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

Assessment Units: 2432C_01 and 2432B_01

Water Quality Planning Division, Office of Water

TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

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This total maximum daily load report is based in large part on the report titled:
"Technical Support Document for Two Total Maximum Daily Loads for Indicator Bacteria the Halls Bayou Tidal and Willow Bayou Watersheds"
prepared by Steven Johnston of the Houston-Galveston Area Council

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Abbreviations

AU	assessment unit
BMP	best management practice
CFR	Code of Federal Regulations
cfu	colony forming units
cfs	cubic feet per second
E. coli	*Escherichia coli*
EPA	Environmental Protection Agency (United States)
FDC	flow duration curve
FG	future growth
GIS	Geographic Information System
GPCD	gallons per capita per day
H-GAC	Houston-Galveston Area Council
H3M	hexagonal grid of three-square miles
I&I	inflow and infiltration
I-Plan	implementation plan
LA	load allocation
LDC	load duration curve
MCM	minimum control measure
mL	milliliter
MGD	million gallons per day
MOS	margin of safety
MS4	municipal separate storm sewer system
MSGP	multi-sector general permit
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
OSSF	on-site sewage facility
SSO	sanitary sewer overflow
SWMP	Stormwater Management Program
SWQM	surface water quality monitoring
TAC	Texas Administrative Code
TCEQ	Texas Commission on Environmental Quality
TMDL	total maximum daily load
TPDES	Texas Pollutant Discharge Elimination System
TSSWCB	Texas State Soil and Water Conservation Board
UA	urbanized area
U.S.	United States
USCB	U.S. Census Bureau
USDA	U.S. Department of Agriculture
USGS	United States Geological Survey

WLA	wasteload allocation
WQBELs	water quality-based effluent limits
WQMP	Water Quality Management Plan
WWTF	wastewater treatment facility

Executive Summary

This report describes total maximum daily loads (TMDLs) for Halls Bayou Tidal and Willow Bayou where concentrations of fecal indicator bacteria exceed the criteria used to evaluate attainment of the primary contact recreation 1 use. The Texas Commission on Environmental Quality (TCEQ) first identified the impairments to Halls Bayou Tidal in the *2012 Texas Integrated Report of Surface Water Quality for Clean Water Act Sections 305(b) and 303(d)* (Texas Integrated Report, TCEQ, 2012). The impairment to Willow Bayou was first identified in the 2018 Texas Integrated Report (TCEQ, 2018). This document will consider bacteria impairments in two water bodies, 2432C and 2432B, each consisting of one assessment unit (AU):

- Willow Bayou - AU 2432B_01
- Halls Bayou Tidal - AU 2432C_01

Halls Bayou Tidal is an unclassified water body located within the Chocolate Bay watershed, located along the upper Texas Gulf Coast. This 19.6 mile-long tidal stream originates in Brazoria County and travels southeast, running parallel to the Galveston County line into Halls Lake before emptying into Chocolate Bay, an embayment of West Galveston Bay. Willow Bayou, a freshwater tributary to Halls Bayou Tidal, begins in western Galveston County and flows southwest to its mouth on Halls Bayou at the Brazoria County line. The Halls Bayou watershed includes both Halls Bayou Tidal and Willow Bayou.

Escherichia coli (E. coli) and Enterococci are widely used as indicator bacteria to determine attainment of the contact recreation use in freshwater and saltwater, respectively. The criterion for determining attainment of the contact recreation use is expressed as the number of bacteria, typically given as colony forming units (cfu) in 100 milliliters (mL) of water. The primary contact recreation 1 use is not supported when the geometric mean of all samples during the assessment period exceeds the respective contact recreation criteria for indicator bacteria. For freshwater, the primary contact recreation 1 criterion is 126 cfu/100 mL of *E. coli*. For saltwater, the primary contact recreation 1 criterion is 35 cfu/100 mL of Enterococci.

E. coli and Enterococci data were collected at two TCEQ surface water quality monitoring (SWQM) stations, one in Willow Bayou and one in Halls Bayou Tidal from Dec. 1, 2013 through Nov. 30, 2020. The assessed data, as described in the Environmental Protection Agency (EPA)-approved 2022 Texas Integrated Report, indicate non-attainment of the contact recreation standard in AUs 2432C_01 and 2432B_01 (TCEQ, 2022a).

Within the Halls Bayou Tidal and Willow Bayou watersheds, probable sources of bacteria include regulated stormwater runoff, sanitary sewer overflows (SSOs), illicit discharges, on-site sewage facilities (OSSFs), agricultural activities, and contributions from wildlife and domesticated animals.

A review of the TCEQ Central Registry for active permits found that there are currently no permitted domestic or industrial wastewater treatment facilities (WWTFs) within the watershed. A review of active general wastewater permits found one concrete production facility. General stormwater permits were also reviewed. One stormwater construction permit was found, but it was recently terminated. There is one active municipal separate storm sewer system (MS4) in the watershed, covering approximately 15% of the Halls Bayou Tidal and 11% of Willow Bayou watersheds. There is also one active multisector general permit located within the watershed.

A modified load duration curve (LDC) analysis was done for the TMDL Project watershed to quantify allowable pollutant loads, as well as allocations for point and nonpoint sources of bacteria. The wasteload allocation (WLA) for WWTFs was not applicable for this TMDL, as there are no permitted WWTFs within the Halls Bayou Tidal and Willow Bayou watersheds. As OSSFs are the primary mode of sewage treatment in the watershed, the number of permitted OSSFs were compiled and the number of unpermitted OSSFs were estimated. Since there are no existing domestic point sources in the watershed, future growth (FG) was calculated using population growth projections and a hypothetical new permitted discharge based on requirements in Title 30, Texas Administrative Code (TAC), Chapter 217, Subchapter B, Section 217.32 (30 TAC 217.32).

The TMDL calculations in this report will guide determination of the assimilative capacity of each water body under changing conditions, including FG.

Introduction

Section 303(d) of the federal Clean Water Act requires all states to identify waters that do not meet, or are not expected to meet, applicable water quality standards. States must develop a TMDL for each pollutant that contributes to the impairment of a water body included on a state's 303(d) list of impaired waters. 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 applicable water quality standards. TMDLs are the best possible estimates of the assimilative capacity of the water body for a pollutant under consideration. A TMDL is commonly expressed as a load with units of mass per period of time but may be expressed in other ways.

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

This TMDL report addresses impairments to the primary contact recreation 1 use due to elevated levels of indicator bacteria in Halls Bayou Tidal, 2432C_01, and Willow Bayou, 2432B_01. This TMDL takes a watershed approach to addressing indicator bacteria impairments. While TMDL allocations were developed only for the impaired AUs identified in this report, the entire project watershed (Figure 1) and all regulated discharges within it are included within the scope of this TMDL. Information in this TMDL report was derived from the *Technical Support Document for Two Total Maximum Daily Loads for Indicator Bacteria in the Halls Bayou Tidal and Willow Bayou Watersheds* (H-GAC, 2022a).

Section 303(d) of the Clean Water Act and the implementing regulations of the United States (U.S.) EPA in Title 40 of the Code of Federal Regulations (CFR), Chapter 1, Part 130 (40 CFR 130) describe the statutory and regulatory requirements for acceptable TMDLs. EPA provides further direction in its *Guidance for Water Quality-Based Decisions: The TMDL Process* (EPA, 1991). This TMDL report has been prepared in accordance with those regulations and guidelines.

TCEQ must consider certain elements in developing a TMDL. They are described in the following sections of this report:

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

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

Problem Definition

TCEQ first identified the impairment of the primary contact recreation 1 use within Halls Bayou Tidal (2432C_01) in the 2012 Texas Integrated Report (TCEQ, 2012) and again in each subsequent edition through the EPA-approved 2022 Texas Integrated Report (TCEQ, 2022a). The impairment of the primary contact recreation 1 use in Willow Bayou, a freshwater tributary to Halls Bayou Tidal, was first identified in the 2018 Integrated Report and again in each subsequent edition through the EPA-approved 2022 Texas Integrated Report (TCEQ, 2022a).

This document will consider two bacteria impairments to two AUs within the Willow Bayou and Halls Bayou Tidal watersheds, 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.

Recent surface water *E. coli* and Enterococci monitoring within the TMDL Project watershed has occurred at two TCEQ SWQM stations (Table 1 and Figure 1). *E. coli* data, collected at SWQM Station 18668 from Dec. 1, 2013 to Nov. 30, 2020, and Enterococci data, collected at SWQM Station 11422 from Dec. 1, 2013 to Nov. 30, 2020, were used to determine attainment of primary contact recreation use 1 as reported in the 2022 Texas Integrated Report (TCEQ, 2022a). Data assessed indicate non-support of primary contact recreation 1 use because the geometric mean concentrations of available samples exceed the geometric mean criterion of 126 cfu/100 mL for *E. coli* and 35 cfu/100 mL for Enterococci, as summarized in Table 1.

