Technical Support Document for Two Total Maximum Daily Loads for Indicator Bacteria in Chocolate Bayou

Assessment Units: 1107_01 and 1108_01

Chocolate Bayou at Camp Mohawk County Park near Hwy. 35

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Abbreviations

AA	authorized agent
AU	assessment unit
AVMA	American Veterinary Medical Association
CFR	Code of Federal Regulations
cfs	cubic feet per second
cfu	colony forming unit
DAR	drainage-area ratio
DMR	discharge monitoring report
DMU	deer management unit
E. coli	*Escherichia coli*
EPA	(United States) Environmental Protection Agency
FIB	fecal indicator bacteria
FDC	flow duration curve
FG	future growth
GCWA	Gulf Coast Water Authority
H-GAC	Houston-Galveston Area Council
LA	load allocation
LDC	load duration curve
MCM	Minimum control measures
MGD	million gallons per day
mL	milliliter
MOS	margin of safety
MS4	municipal separate storm sewer system
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
ODEQ	Oregon Department of Environmental Quality
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
TPWD	Texas Parks and Wildlife Department
USCB	United States Census Bureau
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WLA	wasteload allocation
WLA_{SW}	wasteload allocation from regulated stormwater
WLA_{WWTF}	wasteload allocation from wastewater treatment facilities
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 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.

TCEQ first identified bacteria impairment within the tidal portion, assessment unit (AU) 1107_01, of Chocolate Bayou in the 2010 *Texas Integrated Report of Surface Water Quality for the Clean Water Act Sections 305(b) and 303(d)* (Texas Integrated Report, TCEQ, 2011). The impairment for Chocolate Bayou Above Tidal, AU 1108_01, was later determined in the 2014 Texas Integrated Report (TCEQ, 2015). The bacteria impairments have been identified in each subsequent edition through the EPA-approved 2022 Texas Integrated Report (TCEQ, 2022a).

This document will consider two bacteria impairments in two AUs of Chocolate Bayou. The impaired AUs and their identifying numbers are:

- Chocolate Bayou Tidal – AU 1107_01,
- Chocolate Bayou Above Tidal – AU 1108_01

1.2. Water Quality Standards

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

The Standards are rules that do all of the following:

- 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 (FIB) are used to assess the risk of illness during contact recreation (e.g., swimming) from ingestion of water. FIB 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, aquatic birds, wildlife, and failing septic systems (TCEQ, 2018b). The FIB used for fresh and tidal water bodies are *Escherichia coli* (*E. coli*) and Enterococci, respectively.

On February 7, 2018, TCEQ adopted revisions to the *Texas Surface Water Quality Standards* (TCEQ, 2018a) and on May 19, 2020, the United States Environmental Protection Agency (EPA) approved the categorical levels of recreational use and their associated criteria. Recreational use in freshwater consists of five categories:

- **Primary contact recreation 1** – Activities that are presumed to involve a significant risk of ingestion of water (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 ingestion of water 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. The geometric mean criterion for *E. coli* is 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 ingestion of water (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 (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.

Chocolate Bayou is a water body designated for primary contact recreation 1 use. The associated standards for FIB are an *E. coli* geometric mean of 126 cfu per 100 mL for AU 1108_01, the freshwater portion, and an Enterococci geometric mean of 35 cfu per 100 mL in 1107_01, the tidal portion.

1.3. Report Purpose and Organization

The Chocolate Bayou 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 AUs. This report contains:

- Information on historical data.
- Watershed properties and characteristics.
- Summary of historical bacteria data that confirm the State of Texas 303(d) listings of impairment due to concentrations of indicator bacteria (*E. coli* and Enterococci).
- Development of load duration curves (LDCs).
- Application of the LDC approach for developing the pollutant load allocation.

Section 2. Historical Data Review and Watershed Properties

2.1. Description of Study Area

The Chocolate Bayou watershed lies in southeast Texas within the Houston-The Woodlands-Sugarland Metropolitan Statistical Area. Chocolate Bayou originates in central Brazoria County, with a major tributary beginning in southeast Fort Bend County and travels southeastward in eastern Brazoria County before emptying into Chocolate Bay, an embayment of West Galveston Bay. West Galveston Bay is part of Galveston Bay separated from the Gulf of Mexico by a barrier island, Galveston Island. West Galveston Bay is connected to the Gulf of Mexico by Bolivar Roads to the east, between the City of Galveston and the unincorporated community of Port Bolivar on Bolivar Peninsula, and San Luis Pass to the west, a pass between Galveston Island and Follet's Island.

The Chocolate Bayou watershed is 173.2 square miles and comprises two segments, Tidal (1107) and Above Tidal (1108) (Figure 1). Each segment is comprised of a single AU. The tidal AU (1107_01) begins approximately 1.5 miles northeast of the City of Liverpool at a saltwater barrier in Brazoria County and traverses 16 miles southeastward to the mouth of Chocolate Bay. The tidal AU has a watershed area of 35.5 square miles and tributaries include Corner, Cottonwood, Perry, Pleasant, and Salt Bayous. The unincorporated communities of Amsterdam, Chocolate Bayou, Chocolate Bayou Springs, and Peterson Landing can also be found in the AU watershed (Damon, 2010).

The above tidal AU (1108_01) begins approximately 1.4 miles west of the City of Manvel in Brazoria County. The headwaters of the West Fork of Chocolate Bayou, a large tributary to Chocolate Bayou, begins near the City of Arcola in extreme southeast Fort Bend County before joining Chocolate Bayou in Brazoria County approximately 2.5 miles south of FM 1128, south of Manvel (Snowden, 1989). Hayes Creek is also a tributary to Chocolate Bayou. AU 1108_01 is 22 miles in length prior to terminating at the tidal segment boundary. Most of AU 1108's 137.7 square mile watershed is contained in Brazoria County and includes parts of the cities of Arcola (Fort Bend County), Manvel, Alvin, and the Village of Iowa Colony.

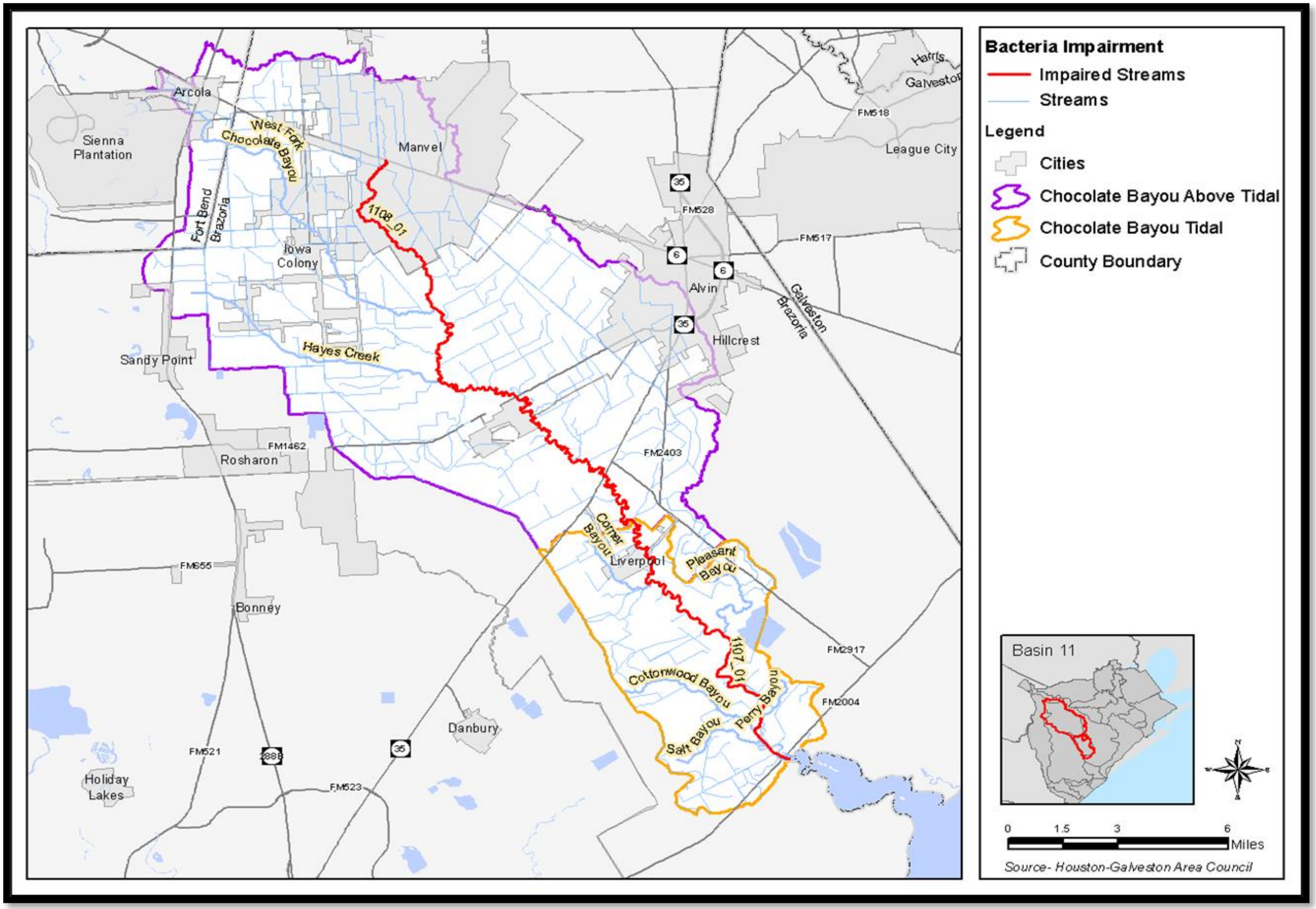


Figure 1. Map of the Chocolate Bayou watershed

The 2022 Texas Integrated Report (TCEQ, 2022a) has the following water body and AU descriptions:

- Segment 1107 Chocolate Bayou Tidal – from the confluence with Chocolate Bay 1.4 kilometer (0.9 miles) downstream of Farm to Market Road 2004 in Brazoria County to the saltwater barrier (immediately downstream of the Chocolate Bayou Rice Canal) 5.2 kilometer (3.2 miles) downstream of State Highway 35 in Brazoria County; and
    - AU 1107_01 – from the confluence with Chocolate Bay 1.4 kilometer (0.9 miles) downstream of Farm to Market Road 2004 in Brazoria County to the saltwater barrier (immediately downstream of the Chocolate Bayou Rice Canal) 5.2 kilometer (3.2 miles) downstream of State Highway 35 in Brazoria County.
- Segment 1108 Chocolate Bayou Above Tidal – from the saltwater barrier (immediately downstream of the Chocolate Bayou Rice Canal) 5.2 kilometer (3.2 miles) downstream of State Highway 35 in Brazoria County to State Highway 6 in Brazoria County.
    - AU 1108_01 – from the saltwater barrier (immediately downstream of the Chocolate Bayou Rice Canal) 5.2 kilometer (3.2 miles) downstream of State Highway 35 in Brazoria County to State Highway 6 in Brazoria County.

2.2. Review of Routine Monitoring Data for TMDL Watershed

2.2.1. Analysis of Bacteria Data

Chocolate Bayou Tidal (AU 1107_01) was first identified as impaired in the 2010 Texas Integrated Report for recreation use due to high levels of bacteria. Chocolate Bayou Above Tidal (AU 1108_01) was first identified as impaired in the 2014 Texas Integrated Report for recreation use due to high levels of bacteria.

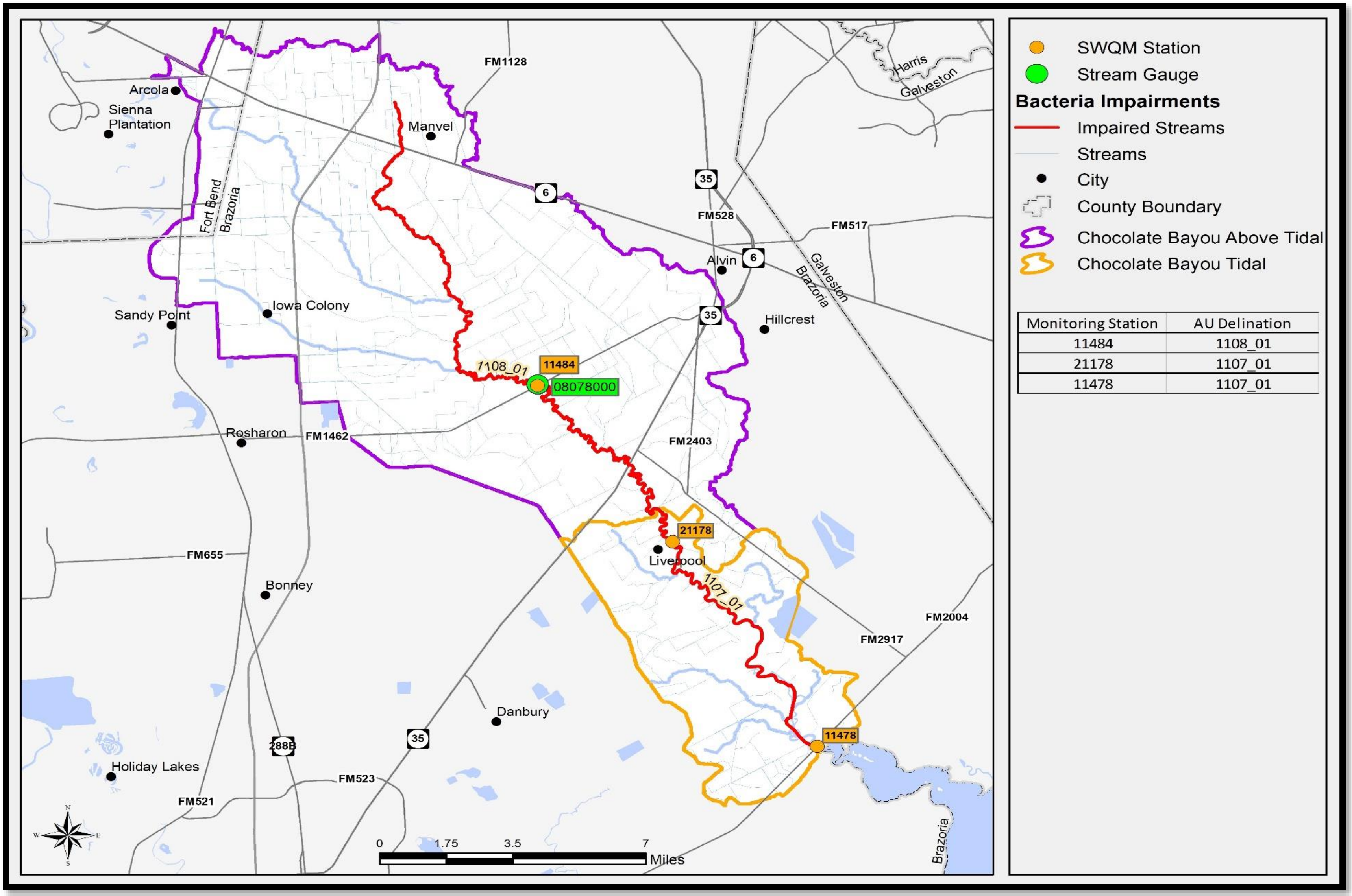
A summary of impairments and concerns identified in the 2022 Texas Integrated Report, the most recent TCEQ– and EPA–approved edition at the time of this report, are shown in Table 1. This document will investigate the potential sources of fecal waste contributing to elevated bacteria levels in Chocolate Bayou to support the development of strategies to reduce the impairment enough to support recreation use.

