Technical Support Document for Five Total Maximum Daily Loads for Indicator Bacteria in the Mustang, Persimmon and New Bayou Watersheds

Assessment Units: 2432A_01, 2432A_02, 2432A_03, 2432D_01 and 2432E_01

Pedestrian bridge across Mustang Bayou at National Oak Park, Alvin, Texas

By Steven Johnston, submitted to TCEQ August 2022
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Abbreviations

AU	assessment unit
CR	county road
cfs	cubic feet per second
cfu	colony forming units
DAR	drainage area ratio
E. coli	*Escherichia coli*
EPA	United States Environmental Protection Agency
Eq.	equation
FM	farm to market
FDC	flow duration curve
H-GAC	Houston-Galveston Area Council
km	kilometer
LA	load allocation
LDC	load duration curve
MGD	million gallons per day
mL	milliliter
MOS	margin of safety
MS4	municipal separate storm sewer system
MSGP	multi-sector general permit
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
OSSF	on-site sewage facility
ppt	parts per thousand
SSO	sanitary sewer overflow
SH	state highway
SWQM	surface water quality monitoring
SWQMIS	Surface Water Quality Monitoring Information System
TCEQ	Texas Commission on Environmental Quality
TMDL	total maximum daily load
TPDES	Texas Pollutant Discharge Elimination System
USGS	United States Geological Survey
WLA	wasteload allocation
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 water body included on a state's 303(d) list of impaired waters. 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 in mass per period of time but may be expressed in other ways. In addition to the TMDL, an implementation plan is developed, which is a description of the regulatory and voluntary measures necessary to improve water quality and restore full use of the water body.

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

TCEQ has identified five bacteria impairments within the Mustang, Persimmon, and New Bayou watersheds, Segments 2432A, 2432D, and 2432E, respectively, in the *2022 Texas Integrated Report of Surface Water Quality for the Clean Water Act Section 305(b) and 303(d)* (Texas Integrated Report, TCEQ, 2022a), the latest United States Environmental Protection Agency (EPA)-approved edition. AUs 2432A_01, 2432A_02, 2432D_01 and 2432E_01 are listed in Subcategory 5a in the 2022 Texas Integrated Report, making them a high priority for TMDL development. AU 2432A_03 is listed in Subcategory 5c in the 2022 Integrated Report. TCEQ first identified concerns for bacteria within Persimmon and New Bayou in the 2010 Texas Integrated Report. The first impairments were to a portion of Mustang Bayou and Persimmon Bayou watersheds in the 2018 Texas Integrated Report.

This document will consider five bacteria impairments to the Mustang, Persimmon and New Bayou watersheds, which when used together for the remainder of this document will be referred to as the TMDL Project watershed. The impaired water body and identifying assessment unit (AU) numbers are:

- Mustang Bayou 2432A_01, 2432A_02, and 2432A_03
- Persimmon Bayou 2432D_01
- New Bayou 2432E_01

1.2. Water Quality Standards

To protect public health, aquatic life, and development of industries and economies throughout Texas, TCEQ established the *Texas Surface Water Quality Standards* (TCEQ, 2018a). The Standards describe the limits for indicators that are monitored to assess the quality of available water for specific uses. TCEQ monitors and assesses water bodies based on these Standards and publishes the Texas Integrated Report list biennially.

The Standards 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.
- 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 uses assigned to water bodies. The primary uses assigned to water bodies are:

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

Fecal indicator bacteria are indicators of the risk of illness during contact recreation (e.g., swimming) from ingestion of water. Fecal indicator bacteria are bacteria that are present in the intestinal tracts of humans and other warm-blooded animals. The presence of these bacteria indicates that associated pathogens from fecal wastes may be reaching water bodies, because of such sources as inadequately treated sewage, improperly managed animal waste from livestock, pets in urban areas, aquatic birds, wildlife, and failing on-site septic systems (OSSFs) (TCEQ, 2018b). *Escherichia coli* (*E. coli*) and Enterococcus are members of the fecal coliform bacteria group and are used in the state of Texas as the fecal indicator bacteria in freshwater bodies and tidal water bodies, respectfully.

On Feb. 7, 2018, TCEQ adopted revisions to the *Texas Surface Water Quality Standards* (TCEQ, 2018a) and on May 19, 2020, the U.S. Environmental Protection Agency (USEPA) approved the categorical levels of recreational use and their associated criteria.

Recreational use in freshwater consists of five categories:

- **Primary contact recreation 1** – Activities that are presumed to involve significant risk of ingestion of water (e.g., swimming). It has a geometric mean criterion for *E. coli* of 126 colony forming units (cfu) per 100 milliliters (mL) and an additional single sample criterion of 399 cfu per 100 mL;

- **Primary contact recreation 2** – Activities that involve a significant risk of ingestion of water (e.g., swimming, diving, wading and whitewater sports), but occurs less frequently than for primary contact recreation 1 due to physical characteristics of the water body or limited public access. The geometric mean for the standard is 206 cfu per 100 mL.

- **Secondary contact recreation 1** – Activities with limited body contact and a less significant risk of ingestion of water (e.g., fishing). It has a geometric mean criterion for *E. coli* of 630 cfu per 100 mL;

- **Secondary contact recreation 2** – Activities similar to secondary contact 1, but which occur less frequently. The geometric mean criterion for *E. coli* is 1,030 cfu per 100 mL; and

- **Noncontact recreation** – Activities that do not involve a significant risk of water ingestion, such as those with limited body contact incidental to shoreline activity, including birding, hiking, and biking. Noncontact recreation use may also be assigned where primary and secondary contact recreation activities should not occur because of unsafe conditions, such as ship and barge traffic. It has a geometric mean criterion for *E. coli* of 2,060 cfu per 100 mL.

For saltwater, recreational use consists of three categories:

- **Primary contact recreation 1** – Activities that involve a significant risk of water ingestion (e.g., wading by children, swimming, water skiing, diving, tubing, surfing, handfishing, and the following whitewater activities: kayaking, canoeing, and rafting). It has a geometric mean criterion for Enterococci of 35 cfu per 100 mL and an additional single sample criterion of 130 per 100 mL;

- **Secondary contact recreation 1** – Activities with limited body contact and a less significant risk of water ingestion (e.g., fishing, canoeing, kayaking, rafting, and motor boating). The geometric mean criterion for Enterococci is 175 per 100 mL;

- **Noncontact recreation** – Activities that do not involve a significant risk of water ingestion, such as those with limited body contact incidental to shoreline activity, including birding, hiking, and biking. Noncontact recreation use may also be assigned where primary and secondary contact recreation activities should not occur because of unsafe conditions, such as ship and barge traffic. The geometric mean criterion for Enterococci is 350 per 100 mL.

The TMDL Project watershed contains both tidal—Persimmon and New Bayous—and freshwater water bodies—Mustang Bayou. All maintain a contact recreation 1 use. The associated standard for a freshwater stream using the *E. coli* criterion is a geometric mean of 126 cfu per 100 mL. The associated standard for a tidal stream using Enterococci criterion is a geometric mean of 35 cfu per 100 mL.

1.3. Report Purpose and Organization

This TMDL project was initiated through a contract between TCEQ and the Houston-Galveston Area Council (H-GAC). The tasks of this project were to (1) develop, have approved, and adhere to a quality assurance project plan; (2) develop a technical support document for the impaired watersheds; and (3) assist TCEQ with public participation. The purpose of this report is to provide technical documentation and supporting information for developing the bacteria TMDLs for the impaired assessment units. 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 presence of fecal indicator bacteria (*E. coli* and Enterococci).
- Development of load duration curves (LDC).
- Application of the LDC approach for developing the pollutant load allocations.

Section 2. Historical Data Review and Watershed Properties

2.1. Description of Study Area

The 70.60 square mile (sq mi) TMDL Project watershed is in southeast Texas, near the cities of Missouri City, Manvel, and Alvin, and the villages of Fresno and Hillcrest (Figure 1). The watershed consists of three bayous: Mustang Bayou, Persimmon Bayou, and New Bayou, which flow generally southeast from the headwaters in southeast Fort Bend County before heading more directly south near the city of Alvin in Brazoria County. From there, the water flows to Chocolate Bay (Segment 2432), West Galveston Bay, and the Gulf of Mexico.

The Mustang Bayou watershed covers 49.16 sq mi. Mustang Bayou is approximately 42.7 miles long and flows southeast beginning in Fort Bend County and continues through Brazoria County, including portions of the cities and villages of Missouri City, Fresno, Pearland, Manvel, Alvin, and Hillcrest (Figure 1). The headwaters are located within the city limits of Missouri City, in southeast Fort Bend County (Snowden, 1989), while most of the stream is within the boundaries of Brazoria County. Mustang Bayou has been heavily modified and channelized in parts (USGS, 2007). The bayou terminates at its confluence with New Bayou, approximately 0.5 miles up stream of Farm-to-Market Road (FM) 2004.

The Persimmon Bayou watershed is 6.93 sq mi. Persimmon Bayou branches off from Mustang Bayou near the intersection of FM 2004 and County Road (CR) 2917. The bayou flows southeastward for approximately 5.5 miles until it joins New Bayou, near its confluence with Chocolate Bay (Figure 1).

The New Bayou watershed is 14.51 sq mi. New Bayou begins at Ditch C-1, a tributary to Chocolate Bayou, near CR 169 (Snowden, 1989) and flows southeastward 15.8 miles to its confluence with Chocolate Bay.

The 2022 Texas Integrated Report (TCEQ, 2022a) provides the following segment and AU descriptions (downstream to upstream order):

- Segment 2432A Mustang Bayou – From the New Bayou confluence upstream to an unnamed tributary 0.3 kilometers (km) (0.19 miles) upstream of State Highway (SH) 35 to an unnamed tributary downstream of Cartwright Road
    - AU 2432A_01 – From the New Bayou confluence upstream to CR 166
    - AU 2432A_02 – From CR 166 upstream to an unnamed tributary 0.3 km upstream of SH 35
    - AU 2432A_03 – From an unnamed tributary 0.3 km upstream of SH 35 upstream to an unnamed tributary downstream of Cartwright Road

- Segment 2432D Persimmon Bayou – From the New Bayou confluence upstream to the Mustang Bayou confluence;
  - 2432D_01 – From the New Bayou confluence upstream to Mustang Bayou confluence.
- Segment 2432E New Bayou – From the Chocolate Bay confluence upstream 25.4 km (15.8 miles) to an unnamed tributary;
  - 2432E_01 - From the Chocolate Bay confluence upstream 25.4 km (15.8 miles) to an unnamed tributary.

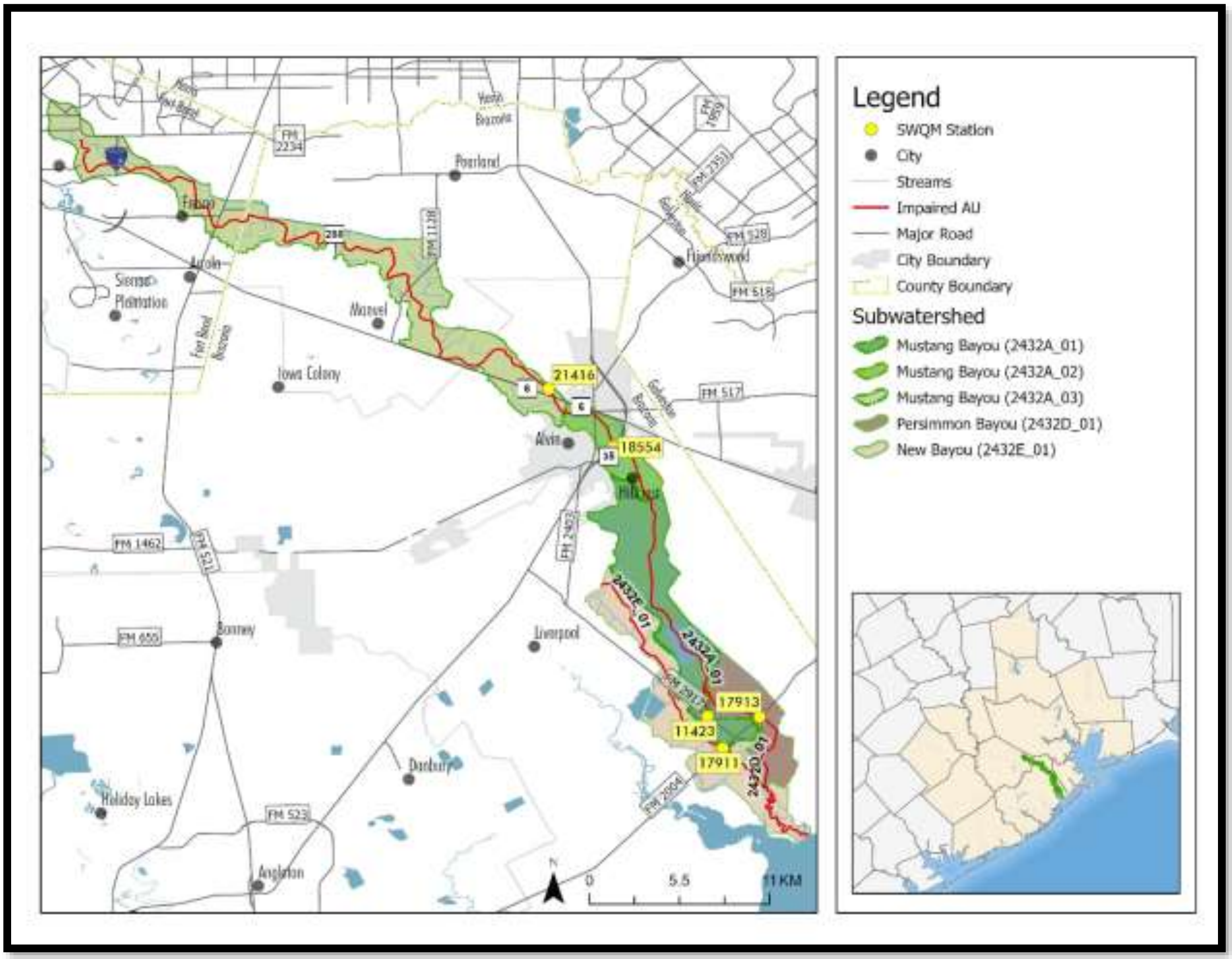

Figure 1. Map of the TMDL Project watershed and SWQM station locations

2.2. Review of Routine Monitoring Data

2.2.1. Analysis of Bacteria Data

The EPA-approved 2022 Texas Integrated Report lists AUs 2432D_01 and 2432E_01 as impaired for primary contact recreation 1 use due to high levels of Enterococci bacteria (TCEQ, 2022a). The AUs have been listed as a concern since 2010 and listed as impaired since the 2020 Texas Integrated Report. TCEQ's 2022 assessment found the geometric mean for Enterococci within the AUs to be 87.46 cfu/100 mL and 80.37 cfu/100 mL for Persimmon Bayou and New Bayou, respectively, above the standard of 35 cfu/100 mL for saltwater (Table 1).

The 2022 Texas Integrated Report lists AUs 2432A_01, 2432A_02 and 2432A_03 as impaired for primary contact recreation 1 use due to elevated levels of *E. coli* bacteria (TCEQ, 2022a). Mustang Bayou has been listed as a concern for bacteria since 2012. The 2018 Texas Integrated Report first listed AU 2432A_02 as impaired. The 2022 assessment found the geomean for *E. coli* within the impaired AUs to be 204.87 cfu/100 mL, 1,143.74 cfu/100 mL, and 321.98 cfu/100mL for 2432A_01, 2432A_02 and 2432A_03, respectively, which is above the standard of 126 cfu/100mL for freshwater (Table 1). All five impaired AUs are in Subcategory 5a in the most recent, EPA-approved 2022 Texas Integrated Report, making them a high priority for TMDL development.

Table 1. 2022 Texas Integrated Report summary for the TMDL Project watershed

Subwatershed	Assessment Unit	Parameter	Station	No. of Samples	Data Date Range	Station Geometric Mean (cfu/100 mL)
Mustang Bayou	2432A_01	*E. coli*	11423	20	07/17/2013 to 11/30/2020	321.98
Mustang Bayou	2432A_02	*E. coli*	18554	26	12/01/2013 to 11/30/2020	1,143.74
Mustang Bayou	2432A_03	*E. coli*	21416	25	12/01/2013 to 11/30/2020	204.87
Persimmon Bayou	2432D_01	Enterococci	17913	27	12/01/2013 to 11/30/2020	87.46
New Bayou	2432E_01	Enterococci	17911	27	12/01/2013 to 11/30/2020	80.37

H-GAC obtained ambient *E. coli* and Enterococci data from TCEQ's Surface Water Quality Monitoring Information System (SWQMIS) between 2004 and 2021. The data represented the routine ambient bacteria and other water quality data collected for the project area by the TCEQ Regional Office and TCEQ's Clean Rivers Program.

The data were collected at five active, and one now inactive, surface water quality monitoring (SWQM) stations during the timeframe. SWQM station locations and general descriptions are (Figure 1, TCEQ, 2022b):

- SWQM Station 11423 (29.26183, -95.1822) in AU 2432A_01 is located on Mustang Bayou at FM 2917 south of the city of Alvin;
- SWQM Station 18554 (29.4095, -95.2339) in AU 2432A_02 is located on Mustang Bayou immediately upstream of East South Street 85 meters west of southbound SH 35 in the city of Alvin;

- SWQM Station 21416 (29.44125, -95.2694) in AU 2432A_03 is located on Mustang Bayou at the Heights-Manvel Road/Cardinal Drive bridge near the city of Alvin.
- SWQM Station 17913 (29.26145, -95.1537) in AU 2432D_01 is located on Persimmon Bayou at FM 2004 south-southwest of the city of Hitchcock; and
- SWQM Station 17911 (29.24425, -95.1739) in AU 2432E_01 is located on New Bayou at FM 2004 south-southwest of the city of Hitchcock.

The sixth station, SWQM Station 20011, was a station where data was collected from March 2007 to March 2008, including bacteria. Data collection at SWQM station 21416 began in October 2013.

The geometric means for the bacteria data collected for each AU are presented in Table 2 covering the data date range provided. All AUs' geometric means are above the bacteria standard for either *E. coli* or Enterococci for the timeframe. The geometric mean for AU 2432A_02 should be highlighted, as it is well above the *E. coli* standard of 126 cfu/100 mL and that of the upstream and downstream AUs' geometric means, in both Table 1 and Table 2.

Table 2. Historic fecal indicator bacteria data

Subwatershed	AU	Parameter	Station	No. of Samples	Data Date Range	Station Geometric Mean (cfu/100 mL)
Mustang Bayou	2432A_01	*E. coli*	11423	38	11/30/2011 to 04/29/2021	252.9
Mustang Bayou	2432A_02	*E. coli*	18554	37	11/28/2011 to 04/15/2021	1,520
Mustang Bayou	2432A_03	*E. coli*	20011 / 21416	36	03/28/07 to 04/15/21	241.91
Persimmon Bayou	2432D_01	Enterococci	17913	57	11/19/2004 to 04/29/2021	127.03
New Bayou	2432E_01	Enterococci	17911	57	03/24/2004 to 04/29/2021	108.82

Daily stream flow records are an essential component of TMDL development. As historical daily stream flow records were not available for any of the TMDL Project AUs, H-GAC obtained the daily flow records from the United States Geological Survey (USGS) streamflow gage 08078000 located on Chocolate Bayou Above Tidal (Segment 1108). Daily stream flow will be discussed in Section 3 in greater detail.

2.3. Watershed Climate and Hydrology

Precipitation and temperature data for 2004 through 2020 were retrieved from the National Climatic Data Center for Freeport (GHCND: USC00413340) (NOAA, 2022). Temperatures and precipitation in the TMDL Project watershed are consistent with subtropical coastal areas.

