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

Assessment Unit: 0801C_01

By Rachel Windham, submitted to TCEQ July 2022

Houston-Galveston Area Council

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Contents

Figures

Tables

Abbreviations

AU	assessment unit
CFR	Code of Federal Regulations
cfs	cubic feet per second
cfu	colony forming unit
CGP	construction general permit
CRP	Clean Rivers Program
DAR	drainage-area ratio
E. coli	*Escherichia coli*
EPA	(United States) Environmental Protection Agency
FDC	flow duration curve
FG	future growth
H-GAC	Houston-Galveston Area Council
IH	Interstate Highway
I&I	inflow and infiltration
LA	load allocation
LDC	load duration curve
MCM	minimum control measure
MGD	million gallons per day
mL	milliliter
MOS	margin of safety
MS4	municipal separate storm sewer system
MSGP	multi-sector general permit
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
OSSF	on-site sewage facility
ppt	parts per thousand
SSO	sanitary sewer overflow
SSURGO	Soil Survey Geographic Database
SWMP	stormwater management program
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
TSSWCB	Texas State Soil and Water Conservation Board
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 its applicable water quality standards. TMDLs are the best possible estimates of the assimilative capacity of the water body for a pollutant under consideration. A TMDL is commonly expressed as a load with units of mass per period of time but may be expressed in other ways.

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 the bacteria impairment within Cotton Bayou in the *2010 Texas Integrated Report of Surface Water Quality for Clean Water Act Sections 305(b) and 303(d)* (Texas Integrated Report, TCEQ, 2010). The bacteria impairment has been identified in each subsequent edition through the Environmental Protection Agency (EPA) approved 2022 Texas Integrated Report (TCEQ, 2022a).

This document will consider one bacteria impairment in one assessment unit (AU) of Cotton Bayou Tidal. The impaired water body and its identifying AU number is shown below:

- Cotton Bayou Tidal 0801C_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 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 are used to assess the risk of illness during contact recreation (e.g., swimming) from ingestion of water. Fecal indicator bacteria are bacteria that are present in the intestinal tracts of humans and other warm-blooded animals. The presence of these bacteria in water indicates that associated pathogens from fecal wastes may be reaching water bodies, because of such sources as inadequately treated sewage, improperly managed animal waste from livestock, pets, aquatic birds, wildlife, and failing septic systems (TCEQ, 2018b). Enterococci is a member of the fecal coliform bacteria group and is used in the state of Texas as the fecal indicator bacteria in tidal water bodies.

On February 7, 2018, TCEQ adopted revisions to the *Texas Surface Water Quality Standards* (TCEQ, 2018a) and on May 19, 2020, the U.S. EPA approved the categorical levels of recreational use and their associated criteria. Recreational use consists of several categories:

- **Primary contact recreation 1** – Activities that are presumed to involve a significant risk of 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 colony forming units (cfu) per 100 milliliters (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.

Cotton Bayou Tidal is a tidal stream and has a primary contact recreation 1 use. The associated criterion for Enterococci is a geometric mean of 35 cfu per 100 mL.

1.3. Report Purpose and Organization

The Cotton Bayou Tidal 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 TMDL for the impaired AU. This report contains:

- Information on historical data.
- Watershed properties and characteristics.
- Summary of historical bacteria data that confirm the State of Texas 303(d) listings of impairment due to presence of Enterococci.
- Development of a load duration curve (LDC).
- Application of the LDC approach for developing the pollutant load allocation.

Whenever feasible, the data development and computations used to develop the LDC and pollutant load allocation remained consistent with the previously completed Watershed Characterization Report (H-GAC, 2020).

Section 2. Historical Data Review and Watershed Properties

2.1. Description of Study Area

The watershed area for Cotton Bayou is near the northern border of Galveston Bay and is bisected by Interstate Highway (IH) 10 in Chambers County, Texas (Figure 1). Though Cotton Bayou was considered to be tidally influenced along its full length as recently as 2020, analyses conducted for the development of the Watershed Characterization Report (H-GAC, 2020) revealed that ambient conditions and biological assessments upstream of a point 0.7 miles from the confluence of Cotton Lake were more characteristic of an above-tidal stream. Therefore, tidal (0801C, AU 0801C_01) and above tidal (0801E, AU 0801E_01) reaches are now recognized in Cotton Bayou. Despite this distinction, all references to the Cotton Bayou or Cotton Bayou Tidal (0801C_01) watershed pertain to the drainage area of the full length of the waterbody including the above tidal reach (0801E_01). These reaches of Cotton Bayou, and its principal tributary Hackberry Gully, are the main water bodies in the 16.2-square-mile watershed area.

Cotton Bayou Tidal is designated as an unclassified water body, which qualifies it as a tributary to a primary, classified segment—in this case Segment 0801, Trinity River Tidal. The impaired reach of Cotton Bayou Tidal (0801C_01) makes up only 0.7 miles of the 5.4 miles of total stream length.

Much of the stream network in the Cotton Bayou watershed consists of modified channels; however, Cotton Bayou itself, as well as its principal tributary, Hackberry Gully, are more natural waterways. The Cotton Bayou watershed drains into Cotton Lake, where the terminal end of Cotton Bayou forms a confluence with the lake. In turn, Cotton Lake receives tidal exchange that ultimately influences Cotton Bayou.

Most of the land in the watershed is cultivated, grassland, and woody; however, development is increasing near Mont Belvieu and other areas experiencing the effects of urban sprawl. This pressure, as well as compounding stresses associated with cultivation and natural pollution, has impacted the water quality in the watershed and will continue to pose challenges as development increases in this region.