Table 1. 2022 Texas Integrated Report summary

Segment Number	AU	Parameter	Station	No. of Samples	Data Date Range	Station Geometric Mean (cfu/100 mL)	Status
1107	1107_01	Enterococci	21178/ 11478	66	12/01/2013–11/30/2020	64.58	NS
1108	1108_01	*E. coli*	11484	23	12/01/2013–11/30/2020	212.23	NS

The ambient *E. coli* and Enterococci data included in the remainder of this report were obtained from TCEQ's Surface Water Quality Monitoring Information System (SWQMIS) between 2004 and 2018. The 2022 Texas Integrated Report was approved after the calculations in this report were completed. The data represented the routine FIB and other water quality data collected for the project area by TCEQ and TCEQ's Clean Rivers Program.

The data are collected at three TCEQ surface water quality monitoring (SWQM) stations (Figure 2), one in AU 1108_01 (TCEQ SWQM Station 11484), and two in AU 1107_01 (TCEQ SWQM stations 21178 and 11478). TCEQ SWQM Station 11484 is located southwest of the City of Alvin on FM 1462 at Chocolate Bayou. TCEQ SWQM Station 21178 is near the town of Liverpool on CR 171. TCEQ SWQM Station 11478 is at FM 2004 at the lower boundary of AU 1107_01 near Chocolate Bay. The United States Geological Survey (USGS) also maintains a flow gauge in AU 1108_01, USGS station 08078000, located at the same location as TCEQ SWQM Station 11484.



Monitoring Station	AU Delination
11484	1108_01
21178	1107_01
11478	1107_01

Figure 2. Active SWQM and USGS monitoring stations

2.3. Climate and Hydrology

Average precipitation recorded between 2000 and 2021 is just over 50 inches per year (Table 2, NOAA, 2022). The highest average monthly precipitation comes in September, while the lowest average monthly precipitation happens in February (Figure 3). Average monthly precipitation ranges from just above two inches to slightly over eight inches. Average monthly air temperature ranges from slightly below 50 ºF in the winter to slightly above 90 ºF in the summer months (NOAA, 2022).

Table 2. Average annual rainfall recorded at a gauge near the Chocolate Bayou watershed

STATION	STATION NAME	LATITUDE	LONGITUDE	Average Annual Rainfall (inches)
GHCND: USC00413340	FREEPORT 2 NW TX US	28.9845	-95.3809	50.09

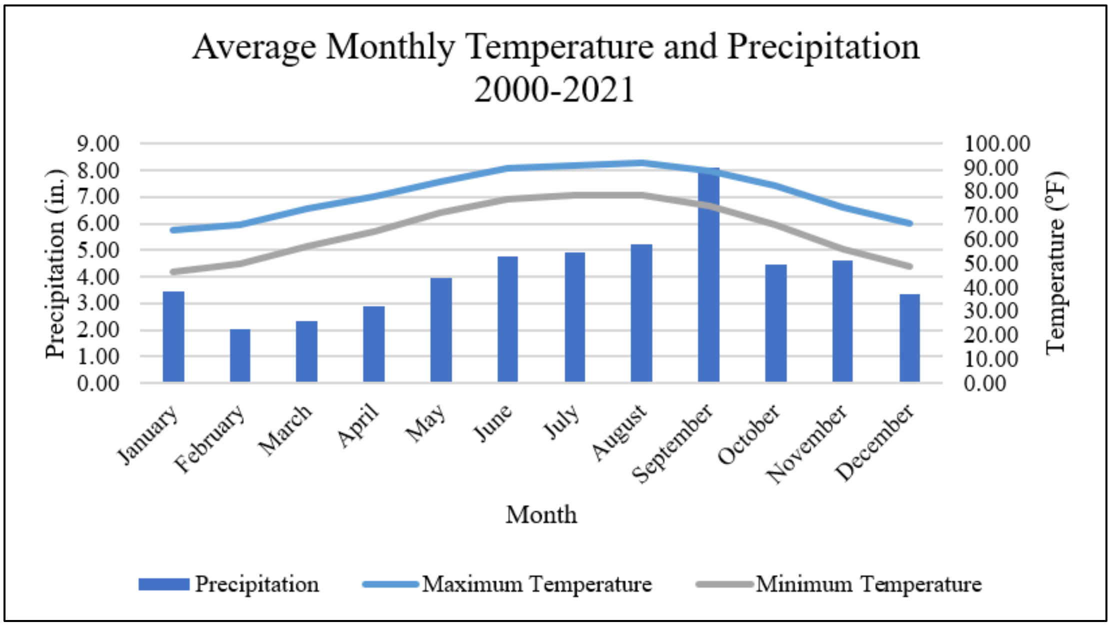


Figure 3. Average monthly precipitation and temperature

Topographical relief is minimal in the Chocolate Bayou watershed, consistent with the flat Texas Gulf Coast Plain. Elevation ranges from just over 50 feet above sea level in Fort Bend County near the City of Arcola to sea level at the shores of Chocolate Bay. The bayou and its tributaries are generally sluggish due to the gentle 0.04% sloping relief (Snowden, 1989) found on the coastal plain.

Riparian vegetation is still common along portions of the bayou. Instream channel modifications, the construction of supplemental drainage canals like ditch C-1 near Manvel, and Gulf Coast Water Authority (GCWA) irrigation and supply canals have altered natural hydrology in the study area (Snowden, 1989). Primary mineral resources within the region include oil and gas fields, sand, and gravel (Damon, 2010).

2.4. Population and Population Projections

H-GAC, through its Regional Growth Forecast (H-GAC, 2018a), routinely assesses the region's population and develops population projections. H-GAC uses the United States Census decadal survey or in the intervening years, the United States Census American Survey, to estimate populations of census block groups. The United States Census decadal survey was available for 2020 and was used to estimate the initial population. Regional Growth Forecast methodology (H-GAC, 2017) was used to estimate regional population and household growth out to the year 2045 as described in Appendix A (H-GAC, 2018a).

The Chocolate Bayou Above Tidal (AU 1108_01) watershed contained a population of 31,642 in 2020 (Table 3, USCB, 2021). That amounts to over 14 times the population of the tidal watershed (AU 1107_01), which had a population of 2,125 in 2020. The population within the two AU watersheds is projected to diverge more in the future. Growth in population for the AU 1108_01 watershed is estimated to reach 205,151 in 2045, a 548% increase. The population in AU 1107_01 is anticipated to decline by 42% or to 1,228 by 2045 (H-GAC, 2018a).

Table 3. Population changes in the Chocolate Bayou watershed

AU	2020	2045	Change
1107_01	2,125	1,228	-42.21%
1108_01	31,642	205,151	548.35%

Most of the population growth in Chocolate Bayou Above Tidal is anticipated to take place along Hwy 6 and Hwy 288 in the cities of Alvin, Manvel, and Arcola, and in the village of Iowa Colony and unincorporated portions of Brazoria and Fort Bend counties.

2.5. Land Cover

As with many urban centers nationwide, areas surrounding the City of Houston have experienced an increase in development associated with urban sprawl, especially along transportation corridors. Due to its proximity to Houston and State Highway 288 corridor, the Chocolate Bayou watershed has shown evidence of this trend and is expected to continue to expand development.

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:

- **High Intensity Development** – Contains significant land area that is covered by concrete, asphalt, and other constructed materials. Vegetation, if present, occupies < 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.

- **Medium Intensity Development** – 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.

- **Low Intensity Development** – 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.

- **Open Space Development** – 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.

- **Cultivated Crops** – 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.

- **Pasture/Grasslands** – 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.

- **Barren Lands** – 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.

- **Forest/Shrubs** – 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.

- **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%.

- **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.

Chocolate Bayou watershed land cover analysis is presented in Table 4 and Figure 4. The Chocolate Bayou watershed covers 110,829.65 acres. Cultivated Crops and Pasture/Grasslands cover types are the largest two in the AU 1107_01 watershed, at 16.55% and 47.97%, respectively. Pasture/Grasslands is the largest type (42.36%) in the AU 1108_01 watershed, followed by Wetlands (15.23%). Agriculture is the most abundant land use in the Chocolate Bayou watershed at 58.09%, reflected when combining Cultivated Crops (14.58%) and Pasture/Grasslands (43.51%).

Low Intensity Development is the largest developed land cover type in the watersheds of both AUs, at 7.24% for 1107_01 and 13.02% for 1108_01. High Intensity Development makes up a larger percentage, 3.19%, of AU 1107_01's watershed, when compared to 1.48% in AU 1108_01's watershed. This is due to the heavy industry near FM 2004 near the terminus of AU 1107_01 at Chocolate Bay. The larger percentage of Medium Intensity (6.82%) and Low Intensity development (13.02%) in AU 1108_01's watershed compared to AU 1107_01's watershed, is reflective of the larger population in AU 1108_01 and consistent with mostly residential uses.

Table 4. Land cover classification percentages

Land Cover Type	1107_01 (Acres)	1107_01 (%Acres)	1108_01 (Acres)	1108_01 (%Acres)	Total (Acres)	Total (%Acres)
Open Water	460.02	2.02	370.94	0.42	830.96	0.75
High Intensity Development	725.09	3.19	1,300.23	1.48	2,025.32	1.83
Medium Intensity Development	660.58	2.91	6,011.76	6.82	6,672.34	6.02
Low Intensity Development	1,645.28	7.24	11,466.73	13.02	13,112.01	11.83
Open Space Development	120.62	0.53	1,019.81	1.16	1,140.43	1.03
Barren Lands	218.91	0.96	538.65	0.61	757.56	0.68
Forest/Shrubs	1,329.39	5.85	4,261.69	4.84	5,591.08	5.04
Pasture/Grasslands	10,905.08	47.97	37,314.70	42.36	48,219.77	43.51
Cultivated Crops	3,763.07	16.55	12,392.38	14.07	16,155.45	14.58
Wetlands	2,903.06	12.77	13,421.68	15.23	16,324.74	14.73
Total	**22,731.08**	**100**	**88,098.57**	**100**	**110,829.65**	**100**

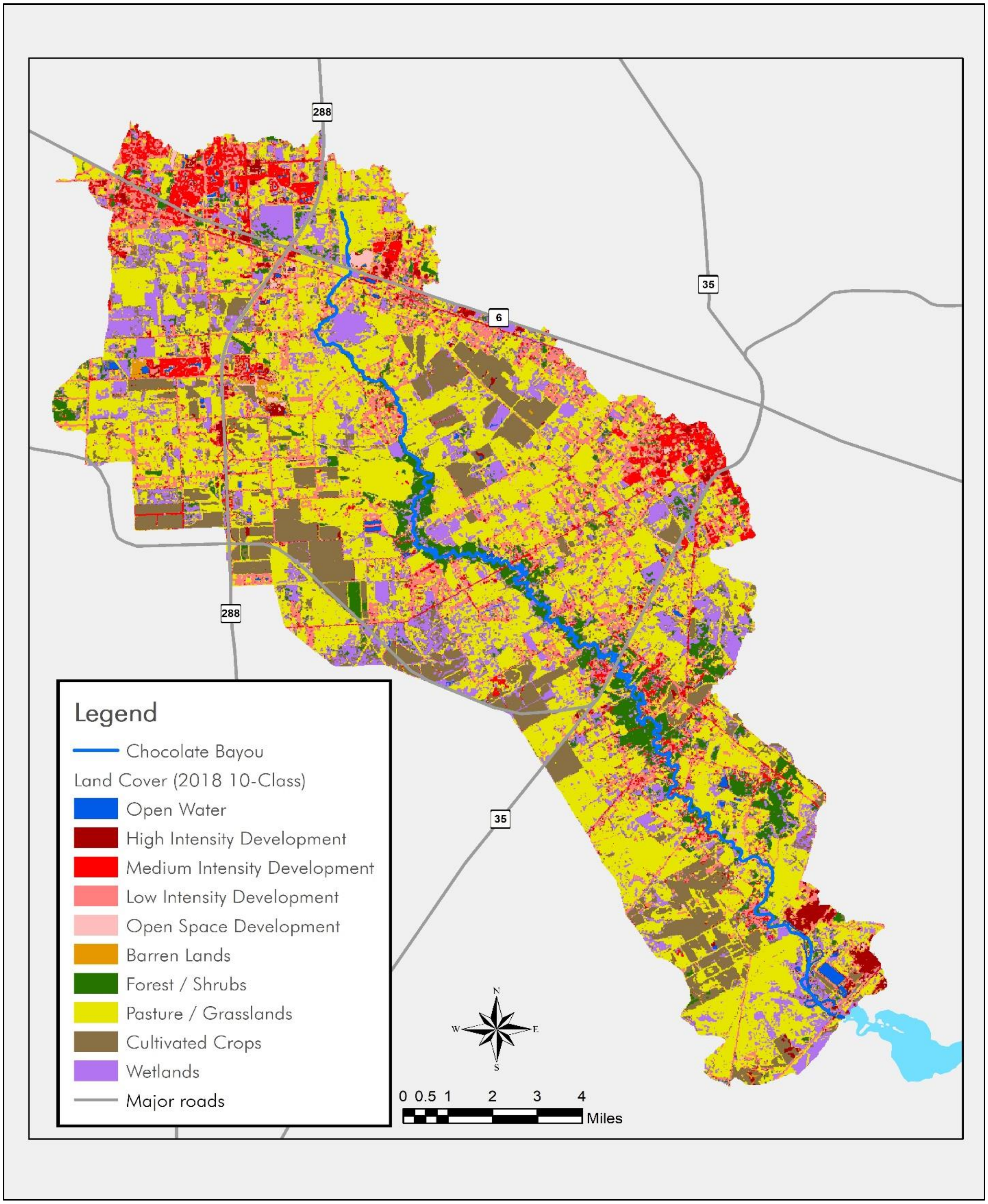


Figure 4. Land cover map of land use classifications

2.6. Soils

Soils within the Chocolate Bayou watershed are characterized by hydrologic groups that describe infiltration and runoff potential. These 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.