Average precipitation for the watershed is 47.78 inches per year (Table 3). This dataset includes measurements recorded during the statewide drought that peaked in 2011, when the measured annual rainfall was only 20.81 inches. The wettest year for this period was 2016, with 73.38 inches. Mean monthly precipitation ranged from a minimum of 2.27 inches in February to a maximum of 6.46 inches in September with a monthly average of 3.98 inches (Figure 2). The driest months typically occur in late winter or early spring. The wettest periods occur in summer and early fall, during hurricane season, where rainfall near or above 20 inches in a month is common.

Table 3. Average annual rainfall recorded at Freeport, TX, 2004 – 2020

Station Number	Station Name	Latitude	Longitude	Average Annual Rainfall (inches)
GHCND: USC00413340	FREEPORT 2 NW TX US	28.9845	-95.3809	47.78

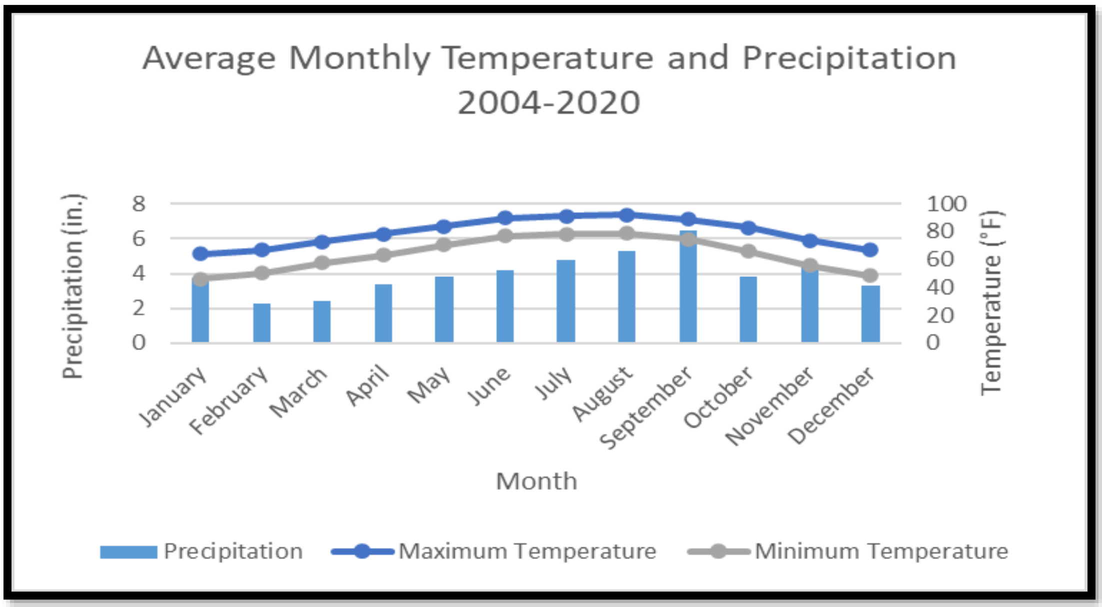

Figure 2. Average monthly temperature and precipitation from 2004-2020, NOAA Station GHCND:USC00413340

Temperatures in the region are consistent with that of a coastal subtropical region. Average annual minimum and maximum temperatures are 63.91 F and 79.30 F, respectively. Figure 2 includes maximum and minimum average monthly temperatures. As shown, December and January are the coolest months with the lowest monthly average minimum temperatures, 48.61 F and 46.26 F, respectively. July and August are the hottest months with the highest average maximum temperatures, 91.34 F and 92.35 F, respectively.

2.4. Watershed Population and Population Projections

H-GAC, through its Regional Growth Forecast, routinely assesses the region's population and develops population projections (H-GAC, 2021a). The most recent analysis was based on the U.S. Census Bureau (USCB) 2020 Decadal Census (USCB, 2021). The TMDL Project watershed had a population of 40,392 in 2020. Within the Mustang Bayou subwatershed, the population in 2020 for AUs 2432A_01, 2432A_02 and 2432A_03 was 2,441, 10,168 and 27,774, respectively (Table 4). The 2020 Census did find a population of nine within the New Bayou subwatershed. The Persimmon Bayou subwatershed did not contain a population in 2020. The population within the TMDL Project watershed is therefore not evenly distributed. Most of the population can be found in the upper watershed near the cities of Alvin, Manvel, and the unincorporated village of Fresno.

The future population within the TMDL Project watershed is projected to increase to 103,095 (157.31%) by 2050 (Table 4). Most of the growth is expected in the 2432A_03 subwatershed. This subwatershed is near SH 288, a main connector to the city of Houston and to industries in the cities of Lake Jackson and Freeport. The Persimmon and New Bayou watersheds are not projected to see population growth in the future. Appendix A provides additional detail on how H-GAC determines population projections.

Table 4. Population changes in the TMDL Project watershed

Subwatershed	AU	2020	2050	Population Change
		Population	Population	%
Mustang Bayou	**2432A_01**	2,441	4,240	73.69%
Mustang Bayou	**2432A_02**	10,168	13,878	36.49%
Mustang Bayou	**2432A_03**	27,774	84,977	205.96%
New Bayou	2432E_01	9	No growth	No growth
Persimmon Bayou	2432D_01	0	0	0%
	Total	**40,392**	**103,095**	**155.23%**

2.5. Land Cover

The TMDL Project watershed in the past was primarily coastal prairies and marshes, broken up by ribbons of riparian hardwoods, continually influenced by the sea, wind, rain, and hurricanes. The flat nature of the coastal plain has seen rivers meander across the project area in geologic time, helping to shape the watershed. Native vegetation consists of tallgrass prairies, live oak woodlands, and a variety of halophilic (salt tolerant) plants with extensive wetland habitats providing food and shelter for numerous bird species and aquatic organisms.

The National Oceanic and Atmospheric Administration (NOAA) has defined land cover and land use. Land cover data describes physical land types such as forests, wetlands, agriculture, impervious surfaces, and other land and water types. Land use documents how people are using the land for development, conservation, or mixed uses (NOAA, 2017).

In 2018, H-GAC used LANDSAT imagery to categorize the Houston-Galveston region into 10 classes of land cover (H-GAC, 2021b). The definitions for the 10 land cover types are:

1. **Developed High Intensity** – Contains significant land area that is covered by concrete, asphalt, and other constructed materials. Vegetation, if present, occupies less than 20% of the landscape. Constructed materials account for 80 to 100% 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.

2. **Developed Medium Intensity** – Contains area with mixture of constructed materials and vegetation or other cover. Constructed materials account for 50 to 79% 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.

3. **Developed Low Intensity** – Contains areas with a mixture of constructed materials and substantial amounts of vegetation or other cover. Constructed materials account for 21 to 49% of total area. This subclass commonly includes single-family housing areas, especially in rural neighborhoods, but may include all types of land use.

4. **Developed Open Space** – 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% of total land cover.

5. **Cropland** – Contains areas intensely managed to produce annual crops. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled.

6. **Pasture/Grassland** – This is a composite class that contains both Pasture/Hay lands and Grassland/Herbaceous.

    a. *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% of total vegetation.

b. *Grassland/Herbaceous* – Contains areas dominated by graminoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling but can be utilized for grazing.

7. **Barren Land** – This class contains both barren lands and unconsolidated shore land areas.

    a. *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% of total cover.

    b. *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.

8. **Forest/Shrub** – This is a composite class that contains all three forest land types and shrub lands.

    a. *Deciduous Forest* – Contains areas dominated by trees generally greater than five meters tall and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.

    b. *Evergreen Forest* – Contains areas dominated by trees generally greater than five meters tall and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.

    c. *Mixed Forest* – Contains areas dominated by trees generally greater than five meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover. Both coniferous and broad-leaved evergreens are included in this category.

    d. *Scrub/Shrub* – Contains areas dominated by shrubs less than five meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes tree shrubs, young trees in an early successional stage, or trees stunted from environmental conditions.

9. **Open Water** – This is a composite class that contains open water and both palustrine and estuarine aquatic beds.

    a. *Open Water* – Include areas of open water, generally with less than 25% cover of vegetation or soil.

b. *Palustrine Aquatic Bed* – Includes tidal and nontidal wetlands and deep-water habitats in which salinity due to ocean-derived salts is below 0.5% 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%.

c. *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% 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%.

10. **Wetlands** – This is a composite class that contains all the palustrine and estuarine wetland land types.

a. *Palustrine Forested Wetland* – Includes tidal and non-tidal wetlands dominated by woody vegetation greater than or equal to five meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean derived salts is below 0.5%. Total vegetation coverage is greater than 20%.

b. *Palustrine Scrub/Shrub Wetland* – Includes tidal and nontidal wetlands dominated by woody vegetation less than five meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5%. Total vegetation coverage is greater than 20%. Species present could be true shrubs, young trees and shrubs, or trees that are small or stunted due to environmental conditions.

c. *Palustrine Emergent Wetland (Persistent)* – Includes tidal and nontidal 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%. Total vegetation cover is greater than 80%. Plants generally remain standing until the next growing season.

d. *Estuarine Forested Wetland* – Includes tidal wetlands dominated by woody vegetation greater than or equal to five 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%. Total vegetation coverage is greater than 20%.

e. *Estuarine Scrub / Shrub Wetland* – Includes tidal wetlands dominated by woody vegetation less than five 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%. Total vegetation coverage is greater than 20%.

f. *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% and that are present for most of the growing season in most years. Total vegetation cover is greater than 80%. Perennial plants usually dominate these wetlands.

The TMDL Project watershed covers 45,185.50 acres (70.60 sq mi). There are 31,460.85 acres (49.16 sq mi), 4,435.11 acres (6.93 sq mi), and 9,289.54 acres (14.51 sq mi) in Mustang, Persimmon and New Bayou watersheds, respectively (Table 5).

The largest single land cover type is Pasture/Grassland at 28.40% within the TMDL Project watershed. Cropland is the second largest land cover type at 20.33% (Table 5, Figure 3). Developed land cover would be the largest land cover type (33.78% of the watershed or 15,263.96 acres) if low, medium, and high-intensity categories were combined. This is consistent with the growth that is taking place in the upper portions of this watershed.

Looking at the subwatershed land cover types, agricultural lands still dominate the area, particularly in the Persimmon Bayou subwatershed, where Cropland (75.44%) and Pasture/Grassland (11.83%) predominate (Table 5, Figure 3). In the New Bayou subwatershed, agricultural lands also dominate at nearly 50% of the land cover with 28.19% and 28.12% for Pasture/Grassland and Cropland, respectively. Wetlands also are a large land cover type for the Persimmon and New Bayou subwatersheds at 10.38% and 25.21%, respectively.

Developed land cover types are predominate in the Mustang Bayou subwatershed, at a total of 44.51% or 14,004.20 acres (Table 5, Figure3). This contrasts with the Persimmon Bayou subwatershed, where developed land cover accounts for 53.89 acres or 1.22%, a reflection of little to no population within this watershed. The New Bayou subwatershed's developed land cover is also lower than the Mustang Bayou subwatershed, but of its developed land cover types, 157.45 acres or 1.69%, is considered Developed, High Intensity. This proportion is like that of the Mustang Bayou subwatershed's 1.65% for the same land cover type. The reason for the large percentage in New Bayou is the heavy industry found along the bayou near the confluence with Chocolate Bay at FM 2004.

Table 5. Land cover classification percentages

Land Cover	Mustang Bayou Subwatershed		Persimmon Bayou Subwatershed		New Bayou Subwatershed		Total	
Type	Area (acres)	Percent	Area (acres)	Percent	Area (acres)	Percent	Area (acres)	Percent
Developed, High Intensity	518.44	1.65%	0.67	0.02%	157.45	1.69%	676.55	1.50%
Developed, Medium Intensity	2,496.35	7.93%	0.89	0.02%	208.40	2.24%	2,705.64	5.99%
Developed, Low Intensity	3,654.56	11.62%	30.40	0.69%	298.70	3.22%	3,983.66	8.82%
Developed, Open Space	7,334.85	23.31%	21.94	0.49%	541.32	5.83%	7,898.11	17.48%
Forest/Shrub	1,536.64	4.88%	0.00	0.00%	1.79	0.02%	1,538.42	3.40%
Open Water	1,590.47	5.06%	50.08	1.13%	503.99	5.43%	2,144.54	4.75%
Barren Lands	95.82	0.30%	0.64	0.01%	4.66	0.05%	101.11	0.22%
Cropland	3,229.20	10.26%	3,345.86	75.44%	2,612.23	28.12%	9,187.29	20.33%
Pasture/Grassland	9,688.72	30.80%	524.46	11.83%	2,618.82	28.19%	12,832.01	28.40%
Wetlands	1,315.82	4.18%	460.18	10.38%	2,342.18	25.21%	4,118.17	9.11%
Total	**31,460.85**	**100.00%**	**4,435.11**	**100.00%**	**9,289.54**	**100.00%**	**45,185.50**	**100.00%**

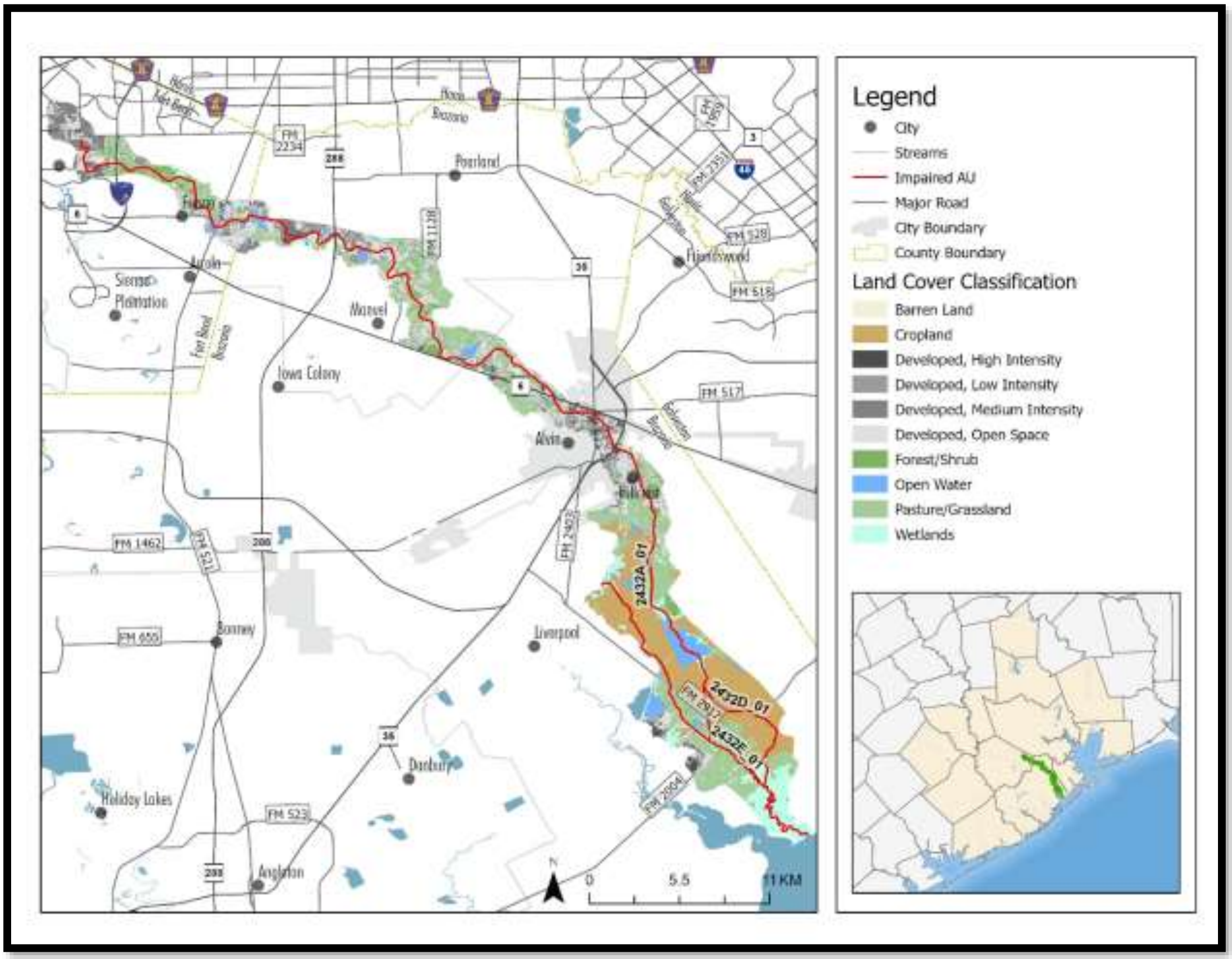

Figure 3. Land cover map of land use classifications

2.6. Soils

Soils within the TMDL Project watershed are characterized by hydrologic groups that describe infiltration and runoff potential.

Soil data are provided by the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Soil Survey Geographic database (SSURGO) (USDA NRCS, 2015). The SSURGO data assigns different soils to one of seven possible runoff potential classifications or hydrologic groups. These classifications are based on the estimated rate of water infiltration when soils are not protected by vegetation, are thoroughly wet, and receive precipitation from long-duration storms. The four main groups are A, B, C, and D, with three dual classes (A/D, B/D, C/D). The SSURGO database defines the classifications below.

- <u>Group A</u> – Soils having high infiltration rate (low runoff potential) when thoroughly wet. These consist mainly of deep, well-drained to excessively drained sands or gravelly sands. These soils have a high rate of water transmission.

- Group B – Soils having a moderate infiltration rate when thoroughly wet. These consist of moderately deep or deep, moderately well-drained or well-drained soils that have moderately fine texture to moderately coarse texture. These soils have a moderate rate of water transmission.
- Group C – Soils having a slow infiltration rate when thoroughly wet. These consist chiefly of soils having a layer that impedes the downward movement of water or soils of moderately fine texture or fine texture. These soils have a slow rate of water transmission.
- Group D – Soils having a very slow infiltration rate (high runoff potential) when thoroughly wet. These consist chiefly of clays that have a high shrink-swell potential, soils that have a high-water table, soils that have a claypan or clay layer at or near the surface, and soils that are shallow over nearly impervious material. These soils have a very slow rate of water transmission.
- Soils with dual hydrologic groupings indicate that drained areas are assigned the first letter, and the second letter is assigned to undrained areas. Only soils that are in group D in their natural condition are assigned to dual classes.

The predominant soil group within the TMDL Project watershed is Group D at 89.16% (Table 6, Figure 4). The second largest soil group is that of Groups C and C/D at 5.36% each. All three soil groups are typical of Texas coastal areas which are made up of very slow to slow-draining alluvial clays and fine textured clay loams.