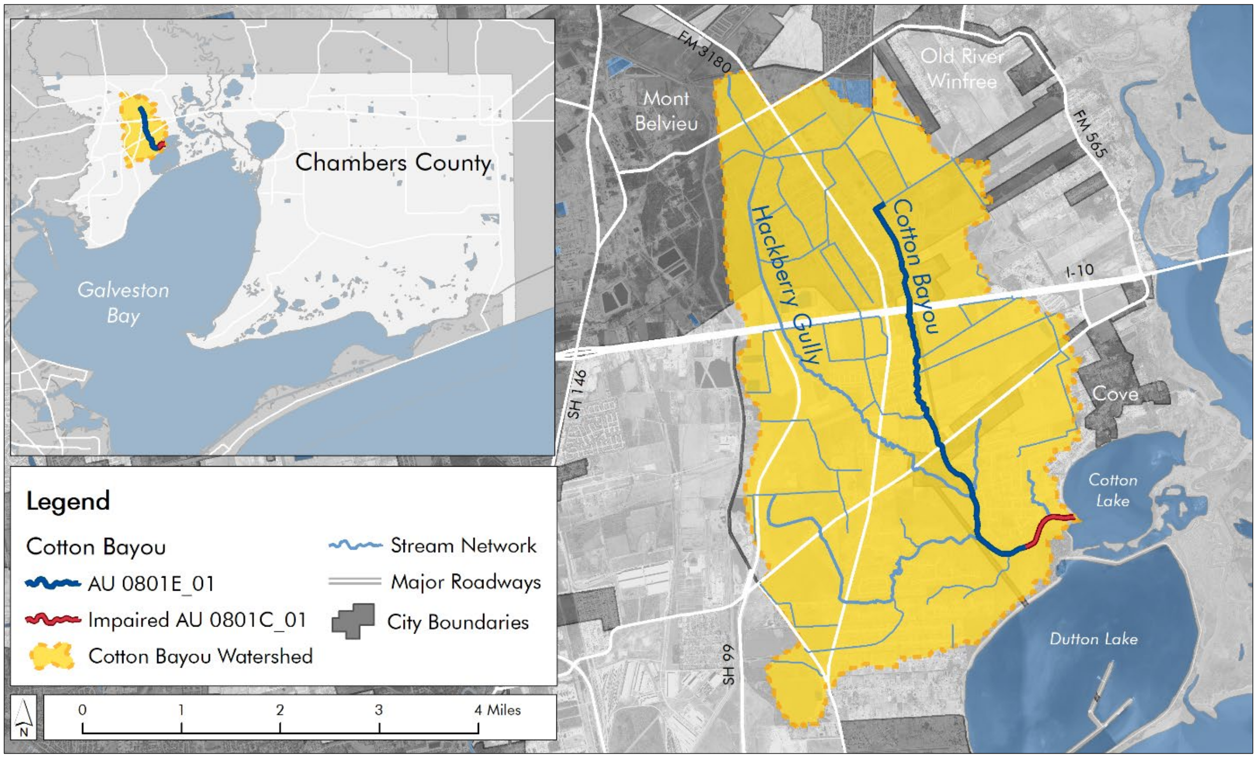

Figure 1. Map of the Cotton Bayou watershed

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

- Cotton Bayou Tidal 0801C (AU 0801C_01) – From the confluence of Cotton Lake southeast of Mont Belvieu to a point upstream 1.19 kilometers (0.74 miles) near The Plantation neighborhood in Chambers County.

2.2. Review of Routine Monitoring Data

2.2.1. Analysis of Bacteria Data

Cotton Bayou (0801C_01; now Cotton Bayou Tidal) was first identified as impaired in the 2010 Texas Integrated Report for recreation use due to high levels of bacteria. A summary of the impairment identified in the 2022 Texas Integrated Report, the most recent TCEQ- and EPA-approved edition at the time of this report, is shown in Table 1. This document will investigate the potential sources of fecal waste contributing to elevated bacteria levels in Cotton Bayou Tidal to support the development of strategies to reduce the impairment enough to support the primary contact recreation 1 use.

Table 1. 2022 Texas Integrated Report summary

Watershed	AU	Parameter	TCEQ SWQM[a] Station(s)	No. of Samples	Data Date Range	Geometric Mean (cfu/100 mL)
Cotton Bayou Tidal	0801C_01	Enterococci	18697	20	10/1/2013 to 11/30/2020	81.2

[a] surface water quality monitoring

At the time of this report, TCEQ SWQM stations 22232, 18696, and 18697 are being actively monitored on Cotton Bayou (Figure 2). After analyses conducted during the development of the Watershed Characterization Report (H-GAC, 2020) for Cotton Bayou identified the upstream portion of Cotton Bayou as above tidal, TCEQ SWQM Station 18696 is now monitored for the freshwater fecal indicator bacteria, *Escherichia coli* (*E. coli*). TCEQ SWQM Station 22232 was newly established as of 2020 and is also monitored for *E. coli*. In this report, data from TCEQ SWQM stations 18696 and 18697 will be evaluated for trends in Enterococci.

Though TCEQ SWQM Station 18696 is now being assessed for *E. coli*, there is an extensive historical record of Enterococci measurements available for this site. Comparing these results to those of TCEQ SWQM Station 18697 will produce a more complete analysis of actively monitored sites with long-term data records to ensure good representation of ambient conditions, and context for how conditions have changed over time. Note that Enterococci can be used as a fecal indicator in freshwater, although the State of Texas does not currently do so. Enterococci samples taken at TCEQ SWQM Station 18696, even though it is freshwater, are still valid for comparison.

