of the watershed. For both watersheds, almost the entire remaining area is classified as either Group B/D or C/D, indicating that these soils naturally have a very slow infiltration rate due to the presence of a high water table, but the infiltration rate will increase if drained.

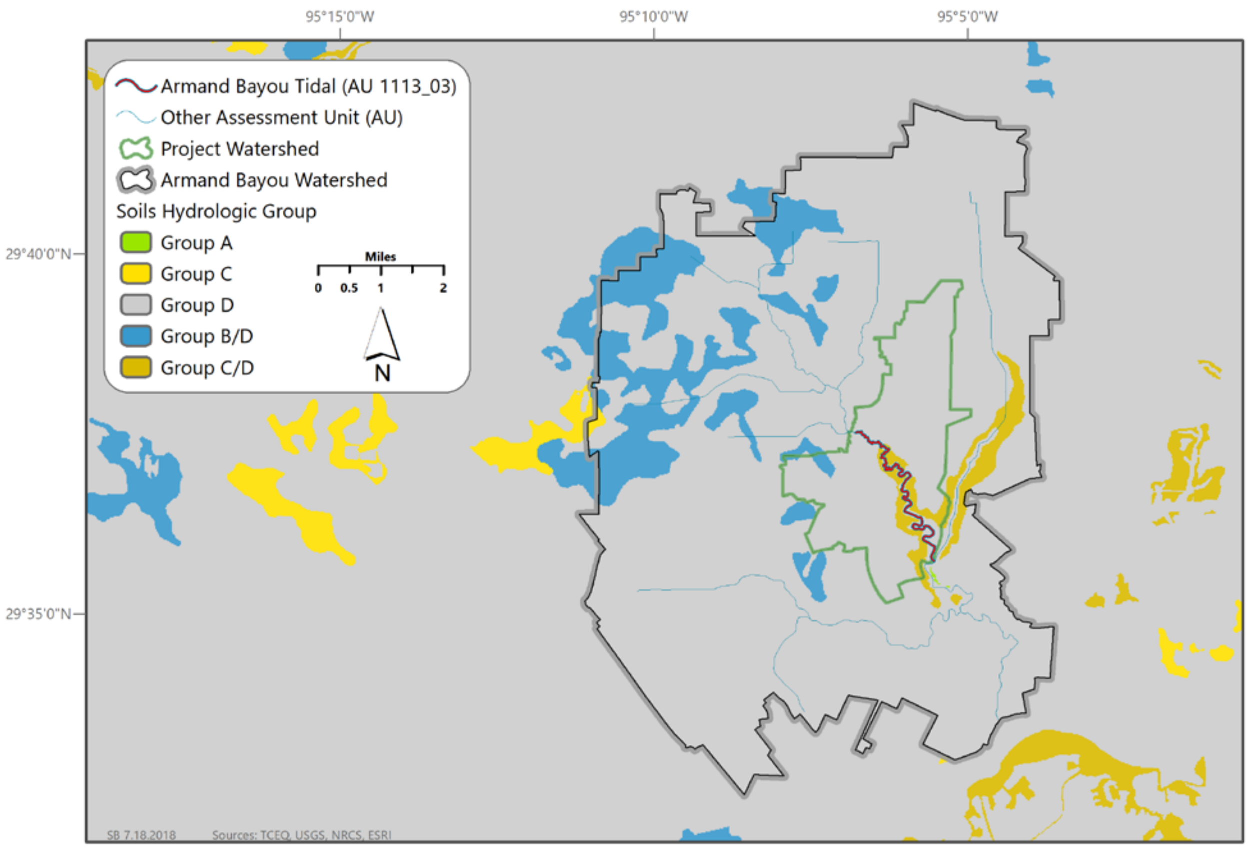

Figure 7. Hydrologic Soil Group categories within the project watershed and the entire Armand Bayou Watershed.

2.6 Review of Routine Monitoring Data

2.6.1 Data Acquisition

Ambient Enterococci data were obtained from the TCEQ Surface Water Quality Monitoring Information System (SWQMIS) on 20 April 2017 (TCEQ, 2018b). The data represented all the historical routine ambient Enterococci and other water quality data collected in the project watershed, and included Enterococci data collected from May 2001 through August 2017. The ambient Enterococci data were available for one station in Assessment Unit 1113_03 (SWQM Station ID # 11505), as shown in Table 3 and Figure 8, below.

Table 3. Summary of historical data set of Enterococci concentrations from SWQMIS.

Water Body	Assessment Unit	Station	Station Location	No. of Enterococci Samples	Geometric Mean (MPN/100 mL)	Data Date Range
Armand Bayou	1113_03	11505	Armand Bayou Tidal at Exxon Oil Rd	53	48.82	2001-2017

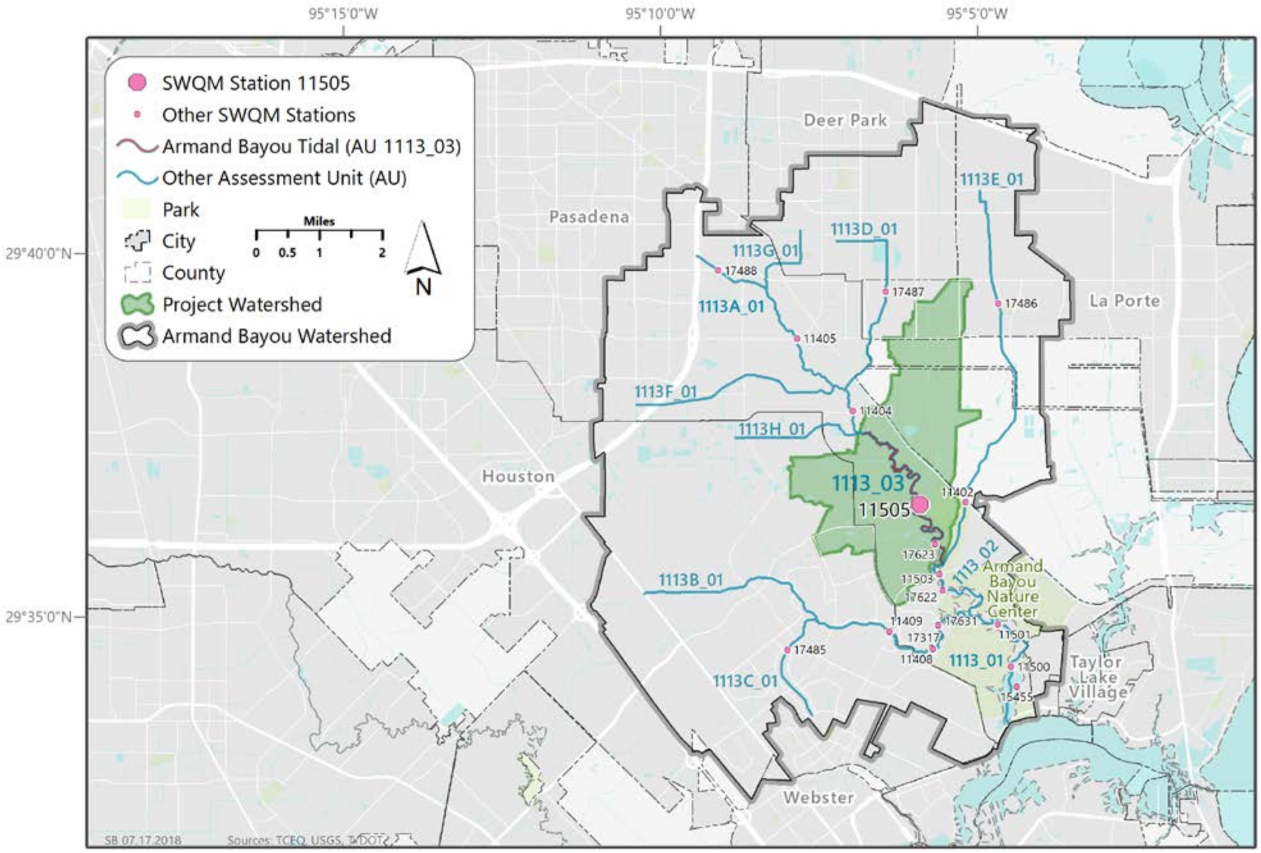

Figure 8. Map showing SWQM stations within the project watershed and the entire Armand Bayou Watershed.

2.6.2 Analysis of Bacteria Data

Recent environmental monitoring within the Armand Bayou Tidal Assessment Unit 1113_03 has occurred at two TCEQ surface water quality monitoring (SWQM) stations within the watershed, but Enterococci data were collected at only SWQM station 1113_03 (Table 3, Figure 8). Enterococci data collected at these stations over the seven-year period of 1 December 2005 through 30 November 2012 were used in assessing attainment of the primary contact recreation use as reported in the 2014 Texas Integrated Report (TCEQ, 2015a) and as summarized in Table 4. The 2014 assessment data indicate non-support of the primary contact recreation use because geometric mean concentrations exceed the geometric mean criterion of 35 MPN/100 mL for Armand Bayou 1113_03.

Table 4. 2014 and Draft 2016 Integrated Report Summary for the project watershed (Armand Bayou 1113_03)

Source: (TCEQ, 2015a), (TCEQ, 2018d)

Integrated Report Year	Water Body	Segment Number	Assessment Unit (AU)	Parameter	Station	No. of Samples	Data Date Range	Station Geometric Mean (MPN/100 mL)
2014	Armand Bayou	1113	1113_03	Enterococcus	11505	24	2005-2012	47.59
2016	Armand Bayou	1113	1113_03	Enterococcus	11505	23	2007-2014	62.02

2.7 Potential Sources of Fecal Indicator Bacteria

Potential sources of indicator bacteria pollution can be divided into two primary categories: regulated and unregulated. Pollution sources that are regulated have permits under the Texas Pollutant Discharge Elimination System (TPDES) and National Pollutant Discharge Elimination System (NPDES) programs. Examples of regulated sources are wastewater treatment facility (WWTF) discharges and stormwater discharges from industries, construction, and municipal separate storm sewer systems (MS4s) of cities.

Unregulated sources are typically nonpoint source in nature, meaning the pollution originates from multiple locations and is usually carried to surface waters by rainfall runoff. Nonpoint sources are not regulated by permit.

With the exception of WWTFs, which receive individual wasteload allocations or WLAs (see report Section 4.7.3, Wasteload Allocation), the regulated and unregulated sources in this section are presented to give a general account of the potential sources of bacteria in the watershed.

2.7.1 Permitted Sources

Permitted sources are regulated by permit under the TPDES and the NPDES programs. For this section, the focus will be on the project watershed (Armand Bayou Tidal 1113_03). Stormwater discharges from MS4s represent the potential permitted sources in the entire Armand Bayou watershed.

2.7.1.1 Domestic Wastewater Treatment Facility Discharges

Currently, no WWTFs exist within or upstream of the project watershed (Armand Bayou Tidal 1113_03). There are currently three permitted WWTFs (five outfalls) within the greater

Armand Bayou watershed, which are shown in Figure 9; the permits were described in the previously-completed TMDL (TCEQ, 2015b).