Table 1. 2022 Texas Integrated Report summary for the impaired AUs

Water Body	AU	Parameter	TCEQ SWQM Station	Date Range	Number of Samples	Geometric Mean (cfu/100 mL)
Willow Bayou	2432B_01	*E. coli*	18668	12/1/2013 – 11/30/2020	13	279.71
Halls Bayou Tidal	2432C_01	Enterococci	11422	12/1/2013 – 11/30/2020	35	78.65

Watershed Overview

Halls Bayou Tidal is an unclassified water body located within the Chocolate Bay watershed along the upper Texas Gulf Coast. This 19.6 mile-long tidal stream originates in Brazoria County and travels southeasterly, running parallel to the Galveston County line into Halls Lake before emptying into Chocolate Bay, an embayment of West Galveston Bay (TSHA, 2010a). Willow Bayou, an unclassified, freshwater tributary to Halls Bayou Tidal, begins in western Galveston County and flows southwest to its mouth on Halls Bayou at the Brazoria County line (TSHA, 2010b). The Halls Bayou watershed includes both Halls Bayou Tidal and Willow Bayou (Figure 1).

The 2022 Texas Integrated Report (TCEQ, 2022a) provides the following descriptions for the unclassified water bodies considered for this document:

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

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

Both Halls Bayou Tidal and Willow Bayou each consist of a single AU.

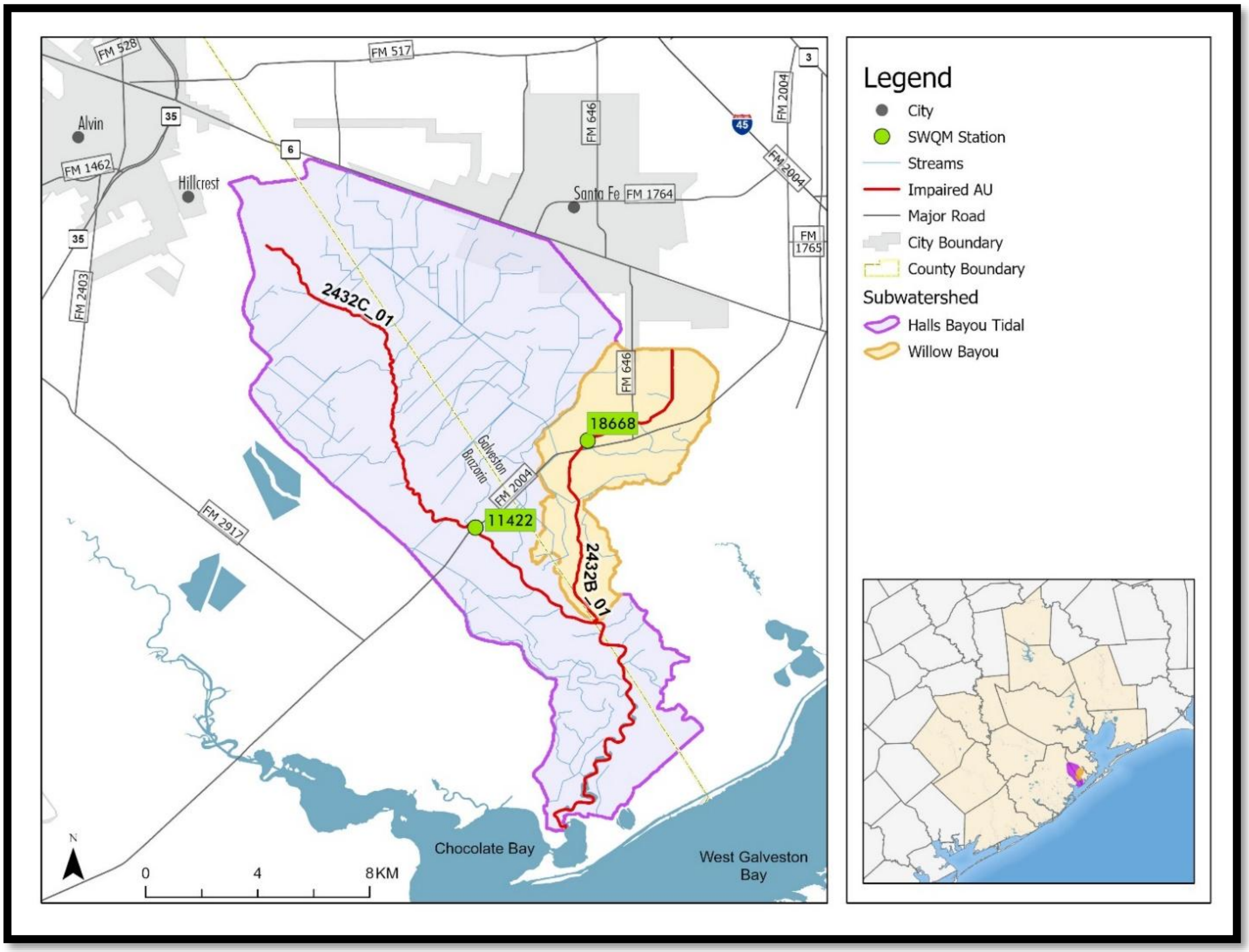

Figure 1. Map of the TMDL Project watersheds

Climate and Hydrology

Precipitation and temperature data recorded between 2004 and 2020 was retrieved from the National Oceanic and Atmospheric Administration (NOAA), 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 2). This dataset includes measurements recorded during the statewide drought that peaked in 2011, when the measured annual rainfall was only 20.81 inches. The wettest year for this period was 2016, with 73.38 inches. Mean monthly precipitation ranged from a minimum of 2.27 inches in February to a maximum of 6.46 inches in September with a monthly average of 3.98 inches (Figure 2). The driest months typically occur in late winter or early spring. The wettest periods occur in summer and early fall during hurricane season, where rainfall near or above 20 inches in a month is common.

Table 2. 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

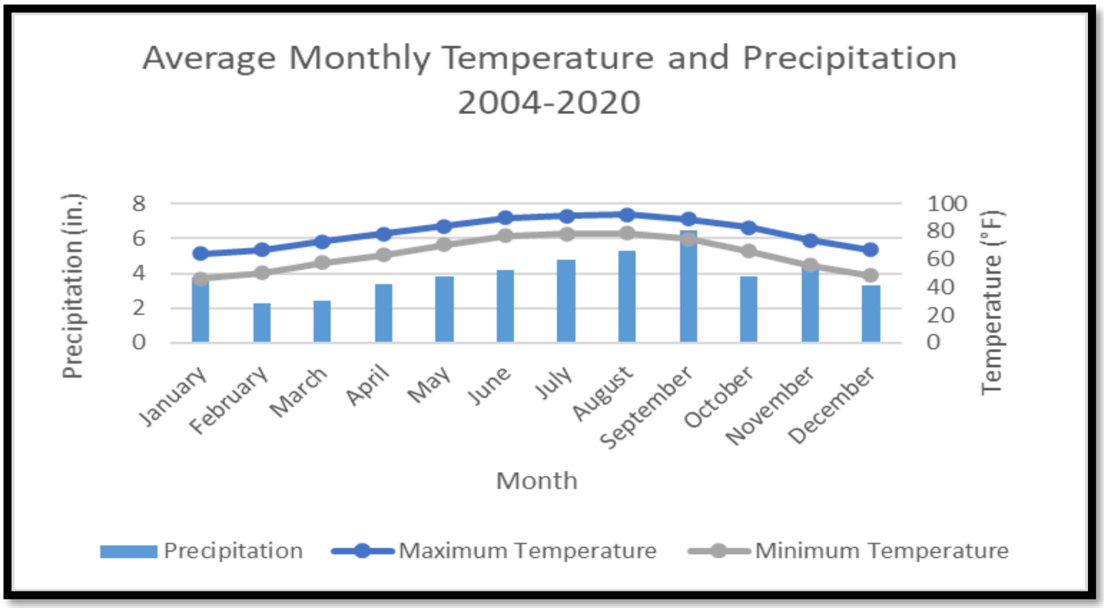

Figure 2. Average monthly temperature and precipitation from 2204-2020, NOAA Station GHCND: USC00413340

Average annual minimum and maximum temperatures are 63.91˚F and 79.30˚F, respectively. Figure 2 includes maximum and minimum average monthly temperatures. As shown, December and January are the coolest months with the lowest monthly average minimum temperatures, 48.61˚F and 46.26˚F, respectively. July and August are the hottest months with the highest average maximum temperatures, 91.34˚F and 92.35˚F, respectively.

Population and Population Projections

The Houston-Galveston Area Council (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; 1,877 and 7,605 within the Willow Bayou and Halls Bayou Tidal subwatersheds, respectively (Table 3). 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 outlined in Appendix A (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 by 81.69% with an estimated population of 17,228 by 2050. All the projected population growth is expected to take place within the Halls Bayou Tidal watershed (H-GAC, 2018a).