Table 6. Soil hydrologic groups

Hydrologic Group	Mustang Bayou Subwatershed		Persimmon Bayou Subwatershed		New Bayou Subwatershed		Total	
Type	**Area (acres)**	**Percent**	**Area (acres)**	**Percent**	**Area (acres)**	**Percent**	**Area (acres)**	**Percent**
B	51.40	0.17%	0.00	0.00%	0.00	0.00%	51.40	0.12%
C	2,006.41	6.63%	223.19	5.03%	128.52	1.38%	2,358.12	5.36%
C/D	1,608.81	5.32%	48.50	1.09%	697.74	7.51%	2,355.04	5.36%
D	26,576.38	87.88%	4,163.42	93.87%	8,463.29	91.11%	39,203.08	89.16%
Total	**30,242.99**	**100.00%**	**4,435.11**	**100.00%**	**9,289.54**	**100.00%**	**43,967.65**	**100.00%**

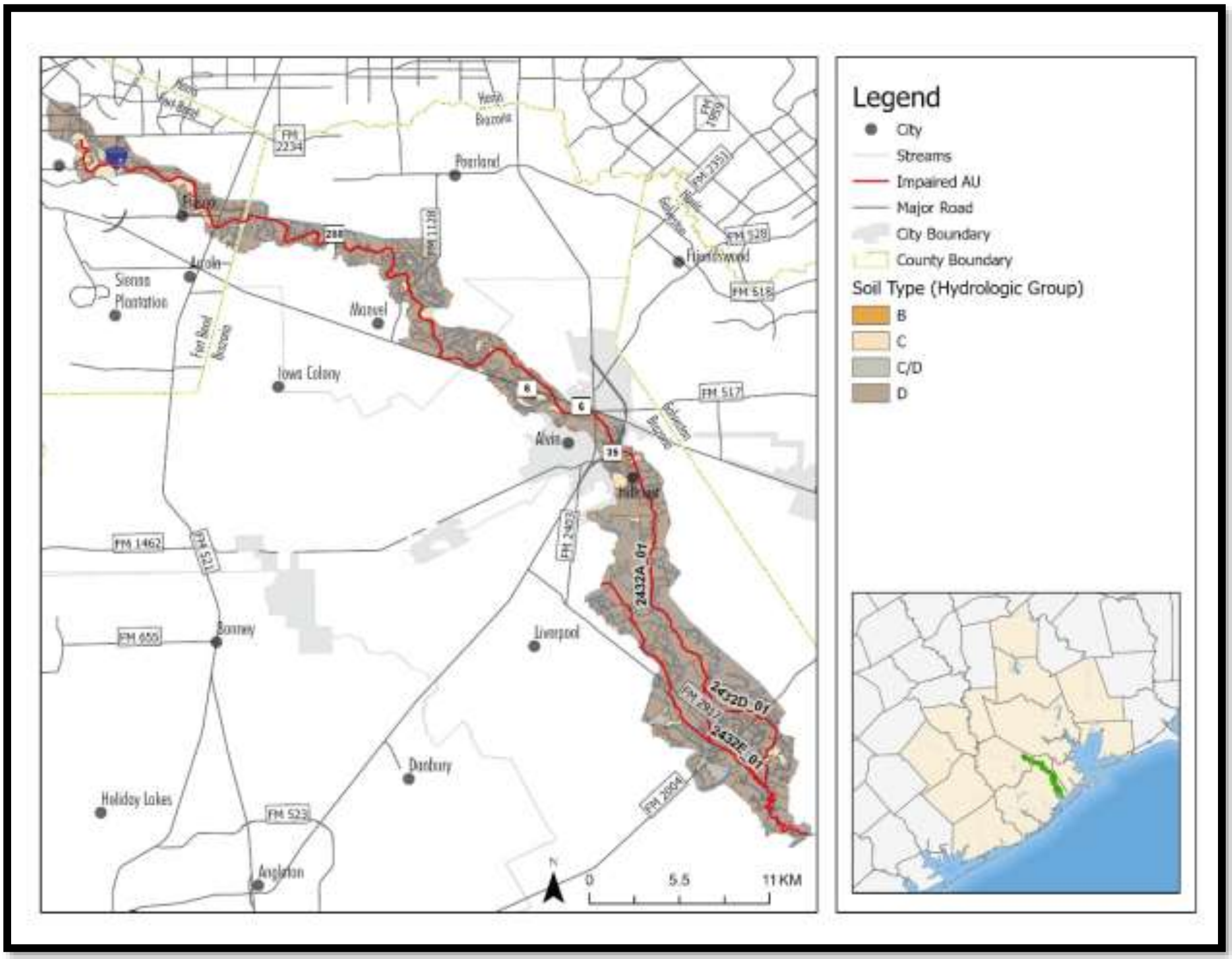

Figure 4. Soils hydrologic groups

2.7. Potential Sources of Fecal Indicator Bacteria

Pollutants may come from several sources, both regulated and unregulated. Regulated pollutants, referred to as “point sources,” come from a single definable point, such as a pipe, and are regulated by permit under the Texas Pollutant Discharge Elimination System (TPDES) program. Wastewater treatment facilities (WWTFs) and stormwater discharges from industrial sites, regulated construction activities, and the separate storm sewer systems of cities are considered point sources of pollution.

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

Except for WWTFs, which receive individual wasteload allocations (WLAs) (see the “WLA” section), the regulated and unregulated sources in this section are presented to give a general account of the different sources of bacteria expected in the watershed.

These are not meant to be used for allocating bacteria loads or interpreted as precise inventories and loadings.

2.7.1. Regulated Sources

Regulated sources are controlled by permit under the TPDES program. The regulated sources in the TMDL watershed include WWTF outfalls, stormwater discharges from regulated construction sites, and municipal separate storm sewer systems (MS4s).

2.7.1.1. Domestic and Industrial Wastewater Treatment Facilities

Seventeen distinct wastewater permits, including 21 outfalls, were found in the TMDL Project watershed (TCEQ, 2022c, Table 7, Figure 5). Three permits are industrial, two in the New Bayou subwatershed, and one in the Mustang Bayou subwatershed. The two industrial WWTFs in the New Bayou subwatershed are not permitted to discharge fecal indicator bacteria through their effluent outfalls. However, the permit holders also maintain a stormwater permit, and both facilities will be reviewed under regulated stormwater in 2.7.1.3.

The remaining 16 wastewater permittees are permitted to discharge treated effluent via their outfalls and were reviewed further. Table 7 includes the facilities reported average daily flow in million gallons per day (MGD) as reported by the facilities in their permit required discharge monitoring reports (DMR). Six of the facilities in Table 7 do not have a reported average daily flow. Permit WQ0014322001, Brazoria County Municipal Utility District (MUD) 25, discharges outside of the AU 2432A_03 subwatershed so their discharge is not relevant to determining the TMDL. However, a portion of their collection system is within the watershed and could potentially contribute to sanitary sewer overflows to the watershed. The remaining five WWTFs are most likely new permits for facilities that are not yet built and producing effluent at the time of this report.

Nine WWTF permit holders are submitting DMRs to the state and EPA. A review of the EPA's Enforcement and Compliance History Online (ECHO, EPA, 2022) in July 2022 of the nine facilities found that all met current compliance for the EPA. A review of the overall compliance on ECHO did find three of the facilities had violations, though only one had bacteria limit violations.

Table 7. Permitted domestic and industrial WWTFs

AU	TPDES/NPDES[a]	Outfall	Permittee Name	Facility Name	Facility Type	Daily Average Flow – Recent Discharge (MGD[b]) [c])	Daily Average Flow – Permitted Discharge (MGD)
2432A_01	WQ0010005001/ TX0024554	1	City of Alvin	City of Alvin WWTP	Domestic	3.180	5
2432A_01	WQ0014039001/ TX0117234	1	AQUA Texas, Inc.	South Meadows East WWTP	Domestic	0.045	0.0924
2432A_02	WQ0010420001/ TX0056057	1	City of Hillcrest Village	City of Hillcrest Village WWTP	Domestic	0.056	0.15
2432A_03	WQ0016073001/ TX0142093	1	Alvin Mustang LLC	Nantucket RV Park WWTF	Domestic	-	0.02
2432A_03	WQ0016089001/ TX0142239	1	Green Raindrops INC	Magnolia RV Resort	Domestic	-	0.0099
2432A_03	WQ0013600001/ TX0094790	1	AQUA Texas, Inc.	Astro WWTP	Domestic	0.010	0.0225
2432A_03	WQ0013735001/ TX0118001	1	Rancho La Fuente Partners LLC	Willow Manor Mobile Home Park	Domestic	0.027	0.075
2432A_03	WQ0004306000/ TX0112461	1	NALCO Production, LLC	NALCO Fresno Facility	Industrial	0.008	0.015
2432A_03	WQ0004306000/ TX0112461	2	NALCO Production, LLC	NALCO Fresno Facility	Industrial	0.019	0.020
2432A_03	WQ0014322001/ TX0124737	1	Brazoria County MUD 25	Brazoria County MUD 25 WWTP	Domestic	-	–
2432A_03	WQ0014188001/ TX0122823	1	Manvel Utilities LP	Oak Crest WWTP	Domestic	0.045	0.099
2432A_03	WQ0014641001/ TX0128163	1	Brazoria County MUD 39	Mustang Creek Development WWTP	Domestic	0.060	0.5

AU	TPDES/NPDES[a]	Outfall	Permittee Name	Facility Name	Facility Type	Daily Average Flow – Recent Discharge (MGD[b]) [c]	Daily Average Flow – Permitted Discharge (MGD)
2432A_03	WQ0014756001/ TX0129178	1	Sedona Lakes MUD 1	Sedona Lake WWTP	Domestic	0.089	0.6
2432A_03	WQ0015077001/ TX0134333	1	AUC Group LP	Tuscany Lakes WWTP	Domestic	-	0.8
2432A_03	WQ0015636001/ TX0138126	1	Hanover Estates LTD	Chimney Rock WWTP	Domestic	-	0.7
2432A_03	WQ0015747001/ TX0138894	1	KB Home Lone Star, INC	Lake Olympia Parkway WWTP	Domestic	-	0.25
2432E_01	WQ0000001000/ TX0003875	4	Ascend Performance Materials Texas, Inc.	Ascend Chocolate Bayou Plant	Industrial	0.302	Intermittent/Flow Variable
2432E_01	WQ0000001000/ TX0003875	5	Ascend Performance Materials Texas, Inc.	Ascend Chocolate Bayou Plant	Industrial	0.756	Intermittent/Flow Variable
2432E_01	WQ0000001000/ TX0003875	6	Ascend Performance Materials Texas, Inc.	Ascend Chocolate Bayou Plant	Industrial	0.264	Intermittent/Flow Variable
2432E_01	WQ0000001000/ TX0003875	7	Ascend Performance Materials Texas, Inc.	Ascend Chocolate Bayou Plant	Industrial	0.239	Intermittent/Flow Variable
2432E_01	WQ0001333000/ TX0004821	5	INEOS USA, LLC	INEOS USA Chocolate Bayou Plant	Industrial	2.610	Intermittent/Flow Variable

[a] NPDES: National Pollutant Discharge Elimination System

[b] MGD: million gallons per day

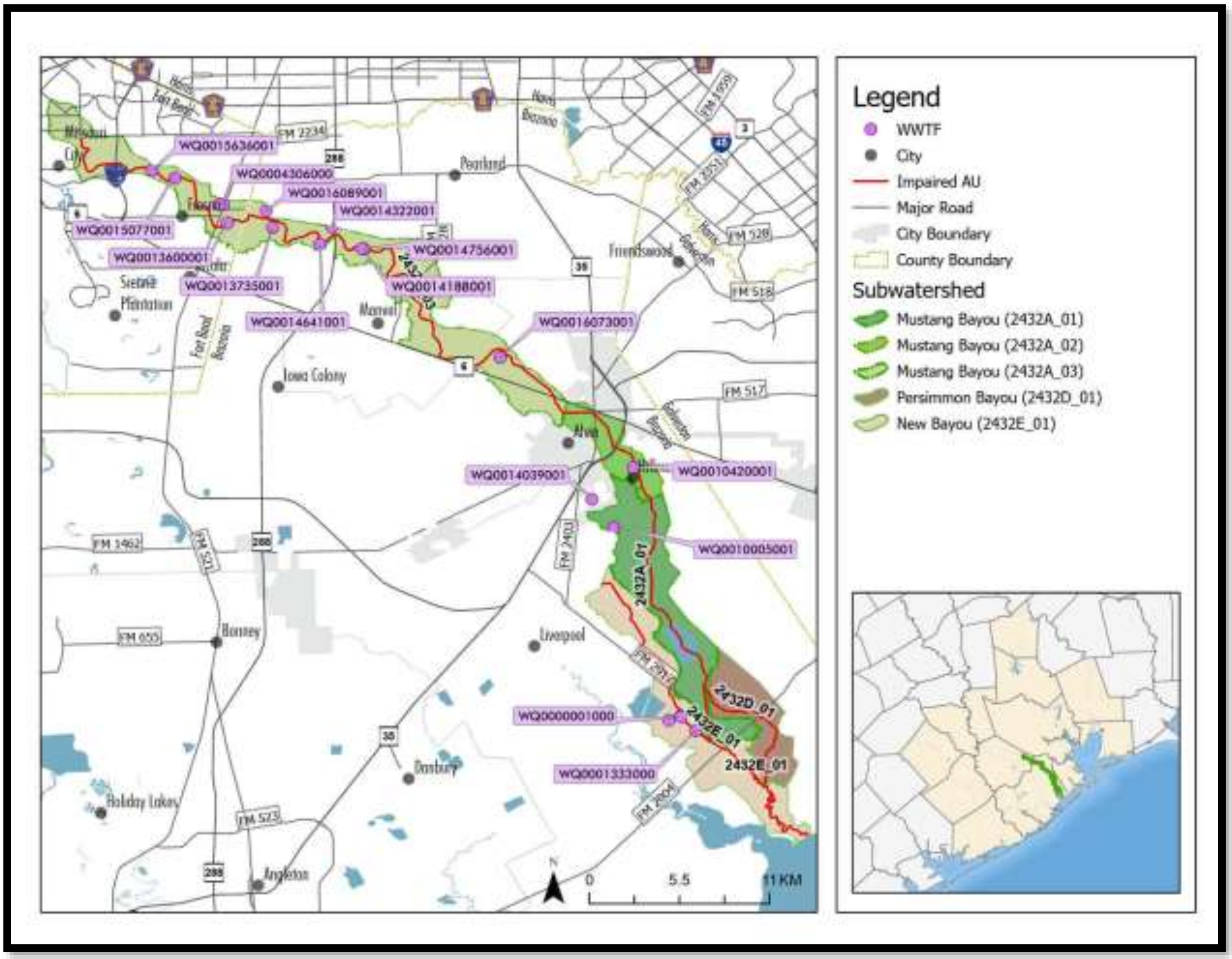

Figure 5. WWTFs within the TMDL Project watershed

2.7.1.2. TCEQ/TPDES General Wastewater Permits

Certain types of activities must be covered by one of several TCEQ/TPDES wastewater general permits:

- TXG110000 – concrete production facilities
- TXG130000 – aquaculture production
- TXG340000 – petroleum bulk stations and terminals
- TXG640000 – conventional water treatment plants
- TXG670000 – hydrostatic test water discharges
- TXG830000 – water contaminated by petroleum fuel or petroleum substances
- TXG870000 – pesticides (application only)
- TXG920000 – concentrated animal feeding operations
- WQG100000 – wastewater evaporation
- WQG200000 – livestock manure compost operations (irrigation only)

Discharges related to the following general permit authorizations are not expected to affect the bacteria loading in the TMDL watershed and were excluded from this investigation:

- TXG640000 – conventional water treatment plants
- TXG670000 – hydrostatic test water discharges
- TXG830000 – water contaminated by petroleum fuel or petroleum substances
- TXG870000 – pesticides (application only)
- WQG100000 – wastewater evaporation

A review of active general permits (TCEQ, 2022d) in the TMDL Project watershed as of May 2022 found two concrete production facilities within the Mustang Bayou subwatershed (AU 2432A_03). The concrete production facilities are authorized to discharge stormwater, so they will be considered in the stormwater allocation analysis (Table 8).

Table 8. General permit authorizations for concrete production facilities

AU	Permit Number	Site Name	City	County	Estimated Acreage
2432A_03	TXG112003	R & S Concrete, L.L.C.	Fresno	Fort Bend	4.48
2432A_03	TXG112023	Gulf Coast Concrete and Shell, Inc.	Manvel	Brazoria	28.71

No other general permits were found that had the potential for effluent to include fecal indicator bacteria. For the concrete production facilities, acreage was estimated by reviewing county appraisal parcel data and/or importing the location information associated with the authorization into GIS and measuring the facility boundaries. Once calculated, the area for the permits were used for development of the stormwater allocations in Section 4.

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-regulated discharge permit and stormwater originating from areas not under a TPDES-regulated discharge permit. Stormwater discharges fall into two categories:

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

TPDES MS4 Phase I and II rules require municipalities and certain other entities in urbanized areas (UA) to obtain permit coverage for their stormwater systems. A regulated MS4 is a publicly owned system of conveyances and includes 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 MS4s with populations of 100,000 or more based on the 1990 United States Census, whereas the Phase II General Permit regulates other MS4s within an urban area with a population of at least 50,000 people.

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 SWMP describes the stormwater control practices that the regulated entity will implement, consistent with permit requirements, to minimize the discharge of pollutants. MS4 permits require that SWMPs specify the best management practices to meet several minimum control measures (MCMs) that, when implemented in concert, are expected to result in significant reductions of pollutants discharged into receiving water bodies. Phase II MS4 MCMs include:

- Public education, outreach, and involvement.
- Illicit discharge detection and elimination.
- Construction site stormwater runoff control.
- Post-construction stormwater management in new development and redevelopment.
- Pollution prevention and good housekeeping for municipal operations.
- Industrial stormwater sources.

Phase I MS4 individual permits have their own set of MCMs that are similar to the Phase II MCMs, but Phase I permits have additional requirements to perform water quality monitoring and implement a floatables program.

Discharges of stormwater from a Phase II MS4 area, regulated industrial facility, construction area, or other facility involved in certain activities must be authorized under the following general permits:

- TXR040000 – Phase II MS4 General Permit for MS4s in UAs (discussed above)
- TXR050000 – Multi-Sector General Permit (MSGP) for industrial facilities
- TXR150000 – Construction General Permit (CGP) for construction activities disturbing more than one acre or are part of a common plan of development disturbing more than one acre

The TPDES General Stormwater Permits found in TCEQ's Central Registry were reviewed in May 2022 (TCEQ, 2022d). The permits for MS4s, individual industrials, MSGPs, and construction pertain only to stormwater. Concrete production facilities are also potential dischargers of wastewater under TPDES general wastewater permits. It was noted that there were two concrete production facilities identified with a TXG110000 number in the TMDL Project watershed. The facilities were discussed under the general wastewater permits. The area for the facilities was retained to calculate the TMDL

A review of active permits covering MS4s in TCEQ Central Registry found that there are 13 active MS4 Phase II permit authorizations, one active MS4 Phase I permit authorization, and one combined Phase I/II MS4 permit (WQ0005011000) within the TMDL Project watershed (Table 9).

Table 9. MS4 permits and authorizations

AU	TPDES Permit No./ *NPDES ID	Type	Regulated Entity	Location
All	TXS002101	Combined Phase I and Phase II MS4	Texas Department of Transportation	Brazoria County and Fort Bend County
2432A_02	TXR040138	Phase II MS4 General Permit TXR040000	City of Alvin	Area within the city of Alvin limits that is located within the Houston Urbanized Area
2432A_02	TXR040148	Phase II MS4 General Permit TXR040000	Brazoria County Reclamation District	Area within Brazoria CRD 3 limits that is located within the Houston Urbanized Area
2432A_03	TXR040144	Phase II MS4 General Permit TXR040000	Brazoria Drainage District 4	Area within the city of Pearland limits that is located within the Houston Urbanized Area
2432A_03	TXR040208	Phase II MS4 General Permit TXR040000	City of Pearland	Area within the city of Pearland city limits that is located within the Houston Urbanized Area
2432A_03	TXS001201	Phase I MS4 General Permit WQ0004685000	City of Houston	This permit covers all portions of the Houston-Harris County Municipal Separate Storm Sewer
2432A_03	TXR040219	Phase II MS4 General Permit TXR040000	Blue Ridge West MUD	This MS4 is located in the area of Blue Ridge West MUD within the city of Missouri City limits that is located within the Houston Urbanized Area in Fort Bend County, Texas.
2432A_03	TXR040252	Phase II MS4 General Permit TXR040000	City of Stafford	Area within the city of Stafford limits that is located within the Houston Urbanized Area
2432A_03	TXR040295	Phase II MS4 General Permit TXR040000	Fort Bend County MUD 26	Area of Fort Bend County MUD 26 is located within the city of Missouri City limits within the Houston Urbanized Area
2432A_03	TXR040296	Phase II MS4 General Permit TXR040000	Meadowcreek MUD	Area of Meadowcreek MUD is located within the City of Missouri City limits within the Houston Urbanized Area
2432A_03	TXR040298	Phase II MS4 General Permit TXR040000	City of Missouri City	The MS4 is located in the area within the city of Missouri City limits that's located within the Houston Urbanized Area n Fort Bend and Harris Counties, Texas

AU	TPDES Permit No./ *NPDES ID	Type	Regulated Entity	Location
2432A_03	TXR040359	Phase II MS4 General Permit TXR040000	Quail Valley UD	Area within the boundaries of Qual Valley Utility District within the City of Missouri City limits that is located within the Houston Urbanized Area
2432A_03	TXR040360	Phase II MS4 General Permit TXR040000	Thunderbird UD	Area within legal district boundaries of Thunderbird Utility District located within the city of Houston Urbanized Area
2432A_03	TXR040362	Phase II MS4 General Permit TXR040000	Palmer Plantation MUD 02	Area within the boundaries of Palmer Plantation MUD 2 that is located within the city of Missouri City limits within the Houston Urbanized Area
2432A_03	TXR040383	Phase II MS4 General Permit TXR040000	Fort Bend County DD	Area within Fort Bend County that is located within the Houston Urbanized Area

To determine the area of the TMDL Project watershed likely under a MS4 Phase II permit, a review of the USCB's census defined urbanized area was made in July 2022 (USCB, 2010). This review determined the total urbanized area for the TMDL Project watershed was 11,059.71 acres or 24.48% (Table 10, Figure 6).