Table 5. Permitted domestic WWTFs discharging to Armand Bayou Tidal (1113), but not to the subject AU (1113_03) or upstream

Source: TPDES Permit

Permit #	Outfall(s)	NPDES #	Permittee
03029-000	1	TX0103900	EQUISTAR CHEMICALS LP
10495-152	1	TX0069736	CITY OF HOUSTON
10539-001	3	TX0022543	CLEAR LAKE CITY WATER AUTHORITY

Figure 6. Land use/ land cover map showing categories within the project watershed and within the entire Armand Bayou Watershed. Figure 9. Map showing WWTF outfalls within the greater Armand Bayou Watershed, labeled by Permittee. (TCEQ, 2007)

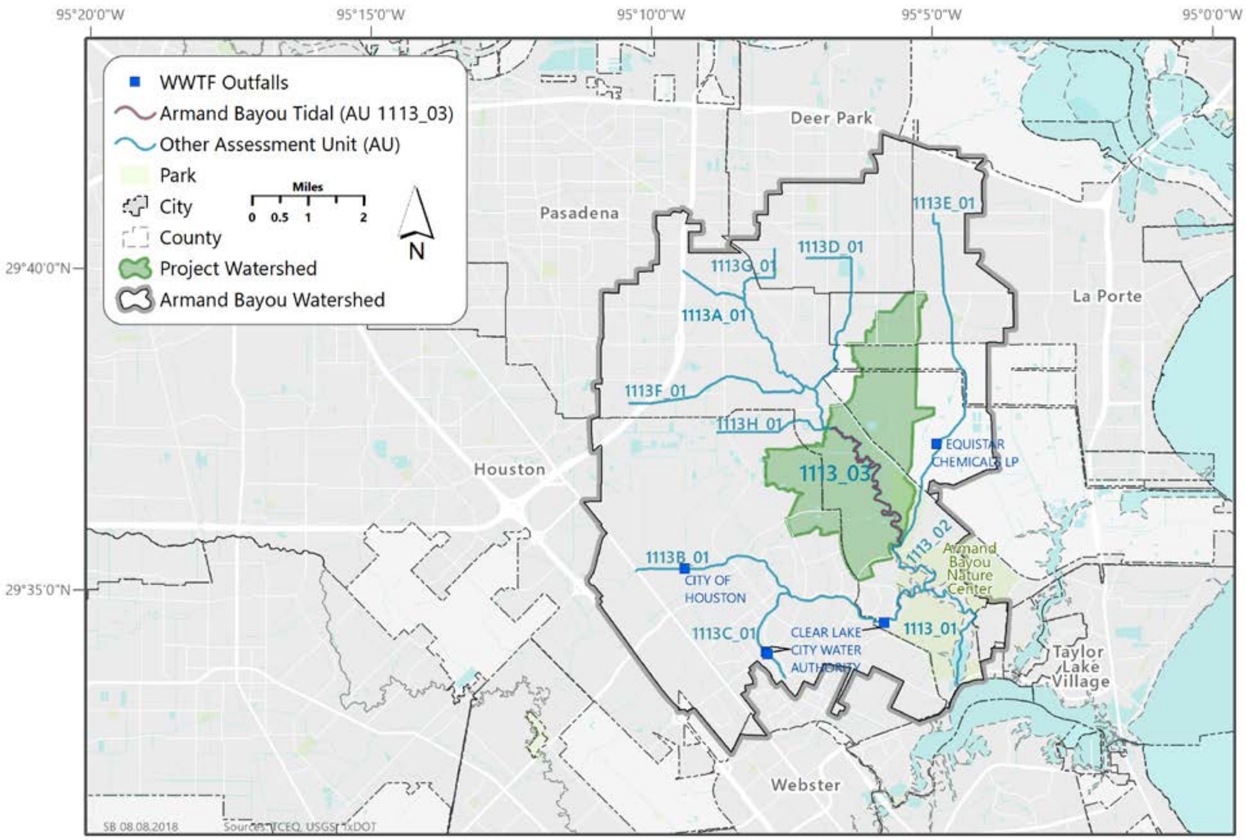

Figure 9. Map showing WWTF outfalls within the greater Armand Bayou Watershed, labeled by Permittee. (TCEQ, 2007)

2.7.1.2 Sanitary Sewer Overflows

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 Region 12 Office maintains a database of SSO data reported by municipalities. These SSO data typically contain estimates of the total gallons spilled, responsible entity and a general location of the spill. For the period between January 2016 and December 2017, there were zero SSO's reported within the project watershed (1113_03). A summary of the reports of SSO events that were determined to have occurred within the entire Armand Bayou watershed between January 2016 and December 2017 are shown in Table 6.

Table 6. Summary of SSO incidences reported in the entire Armand Bayou watershed, in 2016 and 2017.

Source: TCEQ Region 12

Watershed	No. of Incidents	Total Volume (gallons)	Average Volume (gallons)	Minimum Volume (gallons)	Maximum Volume (gallons)
Project Watershed (1113_03)	0	-	-	-	-
Entire Armand Bayou Watershed (1113)	6	56,567	9,428	0.0001	34,325

2.7.1.3 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 Phase I or Phase II MS4, stormwater discharges associated with industrial activities, and stormwater discharges from regulated construction activities; and
2. stormwater runoff not subject to regulation.

The TPDES/NPDES MS4 Phase I and II rules require municipalities and certain other entities in urban areas to obtain permits for their stormwater systems. Both the Phase I and II permits include any conveyance such as ditches, curbs, gutters, and storm sewers that do not connect to a wastewater collection system or treatment facility. Phase I permits are individual permits for large and medium-sized communities with populations exceeding 100,000, whereas Phase II permits are for smaller communities within an USEPA-defined urbanized area that are regulated by a general permit. The purpose of an MS4 permit is to reduce discharges of pollutants in stormwater to the "maximum extent practicable" by developing and implementing a Stormwater Management Program (SWMP). The SWMPs require specification of best management practices (BMPs) for six minimum control measures:

- Public education and outreach;
- Public participation/involvement;
- Illicit discharge detection and elimination;
- Construction site runoff control;
- Post-construction runoff control; and
- Pollution prevention/good housekeeping.

The area of the project watershed (1113_03) is covered by both Phase I and II MS4 permits; the associated permits match the jurisdictional boundaries of the regulated entity. For Phase I permits the jurisdictional area is defined by the city limits and for Phase II permits the jurisdictional area is defined as the intersection or overlapping areas of the city limits and the 2010 Census Urbanized Area.

For the Armand Bayou project watershed entities with Phase I individual permits and Phase II general permits, the areas included under these MS4 permits were used to estimate the regulated stormwater areas for construction, industrial and MS4 permits. For the project watershed (1113_03), there is 100% coverage by the urbanized area. However even in highly urbanized areas such as this one, there remain small areas that are not strictly regulated stormwater and which may receive bacteria loadings from unregulated sources such as wildlife and feral hogs. To account for these small unregulated areas in each impaired watershed, the surface area within the channel of the bayou is excluded from the urbanized area and represents an area of unregulated stormwater contribution. This estimation of an area subject to unregulated direct deposition results in an area regulated by MS4 of 4,561.46 acres or 99.58% of the watershed (Figure 10).

A review of Phase I permits and a review of the TCEQ central registry for Phase II MS4 permit coverage in the entire Armand Bayou watershed revealed one Phase I permit and four Phase II permits (TCEQ, 2018b). For the entire Armand Bayou watershed, the total area under MS4 permits is 35,536.90 acres, or 93.91% of the watershed.

Table 7. TPDES and NPDES MS4 permits associated with the Armand Bayou watershed.

Source: (TCEQ, 2018b)

Entity/ Permittee	Permitted Area	TPDES Permit	NPDES Permit
City of Houston/ Harris County/ HCFCD/ TxDOT	Houston	Phase 1	TXS001201
City of Deer Park	Deer Park	Phase II General Permit	TXR040388
City of La Porte	La Porte	Phase II General Permit	TXR040117
National Aeronautics and Space Administration	Houston	Phase II General Permit	TXR040214
Clear Lake City Water Authority	Pasadena, Houston, Webster and Taylor Lake Village	Phase II General Permit	TXR040388

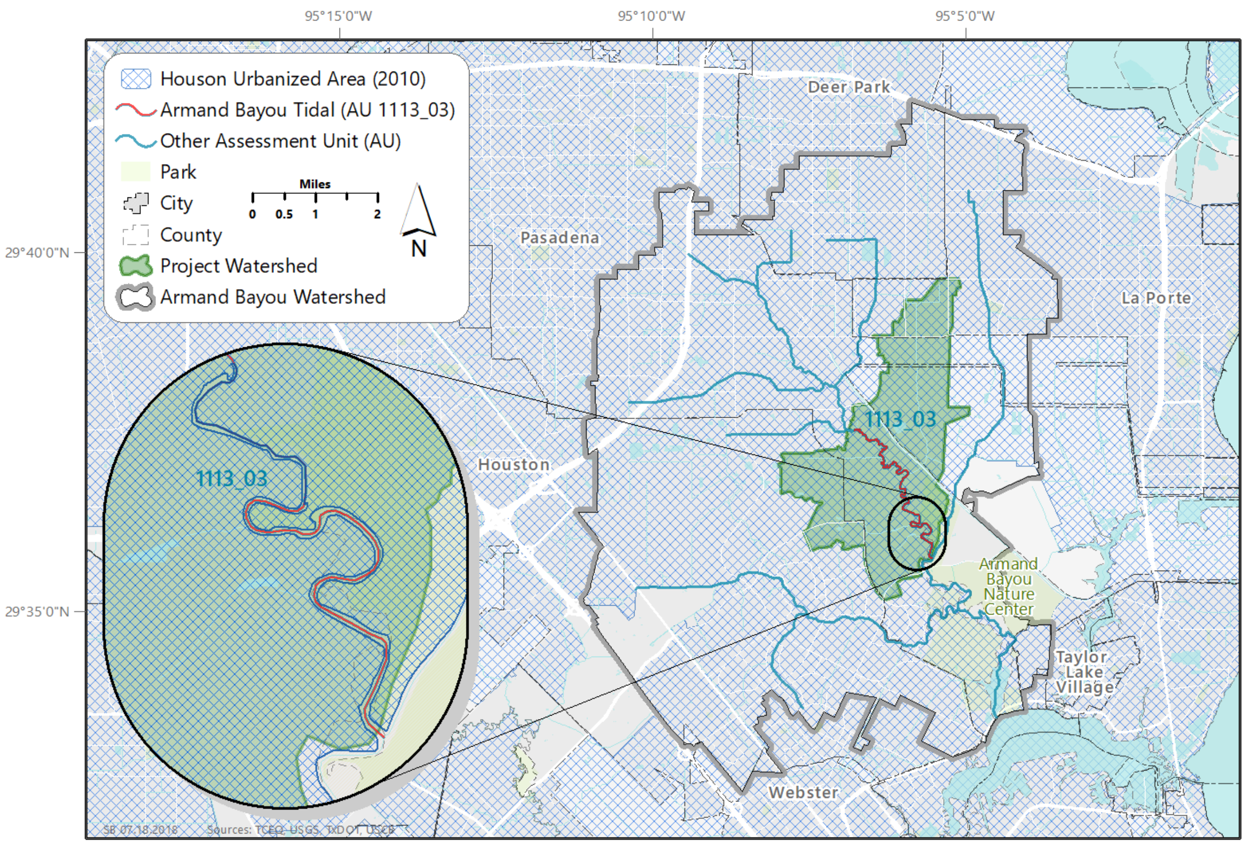

Figure 10. Map showing the regulated stormwater area based on Phase I and Phase II MS4 permits within the Armand Bayou Watershed. (USCB (United States Census Bureau), 2012)

2.7.1.4 Dry Weather Discharges/Illicit Discharges

Bacteria loads from regulated stormwater can enter the streams from permitted outfalls and illicit discharges under both dry and wet weather conditions. The term "illicit discharge" is defined in TPDES General Permit No. TXR040000 for Phase II Municipal Separate Storm Sewer Systems 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) includes:

Direct illicit discharges:

- sanitary wastewater piping that is directly connected from a home to the storm sewer;
- materials (e.g., used motor oil) 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 municipal 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.

