Technical Support Document for Two Total Maximum Daily Loads for Indicator Bacteria in the Halls Bayou Tidal and Willow Bayou Watersheds

Assessment Units: 2432C_01 and 2432B_01

Halls Bayou, Monitoring Station 11422 at FM 2004

By Steven Johnston

Houston-Galveston Area Council
Submitted to TCEQ July 2022

Published by the Texas Commission on Environmental Quality
AS-492

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

By:
Steven Johnston
Jessica Casillas
Rachel Windham
Thushara Ranatunga
Houston-Galveston Area Council
Houston, TX

Submitted to the Texas Commission on Environmental Quality
July 2022

Acknowledgements

The United States Environmental Protection Agency and the Texas Commission on Environmental Quality provided financial support for this study. The Texas Commission on Environmental Quality was the study's lead agency.

Local Chocolate Bay stakeholders provided insights including historical background, technical advice, and feedback as part of the outreach conducted for this project.

Contents

Figures

Tables

Abbreviations

AU	assessment unit
CAFO	concentrated animal feeding operation
cfs	cubic feet per second
cfu	colony forming units
DAR	drainage area ratio
DMR	discharge monitoring reports
E. coli	*Escherichia coli*
EPA	United States Environmental Protection Agency
FDC	flow duration curve
gpcd	gallons per capita per day
H-GAC	Houston-Galveston Area Council
km	kilometer
LA	load allocation
LDC	load duration curve
LR	load regression
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
OSSF	on-site sewage facility
ppt	parts per thousand
SSO	sanitary sewer overflow
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
TSWQS	Texas Surface Water Quality Standards
UA	urbanized area
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.

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, and fishing—of impaired or threatened water bodies.

TCEQ first identified bacteria impairment within the Halls Bayou Tidal watershed, assessment unit (AU) 2432C_01, in the *2012 Texas Integrated Report of Surface Water Quality for the Clean Water Act Section 305(b) and 303(d)* (Texas Integrated Report TCEQ, 2012). The bacteria impairment within Willow Bayou watershed, AU 2432B_01, was first identified by TCEQ in the *2018 Texas Integrated Report* (TCEQ, 2018). The bacteria impairments have been identified in each subsequent editions, up to *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 edition approved by the United States Environmental Protection Agency (EPA).

This document will consider two bacteria impairments to two AUs within the Halls Bayou Tidal and Willow Bayou subwatersheds, which when used together for the remainder of this document will be referred to as the TMDL Project watershed. Both AUs are listed in Subcategory 5a in the *2022 Texas Integrated Report*, making them a high priority for TMDL development. The impaired water bodies and identifying AU numbers are:

- Halls Bayou Tidal – 2432C_01
- Willow Bayou – 2432B_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* (TSWQS) (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 used to assess the risk of illness during contact recreation (e.g., swimming) from the 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 in water indicates that associated pathogens from fecal waste 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 septic systems (TCEQ, 2018b). The fecal indicator bacteria used for saltwater in Texas is Enterococcus, a species of gram-positive bacteria. The fecal indicator bacteria used for fresh water is *Escherichia coli* (*E. coli*), a species of fecal coliform bacteria.

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 consists of several categories:

- **Primary contact recreation 1** – Activities that are presumed to 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

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** – Water recreation activities, such as wading by children, swimming, water skiing, diving, tubing, surfing, handfishing, and whitewater kayaking, canoeing, and rafting, that involve a significant risk of water ingestion but that occur less frequently than for primary contact recreation 1 due to physical characteristics of the water body or limited public access. The geometric mean criterion for *E. coli* is 206 cfu per 100 mL.

- **Secondary contact recreation 1** – Activities that commonly occur but have limited body contact incidental to shoreline activity (e.g., fishing, canoeing, kayaking, rafting, and motor boating). These activities are presumed to pose a less significant risk of water ingestion than primary contact recreation 1 or 2 but more than secondary contact recreation 2. The geometric mean criterion for *E. coli* is 630 cfu per 100 mL.

- **Secondary contact recreation 2** – Activities with limited body contact incidental to shoreline activity (e.g., fishing, canoeing, kayaking, rafting, and motor boating) that are presumed to pose a less significant risk of water ingestion than secondary contact recreation 1. These activities occur less frequently than secondary contact recreation 1 due to physical characteristics of the water body or limited public access. The geometric mean criterion for *E. coli* is 1,030 cfu 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. 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 are presumed to 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 cfu per 100 mL.

- **Secondary contact recreation 1** – Activities that commonly occur but have limited body contact incidental to shoreline activity and (e.g., fishing, canoeing, kayaking, rafting, and motor boating). These activities are presumed to pose a less significant risk of water ingestion than primary contact recreation 1 or 2 but more than secondary contact recreation 2. The geometric mean criterion for Enterococci is 175 cfu 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 cfu per 100 mL.

The TMDL Project watershed contains both a tidal stream, Halls Bayou Tidal, and a freshwater stream, Willow Bayou. Both have been designated for 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 watershed; 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.
- A 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 a load duration curves (LDC).
- Application of the LDC approach for developing the pollutant load allocation (LA).

Section 2. Historical Data Review and Watershed Properties

2.1. Description of Study Area

The TMDL Project watershed is 68.98-square mile and is in southeast Texas, near the cities of Hitchcock, Santa Fe, Hillcrest, and Alvin (Figure 1). The watershed consists of two bayous, Halls Bayou Tidal and Willow Bayou, which flow generally southeasterly to southwesterly to Chocolate Bay (Segment 2432), West Galveston Bay and the Gulf of Mexico.

The Halls Bayou Tidal watershed (2432C_01) is 50.04 square miles. This tidal stream is 19.6 miles long and begins approximately 6 miles southeast of Alvin in Brazoria County with intermittent headwaters (Figure 1). The segment flows southeasterly, briefly enters Galveston County, and then runs parallel to the Galveston County line. The bayou then turns and flows southwesterly into Halls Lake, and then into Chocolate Bay (TSHA, 2010b), an embayment of West Galveston Bay.

The Willow Bayou watershed is 10.94 square miles. Willow Bayou (AU 2432B_01) is the major tributary to Halls Bayou. The intermittent headwaters for Willow Bayou start three miles southwest of the City of Hitchcock in western Galveston County. The stream flows southwest for 8 miles to its confluence with Halls Bayou at the Brazoria County line (TSHA, 2010a) (Figure 1).

The *2022 Texas Integrated Report* (TCEQ, 2022a) provides the following segment and AU descriptions:

- Halls Bayou Tidal (Segment 2432C) – From the Chocolate Bay confluence upstream to a point 31.5 km (19.6 miles) upstream.

- Willow Bayou (Segment 2432B) – From the Halls Bayou confluence to a point 9.7 km (6 miles) upstream.

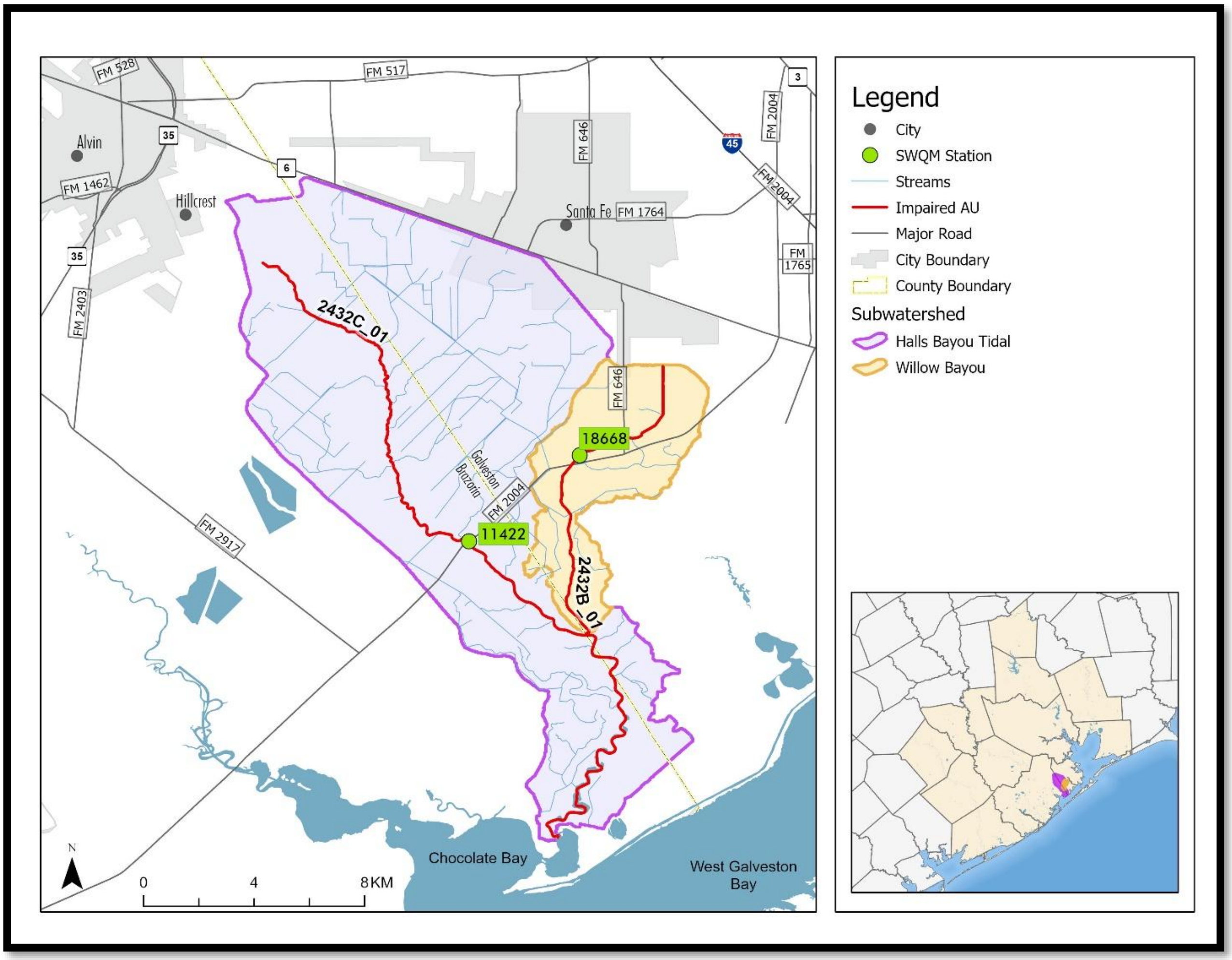

Figure 1. Map of the TMDL Project watershed and SWQM station locations

2.2. Review of Routine Monitoring Data

2.2.1. Analysis of Bacteria Data

The EPA-approved *2022 Texas Integrated Report* lists Halls Bayou Tidal (AU 2432C_01) as impaired for primary contact recreation 1 use due to high levels of Enterococci bacteria (TCEQ, 2022a). The AU has been listed since 2012. TCEQ's assessment found the geometric mean for Enterococci within this AU to be 78.65 cfu/100 mL, above the standard of 35 cfu/100 mL (Table 1).