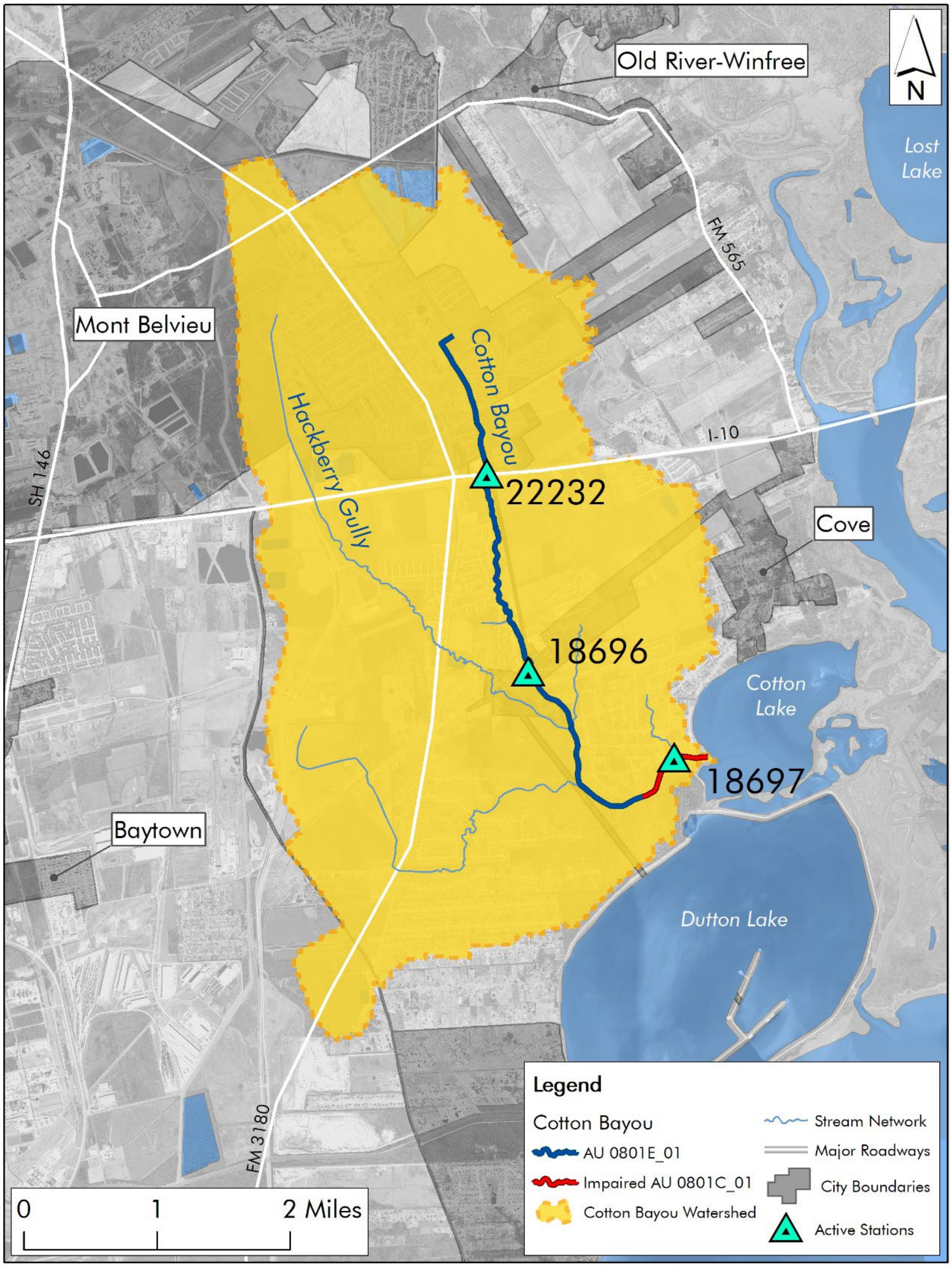

Figure 2. Active TCEQ SWQM stations

Cotton Bayou, 0801C_01, has been considered impaired for bacteria levels since 2010. The EPA-approved 2020 Texas Integrated Report notes the Enterococci geometric mean for this water body from 12/1/2011 through 11/30/2018 as 137.41 cfu/100 mL (TCEQ, 2020). Because TCEQ's Surface Water Quality Monitoring Information System (SWQMIS) dataset examined in this report covers a longer period of study (October 2006 through October 2020), the geometric means calculated for the span of the dataset (Table 2) differ from the IR but continue to exceed the water quality criterion. The results of quarterly Enterococci measurements for TCEQ SWQM stations 18696 (now considered to be on Cotton Bayou Above Tidal) and 18697 (now the sole TCEQ SWQM station on Cotton Bayou Tidal) are shown in Figure 3 and are marked by a highly variable range of values.

Table 2. Enterococci results by SWQM station

Station	Number of Enterococci Samples	Maximum Value (cfu/100 mL)	Geometric Mean
18696	39	24,000	310.4
18697	44	24,192	121.0

Prior to 2020, water quality data for Cotton Bayou were spatially limited to the downstream portion. However, due to the recent establishment of TCEQ SWQM Station 22232, water quality is now being collected upstream north of IH 10. This station is monitored for *E. coli* due to its location in an above-tidal reach and does not have a record of Enterococci measurements to directly compare to TCEQ SWQM stations 18696 or 18697. However, early observations of bacteria levels above the geometric mean criterion for *E. coli* (126 cfu/100 mL) at TCEQ SWQM Station 22232 (Table 3) could indicate that water quality impairments related to fecal waste persist throughout the full length of the bayou. Cotton Bayou Above Tidal (0801E_01) has not been listed as impaired in the Texas Integrated Report since, at the time of this report, there is not enough data collected to perform an assessment.