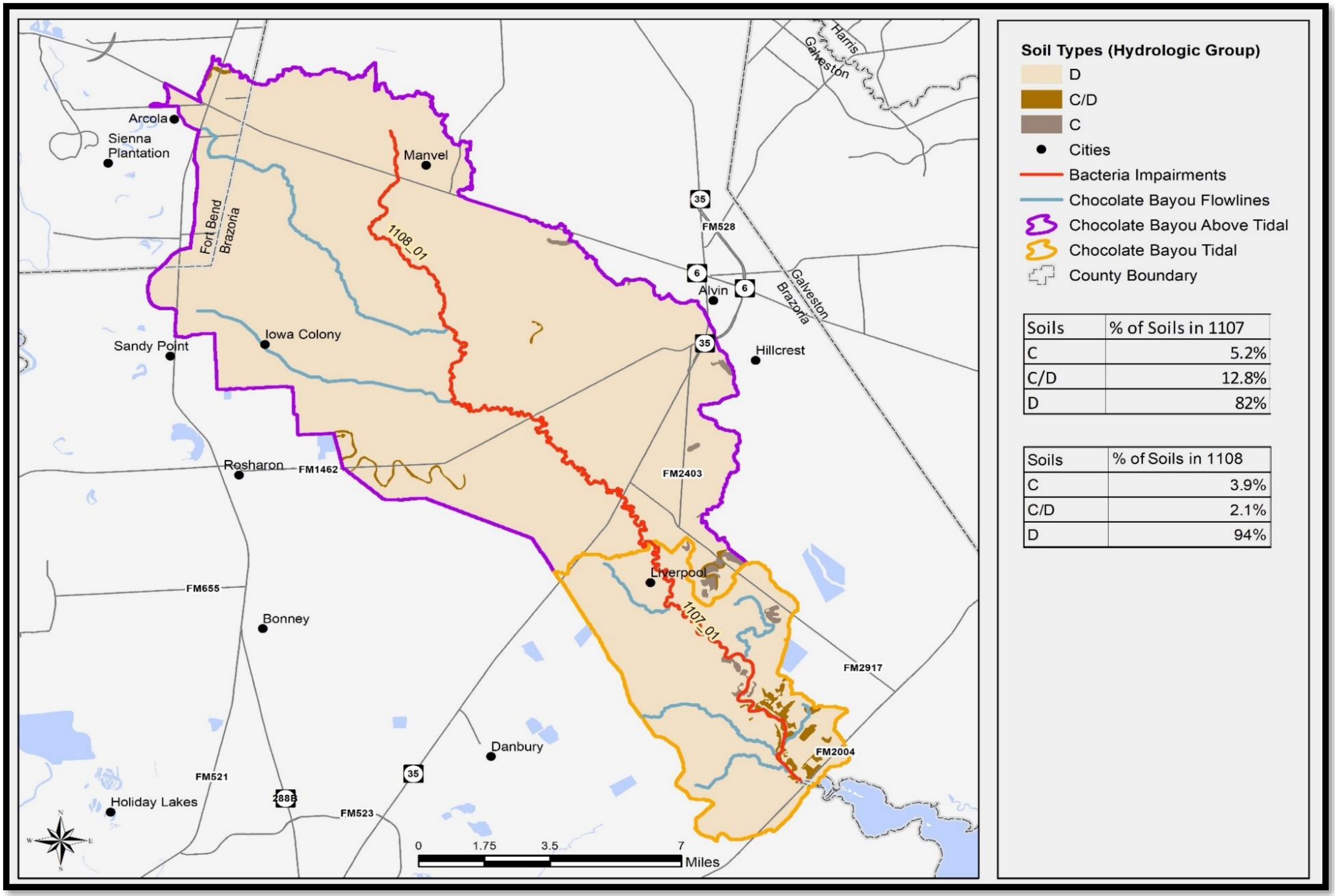
- Group D – Soils having a very slow infiltration rate (high runoff potential) when thoroughly wet. These consist chiefly of clays that have a high shrink-swell potential, soils that have a high-water table, soils that have a claypan or clay layer at or near the surface, and soils that are shallow over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

Soils in the Chocolate Bay watershed are made up of clays with a very slow infiltration rates in the Group D hydrologic group, 91.54%, with smaller percentages in the Group C/D and Group C at 4.29% and 4.17%, respectively (Table 5, Figure 5).

Table 5. Hydrologic soil group classifications

Hydrologic Group	**1107_01**		**1108_01**		**Total**	
Type	Area (acres)	Percentage	Area (acres)	Percentage	Area (acres)	Percentage
C	1,182.02	5.20%	3,435.84	3.90%	4,617.86	4.17%
C/D	2,909.58	12.80%	1,850.07	2.10%	4,759.65	4.29%
D	18,639.49	82.00%	82,812.65	94.00%	101,452.14	91.54%
Total	22,731.08	100.00%	88,098.57	100.00%	110,829.65	100.00%



Soils	% of Soils in 1107
C	5.2%
C/D	12.8%
D	82%

Soils	% of Soils in 1108
C	3.9%
C/D	2.1%
D	94%

Figure 5. Soil hydrologic groups

2.7. Potential Sources of Fecal Indicator Bacteria

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

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

Except for WWTFs, which receive individual wasteload allocations (WLAs) (see the "WLA" section), the regulated and unregulated sources in this section are presented to give a general account of the various 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

As of June 2020, there are 28 WWTFs with permits that discharge into the Chocolate Bayou watershed (Table 6, Figure 6) (TCEQ, 2022b). There are five industrial wastewater permits and 23 domestic wastewater permits.

Three of the industrial permits, WQ0000001000, WQ0001333000, and WQ0003116000 include a bacteria effluent limit contributed through an internal outfall (101). The internal outfalls for WQ0001333000, and WQ0003116000 are permitted as intermittent and variable. These outfalls are not included in the TMDL calculation. The remaining two industrial facilities, WQ0003903000 and WQ0002068000 lack a bacteria effluent limit and will also not be included in the WWTF wasteload allocation of the TMDL. All industrial facilities include an authorized stormwater component which will be discussed under the multi-sector general permits in the TPDES-Regulated Stormwater section, 2.7.1.3.

Table 6. Permitted domestic and industrial WWTFs

AU	TPDES Permit No./NPDES[a] No.	Outfall No.	Facility Name	Permittee Name	Facility Type/ Effluent Type	Average Discharge (MGD[b])	Permitted Discharge (MGD)
1107_01	WQ0000001000 / TX0003875	001	Ascend Performance Materials Chocolate Bayou Plant	Ascend Performance Materials Texas Inc.	Industrial/PME, IW, SW	3.312	7.8
1107_01	WQ0000001000 / TX0003875	101	Ascend Performance Materials Chocolate Bayou Plant	Ascend Performance Materials Texas Inc.	Industrial/WW	**	4
1107_01	WQ0000001000 / TX0003875	002	Ascend Performance Materials Chocolate Bayou Plant	Ascend Performance Materials Texas Inc.	Industrial/SW	N/A	N/A
1107_01	WQ0000001000 / TX0003875	003	Ascend Performance Materials Chocolate Bayou Plant	Ascend Performance Materials Texas Inc.	Industrial/SW	N/A	N/A
1107_01	WQ0001333000 / TX0004821	001	Chocolate Bayou Facility	INEOS USA LLC	Industrial/IW, PME, SW	1.88	8
1107_01	WQ0001333000 / TX0004821	101	Chocolate Bayou Facility	INEOS USA LLC	Industrial/WW	N/A	*
1107_01	WQ0001333000 / TX0004821	002	Chocolate Bayou Facility	INEOS USA LLC	Industrial/IW, SW	N/A	N/A
1107_01	WQ0001333000 / TX0004821	003	Chocolate Bayou Facility	INEOS USA LLC	Industrial/SW	N/A	N/A

AU	TPDES Permit No./NPDES[a] No.	Outfall No.	Facility Name	Permittee Name	Facility Type/ Effluent Type	Average Discharge (MGD[b])	Permitted Discharge (MGD)
1107_01	WQ0001333000 / TX0004821	004	Chocolate Bayou Facility	INEOS USA LLC	Industrial/SW	N/A	N/A
1107_01	WQ0003116000 / TX0105261	001	Best Sea-Pack of Texas Facility	Best Sea-Pack of Texas Inc.	Industrial/IW, PME, SW	0.015	0.26
1107_01	WQ0003116000 / TX0105261	101	Best Sea-Pack of Texas Facility	Best Sea-Pack of Texas Inc.	Industrial/WW	**	*
1107_01	WQ0003903000 / TX0114995	001	Allied Petrochemical Plant	Allied Petrochemical, LLC	Industrial/IW, SW	0.021	0.021
1107_01	WQ0014324001 / TX0119041	001	Weybridge WWTF	Aqua Texas, Inc.	Domestic/WW	0.009	0.05
1107_01	WQ0015657001 / TX0138321	001	St. Ives RV Resort LCC	St. Ives RV Resort WWTF	Domestic/WW	***	0.015
1108_01	WQ0002068000 / TX0072168	001	HC Manvel	HC Manvel, Inc.	Industrial/IW, SW	0.018	0.033
1108_01	WQ0002068000 / TX0072168	002	HC Manvel	HC Manvel, Inc.	Industrial/IW, SW	N/A	N/A
1108_01	WQ0010700001 / TX0023337	001	Oak Manor WWTF	Oak Manor MUD	Domestic/WW	0.056	0.08
1108_01	WQ0012780001 / TX0093823	001	Southwood Estates WWTF	Undine Texas Environmental, LLC	Domestic/WW	0.041	0.4
1108_01	WQ0013367001 / TX0102385	001	City of Arcola WWTF	City of Arcola	Domestic/WW	0.212	0.95
1108_01	WQ0013872001 / TX0118397	001	City of Manvel WWTF	City of Manvel	Domestic/WW	0.115	0.5

AU	TPDES Permit No./NPDES[a] No.	Outfall No.	Facility Name	Permittee Name	Facility Type/ Effluent Type	Average Discharge (MGD[b])	Permitted Discharge (MGD)
1108_01	WQ0014068001 / TX0117927	001	RiceTec WWTF	RiceTec Inc.	Domestic/WW	0.002	0.025
1108_01	WQ0014149001 / TX0123994	001	Savannah Plantation WWTF	SP Utility Co Inc.	Domestic/WW	0.006	0.2
1108_01	WQ0014222001 / TX0123633	001	Brazoria County MUD No. 21 WWTF	Brazoria County MUD No. 21	Domestic/WW	0.231	1.2
1108_01	WQ0014253001 / TX0124001	001	Rodeo Palms WWTF	Brazoria County MUD No. 29	Domestic/WW	0.154	0.45
1108_01	WQ0014279001 / TX0119547	001	Palm Crest WWTF	Aqua Texas Inc.	Domestic/WW	0.009	0.15
1108_01	WQ0014461001 / TX0126055	001	Brazoria County MUD WWTF	Brazoria County MUD No. 30	Domestic/WW	***	0.5
1108_01	WQ0014497001 / TX0126365	001	O'Day Investments CR 81 WWTF	O'Day Investments, LP	Domestic/WW	***	0.099
1108_01	WQ0014546001 / TX0126951	001	Brazoria County MUD No. 31 WWTP	Brazoria County MUD No. 31	Domestic/WW	0.122	2
1108_01	WQ0014724002 / TX0129453	001	Brazoria County MUD 56 WWTF	Rise Communities, LLC	Domestic/WW	***	0.995
1108_01	WQ0014724003 / TX0129470	001	Brazoria County MUD No. 55 WWTF	Brazoria County MUD No. 55	Domestic/WW	0.028	0.98
1108_01	WQ0014992001 / TX0132896	001	Glendale Lakes Subdivision WWTF	Fort Bend County MUD No. 141	Domestic/WW	0.028	0.7

AU	TPDES Permit No./NPDES[a] No.	Outfall No.	Facility Name	Permittee Name	Facility Type/ Effluent Type	Average Discharge (MGD[b])	Permitted Discharge (MGD)
1108_01	WQ0015093001 / TX0134562	001	Lacovia Lakes WWTF	AUC Group, L.P.	Domestic/WW	***	0.95
1108_01	WQ0015279001 / TX0135577	001	Brazoria County MUD No. 43 WWTF	Brazoria County MUD No. 43	Domestic/WW	***	0.3
1108_01	WQ0015486001 / TX0137189	001	Brazoria County MUD No. 42 WWTF	Manvel Town Center, Ltd.	Domestic/WW	***	0.615
1108_01	WQ0015582001 / TX0137804	001	Arcola Estates WWTF	Niranjan Shantilal Patel	Domestic/WW	***	0.075
1108_01	WQ0015637001 / TX0138134	001	Charleston MUD WWTF	Charleston C.M.I., Ltd	Domestic/WW	***	0.245
1108_01	WQ0015714001 / TX0138665	001	Sierra Vista West WWTF	Brazoria County Municipal Utility District No. 53	Domestic/WW	***	0.9

[a] National Pollutant Discharge Elimination System (NPDES)

[b] million gallons per day

*Internal outfall discharge included in permitted discharge through external outfall

**Internal outfall average discharge included with average discharge through external outfall

***DMRs were not found for the facility during the report period 2008-2018.

N/A – No reported effluent discharge

WW – wastewater discharge that includes treatment for bacteria

IW – industrial wastewater discharge not treated for bacteria

SW – stormwater discharge, accounted for during wasteload allocation for stormwater

PME – previously monitored effluent

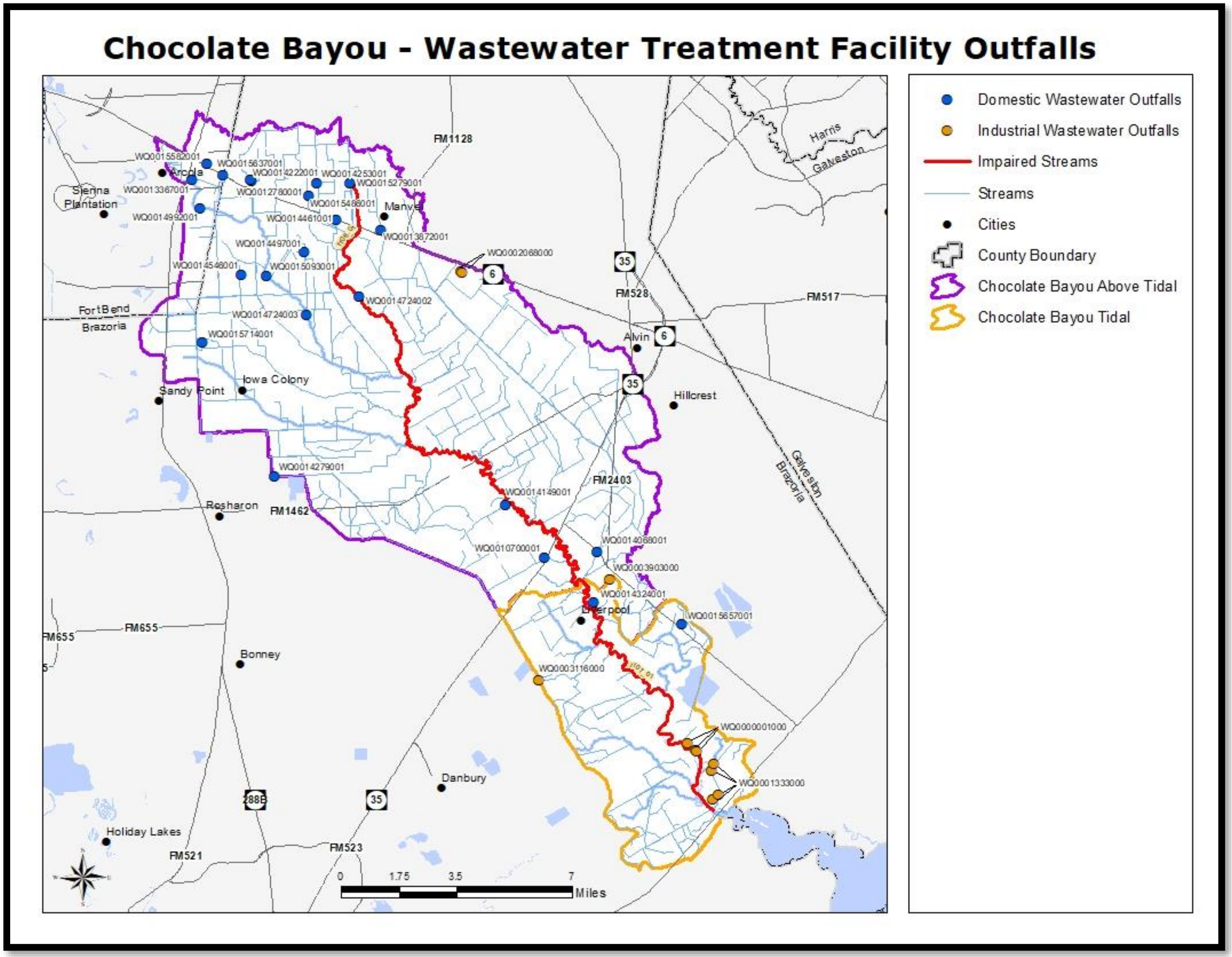


Figure 6. Chocolate Bayou industrial and domestic wastewater outfalls

For the five facilities with bacteria effluent limits in their permits in the AU 1107_01 watershed, the maximum permitted flow ranges from a low of 15,000 gallons per day at the St. Ives RV Resort WWTF, to as much as eight MGD at INEOS Chocolate Bayou Plant (Table 6). For the 21 WWTFs with bacteria effluent limits found in the AU 1108_01 watershed, the permitted maximum daily flow ranges from 25,000 gallons per day to 2 MGD.