The *2022 Texas Integrated Report* lists Willow Bayou (AU 2432B_01) as impaired for primary contact recreation 1 use due to elevated levels of *E. coli* bacteria (TCEQ, 2022a). The AU has been listed as impaired since 2018. TCEQ assessment found the geometric mean for *E. coli* within this AU to be 279.71 cfu/100 mL, which is above the standard of 126 cfu/100 mL (Table 1).

Table 1. ***2022 Texas Integrated Report*** **summary**

Subwatershed	AU	Parameter	SWQM Station	No. of Samples	Data Date Range	Station Geometric Mean (cfu/100 mL)
Willow Bayou	2432B_01	*E. coli*	18668	13	12/1/2013 – 11/30/2020	279.71
Halls Bayou Tidal	2432C_01	Enterococci	11422	35	12/1/2013 – 11/30/2020	78.65

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 two surface water quality monitoring (SWQM) stations, one in Segment 2432B, SWQM Station 18668, and one in Segment 2432C, SWQM Station 11422 (Figures 1). SWQM station locations and general descriptions are as follows (TCEQ, 2022b):

- SWQM Station 18668 (29.314262, -95.095314) in AU 2432B_01 is located on Willow Bayou at Baker St., 404 miles upstream of FM 2004, south of Santa Fe in Galveston County.
- SWQM Station 11422 (29.286369, -95.131227) in AU 2432C_01 is located on Halls Bayou Tidal at FM 2004, southwest of Alto Loma.

Data for SWQM Station 18668 was available from 2007 to 2021 (Table 2). The bacteria geometric mean for this timeframe was 143.49 cfu/100 mL. A review of the historic data for SWQM station 11422 from 2004 to 2021 returned a geometric mean of 116.46 cfu/100 mL (Table 2).

Table 2. Historic fecal indicator bacteria data

Subwatershed	SWQM Station	Parameter	Number of Samples	Data Date Range	Maximum Value (cfu/100 mL)	Geometric Mean (cfu/100 mL)
Willow Bayou	18668	*E. coli*	55	04/29/2007 – 04/29/2021	24,000	143.49
Halls Bayou Tidal	11422	Enterococci	105	03/30/2004 – 10/06/2021	55,000	116.46

Daily stream flow records are an essential component of TMDL development. As historical daily stream flow records were not available, 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 recorded between 2004 and 2020 was 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). For the watershed, the driest months typically occur in late winter and early spring. The wettest periods typically occur in summer and early fall, during hurricane season, when rainfall near or above 20 inches in a month is common.

Table 3. Average annual rainfall recorded from 2004 through 2020 at NOAA Station GHCND: USC00413340,

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

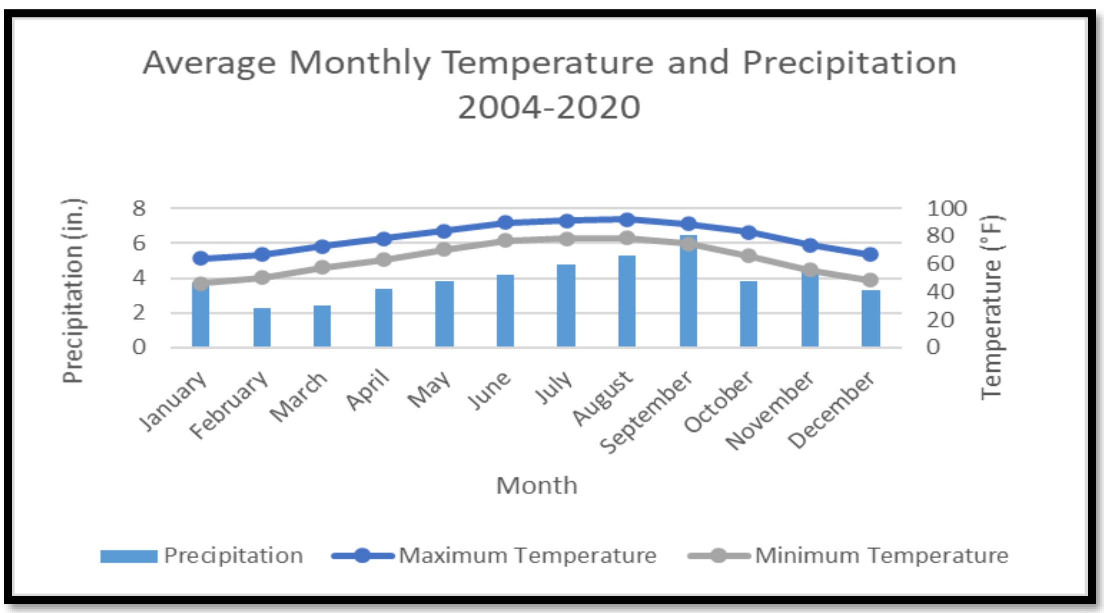

Figure 2. Average monthly temperature and precipitation from 2004 through 2020, NOAA Station GHCND:USC00413340

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 the maximum and minimum average monthly temperatures. As shown, December and January are the coolest months with the lowest 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. Population and Population Projections

H-GAC through its Regional Growth Forecast routinely assesses the region's population and develops population projections (H-GAC, 2018a). 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 9,482 in 2020, with populations of 1,877 and 7,605 within the Willow Bayou and Halls Bayou Tidal subwatersheds, respectively (Table 4). The population in the TMDL Project watershed is not evenly distributed. Most of the population can be found in the upper portion of the watershed near the cities of Santa Fe and Hitchcock.

Regional Growth Forecast methodology (H-GAC, 2017) was used to estimate regional population and household growth out to the year 2050.The population within the TMDL Project watershed is projected to increase slowly in the future with an estimated population of 17,228, or 81.69%, by 2050. All the projected population growth is expected to take place within the Halls Bayou Tidal watershed (H-GAC, 2018a).

Table 4. Population change in the TMDL Project watershed

Subwatershed	AU	2020	2050	% Change
Willow Bayou	2432B_01	1,877	1,799	-4.16%
Halls Bayou Tidal	2432C_01	7,605	15,429	102.88%
Total		**9,482**	**17,228**	**81.69%**

2.5. Land Cover

The TMDL Project watershed is primarily coastal prairie and marsh, broken up by ribbons of riparian hardwood, 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, 2018b). The definitions for the 10 land cover types are:

1. **Developed High Intensity** – Contains significant land areas that are 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 a mixture of constructed materials and vegetation or other cover. Constructed materials account for 50% to 79% of the total area. This class commonly includes single- and multi-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 the 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 consists of 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 lands categorized as both Pasture/Hay 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 shoreland 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 the 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 that account for 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 that account for greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. The canopy is never without green foliage.

    c. **Mixed Forest** – Contains areas dominated by trees generally greater than five meters tall that account for greater than 20% of total vegetation cover. Neither deciduous nor evergreen species account for 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 that typically accounts for greater than 20% of the total vegetation. This class includes tree shrubs, young trees in an early successional stage, and 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 from vegetation or soil.

b. **Palustrine Aquatic Bed** – Includes tidal and non-tidal wetlands and deep-water habitats in which the 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. The total vegetation cover is greater than 80%.

c. **Estuarine Aquatic Bed** – Includes tidal wetlands and deep-water habitats in which the 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. The 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 the salinity due to ocean derived salts is below 0.5%. The total vegetation coverage is greater than 20%.

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

c. **Palustrine Emergent Wetland (Persistent)** – Includes tidal and non-tidal wetlands dominated by persistent emergent vascular plants, emergent mosses or lichens, and all such wetlands that occur in tidal areas in which the salinity due to ocean-derived salts is below 0.5%. The 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 the salinity due to ocean-derived salts is equal to or greater than 0.5%. The 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 the salinity due to ocean-derived salts is equal to or greater than 0.5%. The 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); and wetlands that occur in tidal areas in which the 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. The total vegetation cover is greater than 80%. Perennial plants usually dominate these wetlands.

The TMDL Project watershed covers 44,144.28 total acres with 7,001.05 acres in the Willow Bayou subwatershed and 37,143.23 acres in the Halls Bayou Tidal subwatershed (Table 5, Figures 3). The TMDL Project watershed is mostly rural agriculture.

Pasture/Grasslands makes up the largest single land cover type at 34.72% in the TMDL Project watershed, with 35.29% and 34.61% in the Willow Bayou and Halls Bayou Tidal subwatersheds, respectively (Table 5). Cropland makes up the second largest land cover type at 27.61% in the TMDL Project watershed, 20.6% and 28.93% in the Willow Bayou and Halls Bayou Tidal subwatersheds, respectively.

Table 5. TMDL Project watershed land cover types

Land Cover	Willow Bayou Subwatershed		Halls Bayou Tidal Subwatershed		TMDL Project Watershed	
Type	**Area (Acres)**	**Percent**	**Area (Acres)**	**Percent**	**Area (Acres)**	**Percent**
Open Water	72.33	1.03%	724.31	1.95%	796.64	1.80%
Developed High Intensity	7.41	0.11%	7.79	0.02%	15.20	0.03%
Developed Medium Intensity	25.49	0.36%	99.67	0.27%	125.16	0.28%
Developed Low Intensity	294.47	4.21%	1,009.25	2.72%	1,303.72	2.95%
Developed Open Space	1,356.95	19.38%	5,012.77	13.50%	6,369.73	14.43%
Barren Land	0.97	0.01%	2.42	0.01%	3.40	0.01%
Forest/Shrub	138.60	1.98%	729.22	1.96%	867.82	1.97%
Pasture/Grassland	2,470.76	35.29%	12,856.80	34.61%	15,327.56	34.72%
Cropland	1,441.88	20.60%	10,744.87	28.93%	12,186.75	27.61%
Wetlands	1,192.18	17.03%	5,956.12	16.04%	7,148.30	16.19%
Total	**7,001.05**	**100.00%**	**37,143.23**	**100.00%**	**44,144.28**	**100.00%**

Developed land cover type (which includes High Intensity, Medium Intensity, Low Intensity and Open Space Development land cover types) makes up one of the smallest land cover types in the TMDL Project watershed at a combined 3.26% (Table 5). The largest developed land cover type is Developed Open Space at 2.95%.