Table 10. Estimated area of MS4 permit coverage

Subwatershed	Urbanized Area (acres)	Watershed Area	Percent UA
2432A_01	364.96	9,288.85	3.93%
2432A_02	3,213.34	4,255.91	75.50%
2432A_03	7,481.41	17,916.10	41.76%
Mustang Bayou	**11,059.71**	**31,460.86**	**35.15%**
TMDL Project Area Total	**11,059.71**	**45,185.50**	**24.48%**

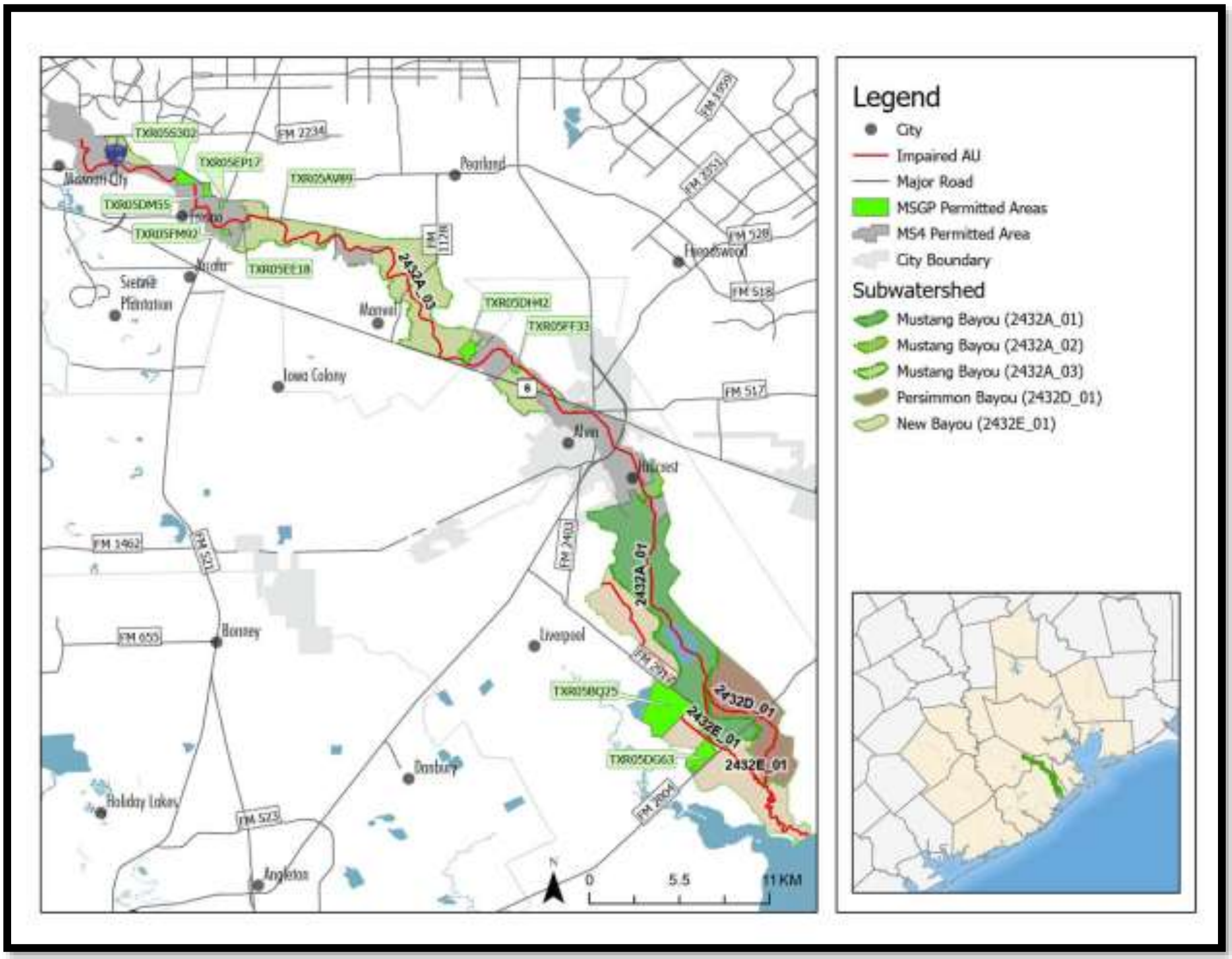

Figure 6. Regulated stormwater area based on MS4s and MSGPs

MSGPs were reviewed in TCEQ's Central Registry in May 2022 for active permits within the TMDL Project watershed (TCEQ, 2022d). Twelve active MSGPs were found within the watershed (Table 11, Figure 6). MSGPs include the three WWTF facilities mentioned previously in section 2.7.1.1.

To eliminate the possibility of overcounting the stormwater permit area, only the area of MSGPs located outside of UA areas were included. Six of the twelve permits were found within the UA and were excluded from TMDL development. The remaining six MSGPs were outside the UA within AUs 2432A_03 and 2432E_01 (Table 11). For the TMDL Project area, the MSGP estimated area under stormwater permit was 1,993.78 acres.

Table 11. Industrial stormwater authorizations

AU	MSGP Permit Number/TPDES	Permittee	County	City	Area (acres)	Area Outside UA (acres)
2432A_02	TXR05FM40/Not Applicable	Riviana Foods Inc.	Brazoria	Alvin	14.62	0.00
2432A_03	TXR05AV89/Not Applicable	Sprint Sand and Clay, LLC	Brazoria	Manvel	1.42	0.00
2432A_03	TXR05DH42/Not Applicable	J D B Services, Inc.	Brazoria	Alvin	201.38	201.38
2432A_03	TXR05DM55/Not Applicable	Sprint Sand and Clay, LLC	Fort Bend	Fresno	73.63	6.36
2432A_03	TXR05EE18/Not Applicable	East Palm Holdings, LLC	Brazoria	Fresno	16.24	0.00
2432A_03	TXR05EP17/ WQ0004306000	Nalco Production LLC	Fort Bend	Fresno	29.01	0.00
2432A_03	TXR05EQ25/Not Applicable	Tierra De Los Lagos, LLC	Fort Bend	Fresno	35.27	35.27
2432A_03	TXR05FF33/Not Applicable	Sand Land, Inc.	Brazoria	Alvin	38.63	38.33
2432A_03	TXR05FM92/Not Applicable	Cherry Crushed Concrete, Inc.	Fort Bend	Fresno	7.71	0.00
2432A_03	TXR05S302/Not Applicable	Blue Ridge Landfill TX, LP	Fort Bend	Fresno	183.87	0.00
2432D_01	TXR05BQ25/ WQ0000001000	Ascend Performance Materials Texas Inc.	Brazoria	Alvin	1,286.21	1,286.21
2432D_01	TXR05DG63/ WQ0001333000	INEOS USA LLC	Brazoria	Alvin	426.23	426.23
				Total	**2,314.22**	**1,993.78**

CGPs are required when one acre or more of land is disturbed during construction. Construction activities within a watershed change over time and the permit data found via the TCEQ Central Registry are only considered accurate for the date that the data was accessed.

Due to the variable nature of these permits, the acres recorded serve here as a representative estimate. The disturbed areas are summed to estimate the amount of the watershed area under a stormwater construction permit at any given time.

In May 2022, review of TCEQ Central Registry was performed for 2016 through 2021 for active, expired, or terminated permits. The permits were first reviewed and filtered to remove duplicates, i.e., permits referring to the same area in the same year, and for permits outside of the TMDL Project watershed. Once the initial review was completed, there were a total of 174 permits that were active, expired, or terminated for the timeframe. The permits were then compared to the UA to further remove any permits found within the UA to prevent duplication. This yielded a total of 45 permits in the TMDL Project watershed with a total 3,694.47 acres of disturbed area for the timeframe (Table 12).

One permit was for pipeline construction across the three subwatersheds. Without additional information other than what is found within the TCEQ database, the estimated disturbed area was split evenly within the three subwatersheds. For four of the AU subwatersheds, there was either one or two permits for the timeframe reviewed. Rather than taking an average across six years, the total disturbed area was retained for the TMDL. Construction within the AU 2432A_03 subwatershed, however, is active, with 40 permits, even after filtering out those permits within the UA. For this subwatershed, a yearly average was determined based on six years (Table 12).

Table 12. Construction stormwater authorization review

Subwatershed	Filtered Permits (2016–2021)	Disturbed Area (acres)	Yearly Average Disturbed Area* (acres)
2432A_01	1	16.11	16.11
2432A_02	1	15.00	15.00
2432A_03	40	3,629.14	604.86
2432D_01	1	16.11	16.11
2432E_01	2	18.11	18.11
TMDL Project Area Total	**45**	**3,694.47**	**670.19**

*Yearly average only calculated for 2432A_03.

2.7.1.4. 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 the permitted system. In dry weather, these overflows most often result from blockages in the sewer collection pipes caused by tree roots, grease, and other debris. Inflow and infiltration are typical sources of SSOs under conditions of high flow in the WWTF system. Blockages may worsen the inflow and infiltration problem. Other causes, such as collapsed sewer line, may occur under any condition.

Table 13 presents the number of SSOs reported and the estimated volume of untreated or partially treated effluent released into the project watershed between 2012 and 2021. A total of 62 SSOs were reported and over 3 million gallons were estimated to be released during that timeframe (TCEQ, 2022e). The largest single cause of SSOs is attributed to blockages due to grease and non-grease, e.g., roots, wipes, etc.

Table 13. Summary of reported SSO events

Year	Number of SSOs Reported	Estimated Volume (Gallons)
2012	2	1,050
2013	4	15,155
2014	5	1,480
2015	5	1,590
2016	2	950
2017	7	502,069
2018	12	2,513,461
2019	13	189,600
2020	10	47,400
2021	2	11,000
Total	**62**	**3,283,755**

2.7.1.5. Dry Weather Discharges/Illicit Discharges

Pollutant loads can enter water bodies from MS4 outfalls that carry authorized sources as well as illicit discharges under both dry- and wet-weather conditions. The term "illicit discharge" is defined in TPDES General Permit TXR040000 for Phase II MS4s as "Any discharge to a municipal separate storm sewer that is not entirely composed of stormwater, except discharges pursuant to this general permit or a separate authorization and discharges resulting from emergency firefighting activities."

Illicit discharges can be categorized as either direct or indirect contributions. Examples of illicit discharges identified in the *Illicit Discharge Detection and Elimination Manual: A Handbook for Municipalities* (NEIWPCC, 2003) include:

Direct Illicit Discharges:

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

Indirect Illicit Discharges:

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

2.7.2. Unregulated Sources

Unregulated sources of bacteria are generally nonpoint. Nonpoint source loading enters the impaired water body through distributed, nonspecific locations, which may include urban runoff not covered by a permit. Potential sources, detailed below, include wildlife, feral hogs, various agricultural activities, agricultural animals, urban runoff not covered by a permit, failing OSSFs, and domestic pets.

2.7.2.1. Wildlife and Unmanaged Animal Contributions

Fecal bacteria are common inhabitants of the intestines of all warm-blooded animals, including wildlife such as mammals and birds. In developing bacteria TMDLs, it is important to identify by watershed the potential for bacteria contributions from wildlife and feral hogs. Wildlife and feral hogs are naturally attracted to riparian corridors of water bodies. 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. Wildlife and feral hogs also leave feces on land, where they may be washed into nearby water bodies by rainfall runoff.

Most avian and mammalian wildlife, including invasive species, are difficult to estimate, as long-term monitoring data or literature values indicating historical baselines are lacking. However, the White-Tailed Deer Program of the Texas Parks and Wildlife Department (TPWD, 2019) estimates deer populations for their Resource Management Units. In the ecoregion surrounding the TMDL Project watershed, TPWD deer population estimates recorded from 2008 through 2020 average 0.03957 deer for every acre, regardless of land cover type. By applying this factor to the acreage in the TMDL Project watershed, the white-tailed deer population can be estimated at 1,788 (Table 14).

Table 14. Estimated deer population

Subwatershed	Area (acres)	Estimated Deer Population
2432A_01	9,288.85	368
2432A_02	4,255.91	168
2432A_03	17,916.10	709
2432D_01	4,435.11	175
2432E_01	9,289.54	368
Total	**45,185.50**	**1,788**

Feral hogs are a non-native, invasive species, which likely impact the watershed with fecal waste contamination. Like deer, factors for estimating feral hog populations based on land area are available. These factors vary depending on land cover types and range between 8.9 and 16.4 hogs per square mile (Timmons, et. Al., 2012). Feral hog population estimates may be weighted more heavily in riparian areas where animals are protected from the stresses associated with development and have more direct access to available food and water resources. The 8.9 hogs per square mile is applied to Barren, Cropland, and Developed Low Intensity land cover types. The 16.4 hogs per square mile is applied to Open Space Development, Forest/Shrub, Pasture/Grassland and Wetland land cover types. Feral hogs were estimated to have a total population of 861 within the TMDL Project watershed (Table 15).

Table 15. Estimated feral hog population

Subwatershed	Low Quality Habitat (acres)	Feral Hogs – Low Quality Habitat	High Quality Habitat (acres)	Feral Hogs – High Quality Habitat	Total Estimated Feral Hogs
2432A_01	3,511.16	49	4,697.93	120	169
2432A_02	915.56	13	2,670.16	68	81
2432A_03	2,552.85	36	12,507.93	321	356
2432D_01	3,376.89	47	1,006.58	26	73
2432E_01	2,915.59	41	5,504.11	141	182
Total	**13,272.06**	**186**	**26,386.71**	**676**	**861**

2.7.2.2. Unregulated Agricultural Activities and Domesticated Animals

Several agricultural activities that do not require permits can be potential sources of fecal bacteria loading. Fecal waste from livestock such as cattle, pigs/hogs, sheep, goats, horses, and poultry can be introduced through direct deposition and as runoff from manure used in crop fertilization.

In Table 16, estimates of livestock in the TMDL Project watershed are shown. These estimates were calculated by applying a ratio of watershed land area compared to county land area times the livestock numbers from the 2022 Census of Agriculture for Brazoria and Fort Bend Counties performed by the USDA (USDA, 2024). This calculation assumes equal distribution of livestock and farm operations throughout the two counties.

These livestock numbers, however, were not used to develop a TMDL allocation of allowable bacteria loading to livestock.

Table 16. Estimated livestock populations

Area Name	Area (Acres)	Cattle and Calves	Hogs and Pigs	Sheep and Goats	Equine	Poultry
Brazoria County	262,076	59,766	2,600	3,607	3,608	202,164
Fort Bend County	197,123	33,343	36	970	1,660	6,232
2432A_01	3,134.63	715	31	43	43	2,418
2432A_02	801.64	183	8	11	11	618
2432A_03	5,752.45	1,232	44	67	72	3,433
2432D_01	524.46	120	5	7	7	405
2432E_01	2,618.82	597	25	36	36	2020
Total TMDL Watershed	**12,832.01**	**2,847**	**114**	**164**	**169**	**8,894**

Fecal bacteria from dogs and cats are transported to streams by runoff in both urban and rural areas and can be a potential source of bacteria loading. Table 17 summarizes the estimated number of dogs and cats in the Mustang Bayou subwatershed. Due to the very small number of households in the New Bayou subwatershed and the complete lack of households in the Persimmon Bayou subwatershed, an analysis on the estimated number of cats and dogs was only performed for the Mustang Bayou subwatershed. Pet population estimates were calculated as the estimated number of dogs (0.614) and cats (0.457) per household according to data from the American Veterinary Medical Association 2017-2018 U.S. Pet Statistics (AVMA, 2018). The number of households in the watershed were estimated using the USCB 2020 census data, with the average household size of 2.71 (USCB, 2021). The actual contribution and significance of bacteria loads from pets reaching the water bodies of the watershed is unknown.

Table 17. Estimated households and pet populations

Mustang Bayou Subwatershed	Estimated Households	Dogs	Cats
2432A_01	904	555	413
2432A_02	3,766	2,312	1,721
2432A_03	10,287	6,316	4,701
Total	**14,957**	**9,183**	**6,835**

2.7.2.3. 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 (Weiskel *et al.*, 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 the Region IV area, which has a reported failure rate of about 12%, providing insights into expected failure rates for the area.

Some OSSFs in the watershed are operated under permit; however, some units are unregistered or not consistently reported. For the purposes of this report, all OSSFs will be treated as unregulated sources of fecal waste due to the nature of their permits, lack of reported data, and diffuse nature.

H-GAC, in coordination with authorized agents in H-GAC's service region, compiled the number of permitted and registered OSSFs in the TMDL Project watershed (H-GAC, 2022a). Brazoria and Fort Bend counties are local authorized agents who have accepted responsibility from TCEQ to permit OSSFs and enforce laws and rules governing OSSFs on behalf of the State. There are 1,666 registered OSSFs in the TMDL Project watershed (Table 18, Figure 7).

In addition to permitted systems, there are OSSFs that are not registered. Non-registered OSSF locations were estimated using H-GAC's geographic information database of potential OSSF locations (H-GAC, 2022b) in the Houston-Galveston area using known OSSF locations, 911 addresses, and WWTF service boundaries. Using H-GAC's estimate of non-registered OSSFs, there are likely another 1,413 non-registered OSSFs within the TMDL Project watershed (Table 18, Figure 7).

Table 18. Registered and non-registered OSSFs

AU	Registered	Non-registered	Total
2432A_01	186	98	284
2432A_01	214	246	460
2432A_03	1,236	1,069	2,305
2432D_01	9	_	9
2432E_01	21	_	21
Total	**1,666**	**1,413**	**3,079**

OSSFs can be an appreciable source of fecal waste when not sited or functioning properly, especially when they are close to waterways. Many factors including soil type, design, age, and maintenance can influence the likelihood of an OSSF failure. By applying the estimated 12% failure rate to the 3,079 OSSFs estimated within the TMDL Project watershed (Table 18), 369 OSSFs are projected to be failing.