2.7.1.5 TPDES General Wastewater Permits

In addition to the individual wastewater discharge permit listed in Table 5, discharges of processed wastewater from certain types of facilities are required to be covered by one of several TPDES general permits:

- TXG110000 – concrete production facilities
- TXG130000 – aquaculture production facilities
- TXG340000 – petroleum bulk stations and terminals
- TXG670000 – hydrostatic test water discharges
- TXG830000 – water contaminated by petroleum fuel or petroleum substances
- TXG920000 – concentrated animal feeding operations
- WQG20000 – livestock manure compost operations (irrigation only)

A review of general permits coverage (TCEQ, 2018c) for the project watershed (1113_03) found zero (0) active permits as of 30 May 2018. A review of general permits coverage for the entire Armand Bayou watershed found two concrete production facilities covered by the general permit (TXG110000), as well as two hydrostatic test water discharges covered by the general permit (TXG670000). No other active general wastewater permit facilities or operations were found. There were no facilities covered under the general permits for aquaculture production, petroleum bulk stations and terminals, water contaminated by petroleum fuel or petroleum substances, concentrated animal feeding operations or livestock manure compost operations. The general permits for both concrete production facilities and hydrostatic test water discharges do not contain bacteria reporting requirements or limits.

2.7.1.6 Review of Compliance Information on Permitted Sources

Since there were no WWTFs located within the subject watershed, there was no effort to review the EPA Enforcement & Compliance History Online (ECHO) database for compliance data.

2.7.2 Unregulated Sources

Unregulated sources of indicator bacteria are generally nonpoint and can emanate from wildlife, feral hogs, various agricultural activities, agricultural animals, land application fields, urban runoff not covered by a permit, failing onsite sewage facilities (OSSFs), and domestic pets.

2.7.2.1 Wildlife and Unmanaged Animal Contributions

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

Unfortunately, quantitative estimates of wildlife are rare, inexact, and often limited to discrete taxa groups or geographical areas of interest so that even county-wide approximations of wildlife numbers are difficult or impossible to acquire. However, population estimates for feral hogs and deer, as well as many species of birds, are readily available for the Armand Bayou watershed.

For feral hogs, the Texas A&M Institute of Renewable Natural Resources (IRNR), recently renamed as the Texas A&M Natural Resources Institute, reported a range of feral hog densities within Texas of 1.33 to 2.45 hogs/ square mile (IRNR, 2013). The average hog density (1.89 hogs/ square mile) was multiplied by the hog-habitat area in the Armand Bayou project watershed (3.74 square miles). Habitat deemed suitable for hogs followed as closely as possible to the land use selections of the IRNR study and include from the 2015 H-GAC Land Cover dataset: Forest/Shrubs, Pasture/Grasslands, Cultivated Crops, Wetlands. Using this methodology, there are an estimated 7 feral hogs in the project watershed. For the entire Armand Bayou watershed, the hog habitat was estimated using the same methodology; there is an estimated 15.69 square miles of hog habitat within the entire watershed, resulting in an estimate of 30 feral hogs.

For deer, the Texas Parks and Wildlife Department (TPWD) publishes data showing deer population-density estimates by Deer Management Unit (DMU) for monitored white-tailed deer range across the state (TPWD, 2017). The entire Armand Bayou watershed, as well as the project watershed, is located within the Urban Houston DMU, one of the few regions for which deer-density estimates were not published. Similarly, both the entire Armand Bayou watershed and the project watershed are not located within the monitored white-tailed deer range. While a quantitative estimate for deer within the project watershed could not readily be calculated, indications are that undeveloped areas along Armand Bayou would provide habitat suitable for a small population of deer (City of Houston, 2018).

2.7.2.2 On-Site Sewage Facilities

Private residential OSSFs, commonly referred to as septic systems, consist of various designs based on physical conditions of the local soils. Typical designs consist of 1) one or more septic tanks and a drainage or distribution field (anaerobic system) and 2) aerobic systems that have an aerated holding tank and often an above-ground sprinkler system for distributing the liquid. In simplest terms household waste flows into the septic tank or aerated tank, where solids settle out. The liquid portion of the water flows to the distribution system which may consist of buried perforated pipes or an above-ground sprinkler system.

Several pathways of the liquid waste in OSSFs afford opportunities for bacteria to enter ground and surface waters, if the systems are not properly operating. Properly designed and operated, however, OSSFs would be expected to contribute virtually no fecal bacteria to surface waters. For example, it has been reported that less than 0.01% of fecal coliforms originating in household wastes move further than 6.5 feet down gradient of the drainfield of a septic system (Weikel, 1996).

Reed, Stowe, and Yanke LLC (2001) provide information on estimated failure rates of OSSFs for different regions of Texas. The TMDL watershed is located within Region IV (covering parts of north, central, and coastal Texas), a region having a reported failure rate of about 12 percent, which provides insights into expected failure rates for the area. Failing OSSFs are a source of fecal pathogens and indicator bacteria loading to streams. Loading from failing OSSFs can be transported to streams in a variety of ways, including runoff from surface discharge or from transport by stormwater runoff.

Estimates of the number of OSSFs in the Armand Bayou watershed were determined using H-GAC supplied spatial data. The H-GAC data indicate that there are no OSSFs located within the project watershed, and 1 OSSF is located within the entire Armand Bayou watershed.

Table 8. OSSF permits for the project watershed (1113_03).

Source: (H-GAC (Houston-Galveston Area Council), 2018a)

Watershed	Segment/ AU Number	Permitted OSSFs
Project Watershed	1113_03	0
Entire Armand Bayou Watershed	1113	1

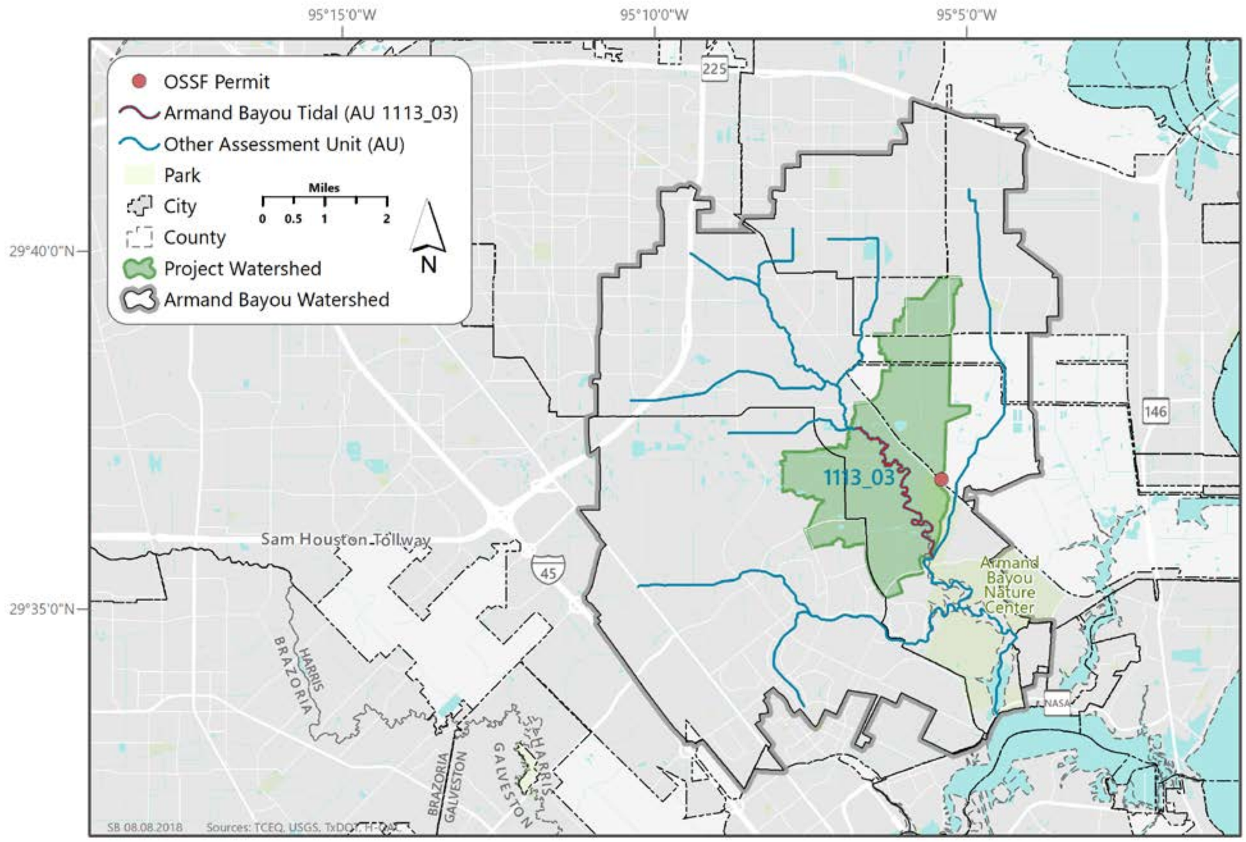

Figure 11. Map showing the single septic system located within the entire Armand Bayou watershed. The OSSF permit is not located within the project watershed.

2.7.2.3 Non-Permitted Agricultural Activities and Domesticated Animals

The number of livestock that are found within the Armand Bayou watershed was estimated from county level data obtained from the 2012 Census of Agriculture (USDA-NASS, 2014). The county-level data were refined to better reflect actual numbers within the impaired AU watersheds. The refinement was performed by dividing the total area of the project watershed by the total area of Harris County. This ratio was then applied to the county-level livestock data Table 9. The livestock numbers below are provided to demonstrate that livestock are a potential source of bacteria in the TMDL watersheds. These livestock numbers are not used to develop an allocation of allowable bacteria loading to livestock.

Table 9. Estimated total livestock inventory, by commodity, for the project watershed and the entire Armand Bayou watershed in 2012.

Source: (USDA-NASS (United States Department of Agriculture – National Agricultural Statistics Service), 2014)

Watershed	AU/ Segment Number	Cattle and Calves	Deer and Elk (Domestic)	Goats and Sheep	Horses, Ponies, Mules, Burros, and Donkeys	Poultry
Project Watershed	1113_03	144	8	15	26	40
Entire Armand Bayou Watershed	1113	1189	65	126	218	329

Fecal matter from dogs and cats is transported to streams by runoff in both urban and rural areas and can be a potential source of bacteria loading. Table 10 summarizes the estimated number of dogs and cats for the TMDL watershed. Pet population estimates were calculated as the estimated number of dogs (0.584) and cats (0.638) per household (AVMA, 2012). The actual contribution and significance of indicator bacteria loads from pets reaching the water bodies of the impaired AU watersheds is unknown.

Table 10. Estimated Households and Pet Populations for the project watershed and the entire Armand Bayou watershed.

Source: (AVMA, 2012)

Watershed	AU/ Segment Number	Estimated Number of Households	Estimated Dog Population	Estimated Cat Population
Project Watershed	1113_03	2,708	1,581	1,728
Entire Armand Bayou Watershed	1113	49,499	28,907	31,580

2.7.2.4 Bacteria Survival and Die-off

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

SECTION 3
BACTERIA TOOL DEVELOPMENT

This section describes the rationale for choosing the LDC method to develop the pollutant load allocations for Armand Bayou Tidal (1113_03) and then details the procedures and results of LDC development.

3.1 Model Selection

For consistency between the TMDLs of Armand Bayou and the previously completed "Six Total Maximum Daily Loads for Indicator Bacteria in the Armand Bayou Watershed" (TCEQ, 2015b), the development activities for the present TMDL build upon the LDC method used and reported in the previously completed TMDL. Details on the previous LDC development are found in a technical support document (TCEQ, University of Houston, CDM Smith, 2014) and the TCEQ TMDL report (2015b). Development activities of LDCs under the present project were covered under a TCEQ-approved QAPP (TIAER, 2017).

The TMDL allocation process for bacteria involves assigning bacteria, e.g., Enterococci, loads to their sources such that the total loads do not violate the pertinent numeric criterion protecting contact recreation use. To perform the allocation process, a tool must be developed to assist in allocating bacteria loads. Selection of the appropriate bacteria tool for the Tres Palacios Creek watershed considered availability of data and other information necessary for supportable application of the selected tool and guidance in the Texas bacteria task force report (Jones, et al., 2009). In general, two basic tools are commonly used for bacteria TMDLs—mechanistic computer models and an empirical approach referred to as the load duration curve (LDC).