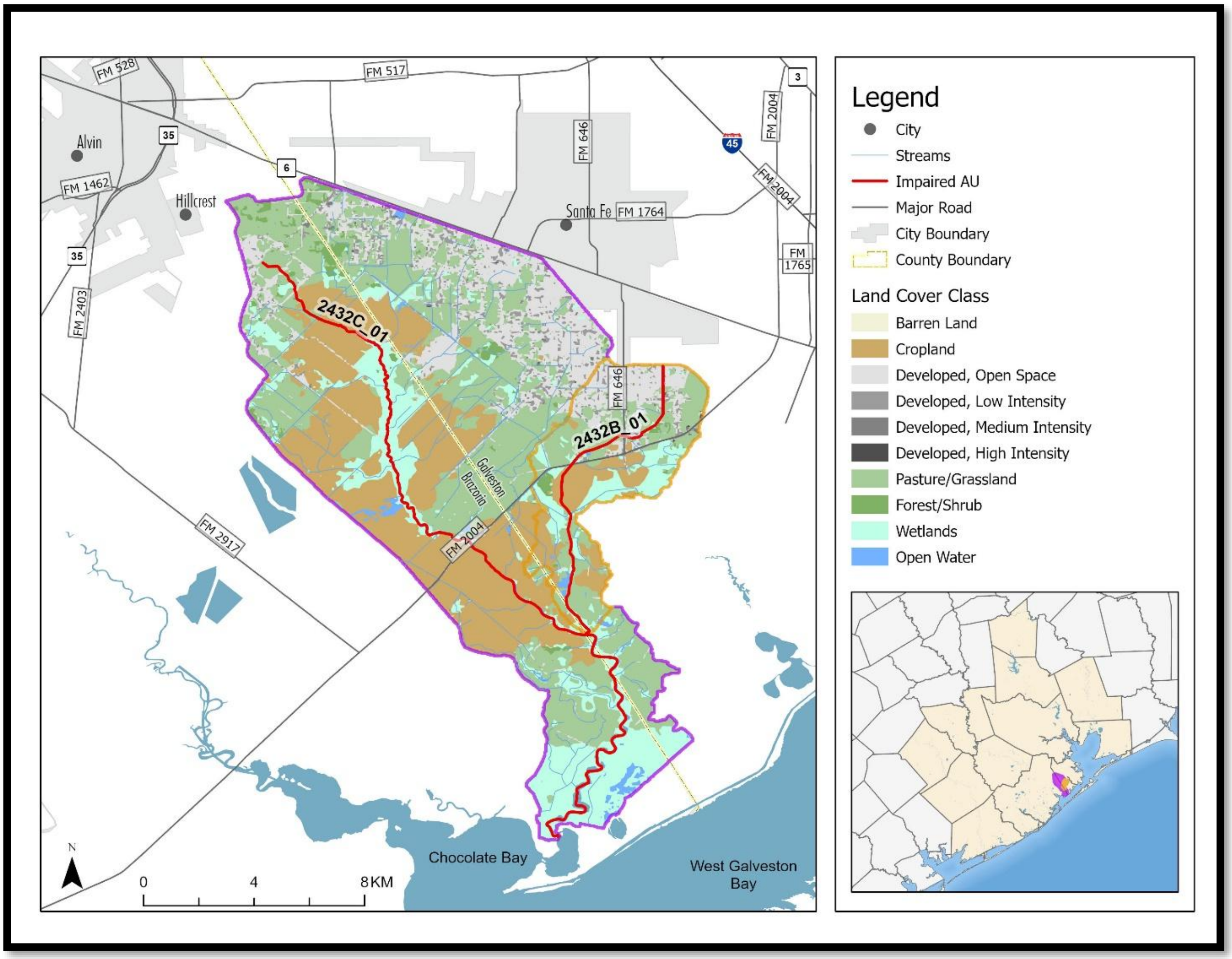

Figure 3. 2018 Land cover map

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 as:

- **Group A** – Soils having a 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 a moderately fine 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 with 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 70.94%, The second largest soil group is that of Group C/D at 27.65% (Table 6 and Figure 4). Both soil groups are typical of Texas coastal areas which are made up of slow draining alluvial clays.

Table 6. Hydrologic soil groups

Hydrologic group	2432B_01 (Acres)	2432B_01 (% area)	2432C_01 (acres)	2432C_01 (% area)	TMDL Project Watershed (acres)	Total (% area)
B	0.00	0.00%	85.20	0.23%	85.20	0.19%
C	0.00	0.00%	536.67	1.44%	536.67	1.22%
C/D	4,034.16	57.62%	8,171.74	22.00%	12,205.89	27.65%
D	2,966.89	42.38%	28,349.62	76.33%	31,316.52	70.94%
Total	**7,001.05**	**100.00%**	**37,143.23**	**100.00%**	**44,144.28**	**100.00%**

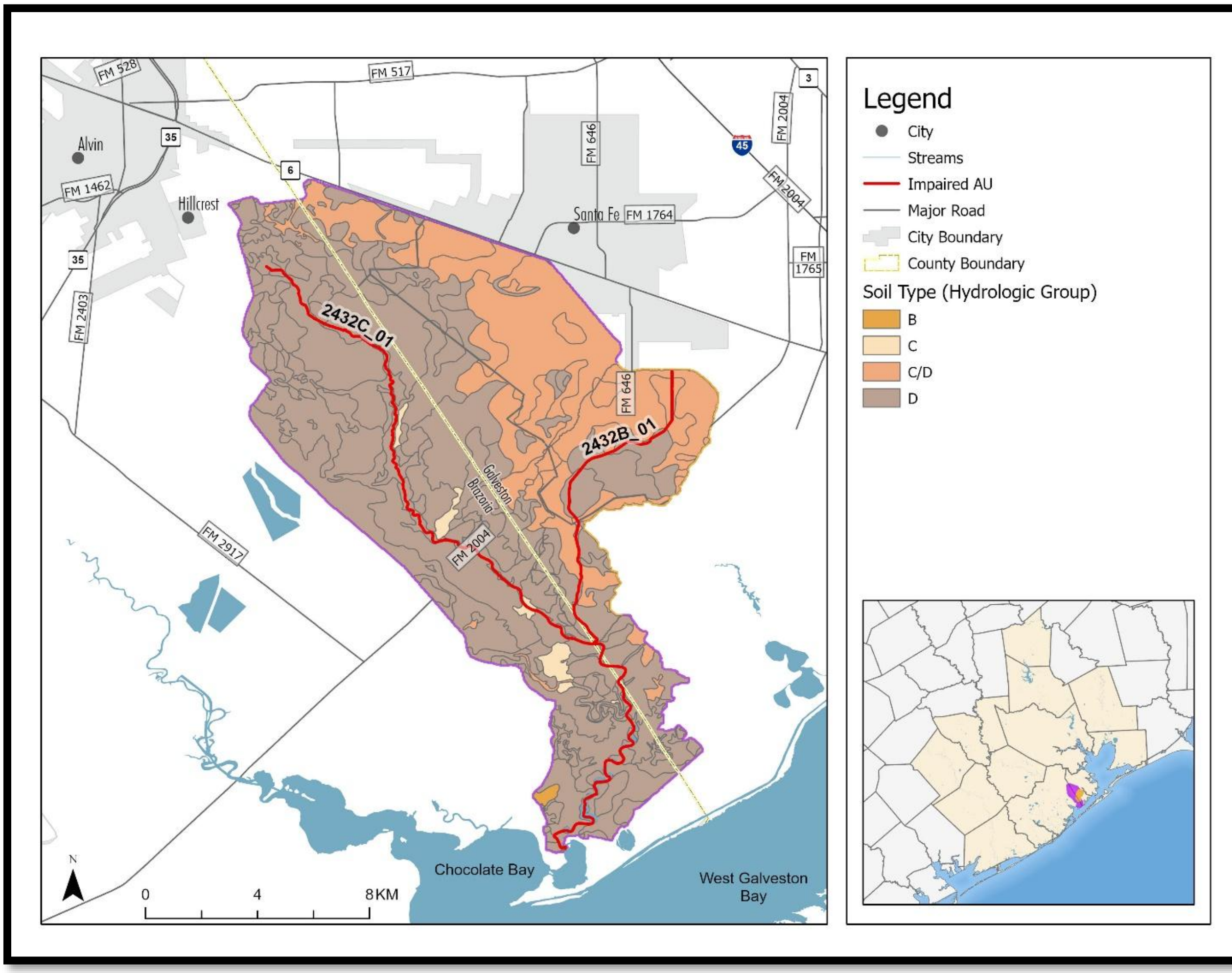

Figure 4. Map of hydrologic soil groups

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

No permits that discharge treated wastewater are found within the TMDL Project watershed (TCEQ, 2022c). Section 4 will discuss how the TMDL will address future growth and potential future permitted wastewater treatment.

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 (CAFO)
- 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 one concrete production facility within the Willow Bayou subwatershed. The concrete production facility is authorized to discharge stormwater thus they will be considered in the stormwater allocation analysis. (Table 7).

Table 7. Concrete production facility

Subwatershed	Permit Number	Permittee	County	City	Estimated Area
Willow Bayou	TXG110000	Mainland Concrete, Inc.	Galveston	Hitchcock	8.48

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

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 and stormwater discharges associated with regulated industrial activities and construction activities.
2. Stormwater runoff not subject to regulation.

TPDES MS4 Phase I and II rules require municipalities and certain other entities in urban areas 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 communities with populations of 100,000 or more based on the 1990 United States Census, whereas the Phase II General Permit regulates other MS4s within a United States Census Bureau (USCB) defined urbanized area (UA).

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). An SWMP describes the stormwater control practices that will be implemented consistent with permit requirements to minimize the discharge of pollutants from an 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. (Only required for MS4s serving a population of 100,000 people or more in an urban area).
- Authorization for construction activities where the small MS4 is the site operator (optional).

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. The Phase I MCMs include:

- MS4 maintenance activities.
- Post-construction stormwater control measures.
- Detection and elimination of illicit discharges.
- Pollution prevention and good housekeeping for municipal operations.
- Limiting pollutants in industrial and high-risk stormwater runoff.
- Limiting pollutants in stormwater runoff from construction sites.
- Public education, outreach, involvement, and participation.
- Monitoring, evaluating, and reporting.

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

- TXR040000 – Phase II MS4 General Permit for small MS4s located in urbanized areas (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 that are part of a common plan of development disturbing more than one acre.

TPDES Stormwater General Permits found in the TMDL Project watershed were reviewed in TCEQ's Central Registry 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 was one concrete production facility identified in the TMDL Project watershed. The area for the facility was applied under stormwater to calculate the TMDL.

A review of active permits covering MS4s in the TCEQ Central Registry found that there is one combined Phase I/II MS4 permit authorization and one active Phase II MS4 permit authorization (Table 8).

Table 8. MS4 permit authorizations

Entity	Authorization Type	TPDES Permit No./ EPA ID	Location
Texas Department of Transportation	Combined Phase I and Phase II MS4 Individual Permit	TXS002101/ WQ0005011000	TxDOT rights-of-way located within Phase I MS4 areas and Phase II urbanized areas
Galveston County	Phase II MS4 General Permit TXR040000	TXR040364/Not applicable	Area within the limits of unincorporated county of Galveston that is located within the Houston and Texas City UA

To determine an estimated area potentially under an MS4 Phase II permit within the TMDL Project watershed, a review of the USCB's census defined UA was made in July 2022 (USCB, 2010). This review determined the total UA for the TMDL Project watershed was 13.17% or 5,811.74 acres. Willow Bayou has UA of 8.98% or 628.70 acres. Halls Bayou Tidal has an UA of 13.95% or 5,183.04 acres. (Table 9, Figure 5).