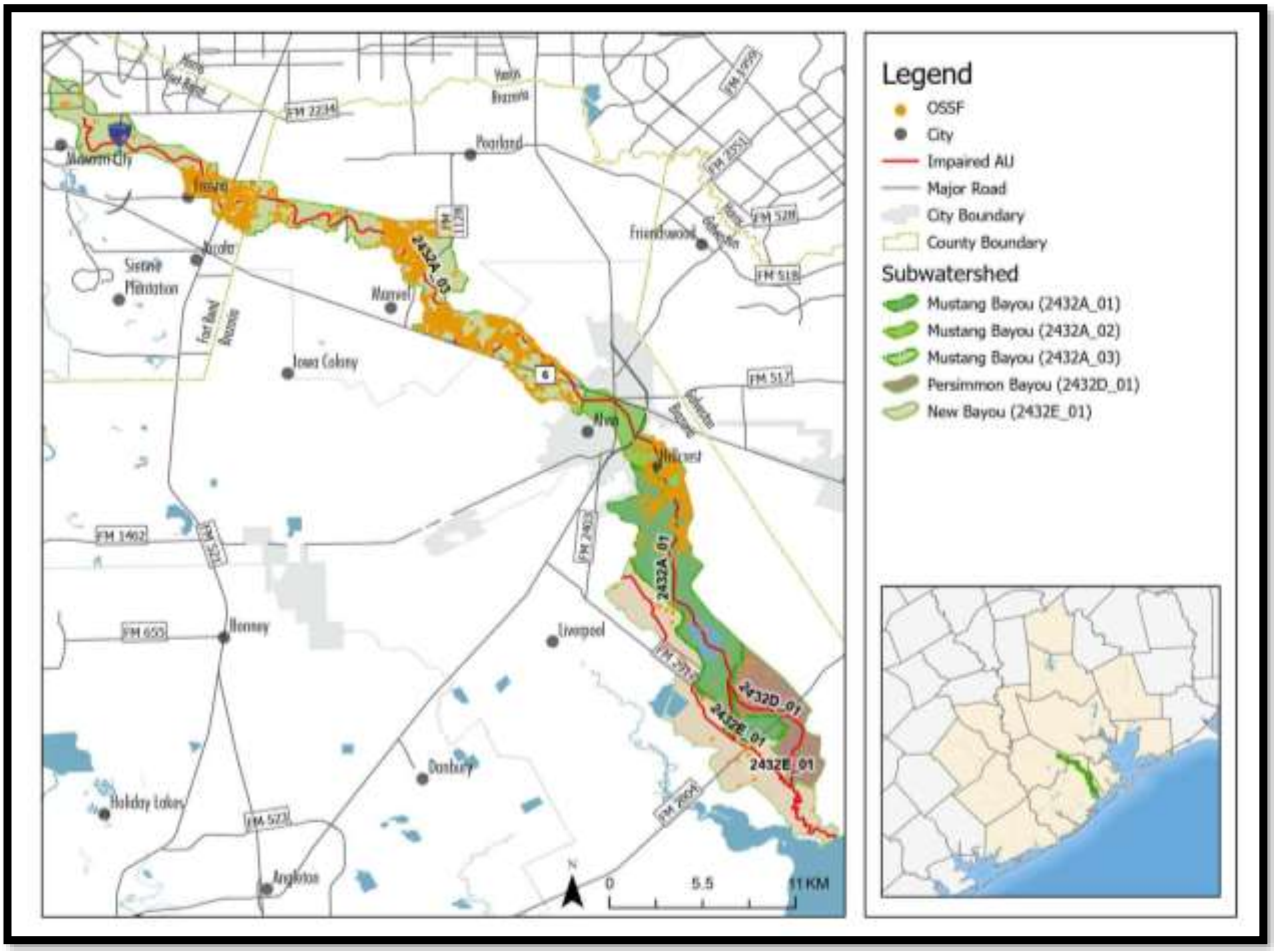

Figure 7. Distribution of OSSFs in the TMDL Project watershed

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 (such as warm temperature). Fecal organisms from improperly treated effluent can survive and replicate during their transport in pipe networks, and they can survive and replicate in organic-rich materials such as improperly treated compost and sewage sludge (or biosolids). While the die-off of indicator bacteria has been demonstrated in natural water systems due to the presence of sunlight and predators, the potential for their regrowth is less well understood. Both replication and die-off are instream processes and are not considered in the bacteria source loading estimates in the TMDL watershed.

Section 3. Bacteria Tool Development

This section describes the rationale for selecting the bacteria tool used for TMDL development and details the procedures and results of LDC and modified LDC development.

3.1. Tool Selection

The LDC method allows for the estimation of existing and allowable loads by using the cumulative frequency distribution of streamflow and measured pollutant concentration data (Cleland, 2003). 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.

Texas and other states have successfully used the LDC method to develop TMDLs which have been accepted by the regulatory community due to the method's simplicity and ability to address information limitations commonly found with bacteria TMDLs. The LDC has become recommended as part of a three-tiered approach by the appointed bacteria task force driven by TCEQ and the Texas State Soil and Water Conservation Board (TWRI, 2007). More recently, Texas began using modified LDCs for TMDLs in tidal waters with the Mission and Aransas Rivers TMDL (Hauck *et al.*, 2013) and Tres Palacios Creek Tidal TMDL (Hauck *et al.*, 2017).

3.2. Data Resources

The TMDL Project watershed data resource availability (i.e., fecal indicator bacteria data), except for daily stream flow, was sufficient to perform LDC analyses in AUs 2432A_01, 2432A_02, 2432A_03, 2432D_01 and 2432E_01. To complete LDCs in AUs 2432D_01 and 2432E_01, salinity data is needed to consider tidal inflow in addition to daily streamflow and fecal indicator bacteria. Streamflow will be discussed further below to address this data limitation.

All the required water quality data (*E. coli,* Enterococci, and salinity) were available through SWQMIS for the period of 2004 to 2021, though the range of available data for some AU bacteria data as presented in Table 2, was a bit shorter. SWQMIS is a database that serves as the repository for TCEQ surface water quality data for the state of Texas. All data used for these analyses were collected under a TCEQ-approved quality assurance project plan. Data with "qualifier" flags associated with potential data quality problems were excluded from the download. All data were combined into a working data set for LDC development.

The daily flow records from the United States Geological Survey (USGS) streamflow gage 08078000, located on Chocolate Bayou Above Tidal (Segment 1108) was used to derive daily stream flow for subwatersheds within TMDL Project for the intended LDC period of 2004 to 2021. This USGS gage was selected because the Chocolate Bayou watershed is close to the TMDL Project watershed (Table 19, Figure 8) and because land cover composition, weather patterns and watershed land use activities (such as development, agriculture, and industries) are similar.

Table 19. Catchment area comparison between the TMDL Project watershed and the Chocolate Bayou flow gage

Station	AU	Catchment Area (square miles)	Area Ratio
USGS 08078000	-	86.5	-
21416	2432A_03	26.03	0.30
18554	2432A_02	30.24	0.35
11423	2432A_01	49.47	0.57
17913	2432D_01	49.47	0.57
17911	2432E_01	58.32	0.67

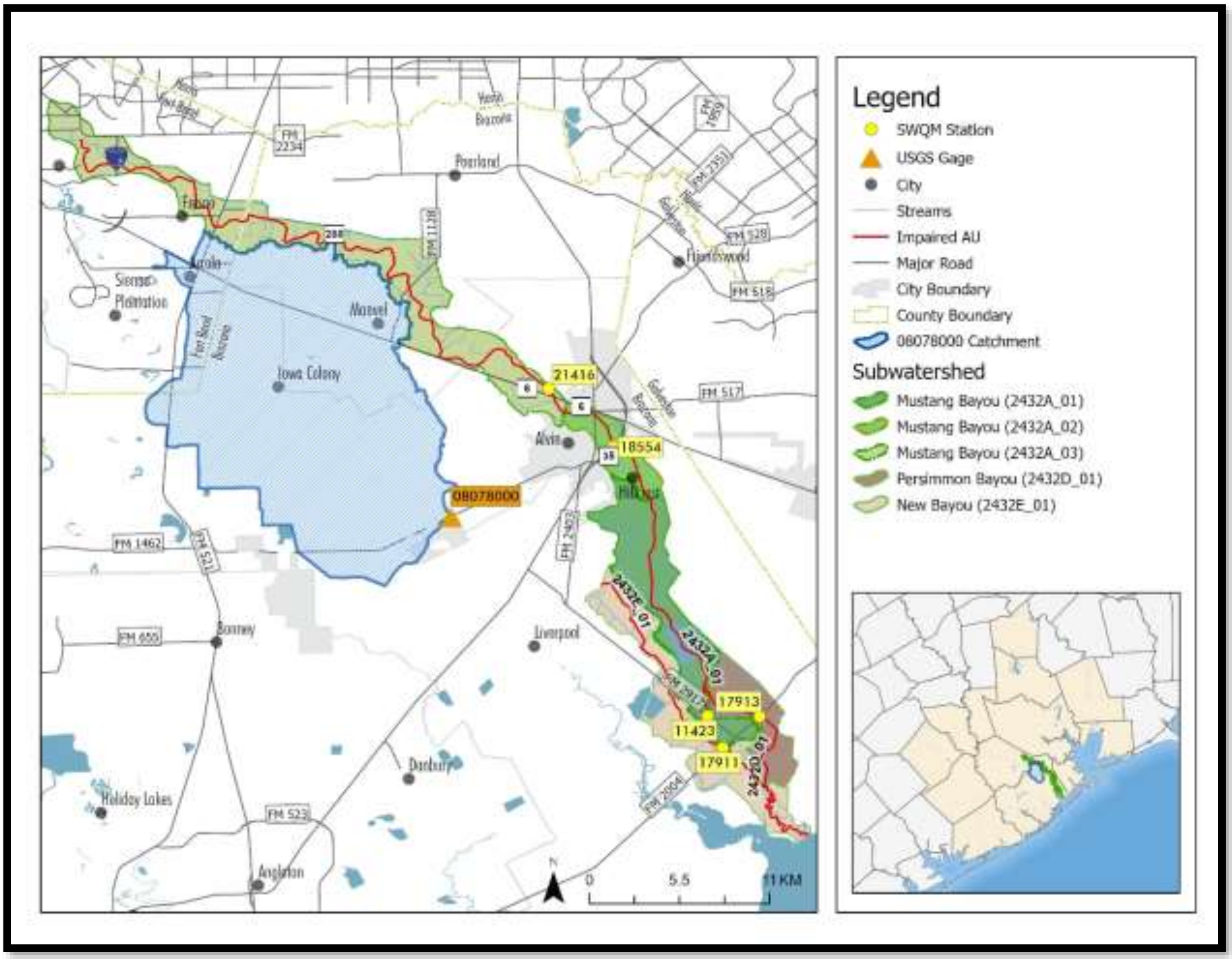

Figure 8. Catchment area for the USGS gage in comparison to SWQM stations

3.3. Methodology for Flow Duration and Load Duration Curve Development

To develop flow duration curves (FDCs) and modified LDCs, the previously discussed data resources were used in the following steps.

1. Determine the hydrologic period of record to be used in developing the FDC.
2. Determine the stream location for which FDC and LDC development is desired.
3. Develop drainage-area ratio parameter estimates.
4. Develop daily streamflow record at desired location.
5. Develop salinity to streamflow regression in the tidal AU.
6. Incorporate daily tidal volumes into streamflow record in the tidal AU.
7. Develop FDC at the desired stream location, segmented into discrete flow regimes.
8. Develop allowable bacteria LDC at the same stream location based on the relevant criteria and the data from the FDC.
9. Superimpose historical bacteria data on the allowable bacteria LDC.

Additional information explaining the LDC method may be found in Cleland (2003) and USEPA (2007). More information explaining the modified LDC method may be found in Chapter 2 and Appendix 1 of the Umpqua Basin Total Maximum Daily Loads and supporting documents (ODEQ, 2006).

3.3.1. Step 1: Determine Hydrologic Period

The daily flow data from the United States Geological Survey (USGS) streamflow gage 08078000, located on Chocolate Bayou Above Tidal (Segment 1108) was used to derive daily stream flow within the TMDL Project watershed for the intended LDC period of 2004 to 2021 (USGS, 2022).

3.3.2. Step 2: Determine Desired Stream Location

TMDLs were developed for SWQM station locations within the impaired AUs. There is only one SWQM station within each AU and LDCs were prepared for each station.

3.3.3. Step 3: Develop Drainage-Area Ratio Parameter Estimates

In addition to WWTF discharges, surface water diversions associated with water rights permits can affect stream hydrology when applying the drainage area ratio (DAR) approach. Flow data from the Chocolate Bayou USGS gage were “naturalized” by correcting the additions of WWTF discharges and withdrawals of upstream water rights diversions. As used herein, naturalized flow is referring to the flow without the additions of permitted discharges and withdrawals from water rights, *i.e.*, the flow that would occur in response to precipitation, evapotranspiration, near-surface geology, soils, land covers of the watershed, and other factors. The naturalized daily streamflow records were developed from existent USGS records.

The estimated average daily DMR reported discharges for the time-period of 2017 to 2021 from all the WWTF outfalls upstream of the USGS gage location (Table 20) were subtracted from the daily gage streamflow records. This resulted in an adjusted streamflow record with point source discharge influences being removed.

Table 20. Average DMR reported discharge of the outfalls upstream of Chocolate Bayou USGS gage

Segment	TPDES	Facility Name	Average Annual MGD
1108	WQ0012780001	Southwood Estates WWTF	0.049
1108	WQ0013367001	City of Arcola WWTF	0.235
1108	WQ0013872001	City of Manvel WWTF	0.131
1108	WQ0014279001	Palm Crest WWTF	0.010
1108	WQ0014222001	Brazoria County MUD 21 WWTF	0.271
1108	WQ0014253001	Rodeo Palms WWTF	0.168
1108	WQ0014546001	Brazoria County MUD 31 WWTP	0.157
1108	WQ0014724003	Brazoria County MUD 55 WWTF	0.040
1108	WQ0014992001	Glendale Lakes Subdivision WWTP	0.031

The water right consumptions (i.e., the balance between diverted amount and returned flow amount) were adjusted from the point source removed streamflow discharge records. The water rights diversion and return flow data were downloaded from the TCEQ Water Right Permitting and Availability Section (TCEQ, 2022f). There were three water rights diversions within the catchment area above the USGS station. The calculated daily average consumption values from all the water rights were added back into the adjusted streamflow records, resulting in an adjusted streamflow records with upstream water right diversion influence being removed.

The daily freshwater flow values were then calculated for each AU based on the “naturalized” derived flow values of Chocolate Bayou and using the DAR method, where the ratio is multiplied by the flow values at the Chocolate Bayou station (Equation (Eq.) 1) (Table 19).

$$Y = X(A_x/A_y) \qquad \text{(Eq. 1)}$$

Where:

Y = streamflow for the ungaged SWQM station,

X = daily streamflow for USGS gage,

Ay = drainage area for the ungaged SWQM station,

Ax = drainage area for USGS

The drainage area for each AU increases as one moves downstream to the next AU within the TMDL Project watershed. The reason for this is the drainage area includes the area contributing to the AU plus any drainage area/ subwatershed upstream.

3.3.4. Step 4: Develop Daily Streamflow Record at Desired Location

Once the daily stream flow estimates are made using the DAR step in 3.3.3, a final procedure is performed to develop the daily streamflow record at each SWQM station location within the Mustang Bayou watershed. The WWTFs full permitted flow and Future Growth component as determined by future WWTF flow are added to the generated daily streamflow record at each AU’s SWQM station location within the Mustang Bayou watershed.

One important factor of note is that based on the geospatial view of the Persimmon Bayou confluence with Mustang Bayou, the flow would appear to split almost evenly. Without the ability to measures this accurately, the authors assumption was to simply set the upstream flow contribution to the SWQM stations 11423 (AU 2432A_01) and 17913 (AU 2432D_01) at 50%.

There are no existing WWTFs in Persimmon or New Bayou. While the expectation is that neither of these watersheds will see population growth in the future, to account for any possible error or changes in this projection and possible platting of a future development property, two hypothetical WWTFs were created, one in each subwatershed. The basis for these hypothetical WWTFs was a recent similar sized recreational vehicle park, St. Ives RV Resort, permitted in Chocolate Bayou Tidal with a permitted flow of 0.015 MGD.

Finally, additional steps are taken for tidal AUs. This will be explained next in the next section.

3.3.4.1 Step 4.1: Develop Salinity to Streamflow regression in the Tidal AUs

As part of the development of the modified FDC and LDC, it is necessary to develop a relationship between estimated daily streamflow and measured salinity for the tidally influenced AUs (TCEQ SWQM Stations 19713 and 19711). The DAR adjusted daily streamflow data was combined with salinity observations taken at the TCEQ SWQM stations.

Enterococci and salinity measurements from 2004 to 2021 were acquired for both SWQM stations. Daily flow records were generated and related to the salinity of the stream at SWQM stations 17913 and 17911. Each salinity measurement was matched with its corresponding calculated daily freshwater flow. The salinity records were then plotted against the log-transformed flow values in a scattered plot (Figures 9 and 10).

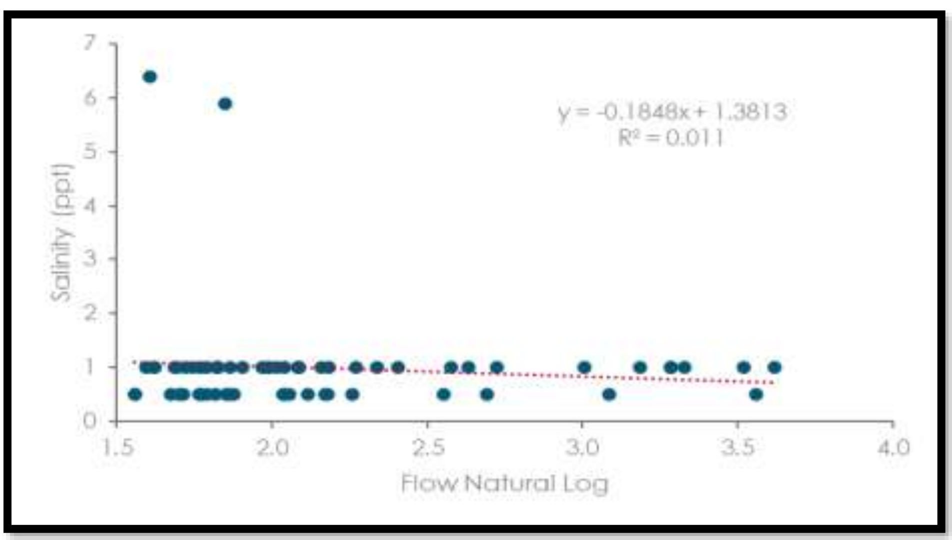

Figure 9. Regression scatter plot of salinity vs. log-transformed flow values for SWQM station 17913

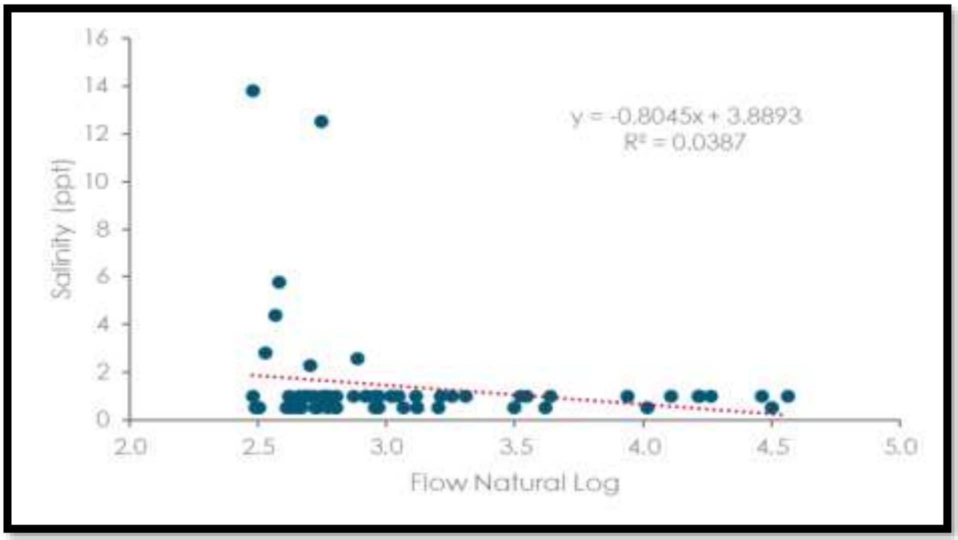

Figure 10. Regression scatter plot of salinity vs. log-transformed flow values for SWQM station 17911

A review of the scatter plots suggests that there are only weak correlations between daily stream flow and salinity, R-squares are less than 4% for both tidal AUs. While tidal inflows do increase salinity in these water bodies, they are minimal when measured at the AUs' SWQM station. Most salinity data points are less than two parts per thousand (ppt) (Figures 9 and 10). This makes it acceptable to complete traditional LDCs instead of modified LDCs.