Table 3. Population change in the TMDL Project watershed

AU	2020 U.S. Census	2050 Population Projection	Projected Increase (2020-2050)	Percentage Increase (2020-2050)
2432B_01	1,877	1,799	-78	-4.16%
2432C_01	7,605	15,429	7,824	102.88%
Total	**9,482**	**17,228**	**7,746**	**81.69%**

Land Cover

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

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

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

housing areas, especially in suburban neighborhoods, but may include all types of land use.

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

4. **Developed Open Space** – Contains areas with a mixture of some constructed materials, but mostly managed grasses or low-lying vegetation planted in developed areas for recreation, erosion control, or aesthetic purposes. These areas are maintained by human activity such as fertilization and irrigation, are distinguished by enhanced biomass productivity, and can be recognized through vegetative indices based on spectral characteristics. Constructed surfaces account for less than 20% of total land cover.

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

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

    a. *Pasture/Hay* – Contains areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle and not tilled. Pasture/hay vegetation accounts for greater than 20% of total vegetation.

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

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

    a. *Barren Land* – Contains areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits, and other accumulations of earth material. Generally, vegetation accounts for less than 10% of total cover.

    b. *Unconsolidated Shore* – Includes material such as silt, sand, or gravel that is subject to inundation and redistribution due to the action of water. Substrates lack vegetation except for pioneering plants that become established during brief periods when growing conditions are favorable.

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

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

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

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

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

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

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

    b. *Palustrine Aquatic Bed* – Includes tidal and non-tidal wetlands and deep-water habitats in which salinity due to ocean-derived salts is below 0.5% and which are dominated by plants that grow and form a continuous cover principally on or at the surface of the water. These include algal mats, detached floating mats, and rooted vascular plant assemblages. Total vegetation cover is greater than 80%.

    c. *Estuarine Aquatic Bed* – Includes tidal wetlands and deep-water habitats in which salinity due to ocean-derived salts is equal to or greater than 0.5% and which are dominated by plants that grow and form a continuous cover principally on or at the surface of the water. These include algal mats, kelp beds, and rooted vascular plant assemblages. Total vegetation cover is greater than 80%.

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

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

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

c. *Palustrine Emergent Wetland (Persistent)* – Includes tidal and non-tidal wetlands dominated by persistent emergent vascular plants, emergent mosses or lichens, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5%. Total vegetation cover is greater than 80%. Plants generally remain standing until the next growing season.

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

e. *Estuarine Scrub / Shrub Wetland* – Includes tidal wetlands dominated by woody vegetation less than five meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is equal to or greater than 0.5%. Total vegetation coverage is greater than 20%.

f. *Estuarine Emergent Wetland* – Includes all tidal wetlands dominated by erect, rooted, herbaceous hydrophytes (excluding mosses and lichens). Wetlands that occur in tidal areas in which salinity due to ocean-derived salts is equal to or greater than 0.5% and that are present for most of the growing season in most years. Total vegetation cover is greater than 80%. Perennial plants usually dominate these wetlands.

The TMDL Project watershed covers 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 4, Figure 3). The TMDL Project watershed is mostly rural, and agriculture is the predominate land use.

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 4). 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. Wetlands make up the third largest land cover type at 16.19%; 17.03% and 16.04% in the Willow Bayou and Halls Bayou Tidal subwatersheds, respectively.

The largest developed land cover type is Developed Open Space at 14.43%. The majority of the developed land cover types (which include High Intensity, Medium Intensity, and Low Intensity) make up a small percentage of the TMDL Project watershed at a combined 3.26% (Table 4).

Table 4. 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%**

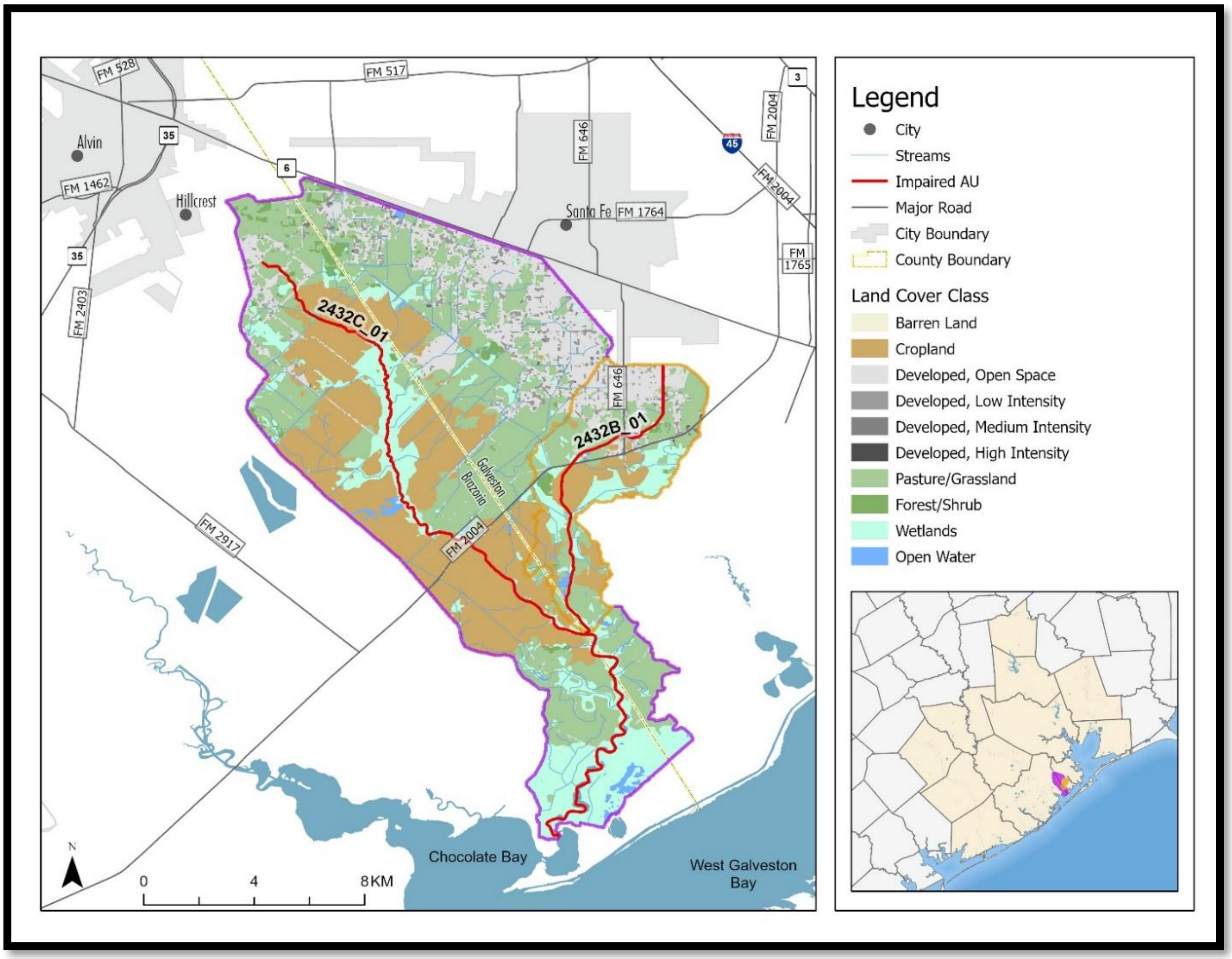

Figure 3. Land cover map of land use classifications

Soils

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

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

- **Group B** – Soils having a moderate infiltration rate when thoroughly wet. These consist of moderately deep or deep, moderately well-drained or well-drained soils that have moderately fine texture to moderately coarse texture. These soils have a moderate rate of water transmission.

- **Group C** – Soils having a slow infiltration rate when thoroughly wet. These consist chiefly of soils having a layer that impedes the downward movement of water or soils of moderately fine texture or fine texture. These soils have a slow rate of water transmission.

- **Group D** – Soils having a very slow infiltration rate (high runoff potential) when thoroughly wet. These consist chiefly of clays that have a high shrink-swell potential, soils that have a high-water table, soils that have a claypan or clay layer at or near the surface, and soils that are shallow over nearly impervious material. These soils have a very slow rate of water transmission.

- Soils with dual hydrologic groupings indicate that drained areas are assigned the first letter, and the second letter is assigned to undrained areas. Only soils that are in group D in their natural condition are assigned to dual classes.

The predominant soil group within the TMDL Project watershed is Group D at 70.94%, The second largest soil group is that of Group C/D at 27.65% (Table 5, Figure 4). Both soil groups are typical of Texas coastal areas which are made up of slow draining alluvial clays.