Table 9. Estimated area of MS4 permit coverage

AU	UA (acres)	Watershed Area	Percent UA
2432B_01	628.70	7,001.05	8.98%
2432C_01	5,183.04	37,143.23	13.95%
TMDL Project Area Total	**5,811.74**	**44,144.28**	**13.17%**

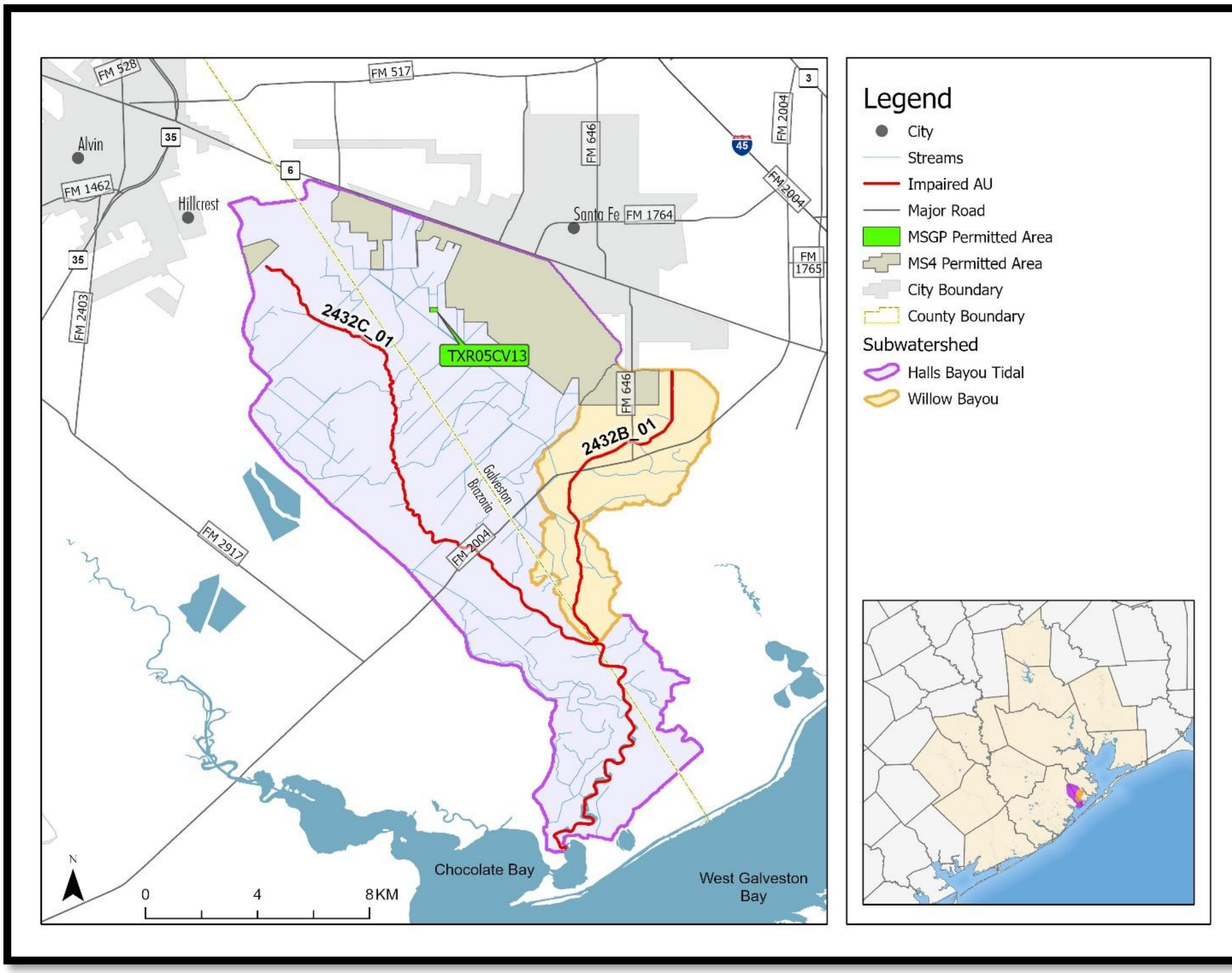

Figure 5. MS4 and MSGP permit areas

MSGPs were reviewed in TCEQ's Central Registry in May 2022 for active permits within the TMDL Project watershed (TCEQ, 2022d). One active MSGP was found within the watershed. To eliminate the possibility of overcounting the stormwater permit area, only the area of MSGPs located outside of the UA are included. The MSGP was found to be outside the UA within the Halls Bayou Tidal subwatershed and had an estimated area of 10.01 acres (Figure 5).

Construction permits are required when one acre or more of land is disturbed during construction. Construction activities within a watershed are typically changing; where construction has wrapped up at some locations, new areas are being simultaneously cleared and prepped for construction. The construction general permit data found at TCEQ is only considered accurate for the date that the data was accessed. A permit field for construction activities retrieved from TCEQ Central Registry records "Area Disturbed." 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 for a period of 2016 through 2021 found only two permits yielding a total of 82.29 acres of disturbed area. One permit was for a pipeline construction across the two watersheds. Without additional information other than what is found within the TCEQ database, the disturbed area was split evenly within the two subwatersheds. The estimated disturbed area under permit is 35.20 acres and 47.1 acres for the Willow Bayou and Halls Bayou Tidal subwatersheds, respectively.

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. These overflows in dry weather most often result from blockages in the sewer collection pipes caused by tree roots, grease, and other debris. Inflow and infiltration (I&I) are typical causes of overflows under conditions of high flow in the WWTF system. Blockages in the line may worsen I&I problems. Other causes, such as a collapsed sewer lines, may occur under any condition.

There are currently no WWTFs within the TMDL Project watershed. In the future this might change, and management of SSOs may become important at that time.

2.7.1.5. Dry Weather Discharges and 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 include wildlife, feral hogs, various agricultural activities, agricultural animals, urban runoff not covered by a permit, failing on-site sewage facilities (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 the riparian corridors of water bodies. With direct access to the stream channel, the direct deposition of wildlife waste can be a concentrated source of bacteria loading to a water body. Fecal bacteria from wildlife are also deposited onto land surfaces, 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) 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 1,747 (TPWD, 2019) (Table 10).

Table 10. Estimated deer population

Subwatershed	Area (acres)	Estimated Deer Population
Willow Bayou	7,001.05	277
Halls Bayou Tidal	37,143.23	1,470
Total	**44,144.28**	**1,747**

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 949 within the TMDL Project watershed (Table 11).

Table 11. Estimated feral hog population

Subwatershed	Low Quality Habitat (acres)	Feral Hogs	High Quality Habitat (acres)	Feral Hogs	Total
Willow Bayou	1,737.33	24	5,158.49	132	156
Halls Bayou Tidal	11,756.54	163	24,554.92	629	793
Total	**13,493.87**	**187**	**29,713.41**	**761**	**949**

2.7.2.2. Unregulated Agricultural Activities and Domesticated Animals

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

Estimates of livestock in the TMDL Project watershed are shown in Table 12. These estimations were calculated by applying a ratio of watershed land area compared to county land area to numbers from the 2022 Census of Agriculture for Brazoria and Galveston 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 12. Estimated livestock populations

Area Name	Area (Acres)	Cattle and Calves	Hogs and Pigs	Sheep and Goats	Equine	Poultry
Brazoria	262,076	59,766	2,600	3,607	3,608	202,164
Galveston	47,972	5,660	76	521	631	19,395
Willow Bayou	2,470.76	299	25	27	33	1,025
Halls Bayou	12,856.80	2,174	70	157	173	7,388
Total	15,327.56	2,473	95	184	205	8,413

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 13 summarizes the estimated number of dogs and cats in the TMDL Project watershed. 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 13. Estimated households and pet populations

Subwatershed	Estimated Households	Dogs	Cats
Willow Bayou	693	425	317
Halls Bayou Tidal	2,806.27	1,723	1,282
Total	**3,499**	**2,148**	**1,599**

2.7.2.3. On-Site Sewage Facilities

Private residential OSSFs, commonly referred to as septic systems, consist of various designs based on the physical conditions of 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.

The 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 drain field 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 Project 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.

The number of permitted and registered OSSFs in this watershed have been compiled by H-GAC in coordination with authorized agents in H-GAC's service region, which includes the TMDL Project watershed (H-GAC, 2022b). Brazoria and Fort Bend counties are local authorities who have accepted responsibility from TCEQ to permit OSSFs and enforce laws and rules governing OSSFs on behalf of the state.

There are 1,619 registered OSSFs in the TMDL Project watershed, with 333 in the Willow Bayou subwatershed and 1,286 in the Halls Bayou Tidal subwatershed (Table 14 and Figure 6).

In addition to permitted systems, there are a number of OSSFs that are not registered. Non-registered OSSF locations were estimated using H-GAC's geographic information database of potential OSSF locations (H-GAC, 2022c) 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 1,571 total OSSFs, with 401 in the Willow Bayou subwatershed and 1,170 in the Halls Bayou Tidal subwatershed (Table 14 and Figure 6).

Table 14. Estimated OSSFs

AU	Registered	Non-registered	Total
Willow Bayou	333	401	734
Halls Bayou Tidal	1,286	1,170	2,456
Total	**1,619**	**1,571**	**3,190**

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 OSSF design, age, maintenance, and soil type can influence the likelihood of an OSSF failure. By applying the estimated 12% failure rate to the 3,190 OSSFs estimated within the TMDL Project watershed (Table 14), 383 OSSFs are projected to be failing.