Discharge Monitoring Reports (DMR) were pulled for each facility between 2008 and 2018 to determine an average discharge (Table 6). DMRs for WWTFs with bacteria effluent limits were available for four of the five WWTFs in AU 1107_01 and 12 of 21 WWTFs in AU 1108_01. WWTFs listed with zero DMRs are likely facilities that are recent permits for planned developments which have not been built or are WWTFs in developments under construction and not in service. DMRs include geometric mean and single grab maximum permit limits as determined by the FIB. Based on self-reported monitored effluent results, five facilities reported exceeding their permit limits on occasion between 2015 and 2018 (EPA, 2020, Table 7).

Table 7. Compliance history for WWTFs

AU	TPDES	Facility Name	FIB	Geometric Mean % Exceedance	Daily Maximum % Exceedance	DMR Reports[a]
1107_01	WQ0000001000	Ascend Performance Materials Chocolate Bayou Plant	Enterococci	3.3	18.3	60
1107_01	WQ0001333000	Chocolate Bayou Facility	Enterococci	34.8	34.8	60
1107_01	WQ0003116000	Best Sea-Pack of Texas Facility	Enterococci	1.7	5.2	59
1107_01	WQ0014324001	Weybridge WWTF	Enterococci	0.0	10.5	59
1107_01	WQ0015657001	St. Ives RV Resort LCC	Enterococci	–	–	0
1108_01	WQ0010700001	Oak Manor MUD WWTF	*E. coli*	–	0.0	60
1108_01	WQ0012780001	Southwood Estates WWTF	*E. coli*	0.0	33.3	60
1108_01	WQ0013367001	City of Arcola WWTF	*E. coli*	0.0	0.0	60
1108_01	WQ0014068001	RiceTec WWTF	*E. coli*	0.0	0.0	59

AU	TPDES	Facility Name	FIB	Geometric Mean % Exceedance	Daily Maximum % Exceedance	DMR Reports[a]
1108_01	WQ0013872001	City of Manvel WWTF	*E. coli*	0.0	0.0	60
1108_01	WQ0014279001	Palm Crest WWTF	*E. coli*	0.0	0.0	60
1108_01	WQ0014222001	Brazoria County MUD No, 21 WWTF	*E. coli*	0.0	0.0	60
1108_01	WQ0014149001	Savannah Plantation WWTF	*E. coli*	0.0	0.0	60
1108_01	WQ0014253001	Rodeo Palms WWTF	*E. coli*	0.0	0.0	60
1108_01	WQ0014461001	Brazoria County MUD No. 30 WWTF	*E. coli*	–	–	0
1108_01	WQ0014497001	O'Day Investments CR 81 WWTF	*E. coli*	–	–	0
1108_01	WQ0014546001	Brazoria County MUD No. 31 WWTP	*E. coli*	0.0	0.0	60
1108_01	WQ0014724002	Brazoria County MUD 56 WWTF	*E. coli*	–	–	0
1108_01	WQ0014724003	Brazoria County MUD 55 WWTF	*E. coli*	0.0	0.0	38
1108_01	WQ0014992001	Glendale Lakes Subdivision WWTF	*E. coli*	0.0	0.0	31
1108_01	WQ0015093001	Lacovia Lakes WWTF	*E. coli*	–	–	0
1108_01	WQ0015279001	Brazoria County MUD No. 43 WWTF	*E. coli*	–	–	0
1108_01	WQ0015486001	Brazoria County MUD No. 42 WWTF	*E. coli*	–	–	0

AU	TPDES	Facility Name	FIB	Geometric Mean % Exceedance	Daily Maximum % Exceedance	DMR Reports[a]
1108_01	WQ0015582001	Arcola Estates WWTF	*E. coli*	–	–	0
1108_01	WQ0015637001	Charleston MUD WWTF	*E. coli*	–	–	0
1108_01	WQ0015714001	Sierra Vista West WWTF	*E. coli*	–	–	0

[a] WWTFs with zero reported DMRs include facilities that have yet to go into service but are listed for transparency

2.7.1.2 TCEQ/TPDES General Wastewater 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)

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 permit coverage (TCEQ, 2022c) in the Chocolate Bayou watershed as of May 1, 2022, found two general permit authorizations for concrete production facilities in the Chocolate Bayou Above Tidal watershed, AU 1108_01, (Table 8). These facilities do not have bacteria reporting requirements or limits in their permits. They are assumed to contain inconsequential amounts of indicator bacteria in their effluent; therefore, it was unnecessary to allocate bacteria loads to these facilities. No other active wastewater general permit authorizations were found.

Table 8. General permit authorizations for concrete production facilities

AU	Permit Number	Site Name	City	County	Latitude	Longitude	Estimated Facility Acreage
1108_01	TXG110060	Campbell Plant 30	Rosharon	Fort Bend	29.52528	-95.46277	1.70
1108_01	TXG111643	Alleyton Resource Plant 5	Manvel	Brazoria	29.472521	-95.367536	10.43

For the two concrete production facilities, acreages were estimated by reviewing county appraisal parcel data and/or importing the location information associated with the authorization into a geographic information system (GIS) database and measuring the facility boundaries. The total combined acreage under a general permit authorization for AU 1108_01 is 12.13 acres.

2.7.1.3. TPDES Regulated Stormwater

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

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

TPDES MS4 Phase I and II rules require municipalities and certain other entities in urbanized areas 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 (USCB, 2010).

The purpose of an MS4 permit is to reduce discharges of pollutants in stormwater to the “maximum extent practicable” by developing and implementing a stormwater management program (SWMP). The SWMP describes the stormwater control practices that the regulated entity will implement, consistent with permit requirements, to minimize the discharge of pollutants. MS4 permits require that SWMPs specify the best management practices (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 all of the following:

- public education, outreach, and involvement.
- illicit discharge detection and elimination.
- construction site stormwater runoff control.
- post-construction stormwater management in new development and redevelopment.
- pollution prevention and good housekeeping for municipal operations.
- industrial stormwater sources.

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

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

- TXR040000 – Phase II MS4 General Permit for 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 are part of a common plan of development disturbing more than one acre

As of May 1, 2022, TCEQ Central Registry included one combined Phase I/II MS4 permit and five active Phase II MS4 permit authorizations in the Chocolate Bayou watershed (Table 9) (TCEQ, 2022c). When mapped (Figure 7) based on USCB, the census designated urbanized areas are only found in the AU 1108_01 watershed (USCB, 2010). This urbanized area covers approximately 10.37% of the AU 1108_01 watershed and 8.25% of the Chocolate Bayou watershed, or 9,138.74 acres.

Table 9. MS4 permits and authorizations

AUs	NPDES Permit	Regulated Entity	County	MS4 Location	Permit Type
1107_01, 1108_01	TXR040148	Brazoria County CRD 3	Brazoria	AREA WITHIN THE BRAZORIA COUNTY CRD 3 LIMITS THAT IS LOCATED WITHIN THE HOUSTON URBANIZED AREA	Phase II
1107_01, 1108_01	TXR040138	City of Alvin	Brazoria	AREA WITHIN THE CITY OF ALVIN LIMITS THAT IS LOCATED WITHIN	Phase II

AUs	NPDES Permit	Regulated Entity	County	MS4 Location	Permit Type
1107_01, 1108_01	TXS002101	Texas Department of Transportation	Brazoria, Galveston, Fort Bend	TXDOT rights-of-way located within Phase I MS4s and Phase II MS4s	Combined Phase I/II
1108_01	TXR040527	BRAZORIA COUNTY MUD 29	Brazoria	AREA OUTSIDE THE CITY OF MANVEL LIMITS THAT IS LOCATED PARTIALLY WITHIN THE HOUSTON URBANIZED AREA	Phase II
1108_01	TXR040144	BRAZORIA DRAINAGE DISTRICT 4	Brazoria	AREA WITHIN THE CITY OF PEARLAND LIMITS THAT IS LOCATED WITHIN THE HOUSTON URBANIZED AREA	Phase II
1108_01	TXR040528	Brazoria County MUD 21	Brazoria	AREA OUTSIDE THE CITY OF ROSHARON LIMITS AND LOCATED WITHIN THE CITY OF HOUSTON URBANIZED AREA	Phase II

MSGP authorizations were reviewed on May 1, 2022, through the TCEQ Central Registry (TCEQ, 2022c) for active permit authorizations in the Chocolate Bayou watershed. A total of 16 MSGP authorizations were found (Table 10). The 16 authorizations were mapped, and their areas estimated. To eliminate the possibility of over counting with the stormwater permit area, only the regulated areas located outside or partially outside of the urbanized area was determined (Figure 7).

Five MSGP authorizations were found in the AU 1107_01 watershed with a total area of 2,301.70 acres. Twelve MSGP authorizations were found in the AU 1108_01 watershed. One facility, Allied Petrochemical, LLC, is partially within both AU watersheds and is listed twice in Table 10. Included in this list are the facilities that hold wastewater permits as explained in section 2.7.1.1 and MSGPs. The total MSGP regulated area in 1108_01, outside of the UA, was found to be 344.16 acres. The MSGP regulated area outside of the UA was recorded and used in development of the TMDL.

Table 10. Industrial stormwater authorizations

AU	TPDES	MSGP Permit Number	Facility Name	City	County	Facility Acreage	Facility Acreage not in UA
1107_01	WQ0000001000	TXR05BQ25 TXR15303N	Ascend Performance Materials Texas Inc.	Alvin	Brazoria	559.3	559.3

AU	TPDES	MSGP Permit Number	Facility Name	City	County	Facility Acreage	Facility Acreage not in UA
1107_01	WQ0001333000	TXR05DG63 TXR15710P	INEOS USA LLC	Alvin	Brazoria	1462	1462
1107_01	WQ0003903000	TXR05AJ66	Allied Petrochemical, LLC	Alvin	Brazoria	48.8	48.8
1107_01	n/a	TXR05DK43	Poly-Coat Systems Inc.	Liverpool	Brazoria	48.9	48.9
1107_01	n/a	TXR05EE81	Gulf Coast Stabilized Materials LLC	Alvin	Brazoria	182.7	182.7
					Total	**2,301.70**	**2,301.70**
1108_01	WQ0003903000	TXR05AJ66	Allied Petrochemical, LLC	Alvin	Brazoria	16.42	16.42
1108_01	WQ0002068000	n/a	HC Manvel, Inc.	Alvin	Brazoria	14	14
1108_01	n/a	TXR05AF97	Living Earth, Letco Group, LLC	Rosharon	Brazoria	10.5	0
1108_01	n/a	TXR05AQ74	Polymer Chemistry Chocolate Bayou, Bernard	Alvin	Brazoria	15.7	15.7
1108_01	n/a	TXR05CT99	Crest Industrial Chemicals, Inc.	Rosharon	Brazoria	19.5	19.5
1108_01	n/a	TXR05CU61	Cherry Crushed Concrete, Inc.	Rosharon	Brazoria	56.4	56.4
1108_01	n/a	TXR05FE89	Lhoist North America of Texas, Ltd.	Arcola	Fort Bend	18.8	0
1108_01	n/a	TXR05DC67, TXR05EZ01	Sand Land, Inc.	Rosharon	Brazoria	46.44	46.44
1108_01	n/a	TXR05EM71	Cherry Crushed Concrete, Inc.	Rosharon	Brazoria	40.3	40.3

AU	TPDES	MSGP Permit Number	Facility Name	City	County	Facility Acreage	Facility Acreage not in UA
1108_01	n/a	TXR05ES71	Cherry Crushed Concrete, Inc.	Alvin	Brazoria	93.6	93.6
1108_01	n/a	TXR05FJ49	Jam Excavating, LLC	Manvel	Brazoria	20.2	20.2
1108_01	n/a	TXR05L089	Texmore, Inc., Cameron Auto Salvage	Manvel	Brazoria	21.6	21.6
					Total	**373.46**	**344.16**