Table 5. 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%

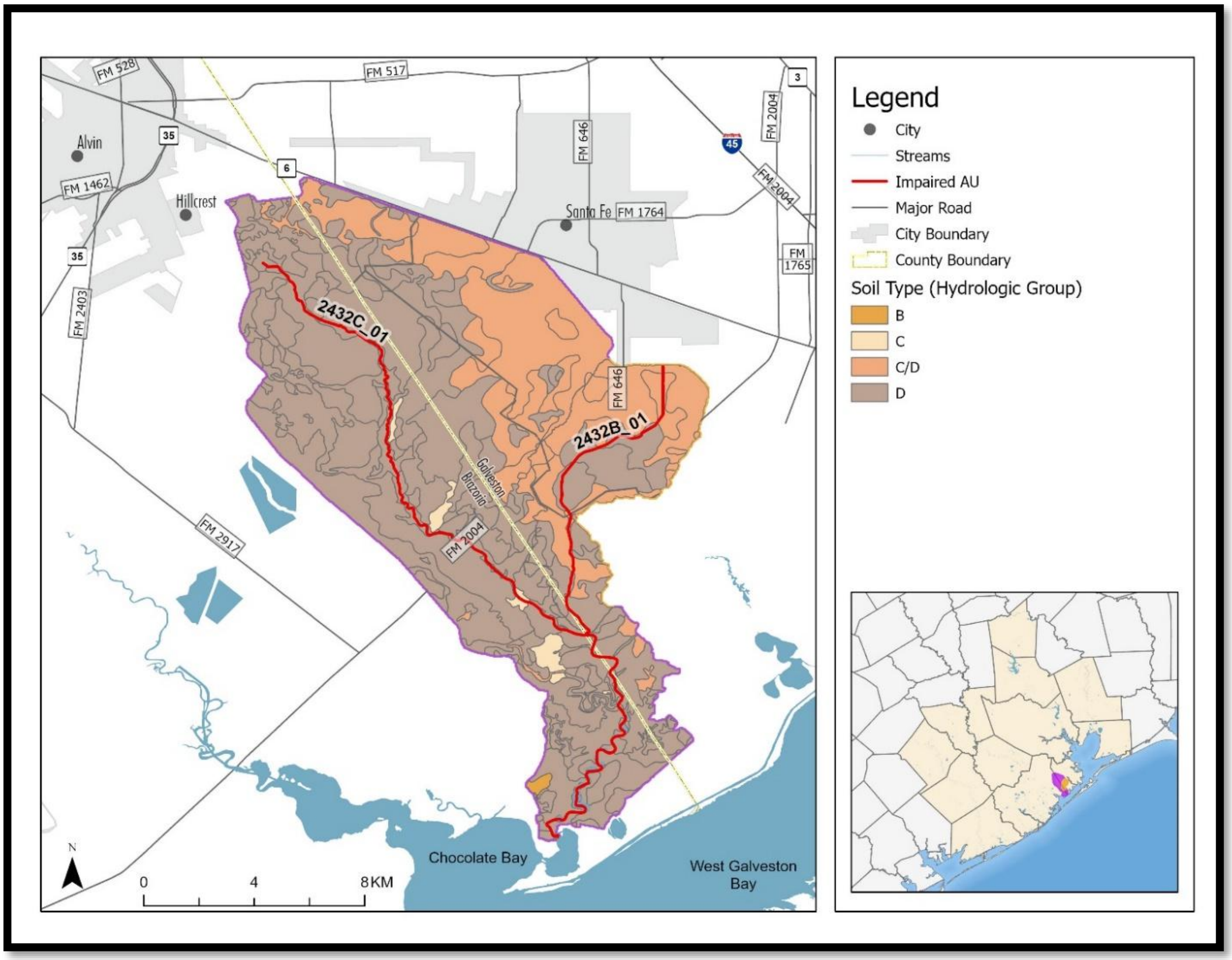

Figure 4. Map of hydrologic soil groups

Water Rights Review

Surface water rights in Texas are administered and overseen by TCEQ. A search of TCEQ's Texas Water Rights Viewer, active water rights database, and geographic information system (GIS) files (TCEQ, 2019c, 2019d) indicated there is one water right in the Halls Bayou Tidal subwatershed. There were no water rights in the Willow Bayou subwatershed.

Due to a lack of streamflow data in the TMDL Project watershed, Chocolate Bayou Above Tidal was used as a surrogate to develop flow data, this process is discussed in more detail in the "Load Duration Curve Analysis" section and the *Technical Support Document for Two Total Maximum Daily Loads for Indicator Bacteria in the Halls Bayou Tidal and Willow Bayou Watersheds* (H-GAC, 2022a). Information regarding the Chocolate Bayou Above Tidal Watershed used as a surrogate to develop flow data can be found in the document *Two Total Maximum Daily Loads for Indicator Bacteria in Chocolate Bayou* (H-GAC, 2024, pp. 5-7). There were three water rights diversions within the catchment area above the United States Geological Survey (USGS) station in Chocolate Bayou Above Tidal.

Endpoint Identification

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

The endpoint for the TMDLs in this report is to maintain concentrations of *E. coli* and Enterococci below the geometric mean criterion of 126 cfu/100 mL and 35 cfu/100 mL, respectively, which is protective of the primary contact recreation 1 use in freshwater and saltwater (TCEQ 2022b).

Source Analysis

Pollutants may come from several sources, both regulated and unregulated. Regulated pollutants, referred to as "point sources," come from a single definable point, such as a pipe, and are regulated by permit under the Texas Pollutant Discharge Elimination System (TPDES) program. WWTFs and stormwater discharges from industries, 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 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.

Regulated Sources

Regulated sources are controlled by permit under the TPDES program. Because much of the area in the TMDL Project watershed is undeveloped, there are few regulated sources. The regulated sources in the TMDL Project watershed include stormwater discharges from regulated construction sites, industrial sites, and an MS4.

Domestic and Industrial Wastewater Treatment Facilities

Based upon a review of TCEQ's Central Permit Registry (TCEQ, 2022c) and TCEQ's GIS Outfall Layer, there are no permitted domestic or industrial WWTFs that discharge to either the Halls Bayou Tidal or Willow Bayou watersheds. The land use/land cover for the watersheds is primarily agricultural, with no major cities or towns located within the watersheds. OSSFs are the primary mode of sewage treatment within the TMDL Project watershed.

TCEQ/TPDES Water Quality General Permits

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

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

The following general permit authorizations are not considered to affect the bacteria loading in the TMDL Project 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 permit coverage (TCEQ, 2022c) in the TMDL Project watershed as of May 2022 found one general permit authorization for a concrete production facility within the Willow Bayou subwatershed. These facilities do not have bacteria reporting requirements or limits in their permits and are assumed to contain inconsequential amounts of indicator bacteria in their effluent; therefore, it was unnecessary to allocate bacteria loads to these facilities. The concrete production facility is authorized to discharge stormwater thus they will be considered in the stormwater allocation analysis. (Table 6).

Table 6. Concrete production facility

AU	Permit Number	Permittee	County	City	Estimated Area (acres)
2432B_01	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/or importing the location information associated with the authorization into GIS and measuring the facility boundaries.

Sanitary Sewer Overflows

SSOs are unauthorized discharges that must be addressed by the responsible party, either the TPDES permittee or the owner of the collection system that is connected to a permitted system. 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 the I&I problem. Other causes, such as a collapsed sewer line, may occur under any condition.

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

TPDES-Regulated Stormwater

When evaluating stormwater for a TMDL allocation, a distinction must be made between stormwater originating from an area under a TPDES-regulated discharge permit and stormwater originating from areas not under a TPDES-regulated discharge permit. Stormwater discharges fall into two categories:

1. Stormwater subject to regulation, which is any stormwater originating from TPDES-regulated MS4 entities, stormwater discharges 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 sanitary wastewater collection system or treatment facility. Phase I permits are individual permits for large and medium-sized MS4swith populations of 100,000 or more based on the 1990 United States Census, whereas the Phase II General Permit regulates other MS4s within an urban area with a population of at least 50,000 people.

The purpose of an MS4 permit is to reduce discharges of pollutants in stormwater to the “maximum extent practicable” by developing and implementing a stormwater management program (SWMP). The SWMP describes the stormwater control practices that the regulated entity will implement consistent with permit requirements to minimize the discharge of pollutants. The MS4 permits require that SWMPs specify the best management practices (BMPs) 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 the 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 an urban area with a a population of at least 50,000 people (discussed above).
- TXR050000 – Multi-Sector General Permit (MSGP) for industrial facilities.
- TXR150000 – Construction General Permit (CGP) for construction activities disturbing more than one acre or are part of a common plan of development disturbing more than one acre.

As of May 2022, a review of TCEQ's Central Registry (TCEQ, 2022c) included one combined Phase I and II MS4 permit held by the Texas Department of Transportation for rights-of-way in their MS4 regulated areas and one Phase II MS4 permit authorization (Table 7).

Table 7. 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 urban 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 urban areas

To determine an estimated area potentially under a MS4 Phase II permit within the TMDL Project watershed, a review of the USCB's 2010 census defined urbanized area (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 a UA of 8.98% or 628.70 acres. Halls Bayou Tidal has a UA of 13.95% or 5,183.04 acres. (Table 8, Figure 5).