3.3.5. Steps 5 through 7: Flow Duration and Load Duration Curves

FDCs and LDCs are graphs that visualize the percentage of time during which a value of flow or load is equaled or exceeded. The traditional approach for FDC and LDC was used for all AUs. As noted, the modified approach was attempted for AUs 2432D_01 and 2432E_01 but was abandoned due to minimal salinity measurements.

The preferable location to develop FDCs and LDCs is the most downstream-positioned station in the segment or AU, one close to the terminating boundary. This was not always possible as the LDCs were limited to location of the available SWQM stations, which in some cases were above the terminating boundary.

To develop the FDCs for the location of each SWQM station, the following steps were taken:

1. Order the daily streamflow data for the location from highest to lowest and assign a rank to each data point (one for the highest flow, two for the second highest flow, and so on).
2. Compute the percentage of days each flow was exceeded by dividing each rank by the total number of data points plus one.
3. Plot the corresponding flow data against exceedance percentages (Figure 10).

Further, when developing an LDC:

1. Multiply the streamflow in cubic feet per second cfs by the appropriate water quality criterion for either Enterococci (geometric mean of 35 cfu/100 mL) or *E. coli* (126 cfu/mL) and the conversion factor ($2.44658X10^9$), which gives you a loading unit of cfu/day.
2. Plot the exceedance percentages, which are identical to the value for the streamflow data points, against the geometric mean criterion for either Enterococci or *E. coli*.

The resulting curve represents the maximum daily allowable loadings for the geometric mean criterion (Figure 11). The next step was to plot the measured bacteria data on the developed FDC using the following steps:

1. Compute the daily loads for each sample by multiplying either the measured *E. coli* or measured Enterococci concentrations on a particular day by the corresponding streamflow on that day and the conversion factor (2.44658×10^9).
2. Plot on the LDC for each station the load for each measurement at the exceedance percentage for its corresponding streamflow.

The plots of the LDC with the measured loads (*E. coli* or Enterococci concentrations times daily streamflow) display the frequency and magnitude at which 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.

3.3.5.1. Flow Duration Curves for the TMDL Watershed

Figure 11 shows the FDC for SWQM station 21416, a freshwater AU. The curve is separated into five flow regimes including high flows (0-10%), moist conditions (10-40%), mid-range flows (40–60%), dry conditions (60–90%), and low flows (90–100%) (Cleland 2003). For reference, the *E. coli* geometric mean criterion curve (load at 126 cfu/100 mL) and the *E. coli* single sample criterion curve (load at 399 cfu/100 mL) are included on the FDC.

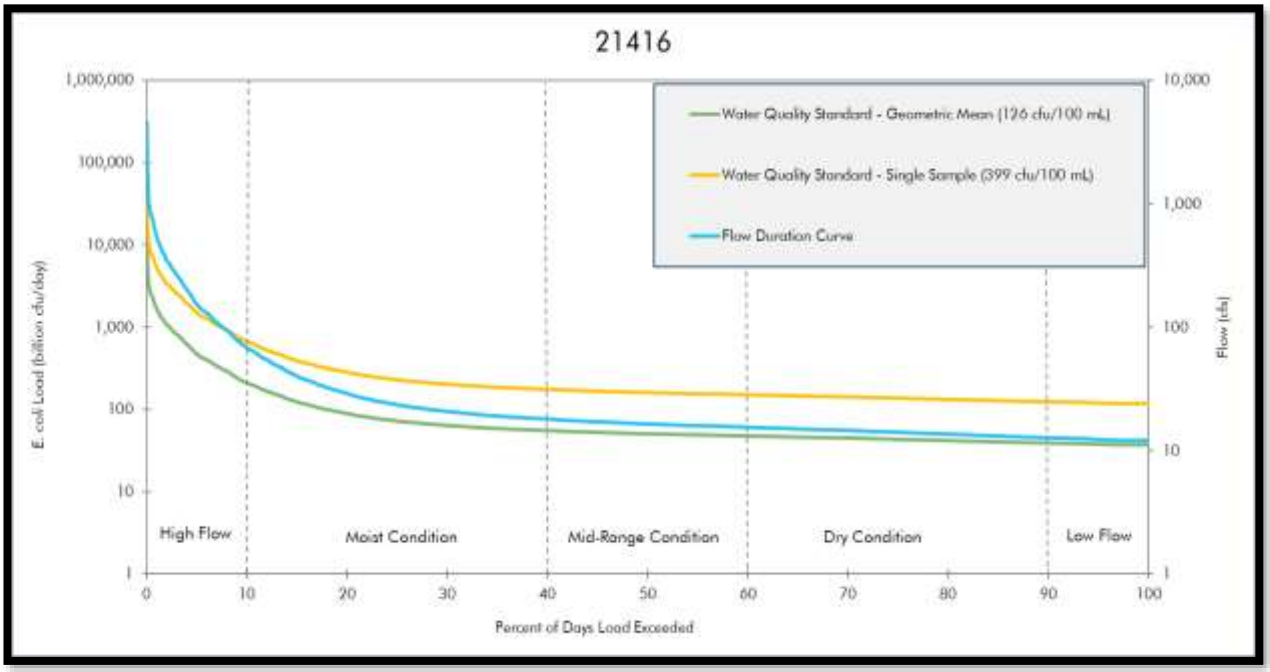

Figure 11. FDC created for SWQM Station 21416 in Mustang Bayou AU 2432A_03

Figure 12 shows the FDC for SWQM station 17911, a tidal AU. For this FDC the standard criterion curves have changed to loads using the Enterococci geometric mean criterion of 35 cfu/100 mL and the single sample criterion of 130 cfu/100 mL.

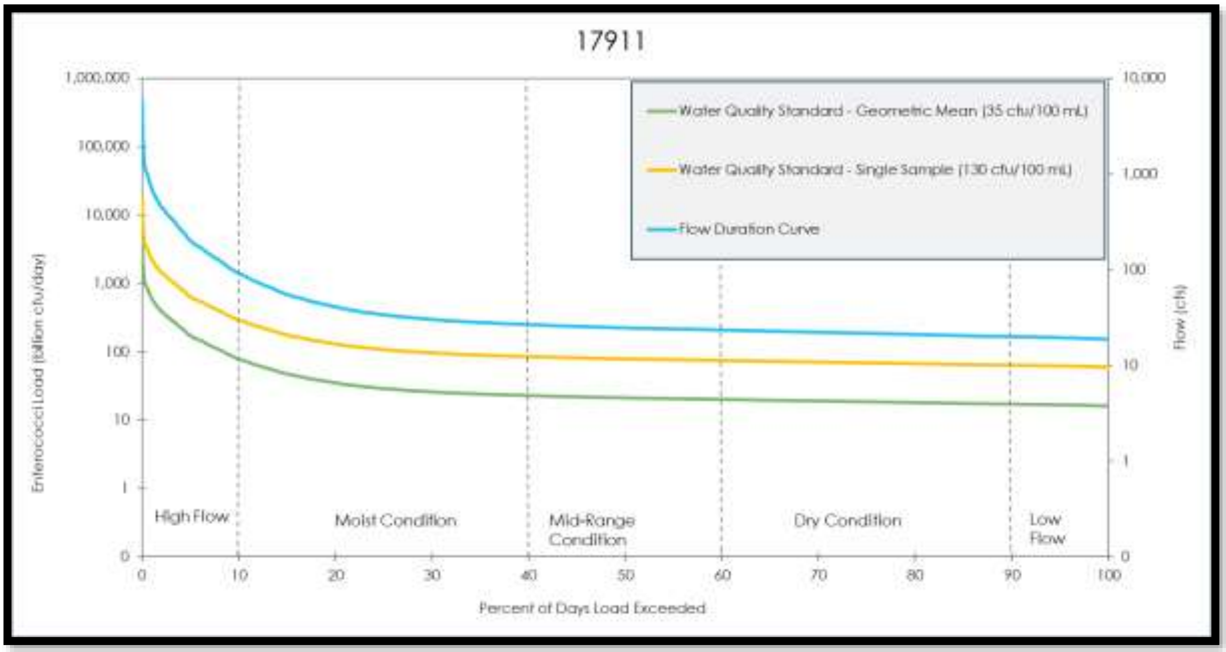

Figure 12. FDC created for SWQM Station 17911 in New Bayou AU 2432E_01

3.3.5.2. Load Duration Curves for the TMDL Watershed

Figures 13-17 present LDCs for the five SWQM stations within the TMDL Project watershed. The figures include the FDC, the geometric mean criterion curves, the single sample criterion curve, the existing load regression curve, the observed bacteria geometric mean load by flow regime (single points), and individual observed bacteria data points.

The LDC for SWQM Station 11423 (Figure 13) presents the load regression curve which falls below the geometric mean curve in the middle of the dry flow condition. Most of the observed bacteria data are found below the single sample standard curve. The geometric mean calculated for the sample data within the dry flow regime falls below the geometric mean standard curve.

Looking at the LDC, for SWQM Station 18554 (Figure 14) the load regression curve is well above the geometric mean curve throughout the duration of all flow regimes. Here, the geometric means of the observed bacteria data all are above the geometric mean standard curve at all conditions.

A review of the LDC for SWQM Station 21416 (Figure 15) is like that of SWQM Station 11423. The load regression curve crosses over the geometric mean standard curve in the dry conditions.

The final two LDCs (Figures 16 and 17) for SWQM Stations 17913 and 17914 exhibit similar tendencies to that of SWQM Station 18554, in that both figures show the load regression curve never crossing the geometric mean standard curve. Both LDCs' load regression curves, however, are much closer to the standard curve in the mid-range, dry, and low flow conditions when compared to the LDC for SWQM Station 18554.

A general interpretation of all five LDCs suggest that the TMDL Project watershed's AUs failed to meet the contact recreation standard for fecal bacteria because of both point and non-point sources of bacteria. Non-point sources (e.g., wildlife, livestock, etc), typically drive the wetter conditions, while point sources (e.g., WWTFs, OSSFs, etc) typically drive drier conditions. This will be discussed further in Section 4.3 and 4.4.