Mechanistic computer models provide analytical abstractions of a real or prototype system. Mechanistic models, also referred to as process models, are based on theoretical principles that provide a representation of governing physical processes that determine the response of certain variables, such as stream flows and bacterial concentrations, to precipitation. Under circumstances where the governing physical processes are acceptably quantifiable, the mechanistic model provides an understanding of the important biological, chemical, and physical processes of the prototype system and reasonable predictive capabilities to evaluate alternative allocations of pollutant load sources.

The LDC method allows for estimation of existing and allowable loads by utilizing the cumulative frequency distribution of streamflow and measured pollutant concentration data (Cleland, 2003). An adaptation of the LDC method to tidal waters has been successfully developed and applied by the State of Oregon (ODEQ, 2006); this approach, which will later be described in detail, is known as the modified Load Duration Curve (modified LDC) method. In addition to estimating stream loads, the LDC method allows for the determination of the hydrologic conditions under which impairments are typically occurring. This information can be used to identify broad categories of sources (point and nonpoint) that may be contributing to the impairment. The LDC method has found relatively broad acceptance among the regulatory community, primarily due to the simplicity of the approach and ease of application. The regulatory community recognizes the frequent information limitations, often associated with bacteria TMDLs that constrain the use of more powerful mechanistic models. Further, the bacteria task force appointed by the TCEQ and the Texas State Soil and Water Conservation Board (TSSWCB) supports application of the LDC method within their three-tiered approach to TMDL development (Jones, et al., 2009). The LDC method provides a means to estimate the difference in bacteria loads and relevant criterion and can give indications of broad sources of the bacteria, i.e., point source and nonpoint source.

3.2 Data Resources of Armand Bayou Tidal

To develop the modified (described later) load duration curve (modified LDC) method for Armand Bayou Tidal various data resources are required. The three main sources are hydrologic data in the form of daily streamflow records, historical indicator bacteria data (Enterococci) and salinity data.

Streamflow, salinity, and Enterococci data availability were used to provide guidance in the allocation tool selection process. (Salinity data provided a measure of the degree of mixing of seawater and freshwater in the tidal segment.) As already mentioned, the information and data necessary to allow adequate definition of many of the physical and biological processes influencing in-stream bacteria concentrations for mechanistic model application are largely unavailable for the Armand Bayou watershed, and these limitations became an important consideration in the allocation tool selection process.

Although the Harris County Flood Control District (HCFCD) does collect rainfall and streamflow data at locations both upstream and downstream of the project watershed, it was determined that the available data were not sufficient for this effort. U.S. Geological Survey (USGS) streamflow records, however, were available for both the Vince Bayou (08075730) and Clear Creek at Mykama Street (08076997). Both were examined for compatibility with the existing salinity dataset, and a determination was made that the Clear Creek gauge provided a better basis on which to develop the modified LDC.

Streamflow records for the Clear Creek watershed are collected and made readily available by the USGS (USGS (United States Geological Survey), 2018), which operates the Clear Creek streamflow gauge (Table 11 and Figure 12). USGS streamflow gauge 08076997 is located along the mainstem of Clear Creek (Segment 1102) and serves as the primary source for streamflow records used in this document.

Table 11. Basic information on the Clear Creek USGS streamflow gauge.

Gauge No.	Site Description	Segment	Drainage Area (sq. miles)	Daily Streamflow Record (beginning & end date)
08076997	Clear Ck at Mykawa St near Pearland, TX	1102	32.7	October 2006 – present

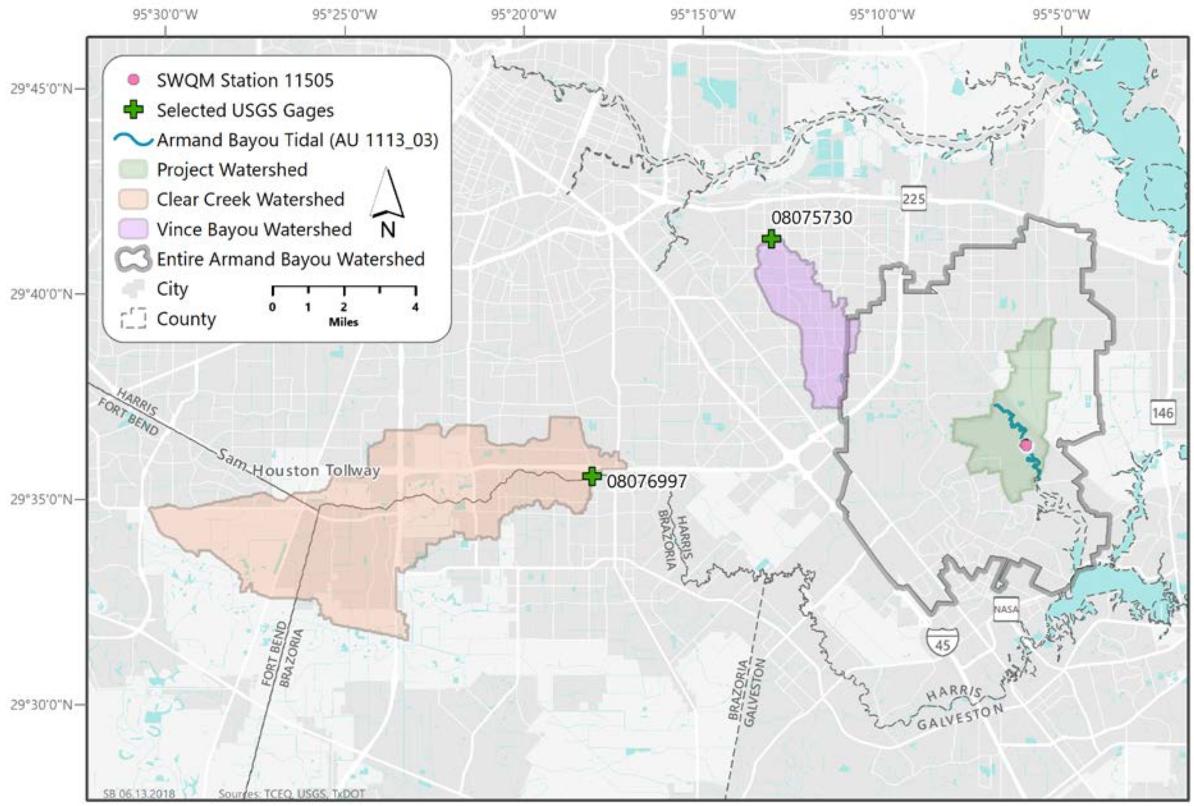

Figure 12. TMDL study area, Clear Creek and Vince Bayou watersheds and USGS Station locations.

Paired ambient Enterococci and salinity data were available through the TCEQ SWQMIS for Station 11505, located in the middle of the project waterbody (AU 1113_03) (Figure 8 and Figure 12).

Table 12. Summary of historical bacteria data sets.

Source: (TCEQ, 2018b)

Water Body	Assessment Unit (AU)	Station	Station Location	Indicator Bacteria	No. of Enterococci Samples	No. of Salinity Samples	Data Date Range
Armand Bayou Tidal	1113_03	11505	Armand Bayou Tidal at Exxon Oil Rd.	Enterococci	54	160	July 1980 - present

3.2.1 Situational Limitations of Mechanistic Modeling

The present surface water bacteria standards do not restrict what streamflow conditions the primary contact recreation criteria should meet; therefore, the allocation process must consider all streamflow conditions ranging from low flows to high flows. Additionally, the water body for TMDL development is tidally influenced, which adds yet another level of complexity to the processes that need to be considered. The TMDL allocation tool, therefore, must be capable of characterizing tidal influences, streamflow and bacteria loads at desired locations under the wide variety of environmental conditions experienced in the TMDL watershed. If a mechanistic modeling tool is applied, it must be capable of simulating response of bacterial loadings to streamflow and tidal conditions during base flow as well as during times of response to rainfall runoff and those intermediate conditions between well-defined base flow and strong rainfall-runoff response. The type of mechanistic tool with capabilities to simulate all these complexities is often referred to as a combined watershed loading and hydrologic/water quality model. These models simulate the hydrologic response of the watershed's land uses and land covers to rainfall, route runoff water through the conveyance channels of the watershed, add in point source contributions, and may include other hydrologic processes such as interaction of surface waters with shallow ground water.

While admittedly the streamflow and tidal processes requiring simulation are complex, these processes are generally better understood and more readily simulated than the bacterial processes. Nonetheless, mechanistic bacteria modeling has progressed significantly over the last several decades beginning in the late 1960s to early 1970s, as increasing computer resources made such endeavors possible. Regrettably for the application of mechanistic bacteria models, while the numerical equations to represent many pertinent processes exist and are incorporated in readily available models, these processes are appreciably more watershed specific than hydrologic processes. As one simple example, failing on-site treatment systems, such as septic systems, rarely makes measurable differences to streamflow, but can dramatically impact fecal bacteria concentrations present in the same streamflow. In the vast majority of circumstances, and the Armand Bayou Tidal watershed is no exception, only very limited watershed-specific information is available to define many of the physical and biological processes that affect bacteria concentrations and loadings. Consequentially, the operator of the mechanistic model must specify, in many circumstances, numerous input parameters governing bacteria processes for which actual numeric values may not be known within a reasonable range of certainty.

3.3 Methodology for Flow Duration & Load Duration Curve Development

LDCs display the maximum allowable load over the complete range of flow conditions by a curved line, using the calculation of flow multiplied by the water quality criterion. Through LDCs, a TMDL can be expressed as a continuous function of flow as expressed through the curved line or as a discrete value derived from a specific flow condition. To develop the flow duraction curve (FDC) and LDC for Armand Bayou, the previously discussed data resources were used in the following series of sequential steps.

- Step 1: Determine the hydrologic period of record to be used in developing the FDC.
- Step 2: Determine desired stream location for which a FDC and LDC will be developed.
- Step 3: Develop naturalized daily streamflow records for desired stream location using the daily gauged streamflow records, drainage area ratios, and future growth flows.
- Step 4: Develop regression of salinity to streamflow for stream location.
- Step 5: Develop daily streamflow records at stream location using the naturalized streamflow from Step 3 and incorporating daily tidal volumes from Step 4.
- Step 6: Develop FDC at stream location, segmented into discrete flow regimes.
- Step 7: Develop the allowable bacteria LDC at the same stream location based on the relevant criteria and the data from the FDC.
- Step 8: Superpose historical bacteria data on the allowable bacteria LDC.

Additional information explaining the LDC method may be found in Cleland (2003) and NDEP (2003). Information on the modified LDC method is found in ODEQ (2006).

3.3.1 Step 1: Determine Hydrologic Period

More than an 11-year period of continuous daily streamflow was available for USGS gauge 08076997 located on nearby Clear Creek at Mykawa St near Pearland, TX (Section 3.2). Optimally, the period of record to develop FDCs should include as much data as possible to capture extremes of high and low streamflow and hydrologic variability from high to low precipitation years, but the flow during the period of record selected should also be representative of recent conditions experienced within the watershed and when the Enterococci data were collected.

An 11.25-year record of daily streamflow from 01 October 2006 through 31 December 2017 was selected to develop the FDC, based on the time frame when daily flow data was collected at the USGS gauge on Clear Creek. An 11-plus-year period is of sufficient duration to contain a reasonable variation of dry and wet periods and, at the same time, is short enough in duration to reflect recent and current conditions in the watershed. The period selected does result in the exclusion from the LDC method of older Enterococci data collected prior to 01 October 2006 within Armand Bayou. With the relative abundance of recent Enterococci measurements collected during the selected 11-year period, the exclusion of the older data does not appreciably decrease the number of data points and allows an emphasis on data representing a more recent period of time when elevated Enterococci concentrations were identified in the subject water body.