Table 8. 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%**

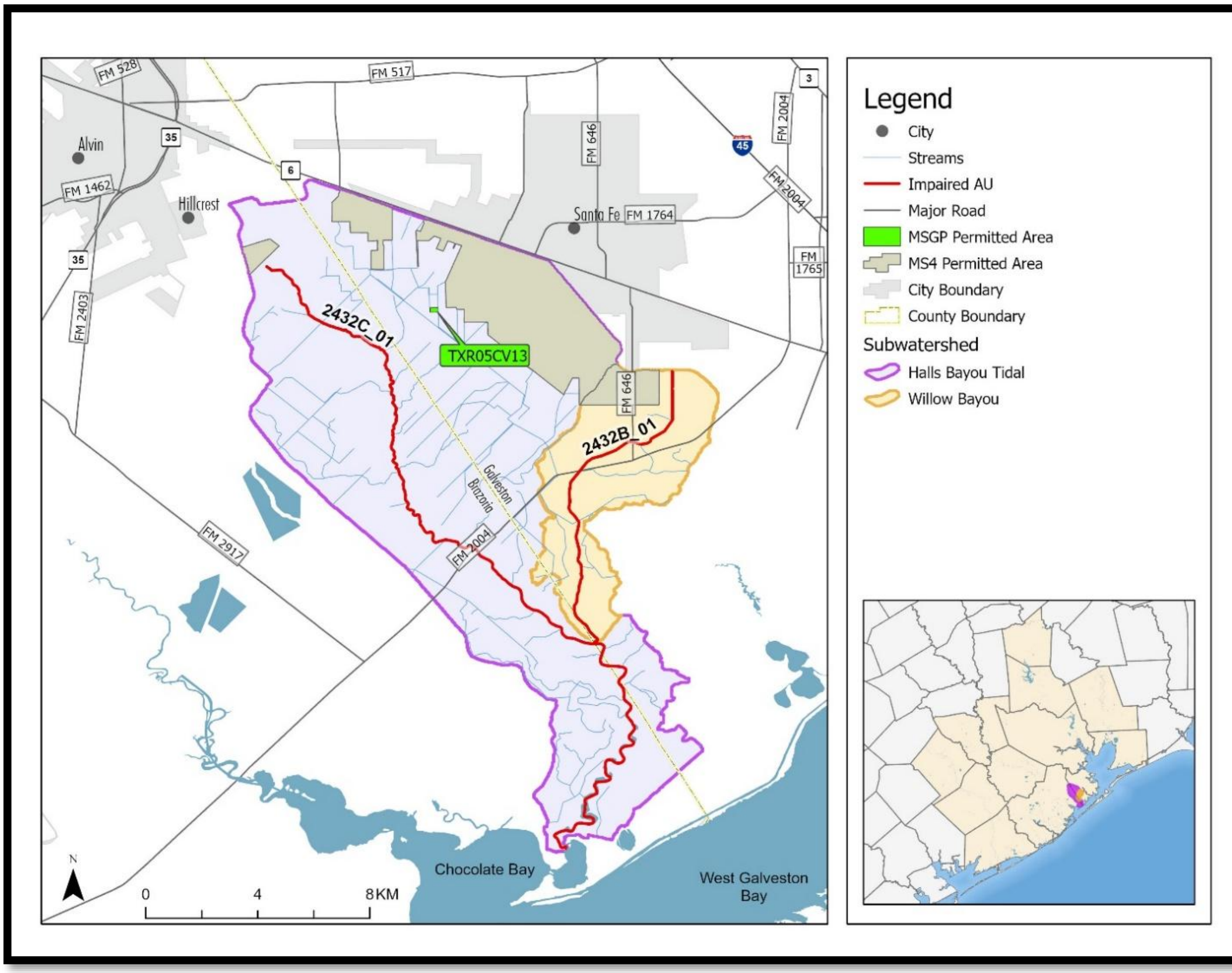

Figure 5. MS4 and MSGP permit area

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

Due to the variable nature of the stormwater construction permits, the acres recorded serve only as a representative estimate of the acres of land disturbed. Additionally, other construction activities may be occurring in the watershed that are not required to have a CGP authorization or are not regulated. In May 2022, review of TCEQ Central Registry for a period of 2016 through 2021 found only two CGP authorizations yielding a total of 82.29 acres of disturbed area. One authorization 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 is 35.20 acres and 47.1 acres for the Willow Bayou and Halls Bayou Tidal subwatersheds, respectively.

The total area of regulated stormwater is approximately 35 square miles or 97% of the Hillebrandt Bayou watershed.

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 system 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.

Unregulated Sources

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

Unregulated Agricultural Activities and Domesticated Animals

A number of agricultural activities that do not require permits can be potential sources of fecal bacteria loading. Activities, such as livestock grazing close to water bodies and the use of manure as fertilizer, can contribute *E. coli* and Enterococci to nearby water bodies. Livestock are present throughout the more rural portions of the project watershed.

Table 9 provides estimated numbers of selected livestock in the TMDL Project watershed based on the 2022 Census of Agriculture conducted by USDA (USDA, 2024). Those populations were determined based on GIS calculations of 2016 National Land Cover Database suitable habitat in the watershed, which included areas classified as Pasture/Hay and Grassland/Herbaceous. The area of suitable habitat within the watershed area (within the corresponding county) was then divided by the total area of the county classified as Pasture/Hay and Grassland/Herbaceous. The resulting ratio of suitable habitat was multiplied by USDA county-level livestock estimates. The Texas State Soil and Water Conservation Board (TSSWCB) staff reviewed the watershed estimated livestock numbers. These livestock numbers, however, were not used to develop an allocation of allowable bacteria loading to livestock.

Table 9. Estimated livestock population

AU	Cattle and Calves	Hogs and Pigs	Sheep and Goats	Horses	Poultry
2432B_01	299	25	27	33	1,025
2432C_01	2,174	70	157	173	7,388
Total	**2,473**	**95**	**184**	**205**	**8,413**

Fecal matter from dogs and cats is transported to water bodies by runoff in both urban and rural areas and can be a potential source of bacteria loading. Table 10 summarizes the estimated number of dogs and cats in the TMDL Project watershed. Pet population estimates were calculated as the estimated number of dogs (0.614) and cats (0.457) per household (AVMA, 2018). The number of households in the watershed was estimated using the USCB 2020 census data (USCB, 2021). The actual contribution and significance of bacteria loads from pets reaching the water bodies of the watershed is unknown.

Table 10. Estimated households and pet population

AU	Estimated Households	Estimated Dog Population	Estimated Cat Population
2432B_01	693	425	317
2432C_01	2,806	1,723	1,282
Total	**3,499**	**2,148**	**1,599**

Wildlife and Unmanaged Animals

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. Wildlife are naturally attracted to 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 per 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 11).

Table 11. Estimated deer population

AU	Area (acres)	Estimated Deer Population
2432B_01	7,001.05	277
2432C_01	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 12).

Table 12. Estimated feral hog population

AU	Low Quality Habitat (acres)	Feral Hogs	High Quality Habitat (acres)	Feral Hogs	Total
2432B_01	1,737.33	24	5,158.49	132	156
2432C_01	11,756.54	163	24,554.92	629	792
Total	**13,493.87**	**187**	**29,713.41**	**761**	**948**

On-Site Sewage Facilities

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

Several pathways of the liquid waste in OSSFs afford opportunities for bacteria to enter ground and surface waters if the systems are not properly operating. Properly designed and operated, however, OSSFs would be expected to contribute virtually no fecal bacteria to surface waters. For example, 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 13, 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 13, Figure 6). By applying the estimated 12% failure rate to the 3,190 OSSFs estimated within the TMDL Project watershed (Table 13), 383 OSSFs are projected to be failing.