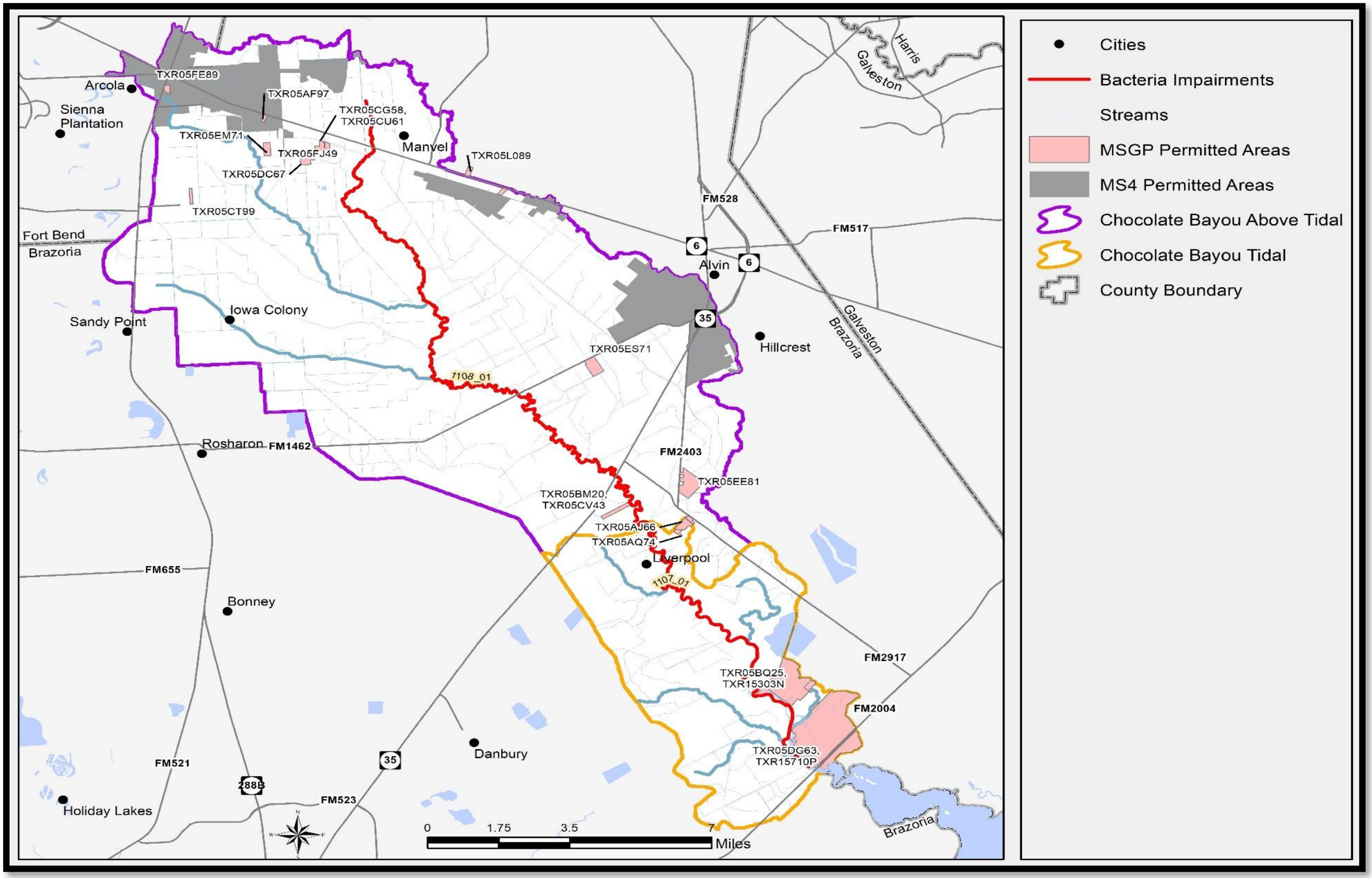


Figure 7. Regulated stormwater area based on MS4s and MSGPs

Construction activities found in the Chocolate Bayou watershed are constantly changing. The permit data is only considered accurate for the date the data was accessed. A review of the TCEQ Central Registry on May 1, 2022, found 128 active CGP authorizations (TCEQ, 2022c).

Due to the variable nature of construction permits, the acres recorded serve only as a representative estimate, after summing up all disturbed areas of the watershed under a stormwater construction permit at any given time.

For the 128 CGP authorizations found, two were within the AU 1107_01 watershed and 126 were within the AU 1108_01 watershed. The estimated disturbed area was 510 acres within the AU 1107_01 watershed. The estimated disturbed area within the AU 1108_01 watershed was 11,213.77 acres. This amount of construction is reflective of the population growth within AU 1108_01.

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 a permitted system. These overflows—when they occur 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.

Responsible parties report SSO data to TCEQ, which provided the data for analysis. Reports include the cause of the spill, an estimate of the size of the spill in gallons, and a general location of the spill. SSO data reviewed for this watershed covers the period of 2016 through 2021 (TCEQ, 2022d). Forty-one SSOs were reported in the Chocolate Bayou watershed, 25 in AU 1108_01 and 16 in AU 1107_01. The total SSO volume for the period was 55,579.10 gallons with an average of 1,355.59 gallons per SSO (Table 11).

Table 11. Summary of reported SSO events

Year	Number	Total Volume[a]	Average Volume per SSO[a]
2016	6	12,195.00	2,032.50
2017	3	628.00	209.20
2018	10	3,506.50	350.65
2019	4	14,125.00	3,531.25
2020	8	4,800.00	600.00
2021	10	20,325.00	2,032.50
Total	**41**	**55,579.50**	**1,355.59**

[a] Volumes are in gallons

2.7.1.5. Dry Weather Discharges/Illicit Discharges

Pollutant loads can enter water bodies from MS4 outfalls that carry authorized sources as well as illicit discharges under both dry- and wet-weather conditions. The term "illicit discharge" is defined in TPDES General Permit TXR040000 for Phase II MS4s as "Any discharge to a municipal separate storm sewer 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.

2.7.2. Unregulated Sources

Unregulated sources of bacteria are generally nonpoint. Nonpoint source loading enters the impaired water body through distributed, nonspecific locations, which may include urban runoff not covered by a permit. Potential sources, detailed below, include wildlife, feral hogs, various agricultural activities, agricultural animals, urban runoff not covered by a permit, failing 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 riparian corridors of water bodies. With direct access to the stream channel, the direct deposition of wildlife and feral hog waste can be a concentrated source of bacteria loading to a water body. Wildlife and feral hogs also leave feces on land, where they may be washed into nearby water bodies by rainfall runoff.

Most avian and mammalian wildlife, including invasive species, are difficult to estimate, as long-term monitoring data or literature values indicating historical baselines are lacking. Deer are one of the few wildlife species where population estimates have been routinely made. Texas Parks and Wildlife Department (TPWD) determines deer population-density estimates by Deer Management Units (DMU) and Ecoregion in the state. H-GAC downloaded the DMU data for the Chocolate Bayou watershed for 2006 to 2016 (TPWD, 2019). The population estimates are available in deer per 1000 acres. H-GAC determined an average density of 0.03957 per acre, for the period. This average density is not based on deer preference for suitable habitat. By applying this average density factor to the acreage in the Chocolate Bayou watershed, the white-tail deer population can be estimated at 4,386 (Table 12).

Table 12. Estimated deer population

Subwatershed	Area (acres)	Estimated Deer Population
1107_01	22,731.08	899
1108_01	88,098.57	3,486
Total	110,829.65	4,385

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 2,244 within the Chocolate Bay watershed (Table 13).

Table 13. Estimated feral hog population

Subwatershed	Low Quality Habitat (acres)	Feral Hogs – Low Quality Habitat	High Quality Habitat (acres)	Feral Hogs – High Quality Habitat	Total Estimated Feral Hogs
1107_01	5,627.26	78	15,258.15	391	469
1108_01	24,397.76	339	56,017.88	1,435	1,774
Total	**30,025.02**	**417**	**71,276.03**	**1,826**	**2,243**

2.7.2.2. Unregulated Agricultural Activities and Domesticated Animals

Several agricultural activities that do not require permits can be potential sources of fecal bacteria loading. Fecal waste from livestock such as cattle, pigs/hogs, sheep, goats, horses, and poultry can be introduced through direct deposition and as runoff from manure used in crop fertilization. While there are no permitted concentrated animal feeding operations in the Chocolate Bayou watershed, livestock and other agricultural pressures should be considered in estimating bacterial source loads.

In Table 14, estimates of livestock in the Chocolate Bayou watershed are shown. These estimations were calculated by applying a ratio of watershed land area compared to county land area times the livestock numbers from the 2017 Census of Agriculture for Brazoria County performed by the USDA (USDA, 2019). 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 14. Estimated livestock populations in Chocolate Bayou

AU	Cattle and Calves	Goats and Sheep	Horses	Hogs and Pigs	Poultry
1107_01	2,851	159	201	188	5,142
1108_01	9,755	543	688	644	17,595
Total	**12,606**	**702**	**889**	**832**	**22,737**

Runoff transports fecal matter from dogs and cats to water bodies in both urban and rural areas and can be a potential source of bacteria loading. Table 15 summarizes the estimated number of dogs and cats in the Chocolate Bayou 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 2020 estimate of 784 households in the AU 1107_01 and 11,676 households in the AU 1108_01 watersheds were determined using the United States Census decadal survey's average household size of 2.71 (USCB, 2021). The actual contribution and significance of bacteria loads from pets reaching the water bodies is unknown.

Table 15. Estimated households and pet populations

AU	Estimated Households	Dogs	Cats
1107_01	784	481	358
1108_01	11,676	7,169	5,336
Total	**12,460**	**7,650**	**5,694**

2.7.2.3. On-Site Sewage Facilities

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

Several pathways of the liquid waste in OSSFs afford opportunities for bacteria to enter ground and surface waters if the systems are not properly operating. Properly designed and operated, however, OSSFs contribute virtually no fecal bacteria to surface waters. For example, Weiskel et al. (1996) 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. Reed, Stowe, and Yanke LLC (2001) provide information on estimated failure rates of OSSFs for different regions of Texas.

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.

Estimates of the number of permitted and registered OSSFs in the Chocolate Bayou watershed have been compiled by H-GAC in coordination with authorized agents (AAs) in H-GAC's service region, which includes the Chocolate Bayou watershed. AAs are local authorities who have accepted responsibility from TCEQ to permit OSSFs and enforce laws and rules governing OSSFs on behalf of the state. Registered OSSFs are presented in Figure 8. There are 4,620 registered OSSFs in the Chocolate Bayou watershed (Table 16).

In addition to registered systems, there are several 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 4,551 OSSFs in the Chocolate Bayou watershed (Table 16).

Table 16. Registered and non-registered OSSFs

Subwatershed	Registered	Non-registered	Total
AU 1107_01	434	470	904
AU 1108_01	4,186	4,081	8,267
Total	**4,620**	**4,551**	**9,171**

OSSFs can be a source of fecal waste when not sited or functioning properly, especially when they are near waterways. Many factors including soil type, design, age, and maintenance can influence the likelihood of an OSSF failure. Literature values suggest that failure rates for OSSFs in Texas occur at a rate of approximately 12% (Reed, Stowe, and Yanke LLC, 2001). By applying this estimate of failure rates to the 9,171 OSSFs estimated in the watershed area (Table 16), there are potentially 1,101 failing OSSFs within the Chocolate Bayou 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 the right conditions prevail (such as warm temperature). Fecal organisms from improperly treated effluent can survive and replicate during their transport in pipe networks, and they can survive and replicate in organic-rich materials such as improperly treated compost and sewage sludge (or biosolids). While the die-off of indicator bacteria has been demonstrated in natural water systems due to the presence of sunlight and predators, the potential for their 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 watershed.

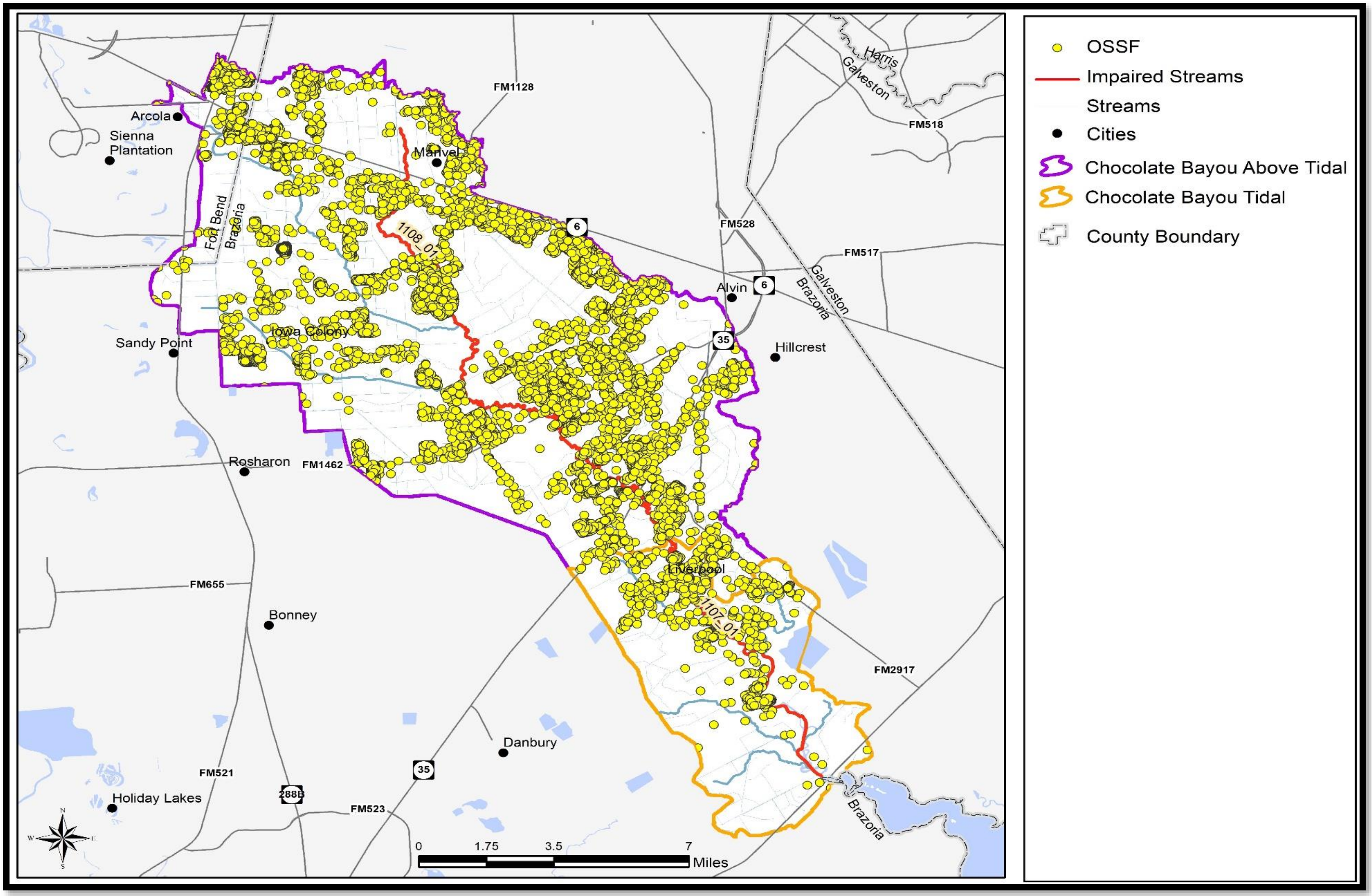


Figure 8. Distribution of OSSFs

Section 3. Bacteria Tool Development

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

3.1. Tool Selection

The goal of the TMDL process is to determine an assimilative loading value, i.e., 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.

Mechanistic models traditionally use mathematically or theoretically described relationships to interpret real systems governed by well-known physical process and response variables (e.g., bacterial concentrations and streamflow to precipitation) (Hauck et.al, 2015). There are several mechanistic models available, many capable of handling the needed response and condition values ranging from tidal flow and streamflow, dry to wet weather, land use and rainfall runoff and other hydrologic processes. Hauck (2015) suggests that "while the ability of bacteria models has advanced, there remain deficiencies in available watershed data to sufficiently fill the physical and biological process identified in the mechanistic models." With other useful and often simpler tools available to develop TMDL loadings, the more complex and sophisticated mechanistic models may not be the better option.