3.3.2 Step 2: Determine Desired Stream Location

When using the LDC method, the optimal location for developing the pollutant load allocation is a currently monitored SWQM station located near the outlet of the watershed with an abundance of historical bacteria data. Within the subject water body (AU 1113_03), there is only one SWQM station at which any Enterococci data were collected – station 11505 (Table 3) (Figure 8). While the location of SWQM station 11505 (near the middle of the assessment unit) is not optimal, the station remains the only reasonable option.

3.3.3 Step 3: Develop Naturalized Daily Streamflow Records

Once the hydrologic period of record and station locations were determined, the next step was to develop the 11.25-year daily streamflow record for SWQM station 11505. As used herein, naturalized flow is referring to the flow without the additions of permitted discharges, i.e., the flows that would occur in response to precipitation, evapotranspiration, near-surface geology, soils, land covers of the watershed, and other factors. The daily streamflow records were developed from extant USGS records (Table 11).

The method to develop the necessary streamflow record for SWQM station 11505 involved a drainage-area ratio (DAR) approach. With this basic approach, the USGS gauge 08076997 daily streamflow value within the 11.25-year period was multiplied by a factor to estimate the flow at a desired SWQM station location. The factor was determined by dividing the drainage area above the desired monitoring station location by the drainage area above the USGS gauge. The Drainage Area Ratios (DARs) for the relevant locations are presented in Table 13.

Table 13. DARs for selected location within the TMDL watershed based on the drainage area of the Clear Creek USGS gauge.

Water Body	Segment/ AU	Gauge/Station	Drainage Area (sq. miles)	Drainage Area Ratio (DAR)
Clear Creek	1102	08076997	34.4980	1.00
Armand Bayou Tidal	1113_03	11505	24.4599	0.7090

In order to properly apply the DAR, the "naturalized" flow at the USGS gage was estimated first. The "naturalized" flow is the gaged flow without permitted discharges. First, WWTF flows in the form of estimated daily DMR reported discharge for all WWTFs upstream of the USGS gage location were subtracted from the streamflow record of the gage, resulting in an adjusted streamflow record with point source discharge influences removed. A search for NPDES/TPDES permitted facilities within the Clear Creek gage watershed returns four active permits upstream of the gauge (USEPA, 2018). Three of the permits are for municipal effluent (City of Pearland [2 permits], Harris County WCID 89), and one is for industrial effluent (Syntech Chemicals). Discharge Monitoring Report (DMR) effluent data (average flows reported monthly) previous to June 2009 was acquired through the EPA Permit Compliance System (PCS) (2017); DMR data for 2009 through 2017 was downloaded through the EPA Enforcement and Compliance History Online (ECHO) website (2018). These DMR flows were compiled and subsequently subtracted from the flow record on a daily basis.

At this point, the "naturalized" flow at the USGS gage has been calculated. The next step was to multiply the DAR for Station 11505 (0.7090) by the naturalized streamflow record at the USGS gage location giving the estimated daily flow record for the selected location in the project watershed. Because of estimates of daily discharges used in this process, negative flows were occasionally computed. All negative flows were set to a value of zero.

3.3.4 Step 4: Perform Salinity to Streamflow Regression

As part of the development of the modified LDC method, it was necessary to develop a relationship between estimated actual daily streamflow and measured salinity for the selected Tidal location (SWQM station 11505). The resulting regression was instrumental in determining the daily volume of saltwater present for each daily freshwater flow in the 11.25-year period of record. A salinity to streamflow regression was developed for Station 11505, located within the tidally-influenced portion of Armand Bayou (Segment 1113). The resultant equation was used to calculate the volume of seawater that would flow through the station cross-section over the period of a day (Figure 12). It is noteworthy that above a streamflow of 20 cfs, tidal influences become minimal and measured salinities are at the background levels of the freshwater inflows.

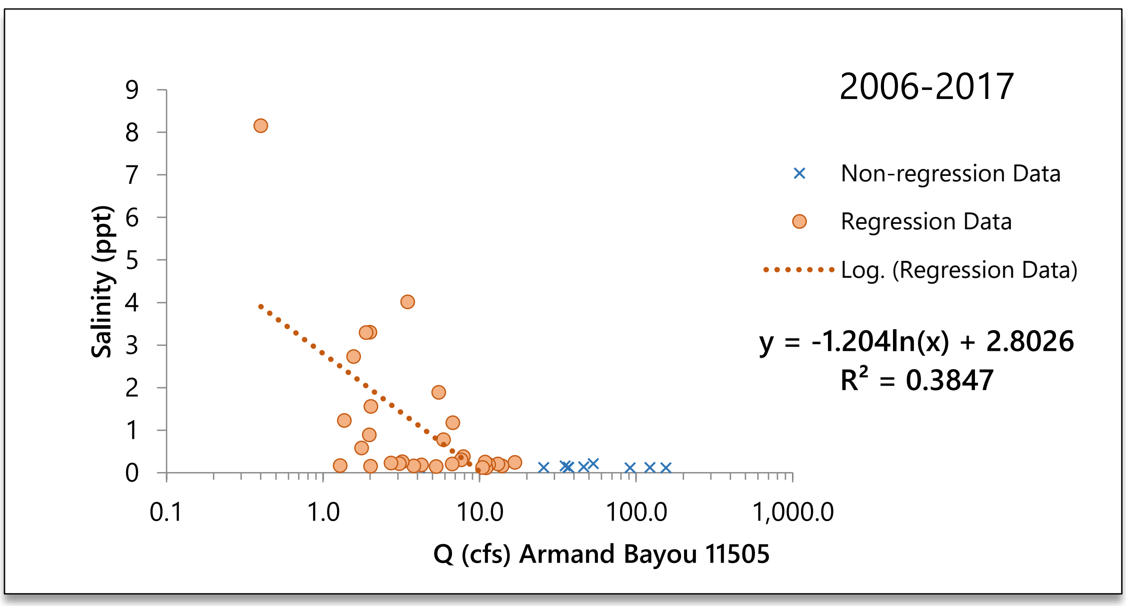

Figure 13. Salinity to Streamflow regression for Station 11505 (AU 1113_03).

3.3.5 Step 5: Incorporate Daily Tidal Volumes into Streamflow Record

As previously mentioned, the daily streamflow record for tidally influenced Station 11505 contains an additional flow component which is not part of the streamflow record for above-tidal stations. The regression equation developed in Step 4 was used to allow computation of a total daily flow volume including freshwater and seawater. The process requires manipulation of the following mass balance equation for salinity at a tidally influenced station:

$$(Q_{river} + Q_{sw}) * S_{river} = Q_{river} * S_b + Q_{sw} * S_{sw} \quad \textbf{(Eq. 1)}$$

Q_{river} = volume of daily freshwater (river) flow

Q_{sw} = volume of daily seawater flow

S_{river} = salinity in river (part per thousand or ppt)

S_b = background salinity of upstream river water (ppt); assumed = 0 ppt

S_{sw} = salinity of seawater (assumed to be 35 ppt)

Through algebraic manipulation this mass balance equation can be solved for the daily volume of seawater required to be mixed with freshwater (again, freshwater having an assumed salinity = 0) giving the equation found in the ODEQ TMDL (2006) technical information:

$Q_{sw} = Q_{river} / (S_{sw}/S_{river} - 1)$; for S_{river} > than background salinity, otherwise $Q_{sw} = 0$ **(Eq. 2)**

Where S_{river} was computed for each day of the 11.25-year streamflow record using the station-specific regression equations of Step 4 and the estimated actual daily streamflow (Q_{river}), also from Step 4, as input to the equation. The calculation of S_{river} allowed Q_{sw} to be computed from Eq. 2.

The modified daily flow volume (Q_{mod}) that includes the daily freshwater flow (Q_{river}) and the daily volume of seawater flow (Q_{sw}) is computed as:

$$Q_{mod} = Q_{river} + Q_{sw} \quad \textbf{(Eq. 3)}$$

Typically, after the calculation of the modified daily flow volume, the full permitted flows for any permitted WWTFs within or upstream of the impaired watershed are added to the streamflow record. Since there are no WWTF outfalls in or above the project watershed (Table 5 and Figure 9), no adjustment was necessary.

Lastly, future growth flows for the project watershed (calculated in Section 4.7.4) were added to the streamflow record. Based on the population projections presented earlier (Section 2.4), a future potential community of 5,000 persons was assumed. This number allows a reasonable buffer for uncertainty related to future development. Based on the TCEQ design guidance for WWTFs (TCEQ, 2010) the daily wastewater flow of 100 gallons/ person was assumed, resulting in a future growth flow of 0.5 MGD for the watershed.

3.3.6 Step 6: Develop Flow Duration Curve (FDC)

A FDC is a graph indicating the percentage of time during which a certain value of flow is equaled or exceeded. To develop an FDC for a location the following steps were undertaken:

- order the daily streamflow data for the location from highest to lowest and assign a rank to each data point (1 for the highest flow, 2 for the second highest flow, and so on);
- compute the percent of days each flow was exceeded by dividing each rank by the total number of data point plus 1, and
- plot the corresponding flow data against exceedance percentages.

Exceedance values along the x-axis represent the percent of days that flow was at or above the associated flow value on the y-axis. Exceedance values near 100% occur during low flow or drought conditions while values approaching 0% occur during periods of high flow or flood conditions. This graphical procedure provides information on basic hydrological characteristics in the stream based upon flows observed within specific reaches.

For Station 11505 within Armand Bayou Tidal, the amount of estimated seawater is presented in the intermediate FDC (Figure 14) using the flows from Step 4. As expected from the modified daily flow volume equation, the amount of seawater present increases as both the freshwater flow decreases and the percent of days the flow is exceeded increases. Note that the x-axis direction of increase on the seawater plot is reversed from that on the FDC, because the seawater is presented separately from the freshwater and combined flows.

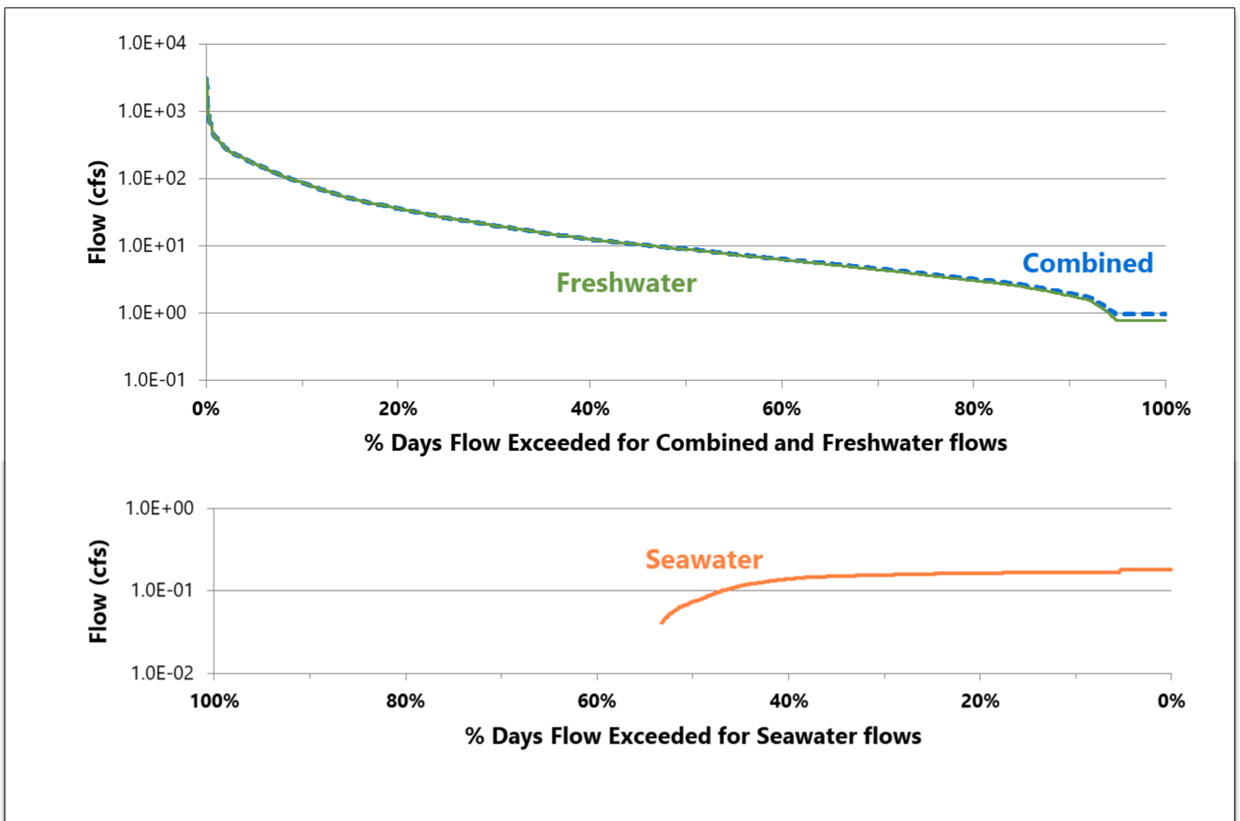

Figure 14. Intermediate FDC for Armand Bayou Tidal (Station 11505) showing the Freshwater and Seawater components.