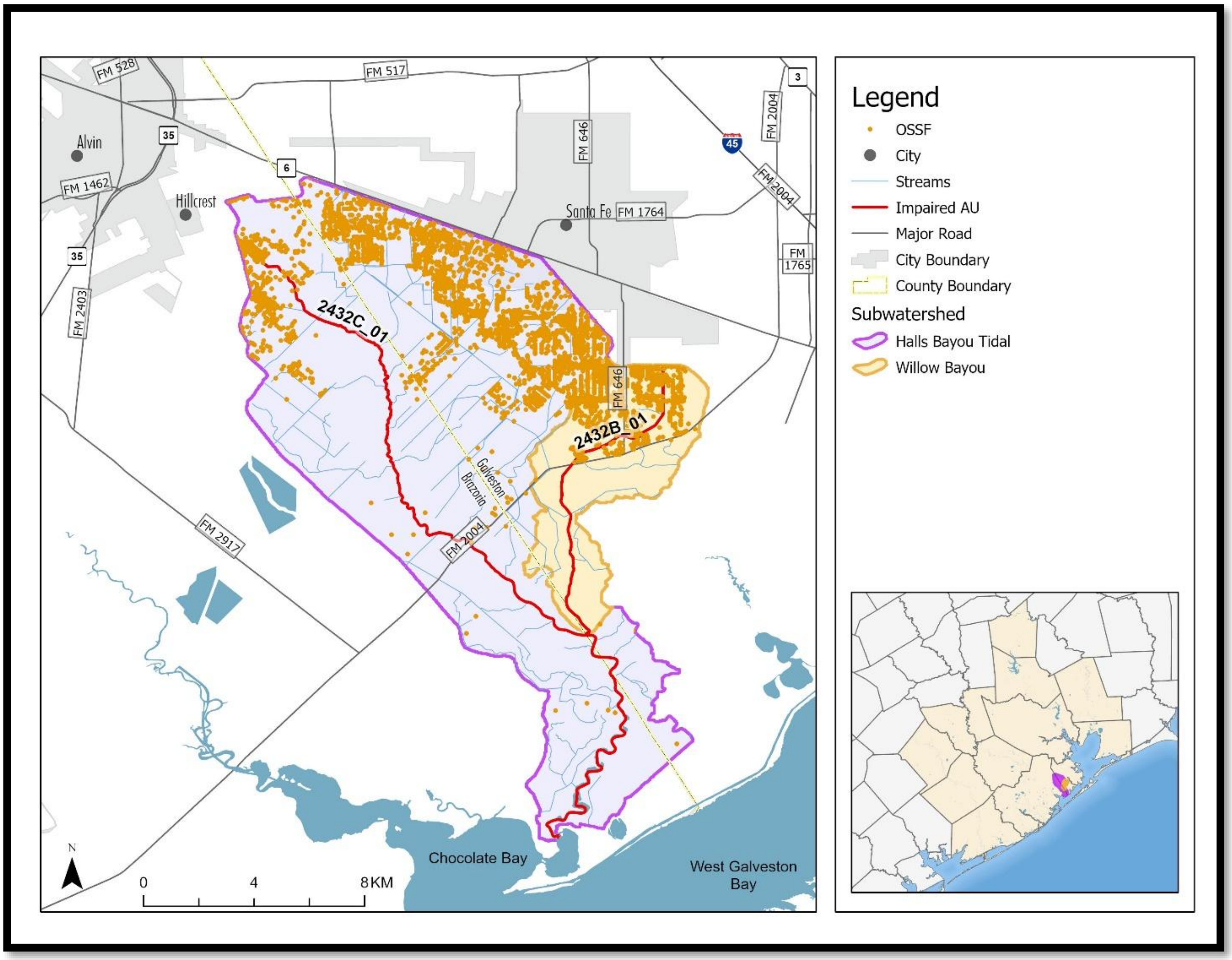

Figure 6. Distribution of OSSFs in the TMDL Project Watershed

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

Section 3. Bacteria Tool Development

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

3.1. Tool Selection

The goal of the TMDL process is to determine an assimilative loading value, e.g., fecal indicator bacteria concentration, for a water body such that the value does not exceed the numeric criterion developed for that pollutant. The loading value cannot be developed with available environmental data that is incomplete or insufficient to describe a spatially and temporally dynamic system like a watershed. A tool or method is usually required to approximate a real-world system. Watershed models "provide an approach, besides monitoring data and export coefficients, for estimating loads, providing source load estimates, and evaluating various management alternatives" (Hauck, 2009). The models can assist in filling in missing data and information by relying on observable or mathematically derived relationships linking physical, chemical, and biological processes.

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 (TSSWCB) (TWRI, 2007). More recently, Texas began using modified LDCs for TMDLs in tidal waters with the Mission and Aransas Bay TMDL (Hauck *et al.*, 2013) and Tres Palacios Creek Tidal TMDL (Hauck *et al.*, 2017). The LDC has limitations, as it will not fully quantify individual source contributions of all point and nonpoint loads, nor is it capable of assessing load reductions provided by specific bacteria reduction management measures. It is recommended here because it provides a simple means for determining the loading value across moisture conditions and can be broadly used to indicate sources of bacteria (i.e., point source and nonpoint source.)

3.2. Data Resources

With the exception of daily streamflow, TMDL Project data resource (i.e., fecal indicator bacteria data) availability was sufficient to perform LDC analysis in AUs 2432B_01 and 2432C_01. To complete LDCs in AU 2432C_01, in addition to daily streamflow and fecal indicator bacteria, salinity data is needed to address tidal inflow. 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, and the period of 2004 to 2020 was chosen. 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 (Table 2).

The daily flow records from the USGS streamflow gage 08078000 (USGS, 2019), located on Chocolate Bayou Above Tidal (Segment 1108) was used to derive daily stream flow for both subwatersheds of the TMDL Project for the intended LDC period of 2004 to 2020. Chocolate Bayou was used as a surrogate watershed because of a lack of streamflow data in the TMDL Project watershed, to make up for this, Determination Assessment Reduction methodology was used to collect data. This USGS gage was selected for several reasons. Chocolate Bayou watershed is close in proximity to the TMDL Project watershed (Table 15 and Figure 7), land cover composition, weather patterns, and watershed land use activities, such as agriculture and industries, are comparable to those of the TMDL Project watershed.

Table 15. Catchment area comparison between the TMDL Project watershed and the Chocolate Bayou flow gage

Station	AU	Catchment Area (sq mi)	Area Ratio
USGS 08078000	-	86.5	--
11422	2432C_01	41.2	0.48
18668	2432B_01	5.2	0.06

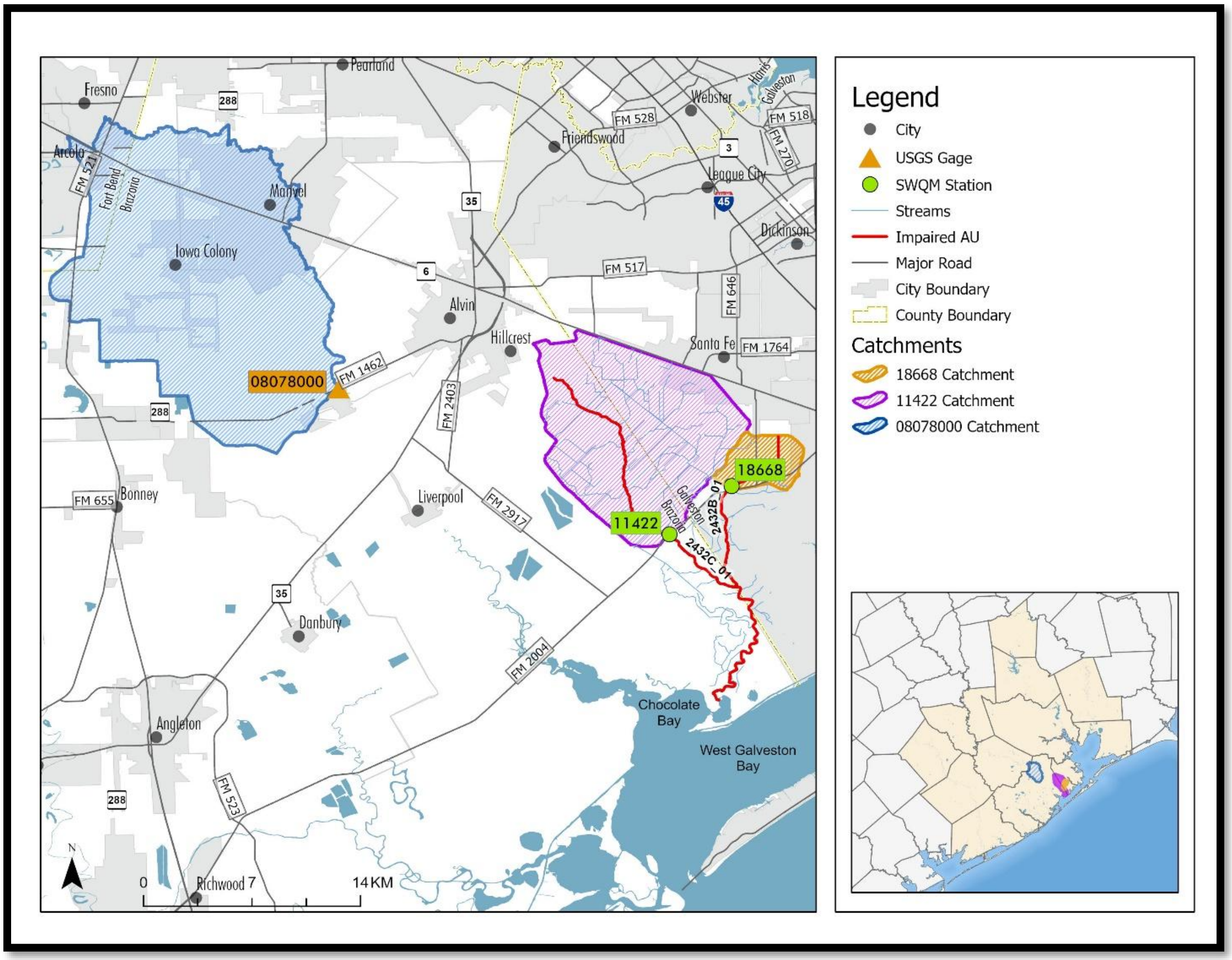

Figure 7. Catchment area comparison between the USGS Gage to SWQM stations

3.3. Methodology for Flow Duration and Load Duration Curve Development

To develop flow duration curves (FDCs) and LDCs, the previously discussed data resources were used in the following series of sequential 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 a daily streamflow record at the desired location.
   4.1: Develop salinity to streamflow regression in the tidal AU.
   4.2: Incorporate daily tidal volumes into the streamflow record in the tidal AU.
5. Develop an FDC at the desired stream location, segmented into discrete flow regimes.

6. Develop an allowable bacteria LDC at the same stream location based on the relevant criteria and the data from the FDC.
7. Superimpose historical bacteria data onto 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 USGS streamflow gage 08078000 (USGS, 2019), 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 2020.

3.3.2. Step 2: Determine Desired Stream Location

LDCs were developed for station locations within the impaired AUs at SWQM stations 11422 an 18668. These stations are the only stations within the AUs with sufficient data to determine LDCs.

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

The daily, freshwater flow values at stations in the TMDL Project watershed were calculated based on the flow values of USGS gage 08078000 and the drainage area ratio (DAR) method. The DAR method involves multiplying a USGS gaging station daily streamflow value by a factor to estimate the flow at a desired TCEQ SWQM station location. The factor is determined by dividing the drainage area upstream of the desired monitoring station by the drainage area upstream of the USGS gage.

The daily freshwater flow values were then calculated for AUs 2432B_01 and 2432C_01 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 1) (Table 15).

$$Y = X(A_X/A_Y) \qquad \text{(Equation 1)}$$

Where:

Y = streamflow for the ungaged SWQM station

X = daily streamflow for USGS gage

A_y = drainage area for the ungaged SWQM station

A_x = drainage area for USGS

Additional steps are taken for tidal AUs. These steps are explained in Section 3.3.4.

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

To derive the daily stream flow for AUs 2432B_01 and 2432C_01, the streamflow for Chocolate Bayou must be “naturalized,” correcting for the average daily flow additions of WWTF discharges (i.e., removing), and withdrawals of upstream water rights diversions (i.e., adding). As used here, 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 extant USGS records.

The estimated average daily discharge monitoring reports (DMR) reported discharges for the period of 2017 to 2020 from all the WWTF outfalls upstream of the USGS gage location (Table 16) were subtracted from the daily gage streamflow records. This resulted in an adjusted streamflow record with point source discharge influences being removed.