The LDC method allows for the estimation of existing and allowable loads by utilizing the cumulative frequency distribution of streamflow and measured pollutant concentration data. 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 as it provides a simple means for determining the loading value across moisture conditions and can be broadly used to indicate sources of bacteria (e.g., point source and nonpoint source).

3.2. Data Resources

Chocolate Bayou data resource availability was sufficient to perform LDCs and modified LDCs in AUs 1107_01 and 1108_01. Unlike AU 1108_01, daily streamflow data was not available within AU 1107_01. The drainage area ratio method was used to estimate streamflow using actual streamflow from AU 1108_01. To complete LDCs, daily streamflow, FIB, and salinity (in the case of tidally influenced waters) is required. Streamflow will be discussed further below to address this data limitation.

All the required ambient water quality data were adequately available through SWQMIS for the period of 2004 to 2018. 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. Qualified data (data added to SWQMIS with “qualifier” codes that identify quality, sampling, or other problems that may render the data unsuitable) were excluded from the download. All data for all stations were combined into a working data set for LDC development (Table 17).

Table 17. Bacteria geometric means for SWQM bacteria data

AU	SWQM Station	Parameter	Data Date Range	Number of Results	Geometric mean
1107_01	11478	Enterococci	3/30/2004-10/12/2018	107	58.2
1107_01	21178	Enterococci	12/18/2005-10/15/2018	53	126.1
1108_01	11484	*E. coli*	3/11/2004-11/06/2018	53	146.2

Streamflow data records were available from a mainstem station found in AU1108_01 for the period of January 1, 2004, to December 31, 2018. Daily streamflow data recorded at the USGS streamflow gauge 08078000 (collocated with TCEQ SWQM Station 11484) were downloaded from the USGS website on January 24, 2019 (USGS, 2019).

3.3. Method for Developing Flow Duration and Load Duration Curves

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

- Step 1: Determine the hydrologic period of record to be used in developing the FDC.
- Step 2: Determine the stream location for which FDC and LDC development is desired.

- Step 3: Develop drainage-area ratio (DAR) parameter estimates.
- Step 4: Develop daily streamflow record at desired location.
  - Step 4.1: Develop salinity to streamflow regression in the tidal AU.
  - Step 4.2: Incorporate daily tidal volumes into streamflow record in the tidal AU.
- Step 5: Develop FDC at the desired stream location, segmented into discrete flow regimes.
- Step 6: Develop allowable bacteria LDC at the same stream location based on the relevant criteria and the data from the FDC.
- Step 7: Superimpose historical bacteria data on the allowable bacteria LDC.

Additional information explaining the LDC method may be found in Cleland (2003) and EPA (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 15-year period of 2004 through 2018 is long enough to cover both drought and flood years and at the same time, it is short enough to contain a hydrology that is responding to both recent and current conditions in the watershed. Sufficient measurable daily stream flow data was available, having been recorded at the USGS streamflow gauge 08078000 on AU 1108_01 for this period of record. This period includes the collection dates of all Enterococci data available at the time of this study.

3.3.2. Step 2: Determine Stream Location

While LDCs could be developed for all three TCEQ SWQM stations, only data from 11478 and 11484—AUs 1107_01 and 1108_01, respectively—will be used to develop LDCs and the TMDLs for the impaired AUs. TCEQ SWQM Station 21178 is located within AU 1107_01 upstream of TCEQ SWQM Station 11478. It is standard procedure to use the station located furthest downstream that is actively monitored for FIB to capture as much as possible of the AU watershed. As there is only one TCEQ SWQM station in AU 1108_01, station 11484 will be used.

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

Once the hydrologic period of record and station location were determined, the next step was to develop the daily streamflow record for the monitoring stations. The daily, freshwater flow values at stations on Chocolate Bayou were calculated based on the flow values of USGS gage 08078000 and the DAR method. The DAR method involves multiplying a USGS gauging 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 gauge. To compute the DAR, the drainage area above USGS gage 08078000 was compared with the area of the Chocolate Bayou watershed contributing to TCEQ SWQM Station 11478 (Table 18). The DARs for each station are then applied to the daily streamflow measurements from USGS gage 08078000 to determine the estimated daily flow value at each monitoring station on Chocolate Bayou.

Table 18. Drainage area ratio calculations for Chocolate Bayou

TCEQ SWQM Station	AU	Station Watershed Area (ac)	Total Watershed Area (ac)	DAR
11484	1108_01	49,628.03	49,628.03	1
11478	1107_01	22,229.55	96,545.11	1.95

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

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

The estimated daily DMR-reported discharges for the time-period of 2008 to 2018 from WWTF outfalls upstream of the USGS gauge location (Table 19) were subtracted from the daily gauge streamflow records. This resulted in adjusted streamflow records with point source discharge influences removed.

Table 19. Outfalls on Chocolate Bayou upstream of USGS Gage 08078000

AU	TPDES	Facility Name	Average Daily Discharge (MGD)
1108_01	WQ0012780001	Southwood Estates WWTF	0.041
1108_01	WQ0013367001	City of Arcola WWTF	0.212
1108_01	WQ0013872001	City of Manvel WWTF	0.114
1108_01	WQ0014279001	Palm Crest WWTF	0.009
1108_01	WQ0014222001	Brazoria County MUD 21 WWTF	0.231
1108_01	WQ0014253001	Rodeo Palms WWTF	0.154
1108_01	WQ0014546001	Brazoria County MUD 31 WWTP	0.122
1108_01	WQ0014724003	Brazoria County MUD 55 WWTF	0.028
1108_01	WQ0014992001	Glendale Lakes Subdivision WWTP	0.028
1108_01	WQ0015093001	Lacovia Lakes WWTF	*
1108_01	WQ0015279001	Brazoria County MUD 43 WWTF	*
1108_01	WQ0015486001	Brazoria County MUD 42 WWTF	*
1108_01	WQ0015582001	Arcola Estates WWTF	*
1108_01	WQ0015637001	Charleston MUD WWTF	*
1108_01	WQ0014461001	Brazoria County MUD 30 WWTF	*
1108_01	WQ0014724002	Brazoria County MUD 56 WWTP	*

AU	TPDES	Facility Name	Average Daily Discharge (MGD)
1108_01	WQ0014497001	O'Day Investments CR 81	*
1108_01	WQ0015714001	Sierra Vista West WWTF	*

* DMRs were not found for the facility during the report period 2008-2018

Next, the water right consumptions (i.e., the balance between the diverted amount and returned flow amount) were evaluated via streamflow discharge records. Water rights diversions and return flow data in AU 1108_01 were downloaded from the TCEQ Water Right Permitting and Availability Section's Water Rights Viewer (TCEQ, 2022e). It was noted in Section 2.3 that several water supply canals deliver water from the Brazos River by the GCWA. The bulk of this water is for industrial users found in AU 1107_01 or outside of the Chocolate Bayou watershed. This source was not anticipated to contribute to the flow measured at the USGS gauge in AU 1108_01. There were three water rights diversions identified within the catchment area above the USGS station. The withdrawals were found to be minimal and infrequent. It was determined that they had little effect on flow and these diversions were not used to naturalize the flow.

The naturalized flow values were then multiplied by the DAR at TCEQ SWQM Station 11478. WWTF outfall average daily permitted flow for facilities downstream of the USGS gauge were added in to estimate flow in AU 1107_01. A final step to address tidal fluctuations will be explained below for modified FDCs and LDCs.

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

As part of the development of the modified FDC and LDC, it was necessary to develop a relationship between estimated actual daily streamflow and measured salinity for the tidally influenced location (TCEQ SWQM Station 11478 on AU 1107_01). The DAR adjusted daily streamflow data was combined with salinity observations taken at the TCEQ SWQM station. The top and bottom 5% were considered outliers and eliminated from further calculations. The resulting regression (Figure 9) was instrumental in determining the daily volume of seawater present for each daily freshwater flow in the period of record. A salinity to streamflow regression was developed for SWQM Station 11478 located within the tidal AU 1107_01. The equations derived from the regression analyses were used to calculate the volume of seawater that would flow through the cross-section of the TCEQ SWQM station over the period of a day. Salinity is presented in parts per thousand (ppt).

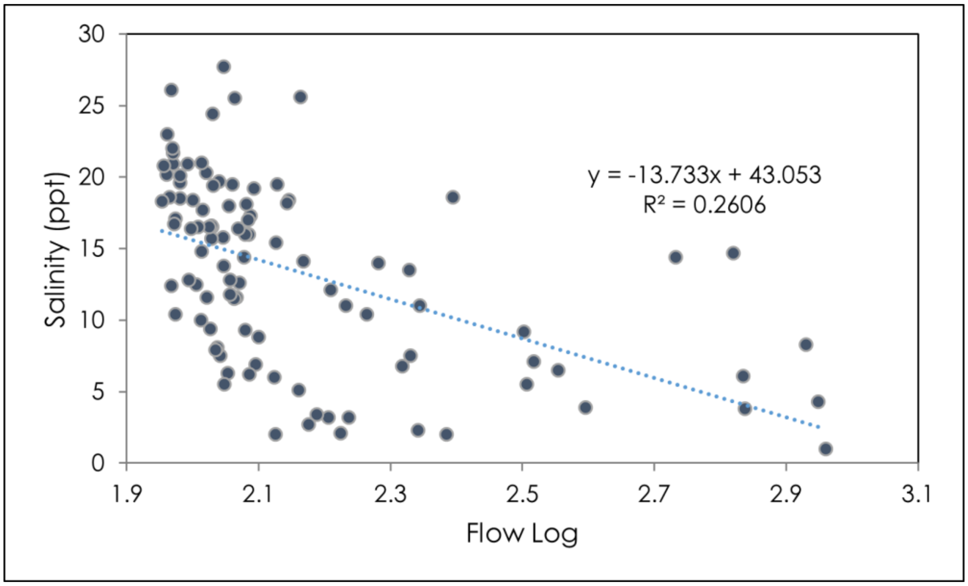


Figure 9. Regression scatter plot of salinity versus daily streamflow in AU 1107_01

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:

$$(V_r + V_s) * S_t = V_r * S_r + V_s * S_s \quad \text{(Equation 1)}$$

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:

$$V_s = V_r / (S_s/S_t - 1)\text{; for } S_t \text{ greater than background salinity, otherwise } V_s = 0 \quad \text{(Equation 2)}$$

Where S_t was computed for each day of the streamflow record using the station-specific regression equation of Step 4.1 and the estimated actual daily streamflow (V_r), from Step 4, as input to the equation. The calculation of S_t allowed V_s to be computed from Equation 2.

The modified daily flow volume (V_t) that includes the daily freshwater flow (V_r) and the daily volume of seawater flow (V_s) is computed as:

$$V_t = V_r + V_s \qquad \text{(Equation 3)}$$

The modified FDC was then developed following similar procedures for creating an FDC in a non-tidal segment, as shown in Steps 5-8.

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. To develop an FDC for a location, all of the following steps were taken in the order shown:

- 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).
- Compute the percentage of days each flow was exceeded by dividing each rank by the total number of data points plus one.
- Plot the corresponding flow data against exceedance percentages.

Further, when developing an LDC:

- Multiply the streamflow in cubic feet per second (cfs) by the appropriate water quality criterion for either Enterococci (geometric mean of 35 cfu/100 mL) or *E. coli* (126 cfu/mL) and by a conversion factor (2.44658×10^9), which gives you a loading unit of cfu/day.
- Plot the exceedance percentages, which are identical to the value for streamflow data points, against the geometric mean criterion for 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 *E. coli* data on the developed LDC using the following steps:

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

The final LDC with the measured loads (FIB concentrations times daily streamflow) display the frequency and magnitude at which measured loads exceed the maximum allowable loadings for the geometric mean criterion. Measured loads that are above a maximum allowable loading curve indicate an exceedance of the water quality criterion, while those below a curve show compliance.

3.3.5.1. Flow Duration Curves

Figures 10 and 11 provide the FDCs for TCEQ SWQM stations 11484 and 11478. The FDC 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%). The FDC includes, for reference, the *E. coli* or Enterococci geometric mean criterion curve (load at either 126 cfu/100 mL or 35 cfu/100 mL) and the *E. coli* or Enterococci single sample criterion curve (load at either 399 cfu/100 mL or 130 cfu/100 mL).

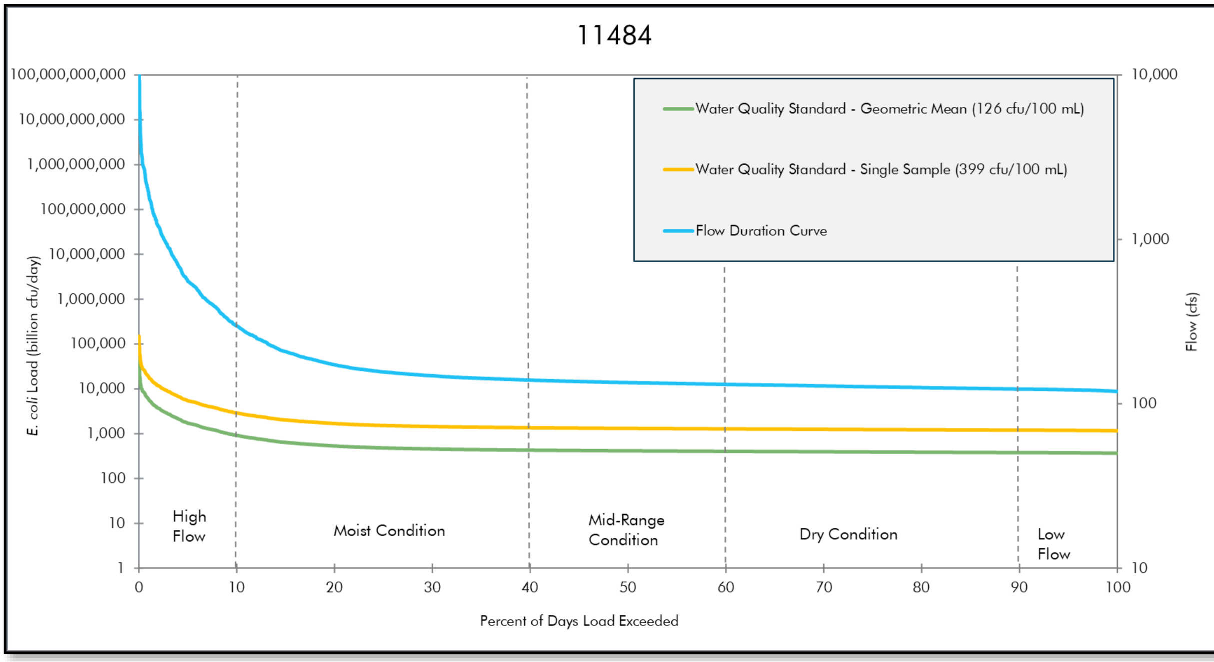


Figure 10. FDC for TCEQ SWQM Station 11484 in Chocolate Bayou Above Tidal (AU 1108_01)