Table 13. Estimated OSSFs

AU	Registered	Non-registered	Total
2432B_01	333	401	734
2432C_01	1,286	1,170	2,456
Total	**1,619**	**1,571**	**3,190**

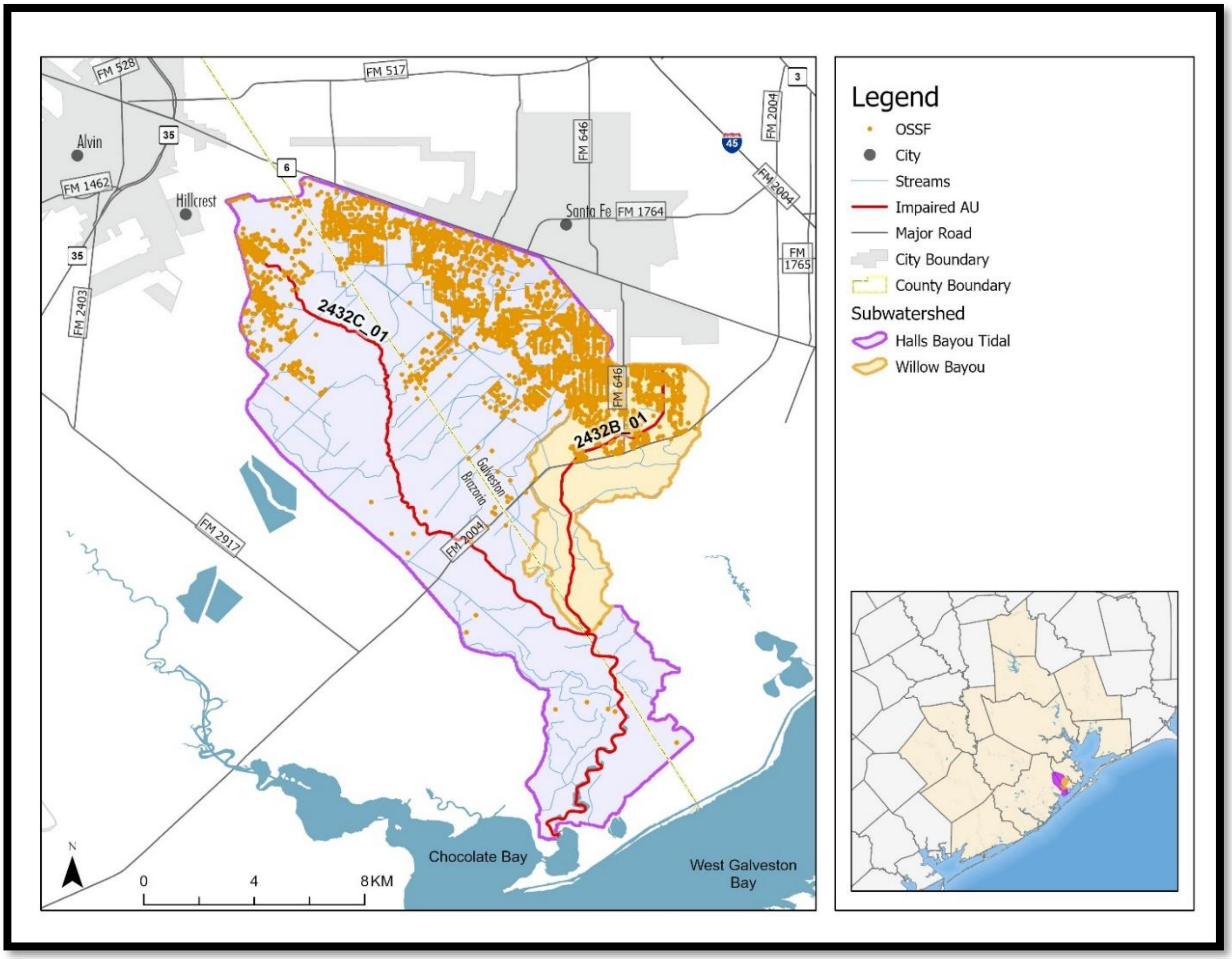

Figure 6. Estimated OSSF density

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.

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.

Load Duration Curve Analysis

LDCs are graphs of the frequency distribution of loads of pollutants in a water body. LDC analyses are used to examine the relationship between instream water quality and broad sources of bacteria loads which are the basis of the TMDL allocations (Cleland, 2003). In the case of these TMDLs, the loads shown are of *E. coli* and Enterococci bacteria in cfu/day.

LDCs are derived from flow duration curves (FDCs) and modified FDCs for tidal water bodies. LDCs shown in the following figures represent the maximum acceptable load in the water bodies that will result in achievement of the TMDL water quality targets. The basic steps to generate LDCs involve:

- Generating a daily flow record – the mean daily streamflow record incorporating full permitted discharges and FG was developed for a TCEQ SWQM station within each AU using the drainage area ratio methodology and the mean daily streamflow reported at USGS Gage 08078000 on Chocolate Bayou Above Tidal.
- Developing the FDC – the mean daily streamflow is plotted against the exceedance probability of the mean daily streamflow for each day.
- Converting the FDC to an LDC – the mean daily streamflow for each day is multiplied by the primary contact recreation 1 use geometric mean criterion and a conversion factor to produce a graph of the frequency distribution of allowable loads.
- Overlaying the LDC with available indicator bacteria loading measurements to understand under what flow conditions indicator bacteria loading exceeds the primary contact recreation 1 use geometric mean criterion.

In watersheds where there are tidal exchanges along the Texas coast, the flow is adjusted to address tidal influences. The LDC developed through this approach is called a modified LDC. A modified LDC assumes that combining freshwater with seawater increases the loading capacity in the tidal river. Modified LDCs are derived from modified FDCs. The modified LDC represents the maximum acceptable load in the stream that will result in achievement of the TMDL water quality target. The basic steps to generate modified LDCs include:

- Generating a daily freshwater flow record – the mean daily freshwater flow record incorporating actual daily average permitted discharges was developed for the most downstream TCEQ SWQM station within the AU using a drainage area ratio methodology and the mean daily streamflow reported at USGS Gage 08078000 on Chocolate Bayou.
- Generating a daily tidal volume record – the daily tidal seawater volume record was generated using salinity to streamflow regressions and mass-balance equations. The tidal seawater volumes were added to the daily freshwater flow record for the tidal AU.
- Accounting for full permitted discharges – the actual daily average permitted discharges are removed from the streamflow and the full permitted daily average discharges and FG discharges are added.
- Developing the modified FDC – the mean daily streamflow including seawater volume, full permitted discharges, and FG is plotted against the exceedance probability of the mean daily streamflow for each day for the tidal AU.
- Converting the modified FDC to a modified LDC – the mean daily streamflow for each day is multiplied by the primary contact recreation 1 use geometric mean

criterion and a conversion factor to produce a graph of the frequency distribution of allowable loads.

- Overlaying the modified LDC with available indicator bacteria loading measurements to understand under what flow conditions indicator bacteria loading exceeds the primary contact recreation 1 use geometric mean criterion.

More information explaining the modified LDC method may be found in Chapter 2 and Appendix 1 of the Umpqua Basin TMDLs and supporting documents (ODEQ, 2006).