Table 3. *E. coli* results by SWQM station

Station	Number of *E. coli* Samples	Maximum Value (cfu/100 mL)	Geometric Mean
22232	4	7,300	947.7

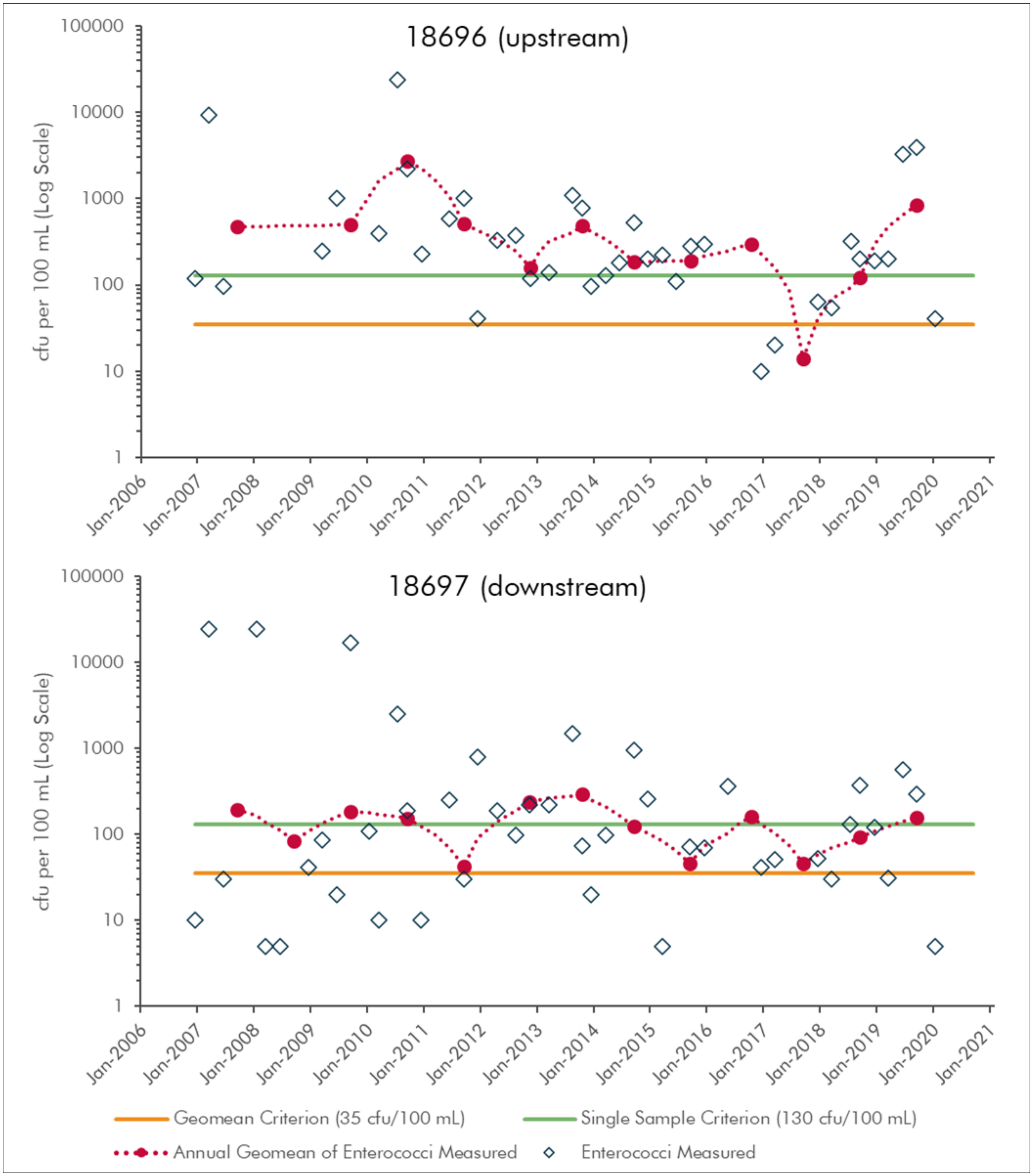

Figure 3. Enterococci measurements at TCEQ SWQM stations 18696 and 18697

2.3. Climate and Hydrology

The National Oceanic and Atmospheric Administration (NOAA) operates a weather station in the City of Baytown near the Cotton Bayou watershed. From this station (GHCND:USC00410586), daily, monthly, and annual averages for weather parameters including temperature and precipitation have been assessed for the period from 2006 through 2020 (NOAA, 2018). From this dataset, the estimate for mean annual precipitation in the region is 65.5 inches. Though this dataset includes measurements recorded during the statewide drought that peaked in 2011, mean monthly rainfall was greater than 3.0 inches for each month. Mean monthly precipitation ranged from a minimum of 3.2 inches in February to a maximum of 8.3 inches in August (Figure 4). The driest months typically occurred in late winter or early spring, and the wettest periods in summer.