Table 16. 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. There were three water rights diversions within the catchment area above the USGS station in Chocolate Bayou. 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.

Once the daily stream flow estimates are made using the DAR step in the Halls and Willow Bayou watersheds, a final procedure is performed to develop the daily streamflow record at each monitoring location. The WWTFs' full permitted flows and future growth components, as determined by future WWTF flows, are added to the generated streamflow record at each location. In the Halls and Willow Bayou subwatersheds there are no existing WWTFS. However, to account for the potential future WWTFs, two hypothetical stations were created, one in each subwatershed. The hypothetical flow from each WWTF was add to the streamflow.

3.3.4.1 Step 4.1: Develop Salinity to Streamflow Regression in Tidal AU

The modified FDC and LDC approach was attempted for AU 2432C_01 as the AU is considered a tidal water body (ODEQ, 2006). The difference in the modified LDC from the traditional approach is the application of salinity in the development of the FDC to account for tidal flux in the segment. AU 2432C_01 contains one SWQM station, 11422.

Enterococci and salinity measurements from 2004 to 2020 were acquired to develop the modified LDC. There were no daily streamflow records available to estimate the daily loads of bacteria. Daily flow measurements from Chocolate Bayou were used.

For SWQM Station 11422, the modified LDC steps were followed. Daily flow records were generated and related to the salinity of the stream at SWQM Station 11422 in the following steps:

1. Available Enterococci and salinity measurements from 2004 to 2020 were acquired or derived as presented previously.
2. Each salinity measurement was matched with its corresponding calculated daily freshwater flow.
3. The salinity records were then plotted against the log-transformed flow values in a scattered plot (Figure 8).

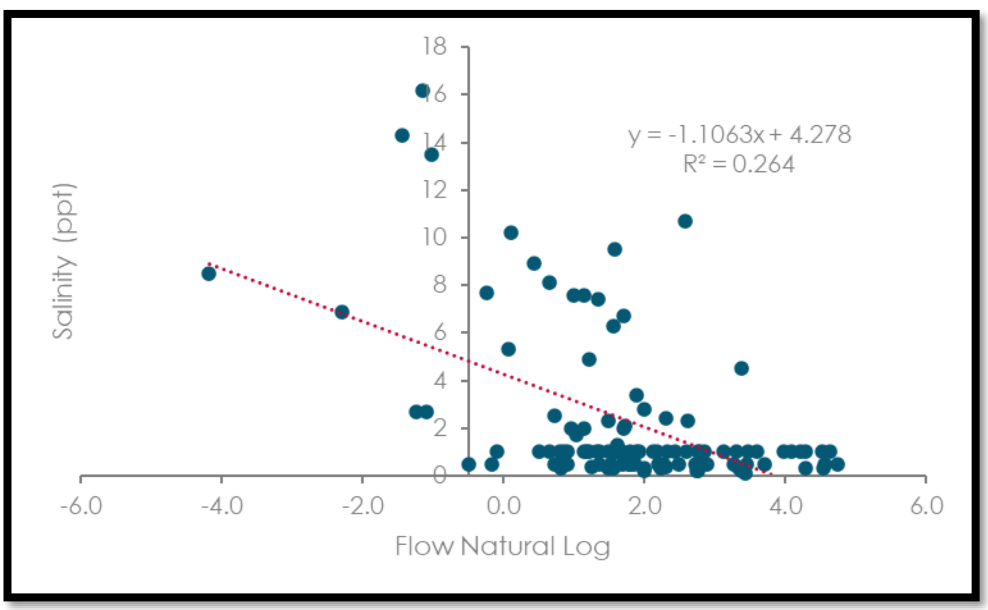

Figure 8. Regression scatter plot for SWQM Station 11422

4. A linear regression equation was estimated for each station to develop a daily freshwater flow-measured salinity relationship. The following equation was used to calculate the daily salinity time series for each station.

For example: the equation for SWQM Station 11422 was:

$$\hat{Y} = b_0 X_1 + b_1 \qquad \text{(Equation 2)}$$

Where,

$\hat{Y}$ = Salinity (parts per thousand (ppt))
b_0 = Slope of the linear regression line = -1.1063
X_1 = Log-transformed Flow (cfs)
b_1 = Intercept = 4.278

3.3.4.2 Step 4.2: Incorporate Daily Tidal Volumes into Streamflow Record in the Tidal AU

The regression equations developed in Step 4.1 were used to compute the total daily flow volume that includes freshwater and seawater. The process requires manipulation of the following mass balance equation for salinity at the tidally influenced stations:

$$(V_r + V_s) \times S_t = V_r \times S_r + V_s \times S_s \qquad \text{(Equation 3)}$$

V_r = volume of daily freshwater (river) flow

V_s = volume of daily seawater flow

S_t = salinity in river (ppt)

S_r = background salinity of upstream river water (ppt); assumed to be 0 ppt

S_s = salinity of seawater; assumed to be 35 ppt

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

$$V_s = V_r / (S_s/S_t - 1) \qquad \text{(Equation 4)}$$

Where,

V_s = volume of daily seawater flow
V_r = volume of daily freshwater (river) flow
S_s = salinity of seawater (assumed to be 35 ppt)
S_t = salinity in river (ppt)

The modified daily flow volume (V_t) at the station (i.e. seawater and freshwater) was estimated using the formula:

$$V_t = V_r + V_s \qquad \text{(Equation 5)}$$

From this point forward, the development of FDCs and LDCs for SWQM Station 11422 follows the same process described in Section 3.3.5.

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 FDCs and LDCs was used for AU 2432B_01. A modified approach was used for FDC and LDC development for AU 2432C_01. To develop an FDC for a location, all of the following steps were taken in the order shown:

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.

Further, when developing an LDC:

1. Multiply the streamflow in cubic feet per second (cfs) by the appropriate water quality criterion, either Enterococci or *E. coli* (geometric means 35 cfu/100 mL or 126 cfu/100 mL, respectively) and the conversion factor (2.44658×10^9), 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. The next step was to plot the measured Enterococci or *E.coli* data on the developed LDC using the following steps:

3. Compute the daily loads for each sample by multiplying the measured Enterococci concentrations on a particular day by the corresponding streamflow on that day and the conversion factor (2.44658×10^9).

4. 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 (Enterococci or *E. coli* 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.

3.4. Flow Duration Curves for the TMDL Watershed

Figure 9 provides the FDC for SWQM Station 18668. 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%). 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.

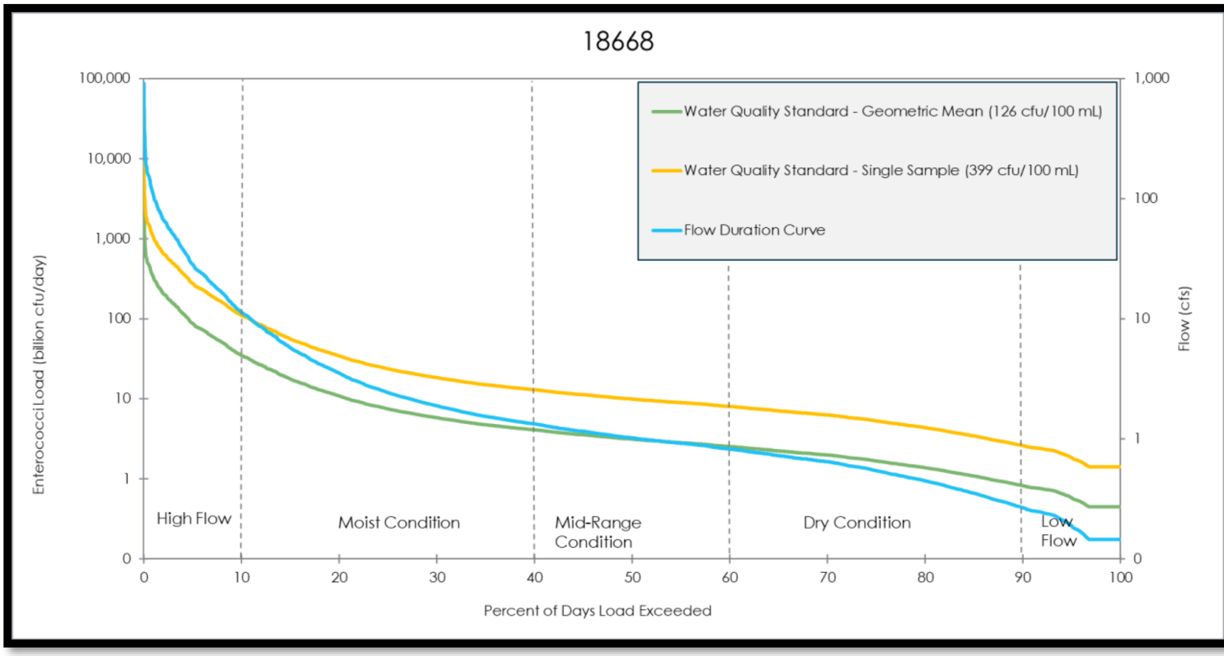

Figure 9. FDC for SWQM Station 18668 in Willow Bayou, AU 2432B_01

Figure 10 is the modified FDC for SWQM Station 11422. It includes the same elements as the FDC for SWQM Station 18668. However, in this instance the Enterococci geometric mean criterion curve (load at 35 cfu/100 mL) and the Enterococci single sample criterion curve (load at 130 cfu/100 mL) are substituted.

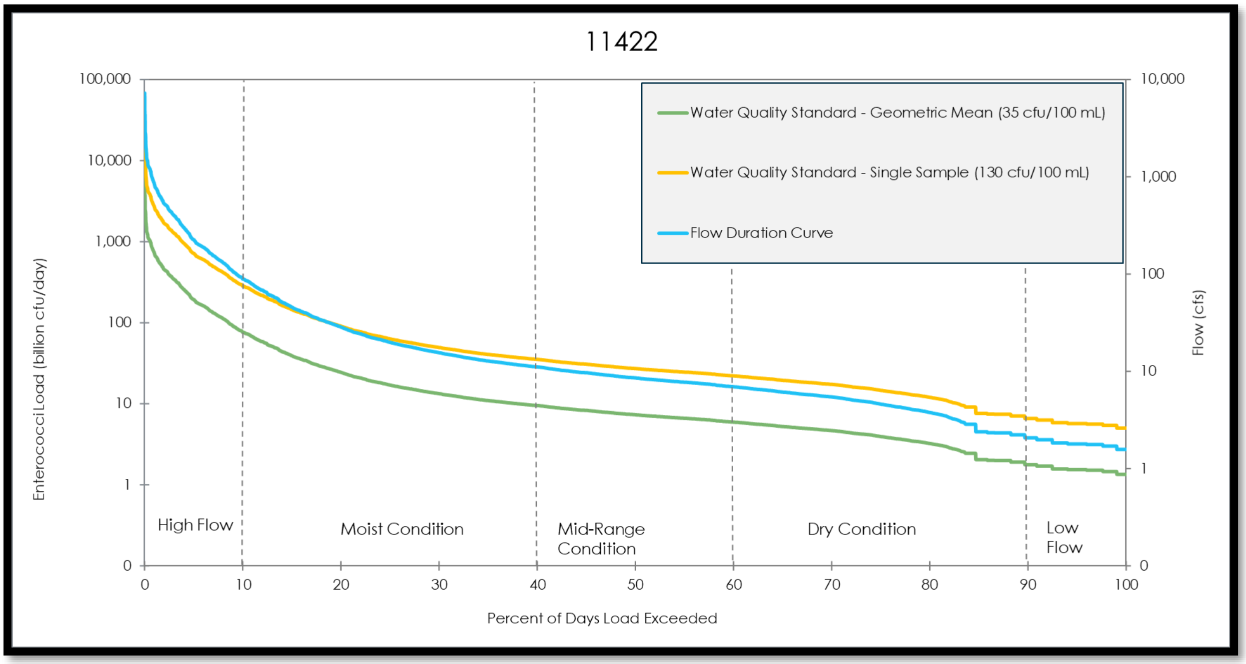

Figure 10. Modified FDC for SWQM Station 11422 in Halls Bayou Tidal, AU 2432C_01

3.5. Load Duration Curves for the TMDL Watershed

Figure 11 and 12, present an LDC and modified LDC for SWQM Stations 18668 and 11422, respectively. The figures include the FDC, the geometric mean criterion curves, the single sample criterion curve, the existing load regression (LR) curve, the observed bacteria geometric mean load by flow regime (single points), and individual observed bacteria data points.