The final FDC was created as previously described, based solely on the freshwater component. Only the freshwater component is used in the final FDC because at high flows the freshwater flows essentially force any seawater out of the system.

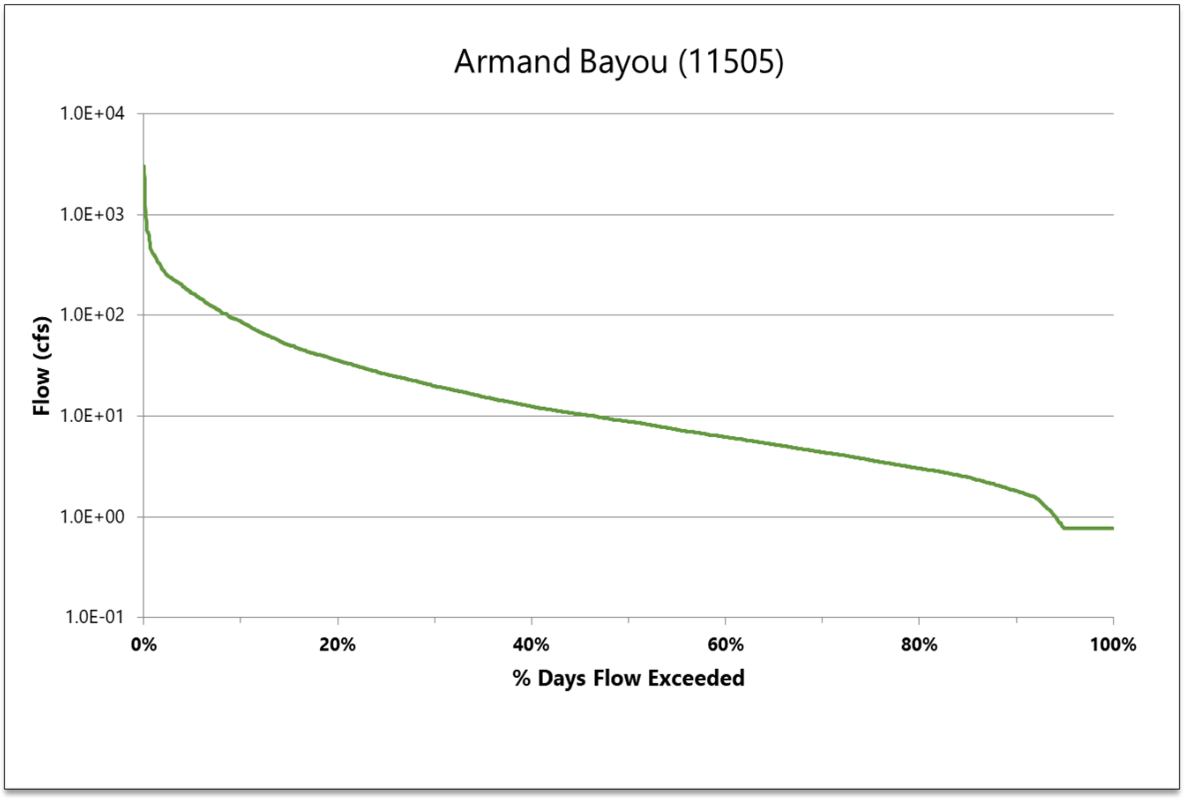

Figure 15. FDC for Armand Bayou Tidal (Station 11505) showing only the Freshwater component.

The Armand Bayou Tidal freshwater flows that were calculated at Station 11505 ranged from a high of 3,025.47 cfs, to a low of 0.77 cfs.

3.3.7 Step 7: Develop Load Duration Curve (LDC)

An LDC is a graph indicating the percentage of time during which a certain value of load is equaled or exceeded. To develop an LDC for a location the following steps were undertaken:

- multiply the streamflow in cubic feet per second (cfs) by the appropriate water quality criteria for Enterococci (geometric mean of 35 MPN/100 mL, single sample of 104 MPN/100 mL) and by a conversion factor (2.44658×10^7), which gives a loading in units of MPN/day; and
- plot the exceedance percentages, which are identical to the value for the streamflow data points, against geometric mean criterion of Enterococci.

The shape of each LDC is identical to that of the FDC for the same station, because the data in the FDCs have all been multiplied by the same conversion factor. The label on the y-axis simply changes from “Flow (cfs)” to “Enterococci (MPN/ day)”, and the label on the x-axis changes from “% Days Flow Exceeded” to “% Days Load Exceeded.”

A useful refinement of the LDC approach is to divide the curve into flow-regime regions to analyze exceedance patterns in smaller portions of the duration curves. This approach can assist in determining streamflow conditions under which exceedances are occurring. A commonly used set of regimes that is provided in Cleland (2003) is based on the following five intervals along the x-axis of the FDCs and LDCs: (1) 0-10% (high flows); (2) 10-40% (moist conditions); (3) 40-60% (mid-range flows); (4) 60-90% (dry conditions); and (5) 90-100% (low flows).

For Station 11505 within Armand Bayou Tidal, streamflow distribution was divided into three flow regimes: High Flows, Mid-range Flows, and Low Flows, which maintains consistency with the previously completed TMDL (Table 14) (TCEQ, 2015b). High flow conditions correspond to large storm-induced runoff events. Mid-range flow conditions typically represent periods of medium base flows but can also represent small runoff events and periods of flow recession following large storm events. Low flow conditions represent relatively dry conditions, resulting from extended periods of little or no rainfall.

Table 14. Flow Regime Classifications

Flow Regime Classification	Flow Exceedance Percentile
High Flows	0 – 20%
Mid-range Flows	20 – 80%
Low Flows	80 – 100%

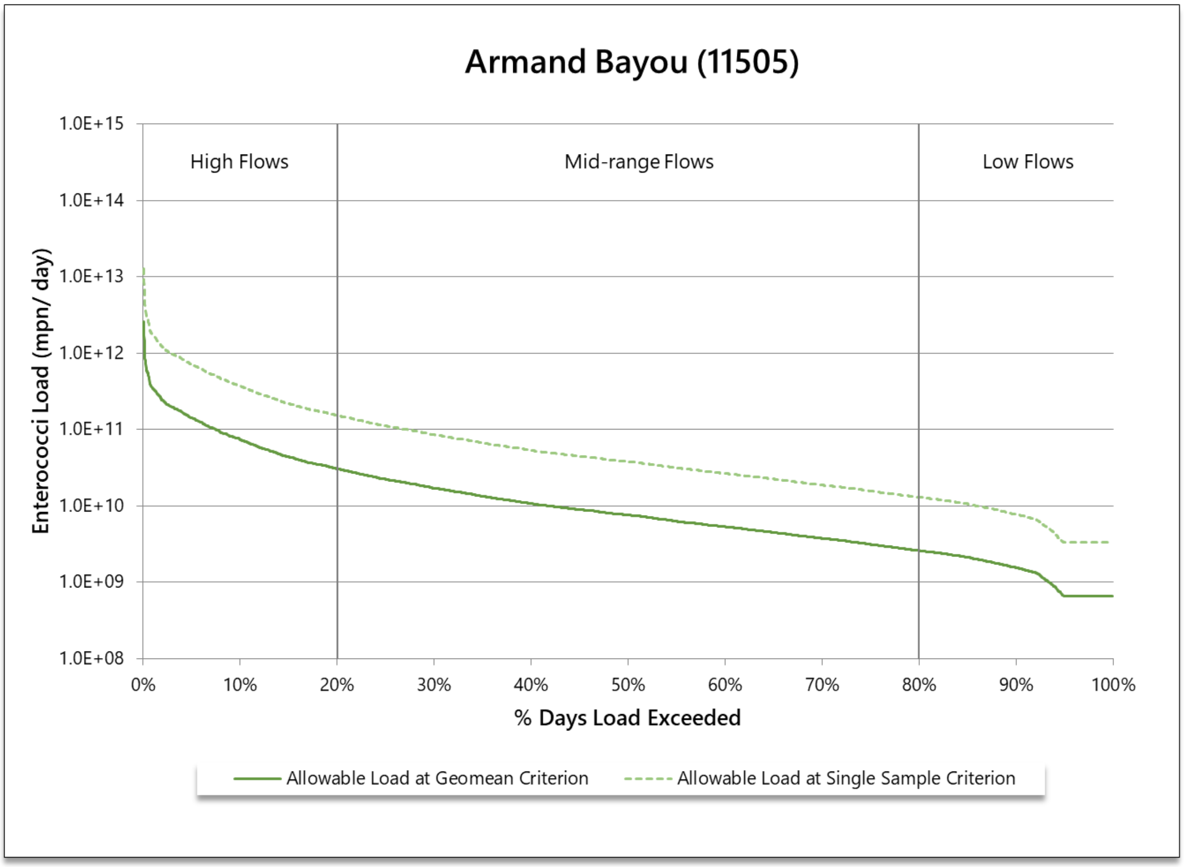

Figure 16. Intermediate LDC for Armand Bayou Tidal (Station 11505).

3.3.8 Step 8: Superpose Historical Bacteria Data

Additionally, historical bacteria measurements (Enterococci) were aligned with the streamflow on the day of measurement. The historical bacteria measurements were then multiplied by the streamflow value and the conversion factor, as described in Section 3.3.7, to calculate a loading associated with each measured bacteria concentration. On each graph the measured Enterococci data are presented as associated with a "wet weather event" or a "non-wet weather event." This determination was made based on the "days since last precipitation" (DSLP) value. If the DSLP equaled 0,1, 2 or 3 days, then the associated event was labeled a "wet" weather event, otherwise the event was labeled "non-wet".

The plot of the LDC with the measured loads (Enterococci concentration multiplied by the daily streamflow) displays the frequency and magnitude with which the measured loads exceed the maximum allowable loadings for the geometric mean criterion. Measured loads that are above a maximum allowable loading curve indicate an exceedance of the water quality criterion, while those below a curve show compliance.

The Enterococci event data plotted on the LDC for station 11505 in Figure 17 shows a pattern of increasing tendency for the Enterococci event data to plot below the geometric mean criterion allowable loading curve as flows decrease, which is indicated in a left to right direction along the graph. This pattern of decreasing occurrence of exceedances in the event data are summarized by the geometric means of the existing data plotted for each of the three flow regimes as compared to the allowable load line for the geometric mean criterion.