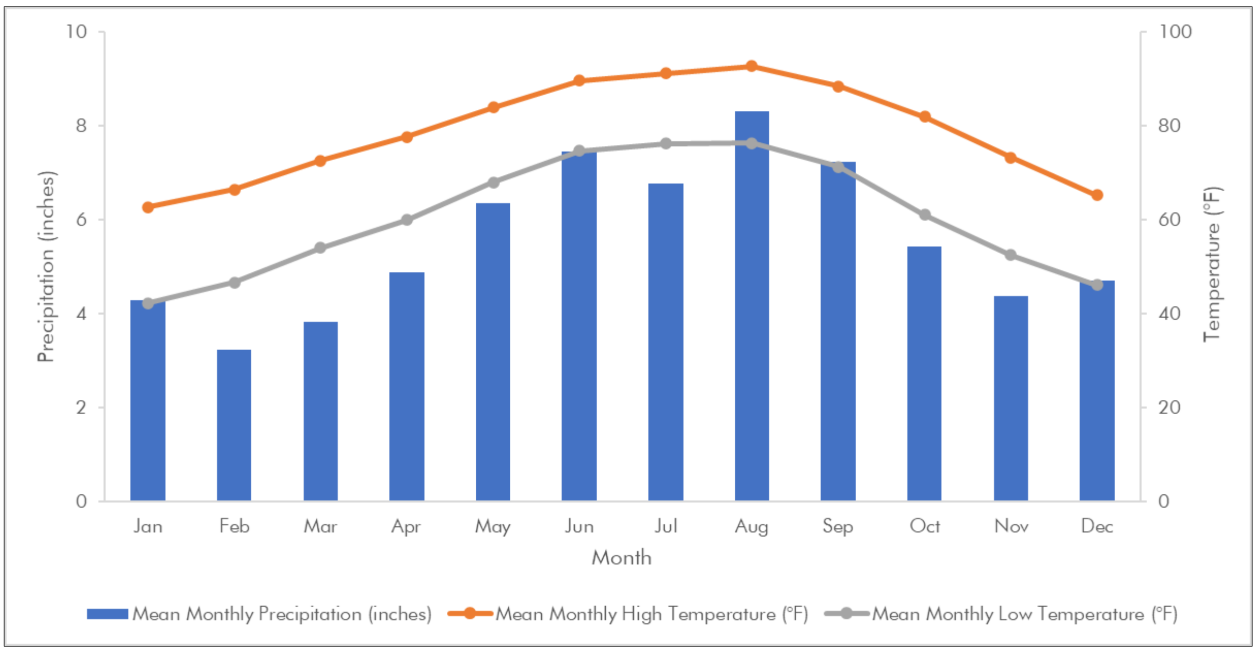

Figure 4. Mean monthly temperature and precipitation, NOAA Station GHCND:USC00410586

Precipitation numbers in the Cotton Bayou watershed and the greater Houston area are increasingly impacted by severe storms associated with flooding in the late spring and hurricane season (Table 4).

Table 4. One-day observations of precipitation ≥ 4.0 inches near the Cotton Bayou watershed since 2015

Date	Observed Precipitation (inches)	Associated Storm Event
5/26/2015	6.4	“Memorial Day Flood”
10/25/2015	7.2	Hurricane Patricia
4/18/2016	4.0	“Tax Day Flood”
8/27/2017	16.6	Hurricane Harvey
8/28/2017	12.7	Hurricane Harvey
8/29/2017	11.9	Hurricane Harvey
9/20/2019	4.1	Tropical Storm Imelda

Temperatures in the Cotton Bayou watershed are consistent with subtropical coastal areas. At NOAA Station GHCND:USC00410586 (Baytown, TX), the annual mean temperature was estimated to be 69.3˚F from an average of mean monthly values recorded from 2006 through 2020. Winters are generally mild, and January is typically the coolest month of the year, with an average low temperature of 42.2˚F. August tends to be the warmest month, with an average high temperature of 92.8˚F.

2.4. Population and Population Projections

H-GAC, through its Regional Growth Forecast, routinely assesses the region’s population and develops population projections. H-GAC uses the United States Census decadal survey or in the intervening years, the American Community Survey, to estimate populations of census block groups. As of 2018, the population of the Cotton Bayou watershed area was approximately 8,598, (H-GAC, 2018). This data was further used to estimate households in the Cotton Bayou watershed at 3,037 in 2018. Regional Growth Forecast methodology (H-GAC, 2017) was used to estimate regional population and household growth out to the year 2045. According to these projections, the population of the Cotton Bayou watershed could increase to approximately 20,011, representing 7,288 households, by the year 2045. Overall, this would represent a 132.74% increase in population, or a net gain of 11,413 residents between 2018 and 2045 (Table 5). See Appendix A for more information.

Table 5. 2018 – 2045 population projection

Location	2018 Population	2045 Population Projection	Projected Population Increase (2018–2045)	Percentage Change
TMDL Watershed	8,598	20,011	11,413	132.74%

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 the IH 10 corridor, the Cotton Bayou watershed has shown evidence of this trend and is expected to continue to expand development in the coming years.

In 2018, H-GAC used LANDSAT imagery to categorize the Houston-Galveston region into 10 classes of land cover (H-GAC, 2019). The definitions for the ten land cover types are as follows:

- **Developed - High Intensity** - 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.
- **Developed - Medium Intensity** - Contains area with mixture of constructed materials and vegetation or other cover. Constructed materials account for 50 to 79% of the total area. This class commonly includes multi- and single-family housing areas, especially in suburban neighborhoods, but may include all types of land use.
- **Developed - Low Intensity** - Contains areas with a mixture of constructed materials and substantial amounts of vegetation or other cover. Constructed materials account for 21 to 49% of total area. This subclass commonly includes single-family housing areas, especially in rural neighborhoods, but may include all types of land use.
- **Developed - Open Space** - Contains areas with a mixture of some constructed materials, but mostly managed grasses or low-lying vegetation planted in developed areas for recreation, erosion control, or aesthetic purposes. These areas are maintained by human activity such as fertilization and irrigation, are distinguished by enhanced biomass productivity, and can be recognized through vegetative indices based on spectral characteristics. Constructed surfaces account for less than 20% of total land cover.
- **Cropland** - Contains areas intensely managed to produce annual crops. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled.
- **Pasture/Grassland** - This is a composite class that contains both Pasture/Hay lands and Grassland/Herbaceous.
    a. *Pasture/Hay* - Contains areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay

crops, typically on a perennial cycle and not tilled. Pasture/hay vegetation accounts for greater than 20% of total vegetation.

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

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

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

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

- **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/Shrubs* - 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* - Includes 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 Wetlands* - 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 Wetlands* - 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 Wetlands (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 Wetlands* - 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 Wetlands* - 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 Wetlands* - 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.

In Figure 5, this assessment is shown specifically for the Cotton Bayou watershed area. Table 6 below summarizes the results of this assessment by showing how much area, by percentage and acreage, each of the ten land cover categories contributes to the total area of the watershed. Just over half (55.4%) of the watershed area is considered “natural” or otherwise undeveloped (open water, barren land, forests and shrubland, pasture and grassland, and wetlands).