The LDC for SWQM Station 18668 presents the LR curve which falls below the geometric mean curve late in the moist flow condition. Here most of the observed bacteria data are found below the standard curve as evidenced by the geometric means calculated within each flow regime, except for low flow conditions.

Looking at the modified LDC for SWQM Station 11422, the LR curve is above the geometric mean curve throughout the duration of all flow regimes until the low flow conditions. Here the geometric means of the observed bacteria data begin to fall below the LR curve at the moist conditions with the exception of low flow conditions.

Considering the rural nature of this watershed, non-point sources of bacteria (diffuse sources from wildlife, agriculture, and OSSFs) are indicative of high and moist flow conditions. At lower flows, points sources such as WWTFs are potential sources. Lacking any WWTFs within this watershed, chronic sources like failing OSSFs can be considered.

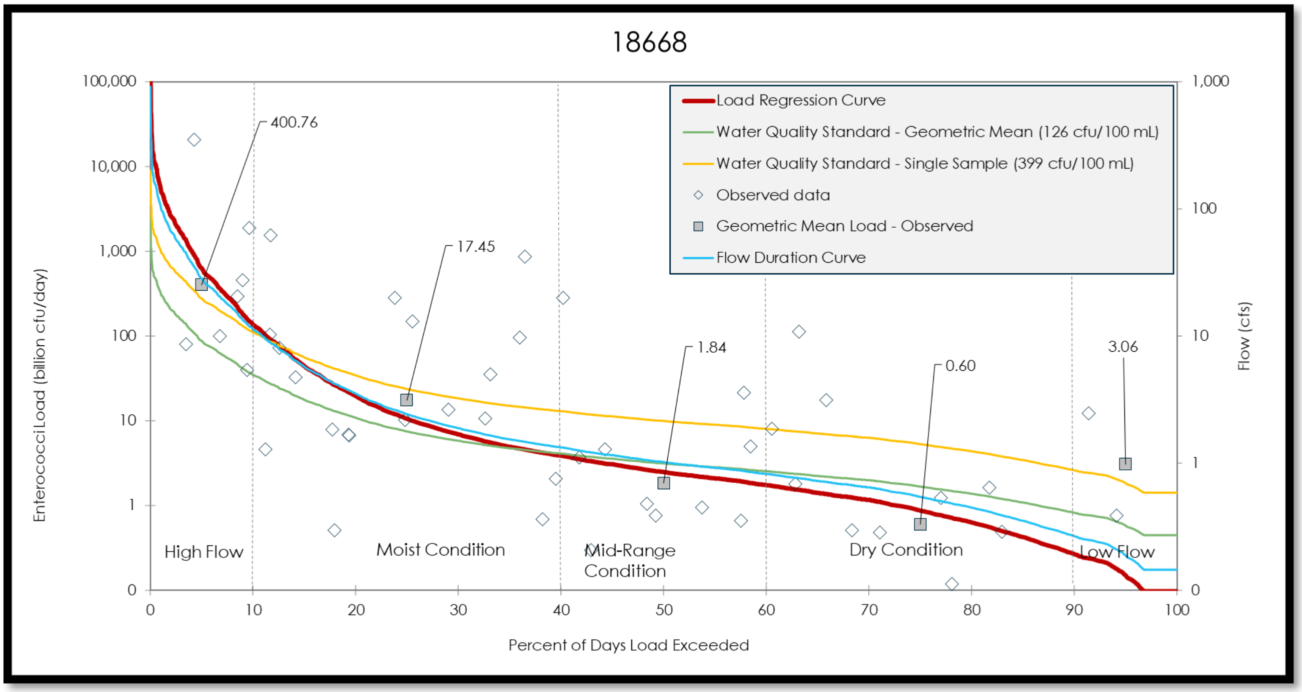

Figure 11. LDC for SWQM Station 18668 in Willow Bayou, AU 2432B_01

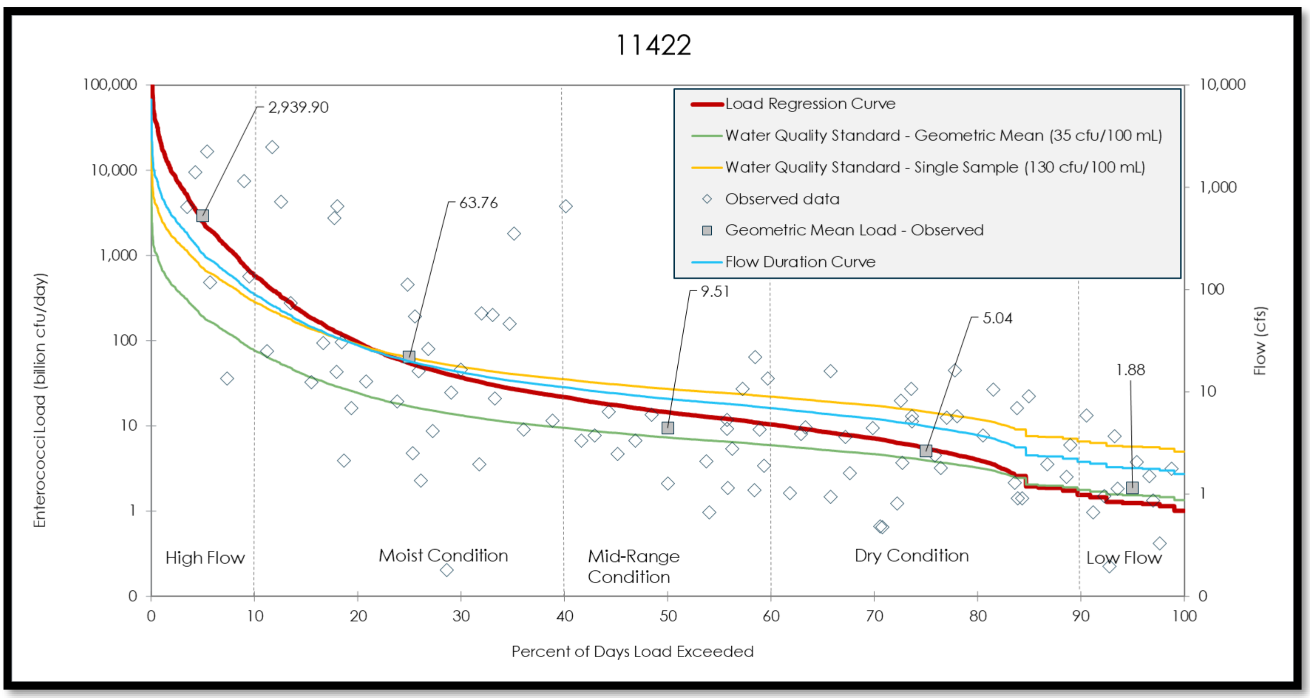

Figure 12. Modified LDC for SWQM Station 11422 in Halls Bayou Tidal, AU 2432C_01

Section 4. TMDL Allocation Analysis

This section contains the bacteria TMDL allocations for the two impaired AUs within the TMDL Project watershed. The allocations are based on the LDCs for AU 2432B_01 and AU 2432C_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.

The endpoint for AU 2432C_01 is to maintain the concentration of Enterococci below the geometric mean criterion of 35 cfu/100 mL, which is protective of the primary contact recreation 1 use in tidal water bodies. The endpoint for AU 2432B_01 is to maintain the concentration of *E. coli* below the geometric mean of 126 cfu/100mL, which is protective of the primary contact recreation 1 use in non-tidal water bodies (TCEQ, 2018a).

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 the 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) (40 CFR 130.7(c)(1))] (EPA, 1991). To evaluate potential seasonal difference, ambient monitoring data for Willow Bayou and Halls Bayou Tidal were 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, has the capacity to 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 because the sources of indicator bacteria are attenuated as runoff washes them from the land surface and the volume of runoff decreases following the rain event.

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. LDC analyses were used to examine the relationship between instream water quality and the broad sources of indicator bacteria loads. These analyses are the basis of the TMDL allocations in this report.

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 using available water quality and flow data. The LDC method does not require any assumptions about loading rates, stream hydrology, land use conditions, or other conditions in the watershed. The USEPA supports the use of this approach to characterize pollutant sources. In addition, many other states use this method to develop TMDLs.

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

The LDC method allows for estimations of existing and TMDL loads by utilizing the cumulative frequency distribution of streamflow and measured pollutant concentration data (Cleland, 2003). In addition to estimating stream loads, this method allows for the determination of the hydrological conditions under which impairments typically occur, 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 both SWQM stations, the LR curve modeled from observed data exceeds the curve representing the geometric mean maximum in high and moist flow conditions (Figures 11 and 12). This indicates that non-point sources are driving the bacteria impairments in both AUs. However, AU 2432C_01 demonstrated continued exceedance into the dry conditions, suggesting there is a chronic loading concern, likely a point source. It should also be noted that in cases where there are only a few bacteria observations, the geometric mean can be easily skewed. Reduction strategies should target improvement of non-point source pollutants and attempt to determine potential point sources to have a positive effect on the 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 TMDL's goal will be met. According to EPA guidance (EPA, 1991), the MOS can be incorporated in the TMDL using either of the following 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

According to LDC analyses, the bacteria load in the watershed is well above the criteria at higher flow conditions. Bacteria reductions in excess of 45% are needed throughout the water body at moist and high flow conditions. 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, point sources should also be considered as targets for improvement.

Based on these results, potential reduction targets for loads at each flow condition are detailed in Table 17.