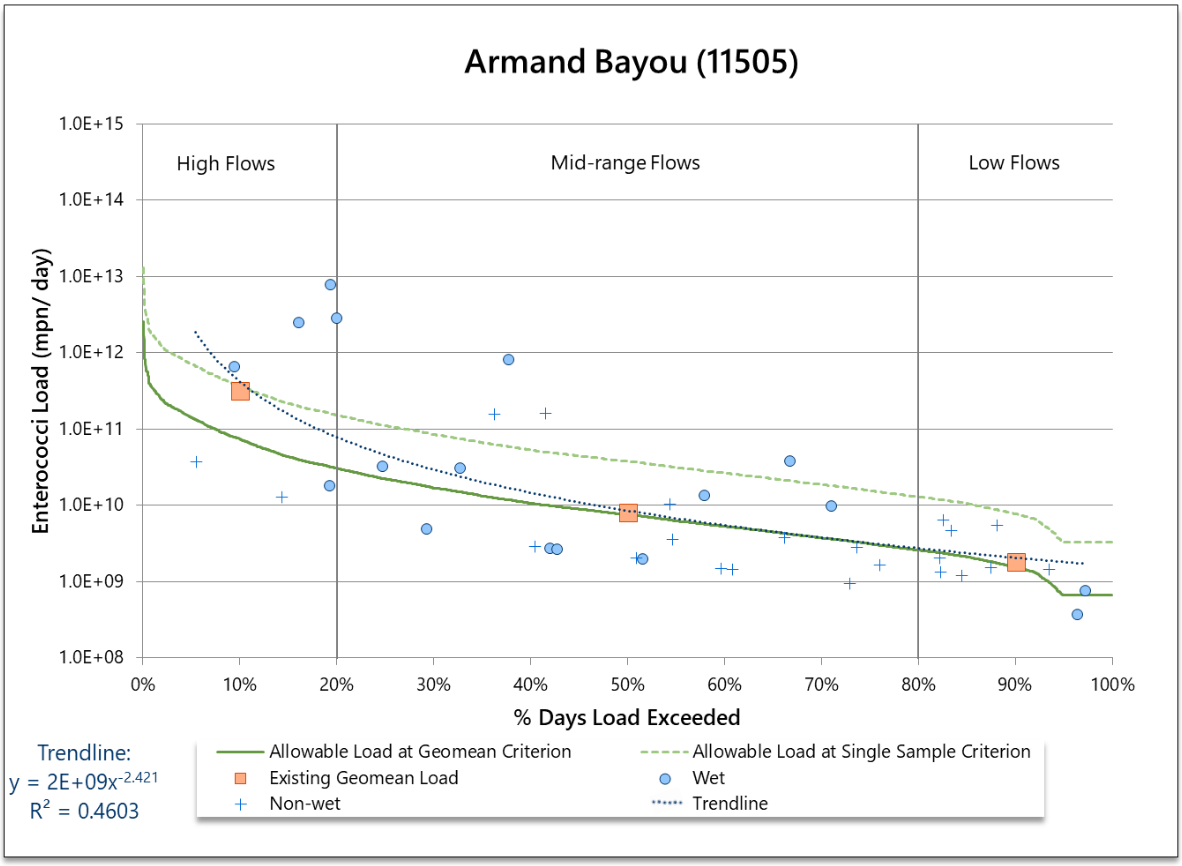

Figure 17. Final LDC for Armand Bayou (11505).

SECTION 4
TMDL ALLOCATION ANALYSIS

Presented in this report section is the development of the bacteria TMDL allocation for the Armand Bayou project watershed. The tool used for developing each TMDL allocation was the LDC method previously described in Section 3 – Bacteria Tool Development. Endpoint identification, margin of safety, load reduction analysis, TMDL allocations, and other TMDL components are described herein.

The LDC method provided a flow-based approach to determine necessary reductions in bacteria loadings and allowable loadings within the Armand Bayou TMDL watershed. As developed previously in this report, the modified LDC method uses frequency distributions to assess a bacteria criterion over the historical range of flows, providing a means to determine maximum allowable loadings and the load reduction necessary to achieve support of the primary contact recreation use.

For the purposes of this TMDL study, the TMDL watershed is the Armand Bayou Tidal 1113_03 watershed as shown in the overview map (Figure 2). Data from only one SWQM station (11505) is available for the project watershed; therefore, TMDL calculations are based on the location of SWQM station 11505.

Additionally, a drainage area ratio approach using historical streamflow records from a nearby USGS gauge on Clear Creek was employed to estimate the daily flow for the station 11505 within the project watershed.

4.1 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. Armand Bayou Tidal (1113_03) has a use of primary contact recreation, which is measured against a numeric criterion for the indicator bacteria Enterococci. Indicator bacteria are not generally pathogenic and are indicative of potential viral, bacterial, and protozoan contamination originating from the feces of warm-blooded animals. The Enterococci criterion to protect contact recreation in saltwater streams consists of a geometric mean concentration not to exceed 35 MPN/100 mL (TCEQ, 2010).

The endpoint for this TMDL is to maintain concentrations of Enterococci below the geometric mean criterion of 35 MPN/100 mL. This endpoint is identical to the geometric mean criterion in the 2010 Surface Water Quality Standards (TCEQ, 2010).

4.2 Seasonality

Seasonal variations or seasonality occur(s) when there is a cyclic pattern in streamflow and, more importantly, in water quality constituents. Federal regulations (40 CFR §130.7(c)(1)) require that TMDLs account for seasonal variation in watershed conditions and pollutant loading. Analysis of the seasonal differences in indicator bacteria concentrations were assessed by comparing Enterococci concentrations obtained from 11 years (2006 – 2017) of routine monitoring collected in the warmer months (May - September) against those collected during the cooler months (October – April). Differences in Enterococci concentrations obtained in warmer versus cooler months were then evaluated by performing a t-test on the natural log-transformed dataset. This analysis of Enterococci data indicated that there was no significant difference in indicator bacteria between cool (M= 3.98, SD = 3.30) and warm (M = 4.03, SD = 3.62) weather seasons for Armand Bayou Tidal at station 11505 (two-sample $t(37) = -0.0772$, $\alpha = 0.05$, $p = 0.0938$).

4.3 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 to be point sources and direct fecal material deposition into the water body. During ambient flows, these 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 and direct deposition is typically diluted, and would, therefore, be a smaller part of the overall concentrations.

Bacteria load contributions from permitted and non-permitted stormwater sources are greatest during runoff events. Rainfall runoff, depending on 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 lower concentrations 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 decline 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.

Load duration curves were used to examine the relationship between instream water quality and the source of indicator bacteria loads. Inherent to the use of LDCs as the mechanism of linkage analysis is the assumption of a one-to-one relationship between instream loadings and loadings originating from point sources and the landscape as regulated and non-regulated sources. Further, this one-to-one relationship was also inherently assumed when using LDCs to define the TMDL pollutant load allocation (Section 4.7).

4.4 Load Duration Curve Analysis

The LDC method was used to examine the relationship between instream water quality, the broad sources of indicator bacteria loads, and are the basis of the TMDL allocations. The strength of this TMDL is the use of the LDC method to determine the TMDL allocations. LDCs are a simple statistical method that provides a basic description of the water quality problem. This tool is easily developed and explained to stakeholders, and uses available water quality and flow data. The LDC method does not require any assumptions regarding loading rates, stream hydrology, land use conditions, and other conditions in the watershed. The USEPA supports the use of the basic LDC approach to characterize pollutant sources. In addition, many other states are using this basic method to develop TMDLs. As discussed in more detail in Section 4.7 (Pollutant Load Allocation), the TMDL loads were based on the median flow within the High flow regime (or 10 percent flow) to remain consistent with the approach of the previous TMDL (TCEQ, 2015b).

The LDC method allows for estimation of existing and TMDL loads by utilizing the cumulative frequency distribution of streamflow and measured pollutant concentration data (Cleland, 2003). In addition to estimating stream loads, this method allows for the determination of the hydrologic conditions under which impairments are typically occurring, can give indications of the broad origins of the bacteria (i.e., point source and stormwater) and provides a means to allocate allowable loadings.

Based on the LDC to be used in the pollutant load allocation process with historical Enterococci data added to the graph (Figure 17) and Section 2.7 (Potential Sources of Fecal Indicator Bacteria), the following broad linkage statements can be made. For the Armand Bayou Tidal watershed (1113_03), the historical Enterococci data indicate that elevated bacteria loadings occur under all three flow regimes. There is some moderation of the elevated loadings under Mid-range and Low flow conditions. As shown in Figure 17, the geometric means of the measured data for each flow regime generally support these observations of decreasing concentration with decreasing flow.

4.5 Margin of Safety

The margin of safety (MOS) is used to account for uncertainty in the analysis performed to develop the TMDL and thus provides a higher level of assurance that the goal of the TMDL will be met. According to EPA guidance (USEPA, 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 TMDL covered by this report incorporates an explicit MOS by setting a target for indicator bacteria loads that is 5 percent lower than the geometric mean criterion. For primary contact recreation, this equates to a geometric mean target for Enterococci of 33.3 MPN/100 mL. The net effect of the TMDL with MOS is that the assimilative capacity or allowable pollutant loading of each water body is slightly reduced.

4.6 Load Reduction Analysis

While the TMDL for the Armand Bayou Tidal 1113_03 was developed using LDC and associated load allocations, additional insight may, in certain situations, be gained through a load reduction analysis. A single percent load reduction required to meet the allowable loading for each of the three flow regimes was determined using the historical Enterococci data obtained from the monitoring station within the impaired water body.

For each flow regime, the percent reduction required to achieve the geometric mean criterion was determined by calculating the difference in the existing (or measured) geometric mean concentration and the 35 MPN/100 mL criterion and dividing that difference by the existing geometric mean concentration (Table 15).

Table 15. Percent reduction calculations for Armand Bayou station 11505 (AU 1113_03).

Flow Regime	Number of Samples	Geometric Mean by Flow Regime (MPN/100 mL)	Percent Reduction by Flow Regime
High Flows (0-20%)	7	154	77%
Mid-range Flows (20-80%)	22	38	8%
Low Flows (80-100%)	10	41	15%

4.7 Pollutant Load Allocation

A 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:

$$TMDL = WLA + LA + FG + MOS \quad \textbf{(Eq. 1)}$$

Where:

TMDL = total maximum daily load

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

LA = load allocation, the amount of pollutant allowed by non-regulated or non-permitted sources

FG = loadings associated with future growth from potential permitted facilities

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, TMDLs are expressed as MPN/day, and represent the maximum one-day load the stream can assimilate while still attaining the standards for surface water quality.

4.7.1 AU-Level TMDL Computations

The bacteria TMDL for Armand Bayou was developed as pollutant load allocation based on information from the LDC for Armand Bayou monitoring station 11505 (Figure 17). As discussed in more detail in Section 3, the bacteria LDC was developed by multiplying each flow value along the flow duration curves by the Enterococci geometric mean criterion (35 MPN/100 mL) and by the conversion factor used to represent the allowable loading in MPN/day. Effectively, the "Allowable Load" displayed in the LDC at 10 percent exceedance (the median value of the high-flow regime) is the TMDL:

TMDL (MPN/day) = Criterion * Flow (cfs) * Conversion factor **(Eq. 2)**

Where:

Criterion = 35 MPN/100 mL (Enterococci)

Conversion factor (to MPN/day) = 283.168 100 mL/ft3 * 86,400 sec/day

The allowable loading of Enterococci that the impaired AU 1113_03 can receive on a daily basis was determined using Equation 2 based on the median value within the high flows regime of the FDC (or 10 percent flow exceedance value) for the SWQM station 11505 (Table 16).

Table 16. Summary of allowable loading calculations for Armand Bayou station 11505 (AU 1113_03).