Of the developed area, low intensity developments, including residential structures, make up the largest land cover contribution (23.8%). However, according to the growing population projections referenced in Table 5, developed areas are predicted to expand and shift the balance of land cover types in the coming decades.

Table 6. Land cover classification by area and percentage

Land Cover Category	Area (acres)	% of Total Land Cover
Open Water	191.4	1.8%
Developed – High Intensity	218.2	2.1%
Developed – Medium Intensity	320.7	3.1%
Developed – Low Intensity	2,467.5	23.8%
Developed – Open Space	691.9	6.7%
Barren Land	140.6	1.4%
Forest/Shrubs	1,174.7	11.3%
Pasture/Grassland	2,593.3	25.1%
Cropland	919.6	8.9%
Wetlands	1,633.0	15.8%
Total	**10,350.9**	**100.0%**

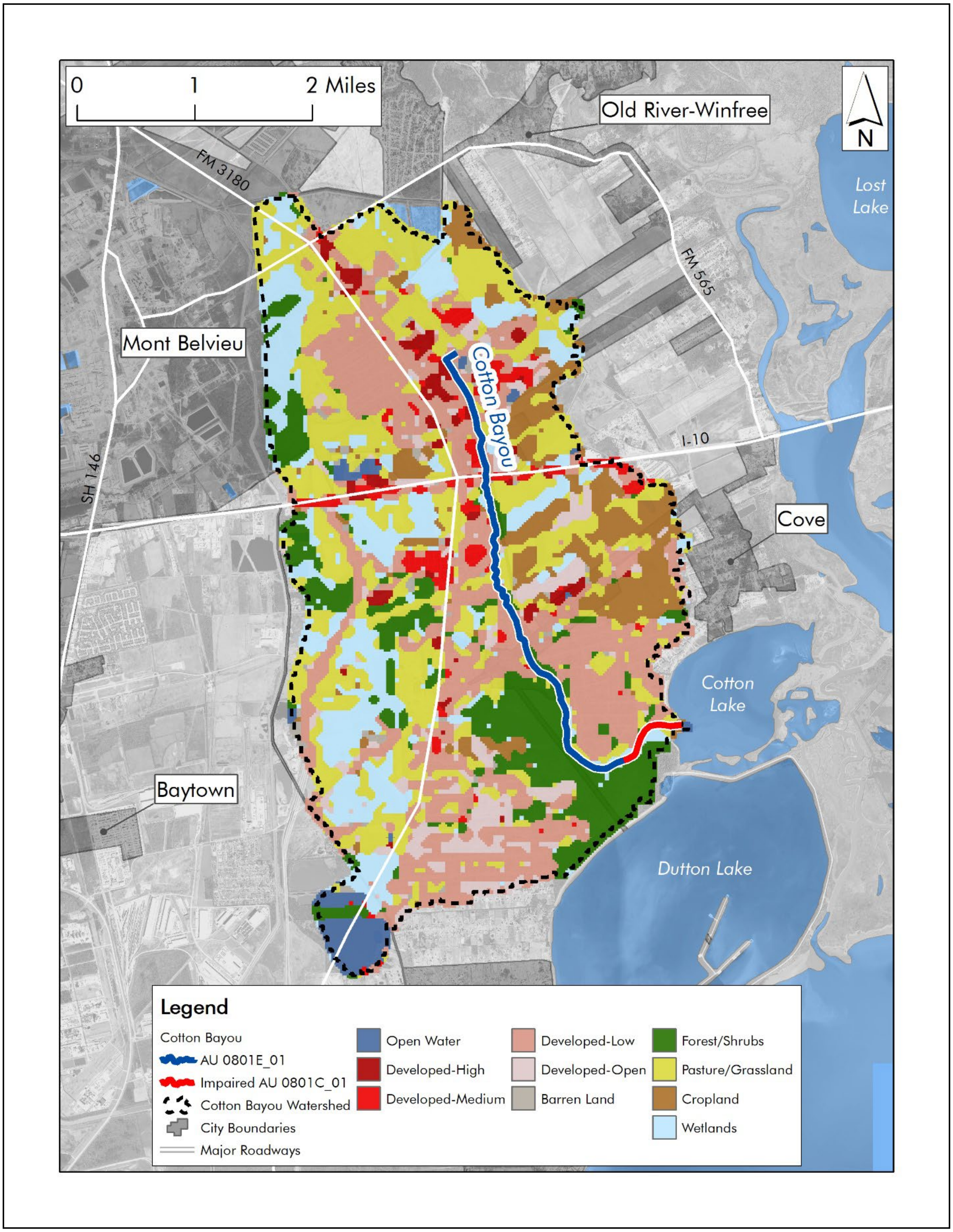

Figure 5. Land cover map showing classifications

2.6. Soils

Soils within the Cotton 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 Cotton Bayou watershed range from fine to fine-silty with the majority of the watershed area covered by soil with very slow infiltration rates (Figure 6). The soil types are clayey and loamy and transition from acidic-neutral in the northern reaches to neutral-alkaline and saline with increasing proximity to Galveston Bay.