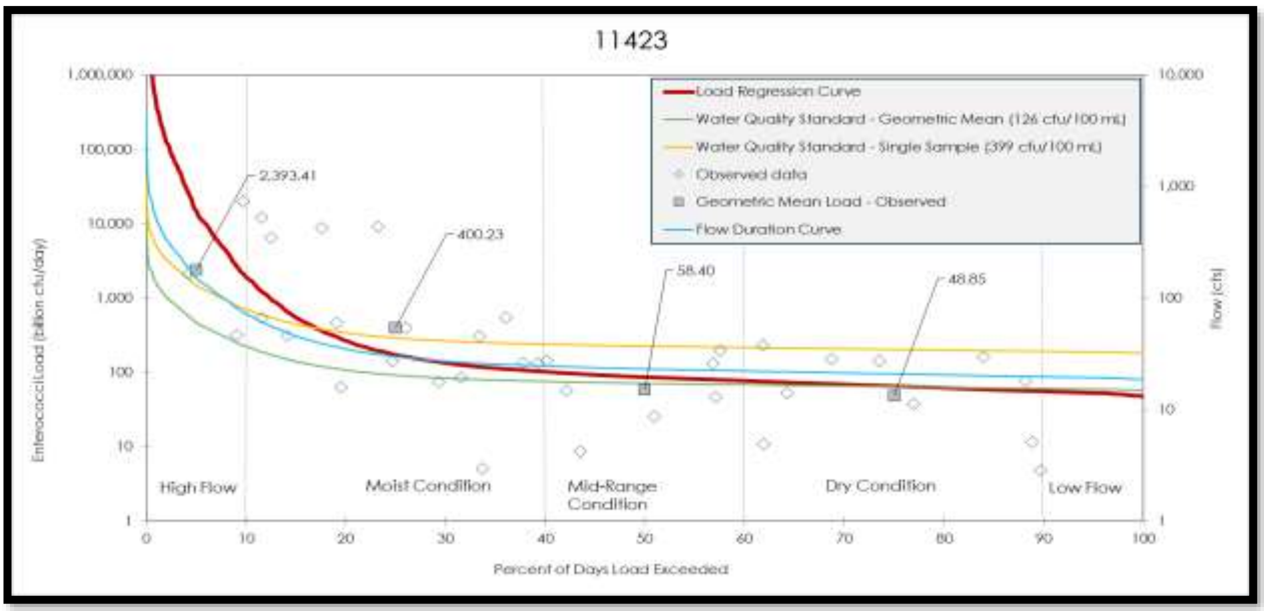

Figure 13. LDC for SWQM Station 11423 in Mustang Bayou, AU 2432A_01

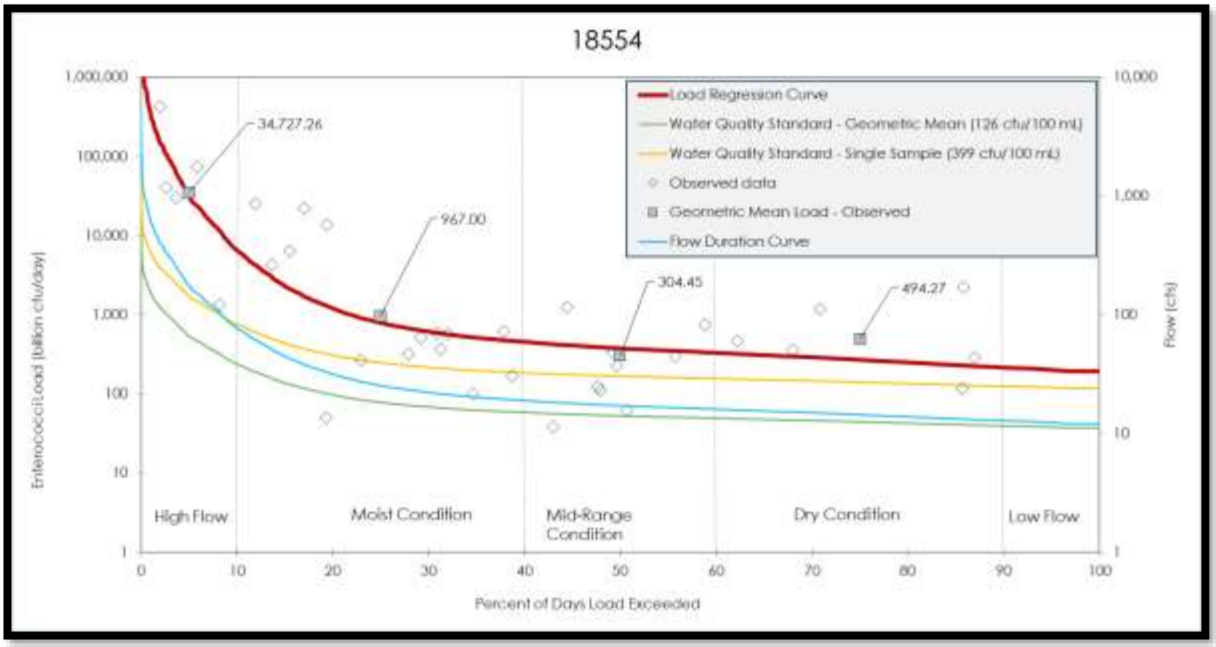

Figure 14. LDC for SWQM Station 18554 in Mustang Bayou, AU 2432A_02

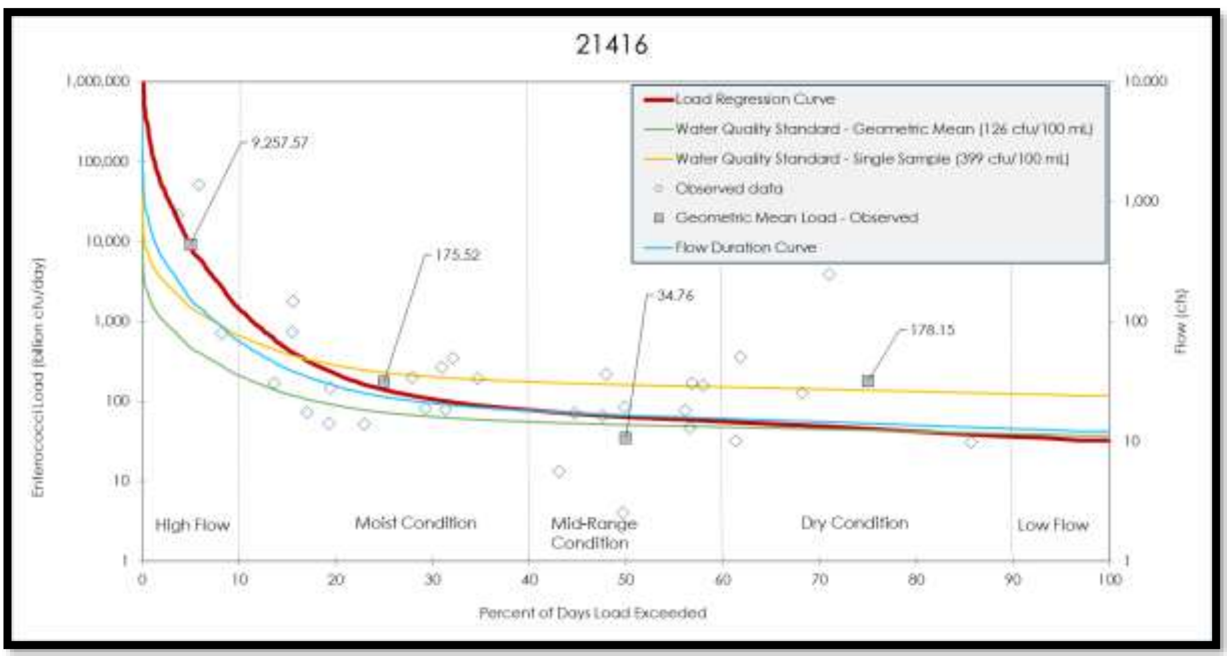

Figure 15. LDC for SWQM Station 21416 in Mustang Bayou, AU 2432A_03

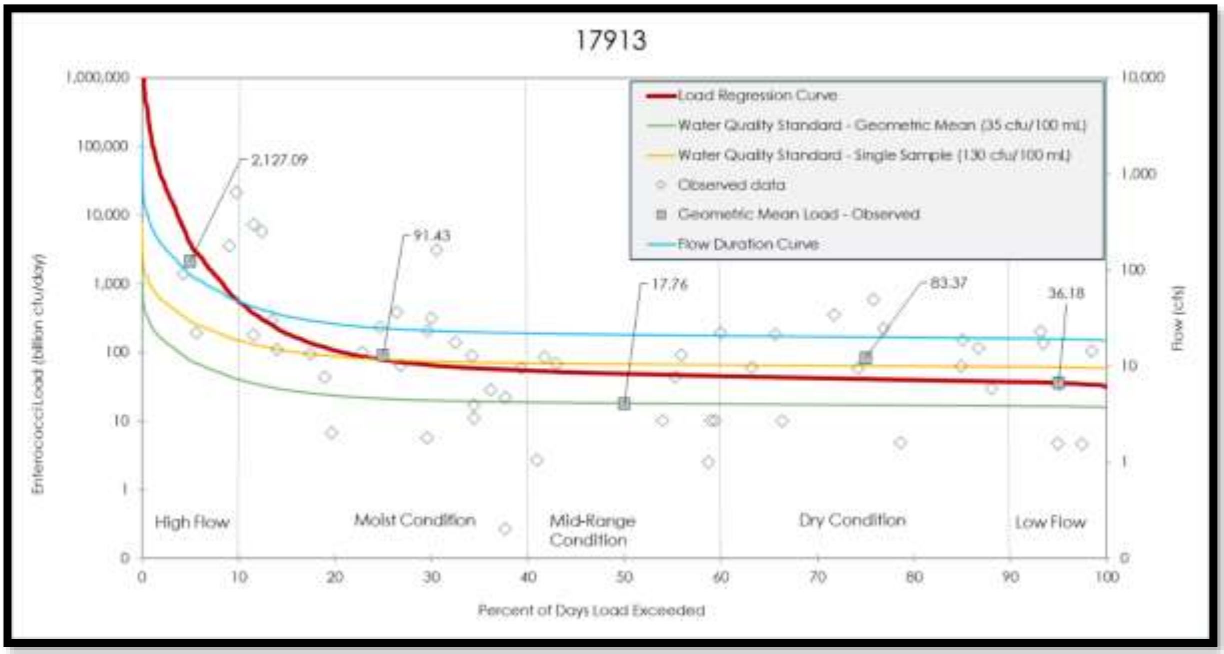

Figure 16. LDC for SWQM Station 17913 in Persimmon Bayou, AU 2432D_01

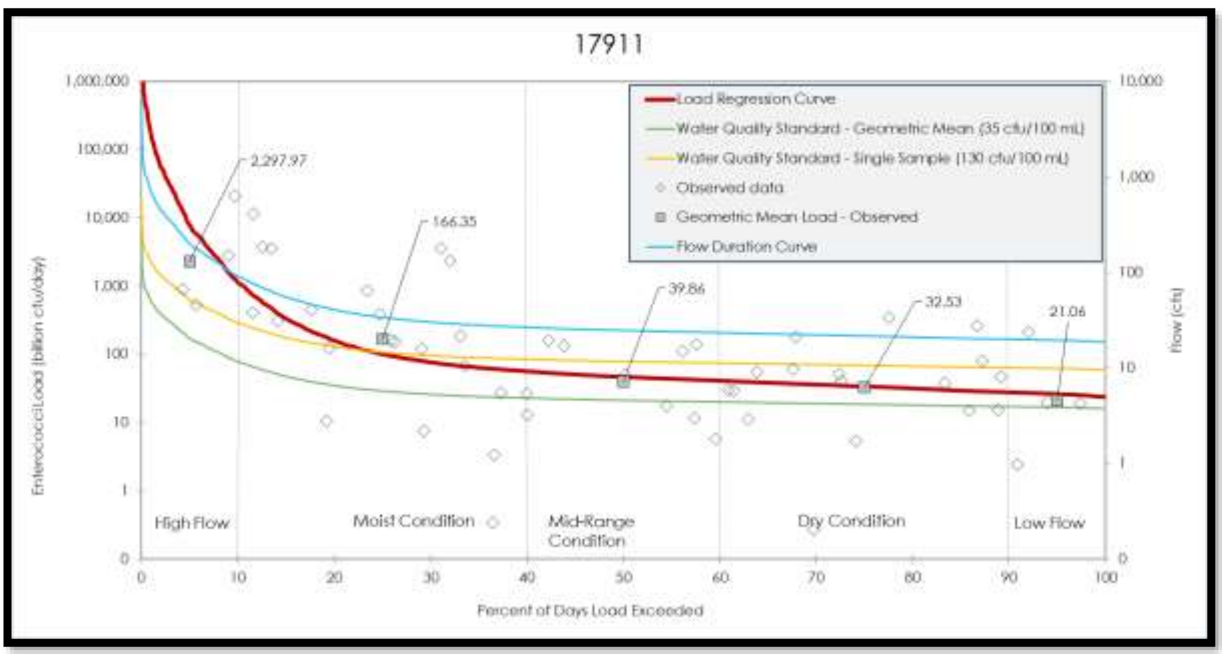

Figure 17. LDC for SWQM Station 17911 in New Bayou, AU 2432E_01

Section 4. TMDL Allocation Analysis

This section contains the bacteria TMDL allocations for the five impaired AUs within the TMDL Project watershed. The allocations are based on the LDCs for AU 2432A_01, 2432A_02, 2432A_03, 2432D_01, and AU 2432E_01, which were described in Section 3.

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. Please note that some calculations completed in this section have been rounded and may not lead to the exact final amounts listed in the text, tables, or figures.

The endpoint for AUs 2432A_01, 2432A_02, and 2432A_03 is to maintain the concentration of *E. coli* below the geometric mean criterion of 126 cfu/100 mL (TCEQ, 2018a), which is protective of the primary contact recreation 1 use in freshwater. The endpoint for AUs 2432D_01 and AU 2432E_01 is to maintain the concentration of Enterococcibelow the geometric mean criterion of 35 cfu/100 mL, which is protective of the primary contact recreation 1 use in tidal water bodies.

4.2. Seasonal Variation

Seasonal variations occur when there is a cyclic pattern in streamflow and, more importantly, in water quality constituents. TMDLs must account for seasonal variation in watershed conditions and pollutant loading, as required by federal regulations [Title 40, Code of Federal Regulations, Chapter 1, Part 130, Section 130.7(c)(1) (or 40 CFR 130.7(c)(1))] (EPA, 1991). To evaluate potential seasonal difference, ambient monitoring data for the TMDL Project watershed was grouped into a cool season (November-March) and a warm season (May–September). Data collected in April and October was excluded, assuming those months are transitions between the two seasons. There was no discernable difference observed comparing seasons using a Wilcoxon rank analysis of the data.

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 flows in the absence of runoff events, the main contributing sources are likely to be point sources and direct deposition (such as direct fecal 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 like direct deposition is typically diluted, and would, therefore, be a smaller part of the overall concentrations.

Bacteria load contributions from regulated and unregulated stormwater sources are greatest during runoff events. Rainfall runoff, depending upon the severity of the storm, can carry indicator bacteria from the land surface into the receiving stream. Generally, this loading follows a pattern of higher concentrations in the water body as the first flush of storm runoff enters the receiving stream. Over time, the concentrations decline as runoff washes fecal bacteria from the land surface and the volume of runoff decreases following the rain event.

LDCs 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 direct relationship between pollutant load sources (regulated and unregulated) and instream loads. Further, this one-to-one relationship was also inherently assumed when using LDCs to define the TMDL pollutant load allocation (Section 4.7). That allocation was based on the flows associated with the watershed areas under stormwater regulation, and the remaining portion was assigned to the unregulated stormwater.

4.4. Load Duration Curve Analysis

LDC analyses were used to examine the relationship between instream water quality and the broad sources of indicator bacteria loads, and they are the basis of the TMDL allocations. The strength of this TMDL is the use of the LDC method to determine the TMDL allocations. An LDC is 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 about loading rates, stream hydrology, land use conditions, and other conditions in the watershed. EPA supports the use of this approach to characterize pollutant sources. In addition, many other states are using this method to develop TMDLs.

The weaknesses of this method include the limited information it provides about the magnitude or specific origin of the various sources. Information gathered about point and nonpoint sources in the watershed is limited. The general difficulty in analyzing and characterizing *E. coli* and Enterococcus in the environment is also a weakness of this method.

The LDC method allows for estimation of existing and TMDL loads by using 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 hydrological 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.

At all SWQM stations, the load regression curve modeled from observed data exceeds the curve representing the geometric mean maximum in high, moist, and mid-range flow conditions (Figures 13–17). This indicates that non-point sources are a major driver of the bacteria impairments in all five AUs. However, only AU 2432A_01 and 2432A_03 exhibit the load regression curve meeting the standard curve in the dry conditions. The remaining three LDCs demonstrated the load regression curve's continued exceedance across all conditions, suggesting the contribution of bacteria from point sources. It should also be noted that in some instances there are only a few bacteria observations which can easily skew a geometric mean. Reduction strategies should target improvement of non-point and point sources of fecal bacteria to have a positive effect on water quality in the TMDL Project watershed.

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 (EPA, 1991), the MOS can be incorporated in the TMDL using one of two methods:

1. Implicitly incorporating the MOS using conservative model assumptions to develop allocations.
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 of 5%.

4.6. Load Reduction Analysis

Potential reduction targets for loads at each flow condition are detailed in Table 21. The observed bacteria geometric means were used to determine potential load reductions. According to the targets, bacteria loads in the watershed are well above the Texas Surface Water Quality Standards criteria at higher flow conditions. Bacteria reductions of more than 50% are needed throughout the TMDL Project area at moist and high flow conditions (Table 21). This indicates that non-point source load pressures are of particular concern in this watershed and should be central to the development of future water quality improvement strategies. However, with elevated levels across lower flow regimes with geometric means greater than 70% in some instances, point sources should also be considered as targets for improvement.

Table 21. Potential fecal indicator bacteria reductions needed by AU

AU	Flow Condition	Exceedance Range	Fecal Indicator Bacteria	Criterion (cfu/100 mL)	Geometric Mean (cfu/100 mL)	Required Percent Reduction
2432A_01	High Flow	(0-10%)	*E. coli*	126	938.72	86.58%
	Moist	(10-40%)	*E. coli*	126	479.84	73.74%
	Mid-Range	(40-60%)	*E. coli*	126	102.24	0.00%
	Dry	(60-90%)	*E. coli*	126	95.66	0.00%
	Low Flow[a]	(90-100%)	*E. coli*	126	_	_
2432A_02	High Flow	(0-10%)	*E. coli*	126	6,454.02	98.05%
	Moist	(10-40%)	*E. coli*	126	1,394.91	90.97%
	Mid-Range	(40-60%)	*E. coli*	126	724.29	82.60%
	Dry	(60-90%)	*E. coli*	126	1,423.86	91.15%
	Low Flow[a]	(90-100%)	*E. coli*	126	_	_
2432A_03	High Flow	(0-10%)	*E. coli*	126	2,758.57	95.43%
	Moist	(10-40%)	*E. coli*	126	266.76	52.77%
	Mid-Range	(40-60%)	*E. coli*	126	86.51	0.00%
	Dry	(60-90%)	*E. coli*	126	499.69	74.78%
	Low Flow[a]	(90-100%)	*E. coli*	126	_	_
2432D_01	High Flow	(0-10%)	Enterococci	35	1,274.67	97.25%
	Moist	(10-40%)	Enterococci	35	140.91	75.16%
	Mid-Range	(40-60%)	Enterococci	35	34.22	0.00%
	Dry	(60-90%)	Enterococci	35	169.79	79.39%
	Low Flow	(90-100%)	Enterococci	35	77.23	54.68%
2432E_01	High Flow	(0-10%)	Enterococci	35	651.52	94.63%
	Moist	(10-40%)	Enterococci	35	178.30	80.37%
	Mid-Range	(40-60%)	Enterococci	35	66.03	46.99%
	Dry	(60-90%)	Enterococci	35	61.48	43.07%
	Low Flow	(90-100%)	Enterococci	35	43.85	20.19%

[a]No observed bacteria data in the flow regime

4.7. Pollutant Load Allocations

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

$$TMDL = WLA + LA + FG + MOS \qquad \text{(Eq. 2)}$$

Where:

TMDL = total maximum daily load

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

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

FG = loadings associated with future growth from potential regulated facilities

MOS = margin of safety load

TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures [40 CFR, 130.2(i)]. For fecal indicator bacteria, TMDLs are expressed as billion cfu/day, and represent the maximum one-day load the stream can assimilate while still attaining the standards for surface water quality.

4.7.1. Assessment Unit-Level TMDL Calculations

The bacteria TMDLs for the water bodies were developed as pollutant load allocations based on information from the LDCs for the SWQM stations located within the watershed. As discussed in more detail in Section 3, the bacteria LDC was developed by multiplying each flow value along the FDC with the criterion (126 cfu/100 mL or 35 cfu/100 mL, respectively) and the conversion factor. Effectively, the "Allowable Load" displayed in the LDC at 5% exceedance (the median value of the high flow regime) is the TMDL.

TMDL (cfu/day) = Criterion * Flow (cfs) * Conversion Factor (Eq. 3)

Where:

Criterion = either 35 cfu/100 mL or 126 cfu/100 mL

Conversion Factor (to billion cfu/day) = 28,316.846 mL/cubic foot (ft^3) * 86,400 seconds/day (s/d) ÷ 1,000,000,000

The allowable loading of *E. coli* or Enterococci that the impaired water bodies can receive on a daily basis was determined using Equation 3 based on the median value within the high regime of the FDC (or 95% flow exceedance value) for the TCEQ SWQM station (Table 22).

Table 22. TMDL calculations at the 5% exceedance flow within the TMDL Project watershed

AU	Indicator Bacteria	Criterion (cfu/ 100 mL)	5% Exceedance Flow (cfs)	5% Exceedance Load (cfu/day)	TMDL (Billion cfu/day)
2432A_01	*E. coli*	126	153.725	4.74E+11	473.886
2432A_02	*E. coli*	126	176.731	5.45E+11	544.804
2432A_03	*E. coli*	126	153.811	4.74E+11	474.149
2432D_01	Enterococci	35	89.775	7.69E+10	76.874
2432E_01	Enterococci	35	201.955	1.73E+11	172.934

4.7.2. Margin of Safety Allocation

The MOS is only applied to the allowable loading for a watershed. Therefore, the MOS is expressed mathematically as:

$$MOS = 0.05 * TMDL \qquad \text{(Eq. 4)}$$

Where:

MOS = margin of safety load

TMDL = total maximum daily load

MOS values are presented in Table 23. An additional step must be taken to account for upstream loading from each AU contributing to the next AU downstream (TCEQ, 2016).

Table 23. MOS calculations

AU	Indicator Bacteria	Criterion (cfu/100 mL)	TMDL[a] (Billion cfu/day)	MOS (Billion cfu/day)
2432A_01	*E. coli*	126	473.886	23.694
2432A_02	*E. coli*	126	544.804	27.240
2432A_03	*E. coli*	126	474.149	23.707
2432D_01	Enterococci	35	76.874	3.844
2432E_01	Enterococci	35	172.934	8.647

[a]TMDL from Table 22

4.7.3. Waste Load Allocations

The WLA consists of two parts—the wasteload that is allocated to TPDES-regulated WWTFs (WLA_{WWTF}) and the wasteload that is allocated to regulated stormwater dischargers (WLA_{SW}).

$$WLA = WLA_{WWTF} + WLA_{SW} \qquad \text{(Eq. 5)}$$

4.7.3.1. Wastewater (WLA_{WWTF})

TPDES-permitted WWTFs are allocated a daily wasteload (WLA_{WWTF}) calculated as their full permitted discharge flow rate multiplied by the instream geometric criterion. The water quality criterion (126 cfu/100 mL for freshwater and 35 cfu/100 mL for saltwater) is used as the WWTF target to provide instream and downstream load capacity. Thus, WLA_{WWTF} is expressed in the following equation:

$$WLA_{WWTF} = Target * Flow * Conversion\ Factor \qquad \text{(Eq. 6)}$$

Where:

Target= 35 cfu/100 mL or 126 cfu/100 mL

Flow = full permitted flow (MGD)

Conversion Factor (to billion cfu/day) = 3,785,411,800 mL/million gallons ÷ 1,000,000,000

There were 16 identified WWTFs within the TMDL Project watershed (Table 24). Using Equation 6, each WWTF's allowable loading was calculated using each facility's full permitted flow. The individual results were summed to arrive at a total allocated loading for each AU. The criterion was applied based on the fecal indicator bacteria designated for the AU. As previously discussed, two of the three industrial WWTFs do not contain allowances for bacteria within their effluents. Both facilities are included in Table 24 for consistency, though no wasteload has been assigned. The wasteloads are cumulative, so from upstream to downstream, the assigned wasteload will be added to the next calculated total wasteload. Additionally, for AUs 2432A_01 and 2432D_01 the wasteload from the contributing upstream wasteloads were split evenly (50%) between both AUs.

Table 24. WLAs for TPDES-permitted facilities

AU	TPDES/NPDES Permit Number	Permittee Name	Facility Name	Monitored Bacteria (cfu/100 mL)	Full Permitted Flow (MGD)	WLA_{WWTF} (billion cfu/day)
2432A_03	WQ0016073001/ TX0142093	Alvin Mustang, LLC	Nantucket RV Park WWTF	126	0.02	0.09539238
2432A_03	WQ0016089001/ TX0142239	Green Raindrops, Inc	Magnolia RV Resort	126	0.0099	0.04721923
2432A_03	WQ0015747001/ TX0138894	KB Home Lone Star, Inc.	Lake Olympia Parkway WWTF	126	0.25	1.19240472
2432A_03	WQ0015636001/ TX0138126	Hanover Estates, Ltd.	Chimney Rock WWTF	126	0.7	3.33873321
2432A_03	WQ0015077001/ TX0134333	AUC Group LP	Tuscany Lakes WWTF	126	0.8	3.81569509
2432A_03	WQ0004306000/ TX0112461	Nalco Company, LLC	Fresno Plant	126	0.015	0.07154428
2432A_03	WQ0004306000/ TX0112461	Nalco Company, LLC	Fresno Plant	126	0.02	0.09539238
2432A_03	WQ0013600001/ TX0094790	Aqua Texas, Inc.	Astro WWTF	126	0.0225	0.10731642
2432A_03	WQ0013735001/ TX0118001	Rancho La Fuente Partners, LLC	Willow Manor Mobile Home Park	126	0.075	0.35772142
2432A_03	WQ0014641001/ TX0128163	Brazoria County Municipal Utility District 40	Brazoria County Municipal Utility District 40 WWTF	126	1.2	5.72354264
2432A_03	WQ0014188001/ TX0122823	Brazoria County Municipal Utility District No. 40	Oak Crest Mobile Home Park WWTF	126	0.099	0.47219227
2432A_03	WQ0014756001/ TX0129178	Sedona Lakes Municipal Utility District 1	Sedona Lakes WWTF	126	0.6	2.86177132

AU	TPDES/NPDES Permit Number	Permittee Name	Facility Name	Monitored Bacteria (cfu/100 mL)	Full Permitted Flow (MGD)	WLA_{WWTF} (billion cfu/day)
			2432A_03	**Total**	**3.8114**	**18.1789254**
2432A_02	WQ0010420001/ TX0056057	City of Hillcrest Village	City of Hillcrest Village WWTF	126	0.15	0.71544283
			2432A_02	**Total**	**0.15**	**0.71544283**
2432A_01	WQ0014039001/ TX0117234	Aqua Texas, Inc.	Ashley Oaks WWTF	126	0.0924	0.44071278
2432A_01	WQ0010005001/ TX0024554	City of Alvin	City of Alvin WWTF	126	5	23.8480943
			2432A_01/2432D_01	**Total**	**5.0924**	**24.2888071**
2432E_01	WQ0000001000/ TX0003875	Ascend Performance Materials Texas, Inc.	Ascend Chocolate Bayou Plant	Not Applicable	Intermittent/Flow Variable	Not Applicable
2432E_01	WQ0001333000/ TX0004821	INEOS USA, LLC	INEOS USA Chocolate Bayou Plant	Not Applicable	Intermittent/Flow Variable	Not Applicable
			2432E_01	**Total**	**9.0538**	**43.1831753**

4.7.3.2. Regulated Stormwater (WLA_{SW})

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

The percentage of the land area included in the TMDL watershed that is under the jurisdiction of stormwater permits is used to estimate the amount of the overall runoff load that should be allocated as the permitted stormwater contribution in the WLA_{SW} component of the TMDL. The LA component of the TMDL corresponds to direct nonpoint runoff and is the difference between the total load from stormwater runoff and the portion allocated to WLA_{SW}.

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

$$WLA_{SW} = (TMDL - WLA_{WWTF} - FG - MOS) * FDA_{SWP} \qquad \text{(Eq. 7)}$$

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 regulated facilities

MOS = margin of safety load

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

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. FDA_{SWP} is calculated by first totaling the area of each stormwater permit. The stormwater sources and how areas were estimated were discussed previously. Those area estimates were summed for each category and imported into Table 25. The stormwater categories are then summed up to determine the total area under stormwater jurisdiction in each segment.