Load Duration Curve Results

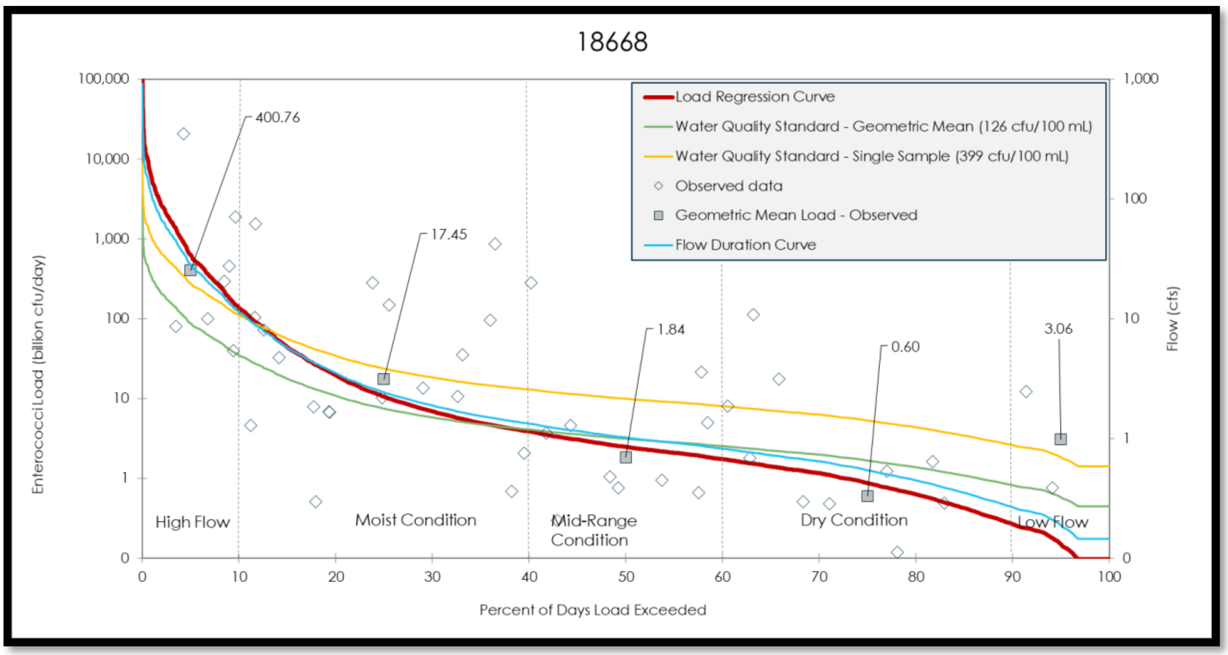

Figure 7. LDC for Willow Bayou AU 2432B_01 at SWQM Station 18668

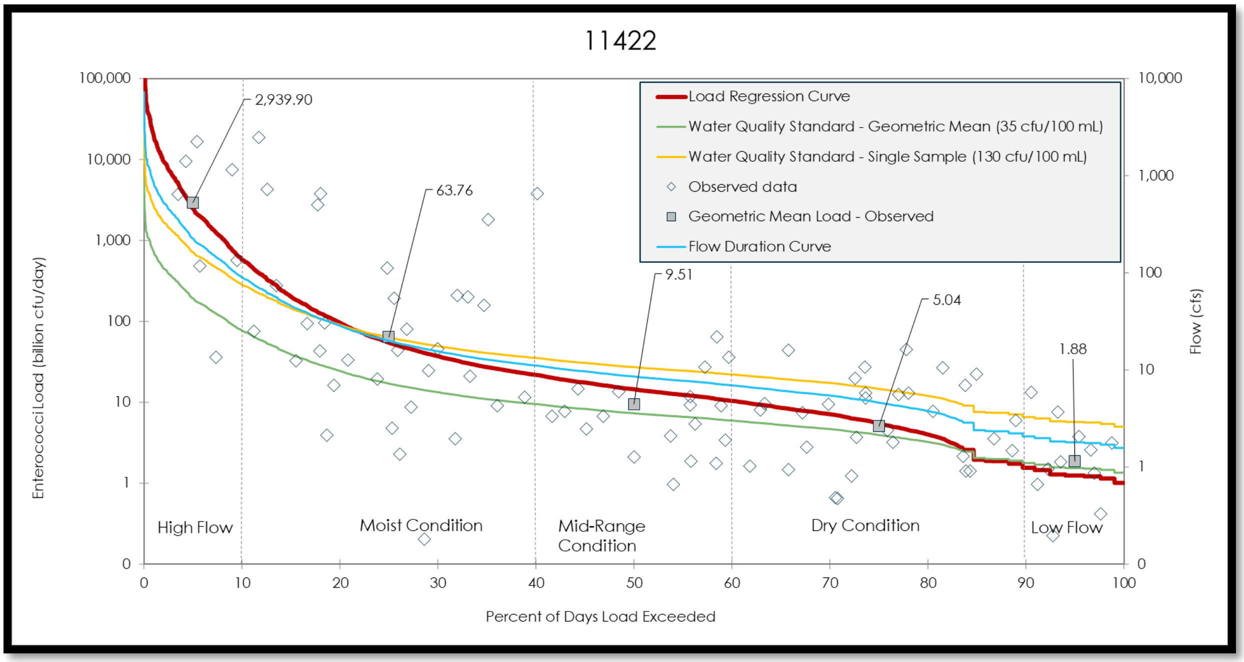

Figure 8. Modified LDC for Halls Bayou Tidal AU 2432C_01 at SWQM Station 11422

Margin of Safety

The margin of safety (MOS) is used to account for uncertainty in the analysis used to develop the TMDL and thus provide a higher level of assurance that the goal of the TMDL will be met. It also accounts 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 an MOS.

According to EPA guidance (EPA, 1991), the MOS can be incorporated into the TMDL using either of the following two methods:

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

This TMDLs incorporate an explicit MOS of 5% of the total TMDL allocation.

Pollutant Load Allocation

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

TMDL = WLA + LA + FG + MOS

Where:

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

LA = load allocations, 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 as cfu/day, and represent the maximum one-day load the stream can assimilate while still attaining the standards for surface water quality.

The TMDL components for the impaired AUs are derived using the median flow within the high-flow regime (or 5% flow) of the LDCs developed for each of the TMDL Project subwatersheds. For the remainder of this report, each section will present an explanation of the TMDL component first, followed by the results of the calculation for that component. Also, please note that some calculations completed in the remainder of this report have been rounded and may not lead to the exact final amounts listed in the text, tables, or figures.

Assessment Unit-Level TMDL Calculations

The TMDLs for the impaired AUs were developed as pollutant load allocations based on information from the LDC developed for TCEQ SWQM Station 18668 and for the modified LDC developed for SWQM Station 11422 (Figures 7 and 8). The bacteria LDC was developed by multiplying the streamflow value along the FDC by the primary contact recreation 1 use geometric mean criterion for *E. coli* and Enterococci (126 cfu/100 mL or 35 cfu/100 mL) and by the conversion factor to convert to loading in cfu per day. This effectively displays the LDC as the TMDL curve of maximum allowable loading:

TMDL (billion cfu/day) = Criterion * Flow * Conversion Factor

Where:

Criterion = 126 cfu/100 mL *E. coli* or 35 cfu/100 mL Enterococci

Flow = 5% exceedance flow from FDC in cubic feet per second (cfs)

Conversion Factor (to billion cfu/day) = 28,316.8 mL/cubic foot (ft^3) * 86,400 seconds/day (s/d) ÷ 1,000,000,000

Table 14 shows the TMDL values at the 5% load duration exceedance.

Table 14. Summary of allowable loadings

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

Margin of Safety Formula

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

$$MOS = 0.05 * TMDL$$

Where:

TMDL = total maximum daily load

The MOS calculations for each AU are shown in Table 15.

Table 15. MOS calculations

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

All loads are expressed in billion cfu/day.

Wasteload Allocations

The WLA is the sum of loads from regulated sources. 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}).

$$WLA = WLA_{WWTF} + WLA_{SW}$$

Wastewater Treatment Facilities

The daily allowable loading of *E. coli* or Enterococci assigned to WLA_{WWTF} was determined to be zero in the TMDL Project watershed because there are no WWTFs in the watershed; therefore, there are no regulated flows from any WWTFs.

Regulated Stormwater

Stormwater discharges from MS4s, industrial facilities, concrete production and construction activities are considered regulated point sources. Therefore, the WLA calculations must also include an allocation for regulated stormwater discharges (WLA_{SW}). A simplified approach for estimating the WLA_{SW} for these areas was used in the development of these TMDLs due to the limited amount of data available, the complexities associated with simulating rainfall runoff, and the variability of stormwater loading.

The percentage of the land area in the TMDL Project watershed that is under the jurisdiction of stormwater permits (i.e., defined as the area designated as UA in the 2010 United States Census) was used to estimate the amount of the overall runoff load that should be allocated as the regulated stormwater contribution in the WLA_{SW} component of the TMDL (Figure 5). The LA component of the TMDL corresponds to direct nonpoint source runoff and is the difference between the total load from stormwater runoff and the portion allocated to WLA_{SW}.

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

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

Where:

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 FDA_{SWP} must be calculated to arrive at the fractional proportion of the drainage area under jurisdiction of stormwater permits. FDA_{SWP} was calculated by first totaling the area of each stormwater permit and authorization. The stormwater sources and area estimates were discussed in the "TPDES Regulated Stormwater" section. Those area estimates were determined for each category and summed up to determine the total area under stormwater jurisdiction in each AU watershed. To arrive at the proportion, the area under stormwater jurisdiction was then divided by the total watershed area. The estimated areas in Table 16 are cumulative, each AU accounts for the upstream area contribution by adding the total area of regulated stormwater for the AU and that of the upstream AU and then dividing by the watershed area.

Table 16. Regulated stormwater FDA_{SWP} calculations

AU	MS4 Area	MSGP Area	CGP Area	Concrete Production Facilities Area	Total Area of Permits	Watershed Area	FDA_{SWP}
2432B_01	628.704	–	35.197	8.480	672.381	7,001.050	0.096
2432C_01	5,183.039	10.010	47.097	–	5,240.146	37,143.231	0.141

All areas are expressed in acres

A value for FG is necessary to complete the WLA_{SW}. The calculation for FG is presented in the later section "Allowance for Future Growth," but the results will be included here for continuity. The WLA_{SW} calculations are presented in Table 17.

Table 17. Regulated stormwater load calculations

AU	Indicator Bacteria	TMDL	WLA_{WWTF}	FG	MOS	FDA_{SWP}	WLA_{SW}
2432B_01	*E. coli*	87.718	0.00	0.448	4.386	0.096	7.960
2432C_01	Enterococci	193.106	0.00	1.037	9.655	0.141	25.735

All loads are expressed in billion cfu/day. With the WLA_{SW} and WLA_{WWTF} terms, the total WLA term can be determined by adding the two parts (Table 18).

Table 18. WLA calculations

AU	WLA_{WWTF}	WLA_{SW}	WLA
2432B_01	0.00	7.960	7.960
2432C_01	0.00	25.735	25.735

In areas currently regulated by an MS4 permit, development, re-development, or both, of land must include the implementation of the control measures/programs outlined in an MS4's approved SWMP. Although additional flow may occur from development or redevelopment, loading of the pollutant of concern should be controlled or reduced through the implementation of BMPs as specified in both the TPDES permit and the approved SWMP.