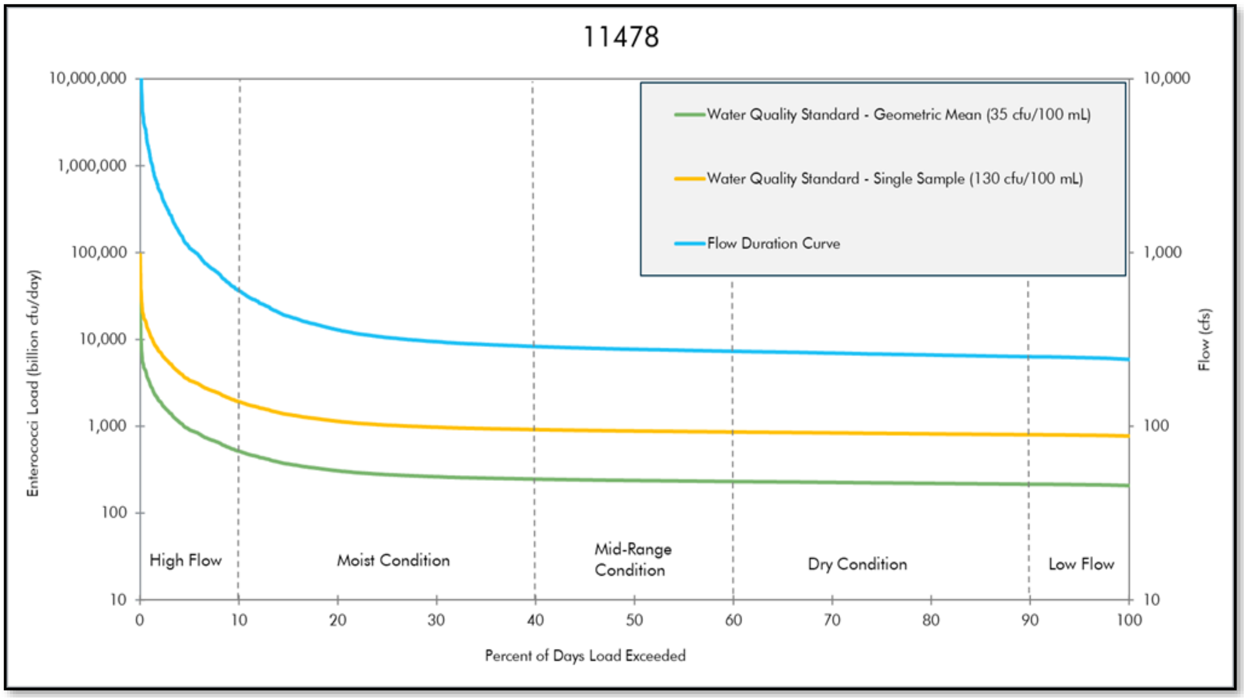


Figure 11. FDC for TCEQ SWQM Station 11478 in Chocolate Bayou Tidal (AU 1107_01)

3.3.5.2. Load Duration Curves

Figures 12 and 13 provide the LDCs for TCEQ SWQM stations 11484 and 11478. Each figure includes the FDC, the *E. coli* or Enterococci geometric mean criterion curve, the *E. coli* or Enterococci single sample criterion curve, the existing load curve, the existing geometric mean load by flow regime (single points), and individual bacteria samples.

Comparing individual bacteria samples to the single sample criterion curve can be useful. This comparison is used in calculating load reductions during TMDL development, visually depicting reduction requirements to the public, and determining whether dry weather conditions or wet weather conditions present the biggest challenge in meeting water quality standards (e.g., dry weather inputs from WWTFs or wet weather sources such as stormwater).

A review of the TCEQ SWQM Station 11484 LDC presented in Figure 12 suggests that wet weather sources of bacteria may play a larger role in AU 1108_01 than dry weather sources. The load regression curve is above the *E. coli* geometric mean criterion curve during high flow conditions. The load regression curve crosses below the geometric mean criterion curve in the moist, mid-range, dry, and low flow conditions.

A review of the TCEQ SWQM Station 11478 modified LDC presented in Figure 13 suggests that wet weather sources and dry weather sources may equally contribute to the Enterococci in the water body. The load regression curve is above the Enterococci geometric mean criterion curve for all flow conditions.

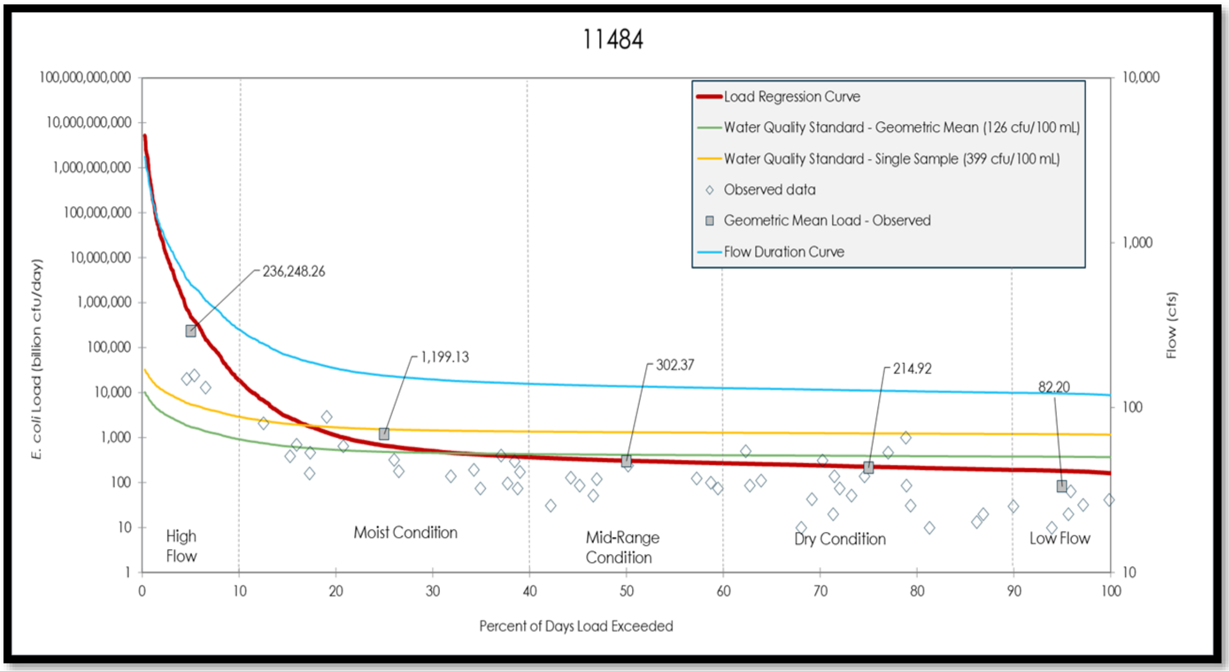


Figure 12. LDC for TCEQ SWQM Station 11484 on Chocolate Bayou Above Tidal (AU 1108_01)

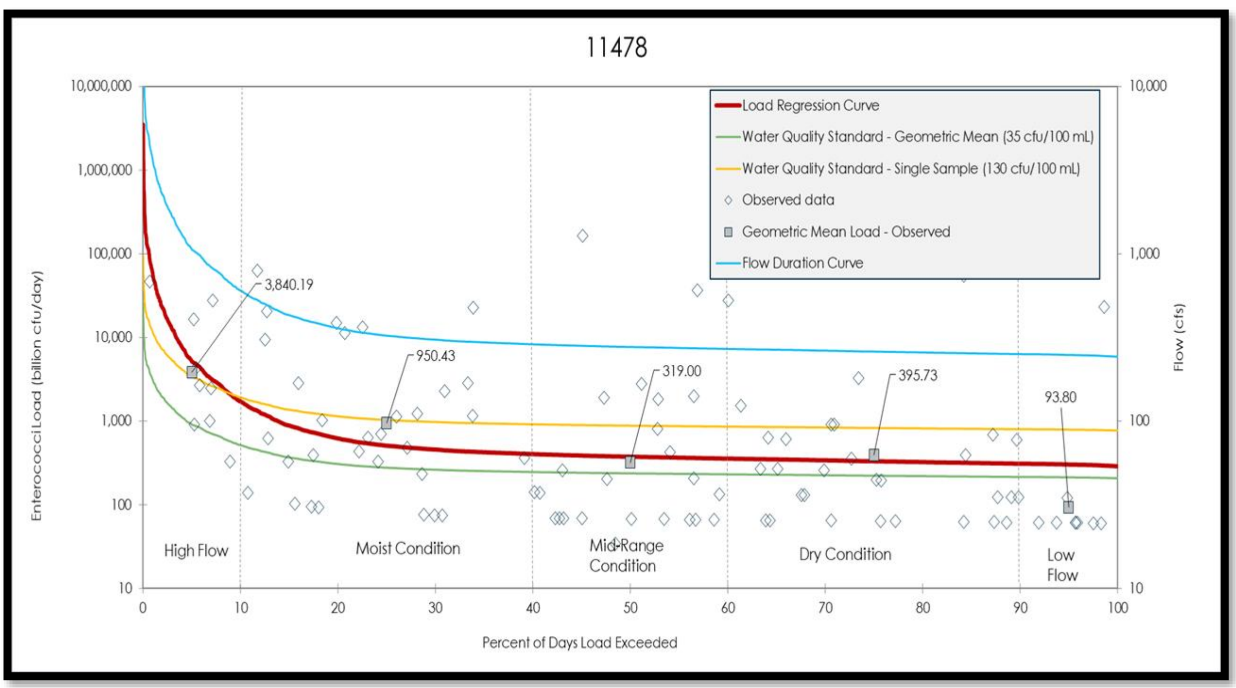


Figure 13. LDC for TCEQ SWQM Station 11478 on Chocolate Bayou Tidal (AU 1107_01)

Section 4. TMDL Allocation Analysis

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 needed and as a criterion against which to evaluate future conditions.

The endpoint for the TMDL is to maintain the concentration of *E. coli* in freshwater and Enterococci in tidal waters below the geometric mean criterion of 126 cfu/100 mL or 35 cfu/100 mL, which is protective of the primary contact recreation 1 use in freshwater and saltwater, respectively.

4.2. Seasonal Variation

Seasonal variations occur when there is a cyclic pattern in streamflow and, more importantly, in water quality constituents. TMDLs must account for seasonal variation in watershed conditions and pollutant loading, as required by federal regulations [Title 40, Code of Federal Regulations, Chapter 1, Part 130, Section 130.7(c)(1) (or 40 CFR 130.7(c)(1))]. To evaluate potential seasonal difference, ambient monitoring data for Chocolate Bayou was grouped into a cool season (November–March) and a warm season (May–September). Data collected in April and October were excluded, assuming those months are transitions between the two seasons. Using a variety of statistical analyses (e.g., Wilcoxon rank analysis, ANOVA/Kruskal-Wallis) yielded no seasonal significant difference in indicator bacteria between cool and warm weather seasons.

4.3. Linkage Analysis

Establishing the relationship between instream water quality and the source of loadings is an important component in developing a TMDL. It allows for the evaluation of management options that will achieve the desired endpoint. The relationship may be established through a variety of techniques.

Generally, if high bacteria concentrations are measured in a water body at low to median flows in the absence of runoff events, the main contributing sources are likely to be point sources and direct deposition (such as direct fecal deposition into the water body). During ambient flows, these inputs to the system will increase pollutant concentrations depending on the magnitude and concentration of the sources. As flows increase in magnitude, the impact of point sources like direct deposition is typically diluted, and would, therefore, be a smaller part of the overall concentrations.

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

LDCs were used to examine the relationship between instream water quality and the source of indicator bacteria loads. Inherent to the use of LDCs as the mechanism of linkage analysis is the assumption of a direct relationship between pollutant load sources (regulated and unregulated) and instream loads. Further, this one-to-one relationship was inherently assumed when using LDCs to define the TMDL pollutant load allocation (Section 4.7). That allocation was based on the flows associated with the watershed areas under stormwater regulation, and the remaining portion was assigned to the unregulated stormwater.

4.4. Load Duration Curve Analysis

LDC analyses were used to examine the relationship between instream water quality and the broad sources of indicator bacteria loads, and they are the basis of the TMDL allocations. The strength of this TMDL is the use of the LDC method to determine the TMDL allocations. An LDC is a simple statistical method that provides a basic description of the water quality problem. This tool is easily developed and explained to stakeholders and uses available water quality and flow data. The LDC method does not require any assumptions about loading rates, stream hydrology, land use conditions, and other conditions in the watershed. The EPA supports the use of this approach to characterize pollutant sources. In addition, many other states are using this method to develop TMDLs.

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

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

At TCEQ SWQM Station 11484, the LDC modeled from observed data exceeds the curve representing the geometric mean maximum in all but the dry and low flow conditions (Figure 12). This indicates that nonpoint sources are influencing the bacteria impairment at this site. While reduction strategies targeting improvement of nonpoint source pollutants will benefit this site more directly, improvements to both point and nonpoint source loading will positively affect the watershed.

At TCEQ SWQM Station 11478, the LDC modeled from observed data exceeds the curve representing the geometric mean maximum in all flow conditions (Figure 13). This indicates that point and nonpoint sources are influencing the bacteria impairment at this site. Reduction strategies targeting improvement of point and nonpoint source pollutants will benefit this site more directly.

4.5. Margin of Safety

The margin of safety (MOS) is used to account for uncertainty in the analysis performed to develop the TMDL and thus provides a higher level of assurance that the goal of the TMDL will be met. According to EPA guidance (EPA, 1991), the MOS can be incorporated in the TMDL using 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.

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 an MOS.

The TMDLs in this report incorporate an explicit MOS of 5%.

4.6. Load Reduction Analysis

According to the LDC analyses, bacteria loads in Chocolate Bayou are well above the SWQS criteria at the high flow condition. Bacteria reductions are needed to meet water quality standards for contact recreation. The elevated levels in the high flow and moist conditions in both tidal and above tidal AUs indicate that nonpoint source bacteria loads are of particular concern in this watershed and should be central to the development of future water quality improvement strategies. However, point sources should also be considered as targets for improvement, as the LDC for TCEQ SWQM Station 11478 results indicated a point source influence on bacteria loads in mid-range, dry, and low flow conditions.

Based on these results, potential reduction targets for Enterococci and *E.coli* loads at each flow condition are detailed in Table 20.

Table 20. Potential indicator bacteria reductions needed by AU

AU	Flow Condition	Exceedance Range	Geometric Mean (cfu/100 mL)	Required Percent Reduction
1107_01	High Flow	(0-10%)	146.35	76.08%
	Moist	(10-40%)	107.32	67.39%
	Mid-Range	(40-60%)	46.91	25.39%
	Dry	(60-90%)	62.18	43.71%
	Low Flow	(90-100%)	15.46	0.00%
1108_01	High Flow	(0-10%)	18,459.29	99.32%
	Moist	(10-40%)	300.19	58.03%
	Mid-Range	(40-60%)	91.68	0.00%
	Dry	(60-90%)	69.13	0.00%
	Low Flow	(90-100%)	27.78	0.00%

[a] The required percent reduction for 1107_01 is calculated from the Enterococci TWQS criterion of 35 cfu/100mL and 1108_01 is calculated from the *E. coli* TWQS criterion of 126 cfu/100mL

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:

$$TMDL = WLA + LA + FG + MOS \quad \text{(Equation 4)}$$

Where:

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

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

FG = loadings associated with future growth from potential 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* or Enterococci, TMDLs are expressed as billion cfu/day, and represent the maximum one-day load the stream can assimilate while still attaining the standards for surface water quality.