Table 25. Total area of stormwater permits

AU	Drainage Area (Acres)	MS4 General Permit (Acres)	Multisector General Permit (Acres)	Concrete General Permit (Acres)	Construction Activities (Acres)	Total Area of Permits (Acres)
2432A_01	9,288.848	364.956	0.000	0.000	16.110	381.066
2432A_02	4,255.907	3,213.342	0.000	0.000	15.000	3,228.342
2432A_03	17,916.097	7,481.414	281.340	33.190	604.860	8,400.804
2432D_01	4,435.109	0.000	0.000	0.000	16.110	16.110
2432E_01	9,289.543	0.000	1,712.440	0.000	18.110	1,730.550

To arrive at the proportion, the area under stormwater jurisdiction is then divided by the total watershed area. The drainage areas and total area of permits are accumulative as one moves downstream. Additionally, to account for the divided flow between 2432A_01 and 2432D_01, the contributing watershed is split by 50%. Table 26 presents the calculated FDA_{SWP} for each subwatershed within the TMDL Project watershed.

Table 26. Basis of unregulated stormwater area and computation of FDA_{SWP} term

AU	Drainage Area[a] (Acres)	Total Area of Permits[a] (Acres)	FDA_{SWP}
2432A_01	15,730.426	6,005.106	0.382
2432A_02	22,172.004	11,629.146	0.524
2432A_03	17,916.097	8,400.804	0.469
2432D_01	20,165.536	6,005.106	0.298
2432E_01	25,019.969	7,735.656	0.309

[a]Drainage Area and Total Area of Permits are adjusted for upstream contributions.

To complete the WLA_{SW}, a value for future growth (FG) is needed. FG is calculated based on future WWTF wasteload. The calculation for FG is presented in Section 4.7.4. The calculated FG is presented here for continuity. All the needed information to complete Equation 10 is known and presented along with the resulting WLA_{SW} in Table 27.

Table 27. Regulated stormwater calculations

AU	TMDL[a] (Billion cfu/day)	MOS[b] (Billion cfu/day)	WLA_{WWTF} [c] (Billion cfu/day)	Adjusted FG[d] (Billion cfu/day)	FDA_{SWP}[e]	WLA_{SW} [f] (Billion cfu/day)
2432A_01	473.886	23.694	21.592	30.938	0.382	151.808
2432A_02	544.804	27.240	18.894	37.702	0.524	242.776
2432A_03	474.149	23.707	18.179	37.441	0.469	185.131
2432D_01	76.874	3.844	5.998	8.614	0.298	17.397
2432E_01	172.934	8.647	5.998	8.614	0.309	46.277

[a] TMDL from Table 22

[b] MOS from Table 23

[c] WLA_{WWTF} wasteload allocation from Table 24

[d] FG from Table 28

[e] FDA_{SWP} from Table 26

[f] WLA_{SW} = (TMDL – WLA_{WWTF} – FG – MOS) *FDA_{SWP} (Eq. 7)

4.7.4. Future Growth

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

The allowance for FG will result in protection of existing uses and conform to Texas' antidegradation policy.

The FG component for TMDL watersheds is typically based on population projections (Table 4) and current permitted wastewater discharges for the entire TMDL Project watershed. As there are no WWTFs present in AUs 2432D_01 or 2432E_01, and the population within these subwatersheds is not expected to grow, a different method was used. Two potential future 0.015 MGD WWTFs were sited within both watersheds to account for any possible unforeseen changes in future population growth. The size of 0.015 MGD was based on a recent RV park sited in Chocolate Bayou Tidal.

Table 28 provides the FG for each AU in the TMDL project watershed. An adjusted FG term is provided to demonstrate the needed adjustment to account for upstream WWTFs on downstream AUs. WWTFs FG calculated using the freshwater criterion were recalculated for the saltwater criterion for the tidal AUs. Additionally, for AUs 2432A_01 and 2432D_01, the adjusted FG applies the 50% reduction in flow.

Thus, the FG is calculated as follows:

$$FG = Criterion * (\%POP_{2020\text{-}2070} * WWTF_{FP}) * Conversion\ Factor \qquad (\text{Eq. 8})$$

Where:

Criterion =126 cfu/100 mL E coli standard and 35 cfu/100 mL Enterococcus standard

$POP_{2020-2070}$ = estimated percentage increase in population between 2020 and 2070

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

Conversion Factor = 3,785,411,800 mL/million gallons ÷ 1,000,000,000

Table 28. FG calculation

Subwatershed	% Population Change (2020-2050)	Full Permitted Discharge (MGD)	FG Flow (MGD)	FG (Billion cfu/day)	Adjusted FG [a] (Billion cfu/100 mL)
2432A_01	99.53%	5.092	5.068	24.175	30.938[b]
2432A_02	36.49%	0.150	0.055	0.261	37.702
2432A_03	205.96%	3.811	7.850	37.441	-
2432D_01	0.0%	-	0.015	0.012	8.614[c]
2432E_01	0.0%	-	0.015	0.012	8.614[c]

[a] Adjusted FG accounts for the contribution of future growth upstream of the AU.

[b] Calculated as the FG 2432A_01 plus Adjusted FG of 2432A_02 divided by 2.

[c] Calculated as the FG plus the Adjusted FG of 2432A_01 when calculated using the tidal criterion, 35 cfu/100 mL. of Enterococci

4.7.5. Load Allocations

The LA is the load from unregulated sources, and is calculated as:

$$LA = TMDL - WLA - FG - MOS \qquad \text{(Eq. 9)}$$

Where:

LA = allowable loads from unregulated sources within the AU

TMDL = total maximum daily load

WLA = sum of all WLA_{WWTF} and WLA_{SW} loads

FG = sum of future growth loads from potential regulated facilities

MOS = margin of safety load

Using Eq. 9, the calculations for LA are presented in Table 29.

Table 29. LA calculation

Load units expressed as billion cfu/day

AU	Indicator Bacteria	TMDL[a]	MOS[b]	WLA_{WWTF}[c]	WLA_{SW}[d]	FG [e]	LA [f]
2432A_01	*E. coli*	473.886	23.694	21.592	151.808	30.938	245.854
2432A_02	*E. coli*	544.804	27.240	18.894	241.776	37.702	219.192
2432A_03	*E. coli*	474.149	23.707	18.179	185.131	37.441	209.691
2432D_01	Enterococci	76.874	3.844	5.998	17.397	8.614	41.022
2432E_01	Enterococci	172.934	8.647	5.998	46.277	8.614	103.399

[a] TMDL from Table 22

[b] MOS from Table 23

[c] WLA_{WWTF} from Table 24

[d] WLA_{SW} from Table 27

[e] FG from Table 28

[f] LA = TMDL – WLA – FG – MOS (Eq. 9)

4.8. Summary of TMDL Calculations

Table 30 summarizes the TMDL calculations for the TMDL Project watershed. The TMDLs in freshwater are calculated using the median flow (5%) in the high flow range for flow exceedance from the LDC developed for SWQM Stations 11423, 18554, and 21416 based on the current geometric mean criterion for *E.coli* of 126 cfu/100 mL for each component of the TMDL. The TMDLs in tidal waters are calculated using the median flow (5%) in the high flow range for flow exceedance from the LDC developed for SWQM Stations 17913 and 17911 based on the current geometric mean criterion for Enterococci of 35 cfu/100 mL for each component of the TMDL.

Table 30. TMDL allocation summary

Load units expressed as billion cfu/day

AU	Indicator Bacteria	TMDL	MOS	WLA_{WWTF}	WLA_{SW}	LA	FG
2432A_01	*E. coli*	473.886	23.694	21.592	151.808	245.854	30.938
2432A_02	*E. coli*	544.804	27.240	18.894	241.776	219.192	37.702
2432A_03	*E. coli*	474.149	23.707	18.179	185.131	209.691	37.441
2432D_01	Enterococci	76.874	3.844	5.998	17.397	41.022	8.614
2432E_01	Enterococci	172.934	8.647	5.998	46.277	103.399	8.614

The final TMDL allocation (Table 31) needed to comply with the requirements of 40 CFR 130.7 include the FG component within the WLA_{WWTF}.

Table 31. Final TMDL allocation

Load units expressed as billion cfu/day

AU	Indicator Bacteria	TMDL	MOS	WLA_{WWTF} [a]	WLA_{SW}	LA
2432A_01	*E. coli*	473.886	23.694	52.530	151.808	245.854
2432A_02	*E. coli*	544.804	27.240	56.597	241.776	219.192
2432A_03	*E. coli*	474.149	23.707	55.620	185.131	209.691
2432D_01	Enterococci	76.874	3.844	14.612	17.397	41.022
2432E_01	Enterococci	172.934	8.647	14.612	46.277	103.399

[a] WLA_{WWTF} includes the FG component

Section 5. References

AVMA (American Veterinary Medical Association). 2018. 2017-2018 U.S. Pet Ownership Statistics. Retrieved June 24, 2020, from: www.avma.org/resources-tools/reports-statistics/us-pet-ownership-statistics.

Cleland, B. 2003. TMDL Development From the "Bottom Up" - Part III: Duration Curves and Wet-Weather Assessments. engineering.purdue.edu/mapserve/ldc/pldc/help/TMDL_Development_from_the_Bottom_UP_PartIV.pdf.

EPA. 1991. Guidance for Water Quality-Based Decisions: The TMDL Process. EPA 440/4-91-001. www.epa.gov/sites/production/files/2018-10/documents/guidance-water-tmdl-process.pdf.

EPA. 2007. An Approach for Using Load Duration Curves in the Development of TMDLs. EPA 841-B-07-006. www.epa.gov/sites/production/files/2015-07/documents/2007_08_23_tmdl_duration_curve_guide_aug2007.pdf.

EPA. 2022. Enforcement and Compliance History Online (ECHO). Accessed July 2022, from: echo.epa.gov/.

Hauck, Larry. 2009. Overview of Models for Estimating Pollutant Loads & Reductions. Presentation. Texas Watershed Planning Short Course. PDF. Jan. 14, 2009.

Hauck, Larry, Stephanie Painter, and David Pendergrass. 2013. Technical Support Document for Total Maximum Daily Loads for Indicator Bacteria in Watersheds of the Mission and Aransas Rivers. Prepared for the Texas Commission on Environmental Quality. Dec. 2013.

Hauck, Larry. 2015. Using Simple Tools: Alternatives to Mechanistic Models. Presentation given as an Introduction to Watershed Model Training. July 8, 2015.

Hauck, Larry, Stephanie Painter, and Anne McFarland. 2015. Technical Support Document for Total Maximum Daily Load for Indicator Bacteria in Tres Palacios Creek Tidal. Prepared for the Texas Commission on Environmental Quality. November 2015.

Hauck, Larry, Stephanie Painter, and Anne McFarland. 2017. Technical Support Document for Total Maximum Daily Load for Indicator Bacteria in Tres Palacios Creek Tidal. Prepared for the Texas Commission on Environmental Quality. www.tceq.texas.gov/assets/public/waterquality/tmdl/108trespalacios/108-trespalacios-tsd.pdf.

H-GAC. 2021a. 2021 H-GAC Regional Growth Forecast. datalab.h-gac.com/rgf2018.

H-GAC. 2021b, Land Use & Land Cover 2020. http://h-gac.com/community/socioeconomic/land-use-data/default.aspx.

H-GAC. 2022a. OSSF Information System. Permitted OSSF within the H-GAC planning area. datalab.h-gac.com/ossf/

H-GAC. 2022b. OSSF Information System-Non-Registered. Non-registered OSSF within the H-GAC planning area, non-published data 2022.

NEIWPCC (New England Interstate Water Pollution Control Commission). 2003. livestock Discharge Detection and Elimination Manual: A Handbook for Municipalities. neiwpcc.org/neiwpcc_docs/iddmanual.pdf.

NOAA. 2017. What is the Difference between Land Cover and Land Use? https://oceanservice.noaa.gov/facts/lclu.html

NOAA. 2022 National Climate Data Center Climate Data Online. Retrieved May 1, 2022, from: www.ncdc.noaa.gov/cdo-web.

ODEQ [Oregon Department of Environmental Quality]. 2006. Chapter 2 and Appendix 1 - Umpqua Basin TMDL. www.oregon.gov/deq/wq/tmdls/Pages/TMDLs-Umpqua-Basin.aspx.

Reed, Stowe & Yanke, LLC. 2001. Study to Determine the Magnitude of, and Reasons for, Chronically Malfunctioning On-site Sewage Facility Systems in Texas. Texas On-site Wastewater Treatment Council.

Snowden Engineering Inc, 1989. Master Drainage Plan Report on Mustang Bayou, Chocolate Bayou, Ditch C-1, Ditch M-1, New Bayou, Halls Bayou, Chigger Creek, Ditch D-4 and Dickinson Bayou Watersheds. Prepared for Brazoria County Conservation and Reclamation District No. 3 and Texas Water Development Board. June 1989.

TCEQ. 2006. Preserving & Improving Water Quality: The Programs of the Texas Commission on Environmental Quality for Managing the Quality of Surface Waters. Retrieved July 13, 2021, from www.tceq.texas.gov/publications/gi/gi-351.

TCEQ. 2008. 2006 Texas Water Quality Inventory and 303(d) List. https://www.tceq.texas.gov/waterquality/assessment/06twqi/twqi06.html.

TCEQ. 2016. Seven Total Maximum Daily Loads for Indicator Bacteria in Lake Houston, East Fork San Jacinto River, West Fork San Jacinto River, and Crystal Creek Watersheds. https://www.tceq.texas.gov/downloads/water-quality/tmdl/houston-galveston-recreational-42/82c-ewfsj-bacteria-tmdl-addendum-one.pdf

TMDL adopted by TCEQ Aug. 24, 2016. US EPA approved Oct. 7, 2016.TCEQ. 2018a. Texas Surface Water Quality Standards, 2018, 30 TAC 307. texreg.sos.state.tx.us/public/readtac%24ext.ViewTAC?tac_view=4&ti=30&pt=1&ch=307&rl=Y.

TCEQ. 2018b. Preserving and Improving Water Quality: The Programs of the Texas Commission on Environmental Quality for Managing the Quality of Surface Waters. www.tceq.texas.gov/publications/gi/gi-351.

TCEQ. 2022a. Draft Texas Water Quality Inventory and 303(d) List. www.tceq.texas.gov/waterquality/assessment/public_comment.

TCEQ, 2022b. TCEQ Surface Water Quality Viewer. Accessed July 2022, from: https://tceq.maps.arcgis.com/apps/webappviewer/index.html?id=b0ab6bac411a49189106064b70bbe778

TCEQ. 2022c. Personal written communication with Jazmyn Milford regarding general wastewater permits in the Mustang, Persimmon, and New Bayou watersheds. June 10, 2022.

TCEQ. 2022d. TCEQ Central Registry. Retrieved July 2022, from: www2.tceq.texas.gov/wq_dpa/index.cfm.

TCEQ. 2022e. Personal written communication with Jason Leifester regarding sanitary sewer overflows within the H-GAC region. Mar. 16, 2022.

TCEQ, 2022f. Texas Water Rights Viewer. Retrieved July 2022, from: https://tceq.maps.arcgis.com/home/item.html?id=44adc80d90b749cb85cf39e04027dbdc.

Timmons, et. al. 2012. Feral Hog Population Growth, Density, and Harvest in Texas. August 2012. Online: agrilife.org/feralhogs/files/2010/04/FeralHogPopulationGrwothDensityandHervestinTexasedited.pdf.

TPWD. 2019. White-tailed deer Management Unit Map Server. TPWD Wildlife Division. Retrieved Oct. 10, 2019, from: tpwd.texas.gov/arcgis/rest/services/Wildlife/TPWD_WL_WTDMU/MapServer.

TWRI (Texas Water Resources Institute). 2007. Bacteria Total Maximum Daily Load Task Force Report, Fourth Draft, June 4, 2007. Prepared for TCEQ and TSSWCB. www.twri.tamu.edu/bacteriatmdl/ twri.tamu.edu/media/4572/bacteria-tmdl-task-force-final-report-6407.pdf. Accessed July 13, 2021.

USCB. 2010. 2010 Census Urban and Rural Classification and Urban Area Criteria. U.S. Department of Commerce Economics and Statistics Administration. www.census.gov/programs-surveys/geography/guidance/geo-areas/urban-rural/2010-urban-rural.html.

USCB. 2021. USCB Decadal Census. Retrieved June 2022, from: www.census.gov/programs-surveys/decennial-census.html.

USDA NRCS. 2015. SSURGO/STATSGO2 Structural Metadata and Documentation. www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/geo/?cid=nrcs142p2_053631.

USDA. 2024. US Department of Agriculture Census of Agriculture 2022. https://www.nass.usda.gov/Publications/AgCensus/2022/Full_Report/Volume_1,_Chapter_2_County_Level/Texas/

USGS. 2007. Sneck-Fahrer, D.A., and East, J.W., 2007, Water-quality, sediment-quality, stream-habitat, and biological data for Mustang Bayou near Houston, TX, 2004-05: U.S. Geological Survey Data Series 263.

USGS. 2019. USGS Current Water Data for the Nation. Retrieved June 2022, from: waterdata.usgs.gov/nwis/rt.

Weiskel, P.K., B.L. Howes, and G.R. Heufelder. 1996. Coliform Contamination of Coastal Embayment: Sources and Transport Pathways. Environmental Science and Technology, 30, 1872-1881.

Appendix. Method Used to Determine Population Projections

H-GAC, through its Regional Growth Forecast, routinely assesses the region's population and develops population projections. To estimate future population, H-GAC used their Demographic Evolution Model. The model creates a virtual accounting of future people and households within an eight-county area. The model accounts for either the addition or removal of residents due to births, deaths, in-migrants, and out-migrants. The model is a computer simulation which uses a probabilistic approach to imitate both the biologic events and social events that drive the addition and/or removal for the synthesized individuals and households (H-GAC, 2018[1]).

To accommodate the future households and populations, H-GAC developed a Real Estate Development Model that acts like a real estate developer and generates predictions for Single-Family and Multi-Family units on specific parcels, given the physical availability/suitability of land and economic feasibility.

Once the new residential units are built, H-GAC's Household Location Choice Model allocates future households to new housing units using the grid-level (three-mile grid) location probabilities categorized by age-race-household size and income.

Finally, the household and population data is summarized by various geographies including Counties, Cities, Census tracts, three square mile grids and Traffic analysis Zone.

The Regional Growth Forecast Methodology, a report that fully discusses the steps H-GAC uses to determine future population growth is available on the H-GAC webpage[2].

The following steps detail the method used to estimate the 2020 and projected 2050 populations in the TMDL Project watershed.

1. The H-GAC regional forecast team obtained USCB 2020 Decadal Census data from the U.S. Census Bureau at the block level.

2. The H-GAC regional forecast team used census block data to develop population estimates for a hexagonal grid of three-square miles each (H3M) for the H-GAC region.

3. H-GAC staff estimated 2020 watershed populations using the H3M data for the portion of the H3M located within the watershed assuming equal distribution.

[1] H-GAC, 2018 – Regional Growth Forecast. Current release 2018. Retrieved 2020. www.h-gac.com/regional-growth-forecast

[2] www.h-gac.com/getmedia/6f706efb-9c6d-4b6a-b3aa-7dc7ad10bd26/read-documentation.pdf

4. Obtained population projections for the year 2050 from the H-GAC regional forecast based on H3M data.

5. Developed population projections using H-GAC regional forecast data for the portion of the H3M located within the watershed assuming equal distribution.

6. Subtracted the 2020 watershed population was from the 2050 population projection to determine the projected population increase. Subsequently, the projected population increase was divided by the 2020 watershed population to determine the percent population increase for the TMDL Project watershed.