Table 17. Potential fecal indicator bacteria reductions

AU	Flow Condition	Exceedance Range	Fecal Indicator Bacteria	Criterion (cfu/100mL)	Geometric Mean (cfu/100mL)	Required Percent Reduction
2432B_01	High Flow	(0-10%)	*E. coli*	126	857.05	85.30%
	Moist	(10-40%)	*E. coli*	126	232.72	45.86%
	Mid-Range	(40-60%)	*E. coli*	126	72.99	0.00%
	Dry	(60-90%)	*E. coli*	126	44.44	0.00%
	Low Flow	(90-100%)	*E. coli*	126	547.72	77.00%
2432C_01	High Flow	(0-10%)	Enterococci	35	727.65	95.19%
	Moist	(10-40%)	Enterococci	35	111.27	68.55%
	Mid-Range	(40-60%)	Enterococci	35	47.10	25.68%
	Dry	(60-90%)	Enterococci	35	48.22	27.42%
	Low Flow	(90-100%)	Enterococci	35	41.76	16.19%

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:

$$TMDL = WLA + LA + FG + MOS \quad \text{(Equation 6)}$$

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 *E. coli* and Enterococci, TMDLs are expressed in billion cfu/day, and represent the maximum one-day load a 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 monitoring stations located within the subwatersheds. As discussed in more detail in Section 3, the bacteria LDCs were developed by multiplying each flow value along the FDC with the criterion (126 cfu/100mL or 35 cfu/100mL, 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 (Equation 7)

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* and Enterococci that the impaired water bodies can receive on a daily basis was determined using Equation 7 based on the median value within the high regime of the FDC (or 5% flow exceedance value) for the SWQM station (Table 18). Using the 5% load duration exceedance, the TMDL values are provided in Table 18.

Table 18. Summary of allowable loadings

AU	Indicator Bacteria	Criterion (cfu/100 mL)	5% Exceedance Flow (cfs)	5% Exceedance Load (cfu/day)	TMDL (Billion cfu/day)
2432B_01	*E. coli*	126	28.460	8.77E+10	87.773
2432C_01	Enterococci	35	225.510	1.93E+11	193.104

4.7.2. Margin of Safety

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

MOS = 0.05 × TMDL (Equation 8)

Where:

TMDL = total maximum daily load

The MOS calculations for each AU are shown in Table 19.

Table 19. MOS calculations

AU	Indicator Bacteria	Criterion (cfu/100 mL)	TMDL[a] (Billion cfu/day)	MOS (Billion cfu/day)
2432B_01	*E. coli*	126	87.718	4.386
2432C_01	Enterococci	35	193.106	9.655

[a]TMDL from Table 18

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}).

$$WLA = WLA_{WWTF} + WLA_{SW} \qquad \text{(Equation 9)}$$

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 accepted instream geometric criterion. Thus, WLA_{WWTF} is expressed in the following equation:

$$WLA_{WWTF} = Target \times Flow \times Conversion\ Factor \qquad \text{(Equation 10)}$$

Where:

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

Flow = full permitted flow in million gallons per day (MGD)

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

No WWTFs were identified within the TMDL Project watershed. No wasteloads were assigned.

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 permitted 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 Project 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 as follows:

$$WLA_{SW} = (TMDL - WLA_{WWTF} - FG - MOS) \times FDA_{SWP} \qquad \text{(Equation 11)}$$

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 in order 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 20. The stormwater categories are then summed up to determine the total area under stormwater jurisdiction in each segment.

To arrive at the proportion, the area under stormwater jurisdiction is then divided by the total watershed area.

Table 20. Basis of regulated stormwater and computation of FDA_{SWP} term

Watershed	AU	Watershed Area*	MS4 General Permit	Industrial Stormwater (Individual and MSGP)	Construction Activities (CGP)	Concrete Production Facilities	Total Area of Permits	FDA_{SWP}
Willow Bayou	2432B_01	7,001.050	628.704	–	35.197	8.48	672.381	0.096
Halls Bayou Tidal	2432C_01	37,143.231	5,183.039	10.01	47.097	–	5,240.146	0.141

* All areas are expressed in acres.

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 11 is known and presented along with the resulting WLA_{SW} in Table 21.

Table 21. Stormwater WLA calculations

AU	Indicator Bacteria	TMDL[a] (Billion cfu/day)	MOS[b] (Billion cfu/day)	WLA_{WWTF}[c] (Billion cfu/day)	FG[d] (Billion cfu/day)	FDA_{SWP}[e]	WLA_{SW}[f] (Billion cfu/day)
2432B_01	*E. coli*	87.718	4.386	0.00	0.448	0.096	7.960
2432C_01	Enterococci	193.106	9.655	0.00	1.037	0.141	25.735

[a] TMDL from Table 18

[b] MOS from Table 19

[c] No wasteload allocation applied

[d] FG from Table 22

[e] FDA_{SWP} from Table 20

[f] $WLA_{SW} = (TMDL - WLA_{WWTF} - FG - MOS) \times FDA_{SWP}$ (Equation 11)

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.

For this TMDL, the conventional FG calculation is hampered by the fact that there are no WWTFs within the watershed. By using TCEQ design guidance for domestic WWTFs, and assuming the potential for a residential development of a density sufficient to require centralized sewer collection, an alternative method was implemented.

A new WWTF must accommodate daily wastewater flow of 75-100 gallons per capita per day (gpcd) as required under Title 30, Texas Administrative Code, Section 217.32 (TCEQ, 2015). Conservatively taking the higher daily wastewater flow capacity (100 gallons) and multiplying it by a potential population change would result in a permitted flow for FG.

Based on the information in Table 4, the projected population change for the Halls Bayou Tidal watershed for 2020–2050 is a growth of 7,824. Multiplying that figure by the higher daily wastewater flow capacity (100 gpcd), yields a value of 0.7824 MGD. This value would be considered the full permitted discharge of a potential future WWTF.

The population growth expected for Willow Bayou is essentially zero (Table 4). To account for possible error with this projection or should a WWTF be sited within the watershed, (e.g., abandonment of some current OSSFs) a facility capable of serving half the size of the current population, or 939, was considered. Multiplying this figure by 100 gpcd yields a future WWTF capable of treating a maximum of 0.09385 MGD.

To remain consistent with the previously completed TMDL, no MOS was included in the computation of FG. Thus, the FG is calculated as follows:

$$FG = Target \times WWTF_{FG} \times Conversion\ Factor \qquad \text{(Equation 12)}$$

Where:

$WWTF_{FG}$ = full permitted WWTF discharge future growth (MGD)

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

Target = 35 or 126 cfu/100 mL

Table 22 provides the FG for both subwatersheds.

Table 22. Future growth calculations

AU	Indicator Bacteria	Criterion (cfu/100 mL)	% Population Change (2020-2050)	Full Permitted Discharge (MGD)	FG Flow (MGD)	FG (Billion cfu/day)
2432B_01	*E. coli*	126	-4.16%	-	0.094	0.448
2432C_01	Enterococci	35	102.88%	-	0.782	1.037

4.7.5. Load Allocations

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

$$LA = TMDL - WLA - FG - MOS \qquad \text{(Equation 13)}$$

Where:

LA = allowable loads from unregulated sources within the AU

TMDL = total maximum daily load

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

FG = sum of future growth loads from potential regulated facilities

MOS = margin of safety load

The calculations for LA are presented in Table 23.

Table 23. Load allocations for non-regulatory stormwater

Load units expressed as billion cfu/day

AU	Indicator Bacteria	TMDL[a]	MOS[b]	WLA_{WWTF}	WLA_{SW}[c]	FG[d]	LA
2432B_01	*E. coli*	87.718	4.386	0.00	7.960	0.448	74.924
2432C_01	Enterococci	193.106	9.655	0.00	25.735	1.037	156.679

[a]TMDL from Table 18

[b]MOS from Table 19

[c]WLA_{SW} from Table 21

[d]FG from Table 22

4.8. Summary of TMDL Calculations

Table 24 summarizes the TMDL calculations for the TMDL Project watershed. The TMDL was calculated based on the median flow (5%) in the high flow range for flow exceedance from the LDCs developed for SWQM Stations 18668 and 11422. Allocations are based on the current geometric mean criterion for *E.coli* (126 cfu/100 mL) or Enterococcus (35 cfu/100 mL) for each component of the TMDL.

Table 24. TMDL load allocation

Load units expressed as billion cfu/day

AU	Indicator Bacteria	TMDL	MOS	WLA_{WWTF}	WLA_{SW}	LA	FG
2432B_01	*E. coli*	87.718	4.386	0.00	7.960	74.924	0.448
2432C_01	Enterococci	193.106	9.655	0.00	25.735	156.679	1.037

The final TMDL allocation (Table 25) needed to comply with the requirements of 40 CFR 130.7 and include the FG component within the $WLA_{WWTF.}$

Table 25. Final TMDL load allocation

Load units expressed as billion cfu/day

AU	Indicator Bacteria	TMDL	MOS	WLA_{WWTF} [a]	WLA_{SW}	LA
2432B_01	*E. coli*	87.718	4.386	0.448	7.960	74.924
2432C_01	Enterococci	193.106	9.655	1.037	25.735	156.679

[a] WLA_{WWTF} includes the FG component

Section 5. References

AVMA (American Veterinary Medical Association). 2018. 2017-2018 U.S. Pet Ownership Statistics. 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.

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. December 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/downloads/water-quality/tmdl/tres-palacios-creek-recreational-108/108b-trespalacios-bacteria-tmdl-adopted.pdf.

H-GAC. 2018a. 2018 H-GAC Regional Growth Forecast. datalab.h-gac.com/rgf2018/.

H-GAC. 2018b, Land Use & Land Cover 2018. www.h-gac.com/land-use-and-land-cover-data

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. Illicit Discharge Detection and Elimination Manual: A Handbook for Municipalities. neiwpcc.org/neiwpcc_docs/iddmanual.pdf.

NOAA. 2022 National Climate Data Center Climate Data Online. 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.

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. www.tceq.texas.gov/publications/gi/gi-351.

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. Retrieved July . tceq.maps.arcgis.com/apps/webappviewer/index.html?id=b0ab6bac411a49189106064b70bbe778

TCEQ. 2022c. Personal written communication with Jazmyn Milford regarding general wastewater permits in the Halls/Willow Bayou watersheds. June 10, 2022.

TCEQ. 2022d. TCEQ Central Registry. Retrieved July 2022. www.tceq.texas.gov/permitting/central_registry

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

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

TSHA. 2010a. Handbook of Texas Online. Willow Bayou. tshaonline.org/handbook/online/articles/rhw05.

TSHA. 2010b. Handbook of Texas Online. Halls Bayou (Brazoria County). tshaonline.org/handbook/online/articles/rbh23.

TWRI (Texas Water Resources Institute). 2007. Bacteria Total Maximum Daily Load Task Force Report, Fourth Draft, June 4, 2007. Prepared for TCEQ and TSSWCB. 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. 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. Accessed June 28, 2021.

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

USEPA. 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.

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 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 or removal of 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 and 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 are summarized by various geographies including counties, cities, census tracts, three square mile grids, and traffic analysis zones.

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

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] https://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.