4.7.1. Assessment Unit-Level TMDL Calculations

The bacteria TMDL for the water body was developed as a pollutant load allocation based on information from the LDCs for the SWQM stations located within the watershed (Figures 12 and 13).

As discussed in more detail in Section 3, the bacteria LDCs were developed by multiplying each flow value along the FDC by the FIB criterion (126 cfu/100 mL or 35 cfu/100 mL) and by the conversion factor used to represent maximum loading in cfu/day. Effectively, the "Allowable Load" displayed in the LDCs at 5% exceedance (the median value of the high flow regime) is the TMDL.

TMDL (cfu/day) = Criterion * Flow (cfs) * Conversion Factor (Equation 5)

Where:

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

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 FIB that the impaired watershed can receive daily was determined using Eq. 5 based on the median value within the high regime of the FDC (or 5% flow exceedance value) for the corresponding TCEQ SWQM station (Table 21).

Table 21. Summary of allowable loading calculation

AU	Parameter	Criterion (cfu/100mL)	5% Exceedance Flow (cfs)	5% Exceedance Load (cfu/day)	TMDL (Billion cfu/day)
1107_01	Enterococci	35	1,059.388	9.072E+11	907.154
1108_01	*E. coli*	126	556.036	1.714E+12	1,714.082

4.7.2. Margin of Safety Allocation

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

MOS = 0.05 * TMDL (Equation 6)

Using the value of TMDL for the AU provided in Table 21, the MOS may be readily computed by proper substitution into Eq. 6 (Table 22).

Table 22. Margin of Safety calculations

AU	Parameter	Criterion (cfu/100mL)	TMDL[a]	MOS
1107_01	Enterococci	35	907.154	45.358
1108_01	*E. coli*	126	1,714.082	85.704

[a] TMDL from Table 21

4.7.3. Wasteload 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}).

$$WLA = WLA_{WWTF} + WLA_{SW} \quad \text{(Equation 7)}$$

4.7.3.1. Wastewater

TPDES-permitted WWTFs are allocated a daily wasteload (WLA_{WWTF}) calculated as their full permitted discharge flow rate multiplied by the instream geometric criterion. Thus, WLA_{WWTF} is expressed in the following equation:

$$WLA_{WWTF} = Target * Flow * Conversion Factor \quad \text{(Equation 8)}$$

Where:

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

Flow = full permitted flow (MGD)

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

Using Equation 8, each WWTF's allowable loading was calculated using the permittee's full permitted flow. The individual results were summed for each AU. The criterion was applied based on the indicator bacteria designated for the segment. To account for the contribution of upstream WWTFs, WLA_{WWTF} for AU 1107_01 includes WWTF loading from AU 1108_01 using 35 cfu/100mL as the criterion. Table 23 presents the WLA for each WWTF and provides a total WLA_{WWTF} for each AU.

Table 23. WLAs for TPDES-permitted facilities

AU	TPDES Number	Permittee	Bacteria Limit (cfu/100 mL)	Full Permitted Flow (MGD)	WLA_{WWTF} (billion cfu/day *E. coli*)	WLA_{WWTF} (billion cfu/day Enterococci)
1107_01	WQ0000001000	Ascend Performance Materials Chocolate Bayou Plant	35 (Enterococci)	4.000	-	5.299
1107_01	WQ0014324001	Weybridge WWTF	35 (Enterococci)	0.050	-	0.066
1107_01	WQ0015657001	St. Ives RV Resort LCC	35 (Enterococci)	0.015	-	0.020
Subtotal for 1107_01				4.065	-	5.386
Subtotal for 1108_01				12.314	-	16.315
Total				**16.379**	**-**	**21.700**
1108_01	WQ0010700001	Oak Manor MUD WWTF	126 (*E. coli*)	0.080	0.382	0.106

AU	TPDES Number	Permittee	Bacteria Limit (cfu/100 mL)	Full Permitted Flow (MGD)	WLA_{WWTF} (billion cfu/day *E. coli*)	WLA_{WWTF} (billion cfu/day Enterococci)
1108_01	WQ0012780001	Southwood Estates WWTF	126 (*E. coli*)	0.400	1.908	0.530
1108_01	WQ0013367001	City of Arcola WWTF	126 (*E. coli*)	0.950	4.531	1.259
1108_01	WQ0013872001	City of Manvel WWTF	126 (*E. coli*)	0.500	2.385	0.662
1108_01	WQ0014068001	RiceTec WWTF	126 (*E. coli*)	0.025	0.119	0.033
1108_01	WQ0014149001	Savannah Plantation WWTF	126 (*E. coli*)	0.200	0.954	0.265
1108_01	WQ0014222001	Brazoria County MUD 21 WWTF	126 (*E. coli*)	1.200	5.724	1.590
1108_01	WQ0014253001	Rodeo Palms WWTF	126 (*E. coli*)	0.450	2.146	0.596
1108_01	WQ0014279001	Palm Crest WWTF	126 (*E. coli*)	0.150	0.715	0.199
1108_01	WQ0014461001	Brazoria County MUD 30 WWTF	126 (*E. coli*)	0.500	2.385	0.662
1108_01	WQ0014497001	O'Day Investments CR 81	126 (*E. coli*)	0.099	0.472	0.131
1108_01	WQ0014546001	Brazoria County MUD 31 WWTP	126 (*E. coli*)	2.000	9.539	2.650
1108_01	WQ0014724002	Brazoria County MUD 56 WWTP	126 (*E. coli*)	0.995	4.746	1.318
1108_01	WQ0014724003	Brazoria County MUD 55 WWTF	126 (*E. coli*)	0.980	4.674	1.298
1108_01	WQ0014992001	Glendale Lakes Subdivision WWTP	126 (*E. coli*)	0.700	3.339	0.927
1108_01	WQ0015093001	Lacovia Lakes WWTF	126 (*E. coli*)	0.950	4.531	1.259
1108_01	WQ0015279001	Brazoria County MUD 43 WWTF	126 (*E. coli*)	0.300	1.431	0.398
1108_01	WQ0015486001	Brazoria County MUD 42 WWTF	126 (*E. coli*)	0.615	2.933	0.815
1108_01	WQ0015582001	Arcola Estates WWTF	126 (*E. coli*)	0.075	0.358	0.099
1108_01	WQ0015637001	Charleston MUD WWTF	126 (*E. coli*)	0.245	1.169	0.325
1108_01	WQ0015714001	Sierra Vista West WWTF	126 (*E. coli*)	0.900	4.293	1.192
Total				**12.314**	**58.733**	**16.315**[a]

[a] The Enterococci values for AU 1108_01 were calculated for use in the WLA_{WWTF} for downstream AU 1107_01

4.7.3.2. Regulated Stormwater (WLA_{SW})

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

The percentage of the land that is under the jurisdiction of stormwater permits in the TMDL watershed was 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 was calculated as follows:

$$WLA_{SW} = (TMDL - WLA_{WWTF} - FG - MOS) * FDA_{SWP} \qquad \text{(Equation 9)}$$

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 fractional proportion of the drainage area under the jurisdiction of stormwater permits (FDA_{SWP}) must be determined to estimate the amount of overall runoff load that should be allocated to WLA_{SW}. The term FDA_{SWP} was calculated based on the combined area under regulated stormwater permits. The stormwater sources and how the regulated areas were estimated was discussed in prior sections. Those area estimates were summed for each category and used for Table 24.

The stormwater categories were then summed to determine the total area under stormwater jurisdiction in each AU. To arrive at the proportion, the area under stormwater jurisdiction was divided by the total watershed area. FDA_{SWP} for AU 1107_01 accounts for the upstream watershed contribution by adding the total area under permit for both the AUs 1107_01 and 1108_01 watersheds and dividing by the total watershed area of both AUs.

Table 24. Basis of unregulated stormwater area and computation of FDA_{SWP} term

Watershed	AU	MS4 Area	MSGP Area	CGP Area	Concrete Production Facilities	Total Area of Permits	Watershed Area	FDA_{SWP}
Chocolate Bayou Tidal	1107_01	0.00	2,301.70	510.00	0.00	23,520.50	110,829.648	21.222%
Chocolate Bayou Above Tidal	1108_01	9,138.74	344.16	11,213.77	12.13	20,708.80	88,098.568	23.506%

All areas are expressed in acres

The daily allowable loading of *E. coli* or Enterococci assigned to WLA_{SW} was determined based on the combined area under regulated stormwater permits. To calculate the WLA_{SW} (Equation 9), the future growth (FG) term must be known. The calculation for that term is presented in the next section, but the results are included here for continuity. Table 25 provides the information needed to compute WLA_{SW}.

Table 25. Regulated stormwater calculations

AU	TMDL[a]	MOS[b]	WLA_{WWTF}[c]	FG[d]	FDA_{SWP}[e]	WLA_{SW}[f]
1107_01	907.154	45.358	21.700	89.534	21.222%	159.286
1108_01	1,714.082	85.704	58.733	322.063	23.506%	293.261

[a] TMDL from Table 21

[b] MOS from Table 22

[c] WLA_{WWTF} for 1107_01 is the sum of WLA_{WWTF} of 1107_01 and 1108_01 from Table 23

[d] FG from Table 27

[e] FDA_{SWP} from Table 24

[f] $WLA_{SW} = (TMDL - WLA_{WWTF} - FG - MOS) * FDA_{SWP}$ (Equation 9)

Now that the WLA_{sw} has been calculated using the term WLA, Equation 7 can be solved, and the results presented in Table 26.

Table 26. Wasteload calculations

AU	Criterion (cfu/100mL)	WLA_{WWTF}[a]	WLA_{SW}[b]	WLA
1107_01	35	21.700	159.286	180.986
1108_01	126	58.733	293.261	351.995

[a] WLA_{WWTF} for 1107_01 is the sum of WLA_{WWTF} of 1107_01 and 1108_01 from Table 23

[b] WLA_{SW} is from Table 25

4.7.4. Future Growth

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

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

The FG component was based on population projections and current permitted wastewater dischargers for the entire TMDL watershed. Recent population and projected population growth between 2020 and 2045 for the TMDL watershed are provided in Table 27. The projected population percentage increase within the watersheds was multiplied by the corresponding WLA_{WWTF} to calculate future WLA_{WWTF}. The permitted flows were increased by the expected population growth per AU between 2020 and 2045 to determine the estimated future flows.

Thus, the FG is calculated as follows:

$$FG = Criterion * (\%POP_{2020\text{-}2045} * WWTF_{FP}) * Conversion\ Factor \qquad \text{(Equation 10)}$$

Where:

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

$POP_{2020\text{-}2045}$ = estimated percent increase in population between 2020 and 2045

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

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

The current population growth projection for the AU 1107_01 watershed is zero through 2045 (Table 27). To account for any possible error or changes in this projection and the potential planning of a future development, a hypothetical WWTF was created for the watershed. The basis for this hypothetical WWTF was the recent permit for a recreational vehicle (RV) park, St. Ives RV Resort, within the watershed. St. Ives RV Resort's WWTF has a permit to discharge a maximum of 0.015 MGD. This value was used for the hypothetical WWTF (Table 27).

The FG calculation results for the impaired TMDL watershed are shown in Table 27.

Table 27. FG calculation

AU	Indicator Bacteria	Criterion (cfu/100 mL)	% Population Change (2020–2045)	Full Permitted Discharge (MGD)	FG (MGD)	FG (Billion cfu/day)
1107_01	Enterococci	35	0.0%[a]	4.065	0.015	89.534[b]
1108_01	*E. coli*	126	548.35%	12.314	67.524	322.063

All loads are expressed in billion cfu/day.

[a] Table 3 lists the population change as -42.21%. Using a negative number in the FG calculation would imply decreased capacity at existing WWTFs. Instead, the percent population change was rounded up to 0.0% in the FG calculation for AU 1107_01

[b] FG in AU 1107_01 is the sum of FG values calculated for each WWTF in AU 1108_01 using Enterococci criterion (35 cfu/100mL) FG values for AU 1107_01 from the hypothetical WWTF with a MGD of 0.015

4.7.5. Load Allocations

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

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

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

The calculation results are shown in Table 28.

Table 28. LA calculation

Load units expressed as billion cfu/day

AU	Criterion (cfu/100 mL)	TMDL [a]	MOS [b]	WLA_{WWTF} [c]	WLA_{SW} [d]	FG [e]	LA [f]
1107_01	35	907.154	45.358	21.700	159.286	89.534	591.276
1108_01	126	1,714.082	85.704	58.733	293.261	322.063	954.320

[a] TMDL from Table 21

[b] MOS from Table 22

[c] WLA_{WWTF} from Table 23

[d] WLA_{SW} from Table 25

[e] FG from Table 26

[f] LA = TMDL – WLA_{WWTF} – WLA_{SW} – FG – MOS (Equation 11)

4.8. Summary of TMDL Calculations

Table 29 summarizes the TMDL calculations for the entire TMDL watershed. The TMDLs were calculated based on the median flow (5%) in the high flow range for flow exceedance from the LDCs developed for TCEQ SWQM stations 11478 and 11484. Allocations are based on the current geometric mean criterion for *E. coli* or Enterococci of 126 cfu/100 mL or 35 cfu/100 mL, respectively, for each component of the TMDL. The TMDL allocation summary for the Chocolate Bayou TMDL watershed is summarized in Table 29.

Table 29. TMDL allocation summary

Load units expressed as billion cfu/day

AU	Criterion (cfu/100mL)	TMDL	MOS	WLA_{WWTF}	WLA_{SW}	LA	FG
1107_01	35	907.154	45.358	21.700	159.286	591.276	89.534
1108_01	126	1,714.082	85.704	58.733	293.261	954.320	322.063

The final TMDL allocation (Table 30) needed to comply with the requirements of 40 CFR 130.7 include the FG component within the WLA_{WWTF}.

Table 30. Final TMDL allocation

Load units expressed as billion cfu/day

AU	Criterion (cfu/100mL)	TMDL	MOS	WLA_{WWTF} [a]	WLA_{SW}	LA
1107_01	35	907.154	45.358	111.234	159.286	591.276
1108_01	126	1,714.082	85.704	380.796	293.261	954.320

[a] WLA_{WWTF} includes the FG component

Section 5. References

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APPENDIX A

Method Used to Determine Population Projections

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

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

Once the new residential units are built, H-GAC's Household Location Choice Model allocates future households to new housing units using the grid-level (3-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 Zone.

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

The following steps detail the method used to estimate the 2020 and projected 2045 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.
4. Obtained population projections for the year 2045 from the H-GAC regional forecast based on H3M data.

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

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

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 2045 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.