Watershed (Station)	AU	10% Exceedance Flow (cfs)	10% Exceedance Load (MPN/ day)	Indicator Bacteria	TMDL (Billion MPN/ day)
Armand Bayou Tidal (11505)	1113_03	86.229	7.38E+10	Enterococci	73.838

4.7.2 Margin of Safety

The margin of safety (MOS) is only applied to the allowable loading for a watershed. Therefore, the MOS is expressed mathematically as the following:

$$MOS = 0.05 * TMDL \qquad \textbf{(Eq. 3)}$$

Where:

MOS = margin of safety load

TMDL = total maximum daily (allowable) load

Since the MOS is based solely on the TMDL term, the calculation is straightforward (Table 17).

Table 17. MOS calculations for Armand Bayou station 11505 (AU 1113_03).

Water Body	AU	TMDL[a]	MOS
Armand Bayou Tidal	1113_03	73.838	3.692

a TMDL from Table 16.

4.7.3 Wasteload Allocation

The Wasteload Allocation (WLA) consists of two parts – the wasteload that is allocated to TPDES-regulated wastewater treatment facilities (WLA_{WWTF}) and the wasteload that is allocated to regulated stormwater dischargers (WLA_{SW}).

$$WLA = WLA_{WWTF} + WLA_{SW} \qquad \textbf{(Eq. 4)}$$

TPDES-permitted WWTFs are allocated a daily wasteload (WLA_{WWTF}) calculated as their full permitted discharge flow rate multiplied by the instream geometric criterion. Due to the absence of any permitted dischargers in the Armand Bayou Tidal (1113_03) watershed, the WLA_{WWTF} term is zero.

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

$$WLA_{SW} = (TMDL – WLA_{WWTF} – FG – MOS) * FDA_{SWP} \qquad \textbf{(Eq. 5)}$$

Where:

WLA_{SW} = sum of all regulated stormwater loads

TMDL = total maximum daily load

WLA_{WWTF} = sum of all WWTF loads

FG = 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 order to calculate the WLA_{SW} component of the TMDL, the fractional proportion of the drainage area under the jurisdiction of stormwater permits (FDA_{SWP}) must be determined to estimate the amount of overall runoff load that should be allocated to WLA_{SW}. The term FDA_{SWP} was calculated based on the combined area under regulated stormwater permits. As described in Section 2.7.1.3, the Armand Bayou project watershed is covered 99.58 percent by MS4 Phase II general permits and/or a Phase I individual permit (Figure 10).

Table 18. Calculation of the FDA_{SWP} term for Armand Bayou station 11505 (AU 1113_03).

Water Body	Total Area (acres)	Area Under MS4 Permits	FDA_{SWP}
Armand Bayou Tidal	4,580.85	4,561.46	99.58%

In order to calculate WLA_{SW} (Equation 5), the Future Growth (FG) term must be known. The calculation for the FG term is presented in the next section, but the results will be included here for continuity. Table 19 provides the information needed to compute WLA_{SW}.

Table 19. Regulated stormwater calculations for Armand Bayou station 11505 (AU 1113_03).

Load units expressed as billion MPN/day Enterococci

Water Body	AU	TMDL[a]	WLA_{WWTF}[b]	FG[c]	MOS[d]	FDA_{SWP}[e]	WLA_{SW}
Armand Bayou Tidal	1113_03	73.838	0.000	0.435	3.692	99.58%	69.418

a TMDL from Table 16
b No permitted dischargers
c FG from Table 20
d MOS from Table 17
e FDA_{SWP} from Table 18

4.7.4 Future Growth

The future growth (FG) component of the TMDL equation addresses the requirement of TMDLs to account for future loadings that may occur as a result of population growth, changes in community infrastructure, and development. The assimilative capacity of streams increases as the amount of flow increases. Increases in flow allow for additional indicator bacteria loads if the concentrations are at or below the contact recreation standard.

For this TMDL, the conventional future growth calculation is hampered by the deficiency of WWTFs. By using TCEQ design guidance for domestic WWTFs, and assuming the potential for a residential development of a density sufficient to require centralized sewer collection, an alternative method was implemented.

According to Rule §217.32 of Texas Administrative Code, new WWTFs are to be designed for a daily wastewater flow of 75-100 gallons per capita per day (gpcd; (TAC (Texas Administrative Code), 2008)). Conservatively taking the higher daily wastewater flow capacity (100 gallons) and multiplying it by a potential population change would result in a future growth permitted flow. Based on the information in Table 1, the projected population change for the subject watershed for the 2010-2050 time period is 5,666. At the present time, only 28% of the Armand Bayou (AU 1113_03) watershed is unincorporated, so a service population of 5,000 was assumed. Multiplying that value by the higher daily wastewater flow capacity, yields a value of 0.50 MGD. This value would be considered the full permitted discharge of a potential future

WWTF. To maintain consistency with the existing TMDLs in Armand Bayou, a reduced Enterococci geometric mean limit for WWTFs of 23 MPN/100 mL was used to calculate the FG component.

$$FG = Criterion * WWTF_{FP} * Conversion\ Factor \quad \textbf{(Eq. 6)}$$

Where:

Criterion = 23 MPN/100 mL for Enterococci

$WWTF_{FP}$ = full permitted discharge (MGD) of potential future WWTF

Conversion Factor = 1.54723 cfs/MGD *283.168 100 mL/ft3 * 86,400 s/d

The calculation results for the impaired AU watershed are shown in Table 20.

Table 20. Future growth calculations for Armand Bayou station 11505 (AU 1113_03).

Water Body	AU	Assumed Service Population	Daily Wastewater (gpcd)	Future Growth Permitted Flow (MGD)	Enterococci FG (Billion MPN/ day)
Armand Bayou Tidal	1113_03	5,000	100	0.50	0.435

4.7.5 Load Allocation

The load allocation (LA) is the loads from unregulated sources, and is calculated as:

$$LA = TMDL - WLA_{WWTF} - WLA_{SW} - FG - MOS \quad \textbf{(Eq. 7)}$$

Where:

LA = allowable loads from unregulated sources within the AU

TMDL = total maximum daily load

WLA_{WWTF} = sum of all WWTF loads

WLA_{SW} = sum of all regulated stormwater loads

FG = sum of future growth loads from potential permitted facilities

MOS = margin of safety load

The calculation results are shown in Table 21.

Table 21. Load allocation calculations for Armand Bayou station 11505 (AU 1113_03).

Units expressed as billion MPN/ day Enterococci

Waterbody	AU	TMDL[a]	WLA_{WWTF}[b]	WLA_{SW}[c]	FG[d]	MOS[e]	LA[f]
Armand Bayou Tidal	1113_03	73.838	0	69.418	0.435	3.692	0.293

a TMDL from Table 16
b No permitted dischargers
c WLASW from Table 19
d FG from Table 20
e MOS from Table 17

4.8 Summary of TMDL Calculations

Table 22 summarizes the TMDL calculations for Armand Bayou Tidal AU 1113_03. The TMDL was calculated based on the median flow in the 0-20 percentile range (10 percent exceedance, High flow regime) for flow exceedance from the LDC developed for the downstream SWQM station 11505. Allocations are based on the current geometric mean criterion for Enterococci of 35 MPN/100 mL for each component of the TMDL.

Table 22. TMDL allocation summary for Armand Bayou station 11505 (AU 1113_03).

Units expressed as billion MPN/ day Enterococci.

Water Body	AU	TMDL[a]	WLA_{WWTF}[b]	WLA_{SW}[c]	LA[d]	FG[e]	MOS[f]
Armand Bayou Tidal	1113_03	73.838	0	69.418	0.293	0.435	3.692

a TMDL from Table 16
b No permitted dischargers
c WLA_{SW} from Table 19
d LA from Table 21
e FG from Table 20
f MOS from Table 17

The final TMDL allocations (Table 23) needed to comply with the requirements of 40 CFR §130.7 include the future growth component within the WLA_{WWTF}.

Table 23. Final TMDL allocations for Armand Bayou Tidal AU 1113_03.

Units expressed as billion MPN/ day Enterococci.

AU	TMDL	WLA_{WWTF}[a]	WLA_{SW}	LA	MOS
1113_03	73.838	0.435	69.418	0.293	3.692

a WLAWWTF includes the FG component.

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 Table 23. Figure A-1 for was developed to demonstrate how assimilative capacity, TMDL calculations, and pollutant load allocations change in relation to a number of proposed water quality criteria for

Enterococci. The accompanying equations allow calculation of a new TMDL and pollutant load allocation based on any potential new water quality criterion for Enterococci.

SECTION 5
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Appendix A.
Equations for Calculating TMDL Allocations for Changed Contact Recreation Standard

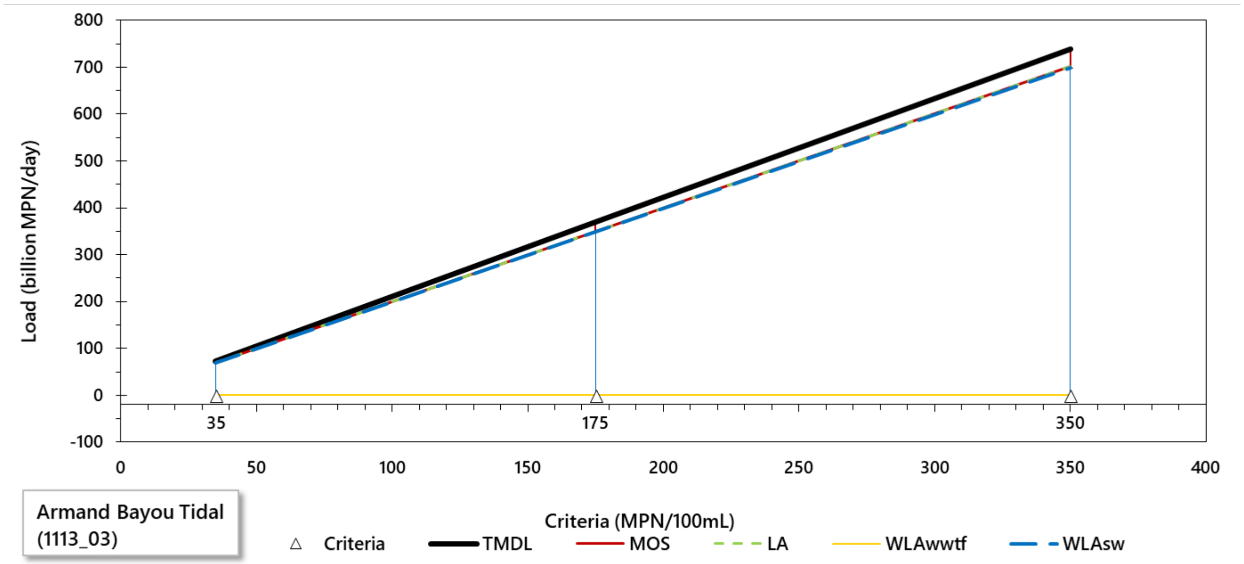

Figure A-1. Allocation loads for Armand Bayou (1113_03) as a function of water quality criteria.

All loads below are in billion MPN/day

Term	Criterion 35 MPN/100 mL	Criterion 175 MPN/100 mL	Criterion 350 MPN/100 mL
TMDL	73.8380	369.1895	738.3790
MOS	3.6920	18.4595	36.9190
LA	0.2930	1.4712	2.9443
WLA_{WWTF}	0.4350	0.4350	0.4350
WLA_{SW}	69.4182	348.8238	698.0807

Equations for calculating new TMDL and allocations (billion MPN/day)

TMDL =2.10965398 * Std

MOS =0.10548255 * Std

LA =0.00841747 * Std -0.00182787

WLA_{WWTF} =0.435

WLA_{SW} =1.99575396 * Std -0.43317213

Where:

Std = Revised Contact Recreation Standard

MOS = Margin of Safety

LA = Total load allocation (non-permitted source contributions)

WLA_{WWTF} = Wasteload allocation (permitted WWTF load + future growth)