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

Implementation of Wasteload Allocations

The TMDLs in this document will result in protection of existing uses and conform to Texas' antidegradation policy. The three-tiered antidegradation policy in the Texas Surface Water Quality Standards prohibits an increase in loading that would cause or contribute to degradation of an existing use. The antidegradation policy applies to point source pollutant discharges. In general, antidegradation procedures establish a process for reviewing individual proposed actions to determine if the activity will degrade water quality.

As there are no regulated sources discharging into the TMDL Project watershed at this time, TCEQ will plan to implement individual WLAs for any future sources through the permitting process as monitoring requirements, effluent limitations, or both as required by the amendment of Title 30, TAC Chapter 319, which became effective Nov. 26, 2009. Any future WWTFs discharging to the TMDL segments will be assigned an effluent limit based on the TMDL. Monitoring requirements will be based on permitted flow rates and are listed in 30 TAC Section 319.9.

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

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

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

The Nov. 26, 2014 memorandum from EPA (EPA, 2014) relating to establishing WLAs for stormwater sources states:

> Incorporating greater specificity and clarity echoes the approach first advanced by EPA in the 1996 Interim Permitting Policy, which anticipated that where necessary to address water quality

concerns, permits would be modified in subsequent terms to include "more specific conditions or limitations [which] may include an integrated suite of BMPs, performance objectives, narrative standards, monitoring triggers, numeric WQBELs, action levels, etc."

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

Updates to Wasteload Allocations

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

Load Allocation

The LA is the sum of loads from unregulated sources, and is calculated as:

$$LA = TMDL - WLA - FG - MOS$$

Where:

TMDL = total maximum daily load

WLA_{WWTF} = sum of all WWTF loads

WLA_{SW} = sum of all regulated stormwater loads

FG = sum of future growth loads from potential regulated facilities

MOS = margin of safety load

Table 19 summarizes the LA.

Table 19. LA calculations

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

All loads are expressed as billion cfu/day.

Allowance for 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 these TMDLs, the conventional FG calculation is not applicable since 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, TAC, Chapter 217, Subchapter B, Section 217.32 [30 TAC 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 3, the population in the Halls Bayou Tidal subwatershed is expected to grow by approximately 7,824 people between 2020 and 2050. Multiplying that figure by the higher daily wastewater flow capacity (100 gpcd), yields a value of 0.7824 million gallons per day (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 3). 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 previously completed TMDLs, no MOS was included in the computation of FG. Thus, the FG is calculated as:

$$FG = WWTF_{FG} * \text{Conversion Factor} * \text{Target}$$

Where:

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

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

Target = 126 cfu/100 mL *E. coli* or 35 cfu/100 mL Enterococci

Table 20 provides the FG for both subwatersheds.

Table 20. 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

Compliance with these TMDLs is based on keeping the bacteria concentrations in the selected waters below the limits that were set as criteria for the individual sites. FGs of existing or new point sources are not limited by these TMDLs if the sources do not cause bacteria to exceed the limits. The assimilative capacity of water bodies increases as the amount of flow increases; consequently, increases in flow allow for increased loadings. The LDC and tables in this TMDL report will guide determination of the assimilative capacity of the water body under changing conditions, including FG.

Summary of TMDL Calculations

The TMDLs were calculated based on the median flow in the 0–10 percentile range (5% exceedance, high flow regime) for flow exceedance based on the LDCs developed at TCEQ SWQM stations 18668 and 11422.

Allocations are based on the current geometric mean criterion for *E. coli* or Enterococci of 126 cfu/100 mL or 35 cfu/100 mL for each component of the TMDLs. The TMDL allocation summaries for Willow Bayou and Halls Bayou Tidal are summarized in Table 21.

Table 21. TMDL allocations

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

All loads are expressed in billion cfu/day.

The final TMDL allocation (Table 22) needed to comply with the requirements of 40 CFR 130.7 include the FG component within the $WLA_{WWTF.}$

Table 22. Final TMDL load allocation

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

All loads are expressed in billion cfu/day.

Seasonal Variation

Federal regulations require that TMDLs account for seasonal variation in watershed conditions and pollutant loading [40 CFR Section 130.7(c)(1)].

Analysis of the seasonal differences in indicator bacteria concentrations were assessed by comparing *E. coli* concentrations obtained from 14 years (2007-2021) and Enterococci concentrations obtained from 17 years (2004-2021) of routine monitoring data collected in the warmer months (May through September) against those collected during the cooler months (November through March). The months of April and October were considered transitional between warm and cool seasons and were excluded from the seasonal analysis.

Differences in fecal bacteria concentrations obtained in warmer versus cooler months were then evaluated by performing a Wilcoxon Rank Sum test (also known as the "Mann-Whitney" test). This analysis of fecal bacteria data indicated that there was no significant difference ($\alpha=0.05$) in indicator bacteria between cool and warm weather seasons for the TMDL Project watershed ($p=0.271$). Seasonal variation was also addressed by using all available flow and *E. coli* or Enterococci records (covering all seasons) from the period of record used in LDC development for this project.

Public Participation

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

TCEQ and H-GAC are jointly coordinating public participation in development of both the TMDLs and implementation plan (I-Plan). The TMDLs for Halls Bayou Tidal and Willow Bayou are part of the ongoing projects in Basin 11. For Basin 11, a variety of stakeholder engagement methods were employed to generate and maintain stakeholder interest. Direct e-mail, letters, and phone calls were made with identified stakeholders to provide information and encourage participation in future meetings.

Press releases and general e-mails were created by H-GAC to cast a broad net using listservs and news outlets. Project webpages and informational brochures were developed to provide information, meeting notifications, and project updates. Stakeholders that could potentially be impacted by the TMDLs and their I-Plan were contacted, and one-on-one meetings were held with some to foster interest, build support, and generate trust.

Notices of meetings were posted on the project webpages for both TCEQ and H-GAC. At least two weeks prior to scheduled meetings, H-GAC issued media releases and formally invited stakeholders to attend. To ensure that absent or new stakeholders could get information about past meetings and pertinent material, the H-GAC project webpage[1] provided meeting summaries, presentations, ground rules, and documents produced for stakeholder review.

Five public meetings and three presentations were held, on Dec. 6, 2016; Aug. 10, Nov. 11, and Nov. 14, 2017; Nov. 18 and Jan. 10, 2018; Jan. 30, 2020; and May 11, 2022. Most meetings were held at the Brazoria County Public Library in Alvin, TX. The first public meeting was used to:

- introduce the TCEQ's basin approach to improving water quality,
- review that status of water quality impairments in Basin 11,
- discuss potential watershed management tools to improve water quality, and
- highlight water bodies, e.g., Chocolate Bayou, to employ watershed management tools.

Stakeholders expressed an interest in pursuing a watershed stakeholder process and drafting an I-Plan. Public outreach shifted to the creation of the Chocolate Bay Coordination Committee and drafting elements of the Chocolate Bay Bacteria I-Plan, a regional plan which will include Halls Bayou Tidal and Willow Bayou.

Implementation and Reasonable Assurance

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

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

Because the TMDL does not reflect or direct specific implementation by any single pollutant discharger, the TCEQ certifies additional elements to the WQMP after the I-Plan is approved by the commission. Based on the TMDL and I-Plan, TCEQ will propose and certify WQMP updates to establish required water-quality-based effluent limitations necessary for specific TPDES wastewater discharge permits.

For MS4 entities, where numeric effluent limitations are infeasible, the permits require that the MS4 develop and implement BMPs under each MCM, which are a substitute for effluent limitations, as allowed by federal rules. How a regulated MS4 meets each MCM is not prescribed in detail in the MS4 permits but is included in the permittee's SWMP. During the permit renewal process, TCEQ revises its MS4 permits as needed to require

[1] www.h-gac.com/watershed-based-plans/san-jacinto-brazos-coastal-basin-tmdl-and-implementation-plan

the implementation of other specific revisions in accordance with an approved TMDL and I-Plan.

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

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

Key Elements of an I-Plan

An I-Plan includes a detailed description and schedule of the regulatory and voluntary management measures to implement the WLAs and LAs of particular TMDLs within a reasonable time. I-Plans also identify the organizations responsible for carrying out management measures, and a plan for periodic evaluation of progress.

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

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

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

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

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Appendix A.
Population and Population Projections

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

1. Obtained 2020 American Community Survey data from the USCB at the block level.
2. Used U.S. Census block data to develop population estimates for a hexagonal grid of three-square miles each (H3M) for the H-GAC region.
3. Determined the 2020 population for H3Ms that do not lie entirely in the watershed by multiplying the H3M population by the portion of the H3M located within the watershed assuming equal distribution.
4. Obtained population projections for the year 2050 from the H-GAC regional forecast based on H3M data.
5. Determined the 2050 population projections for H3Ms that do not lie entirely in the watershed by multiplying the H3M population by the portion of the H3M located within the watershed assuming equal distribution.
6. Subtracted the 2020 watershed population 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.