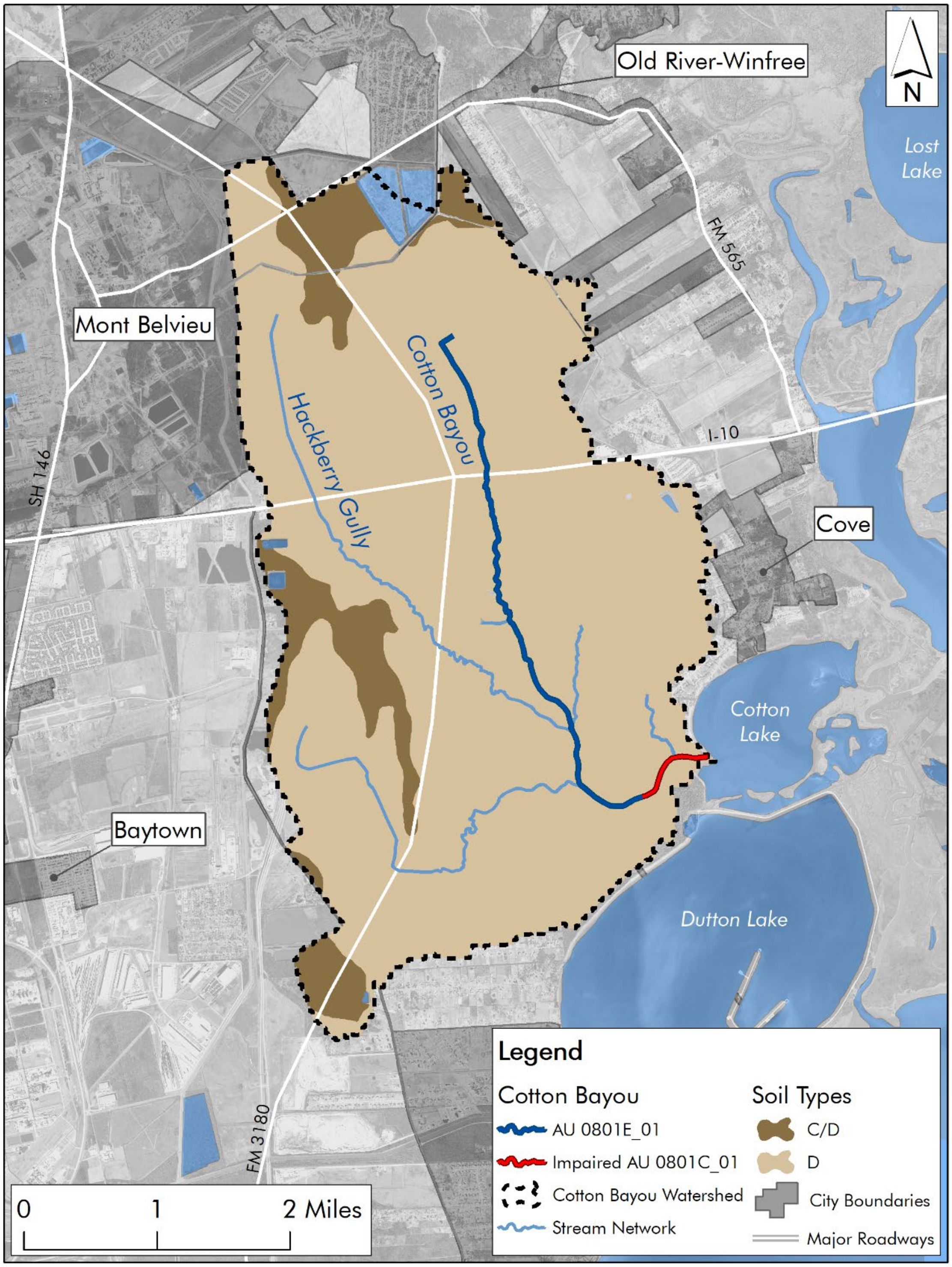

Figure 6. Hydrologic soil group categories

2.7. Potential Sources of Fecal Indicator Bacteria

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

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

Except for WWTFs, which receive individual wasteload allocations (WLAs) (see the "WLA" section), the regulated and unregulated sources in this section are presented to give a general account of the different sources of bacteria expected in the watershed. These are not meant to be used for allocating bacteria loads or interpreted as precise inventories and loadings.

2.7.1. Regulated Sources

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

2.7.1.1. Domestic and Industrial Wastewater Treatment Facilities

There are six domestic WWTF permittees in the Cotton Bayou watershed that maintain active wastewater discharge permits, including three facilities that have acquired permits but are not yet actively discharging (Table 7, Figure 7). There are no industrial WWTFs in the watershed. This information is based on the EPA's Integrated Compliance Information System (EPA, 2022), TCEQ's Central Registry (TCEQ, 2022b), and TCEQ's Outfall Data Layer (TCEQ, 2022c), last reviewed March 28, 2022. All permits are in the drainage area of 0801E_01. No permits were found in that discharge to 0801C_01. However, the TMDL takes a watershed approach, so these permits are all relevant to the project.

The maximum permitted discharge flows in million gallons per day (MGD) from each facility were recorded for use in development of the TMDL calculation.

Table 7. Permitted domestic WWTFs

Water Body	TPDES/NPDES[a] Number	Facility Name	Permittee	Outfall Number	Primary Discharge Type	Bacteria Limits (cfu/100 mL)	Daily Average Flow – Permitted Discharge (MGD)	Daily Average Flow – Recent Discharge (MGD)[b]
0801E_01	WQ0011109001/ TX0085961	Cotton Bayou Park WWTF	Tiki Leasing Company, Ltd.	1	Domestic Wastewater	35 (Enterococci)	0.032	0.007
0801E_01	WQ0011449001/ TX0066656	Veranda WWTF	Aqua Texas, Inc.	1	Domestic Wastewater	126 (*E. coli*)	0.90	0.219
0801E_01	WQ0014807001/ TX0053317	Cotton Bayou WWTF	City of Mont Belvieu	1	Domestic Wastewater	126 (*E. coli*)	3.0	0.939
0801E_01	WQ0015245001/ TX0135348	Rush Gas Station WWTF	3180 Maverick Investments, LLC	1	Domestic Wastewater	126 (*E. coli*)	0.015	NA[c]
0801E_01	WQ0015887001/ TX0140333	Chambers County Improvement District No. 3 WWTF	Chambers County Improvement District No. 3	1	Domestic Wastewater	126 (*E. coli*)	0.80	NA[c]
0801E_01	WQ0016031001/ TX0141631	Oakville Ranch RV Park and Resort	Parkland Development LLC	1	Domestic Wastewater	126 (*E. coli*)	0.2	NA[c]

[a] NPDES: National Pollutant Discharge Elimination System

[b] Reflects discharges available from October 1, 2015 – September 30, 2020

[c] Permits established but not yet actively discharging

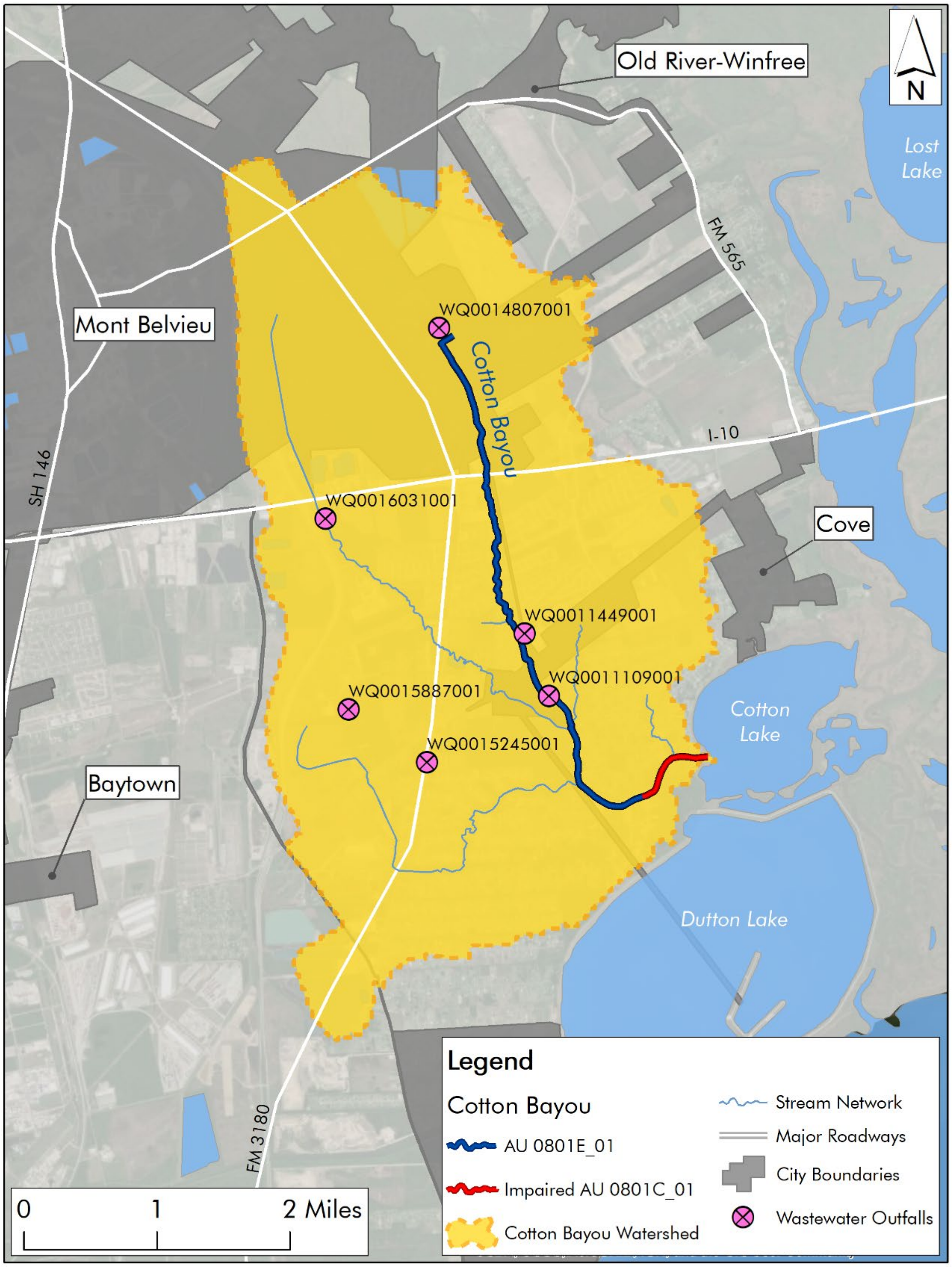

Figure 7. WWTFs in the TMDL watershed

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, 2021) in the Cotton Bayou watershed, as of July 2021, found no active general wastewater permit facilities or operations.

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 activities, and construction activities.
2. Stormwater runoff not subject to regulation.

TPDES MS4 Phase I and II rules require municipalities and certain other entities in 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, while the Phase II General Permit regulates other MS4s within a United States Census Bureau (USCB) defined urbanized area.

The purpose of an MS4 permit is to reduce discharges of pollutants in stormwater to the "maximum extent practicable" by developing and implementing a stormwater management program (SWMP). The SWMP describes the stormwater control practices that the regulated entity will implement, consistent with permit requirements, to minimize the discharge of pollutants. MS4 permits require that SWMPs specify the best management practices to meet several minimum control measures that, when implemented in concert, are expected to result in significant reductions of pollutants discharged into receiving water bodies. The measures for Phase II MS4s 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 minimum control measures that are similar to those for Phase II, but Phase I permits have additional requirements to perform water quality monitoring and implement a floatables program.

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

- TXR040000 – Phase II MS4 General Permit for MS4s 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

Three MS4 permits pertaining to the 3,355.7 acres of USCB urbanized area within the Cotton Bayou watershed were identified (Table 8; Figure 8). No MSGP-regulated facilities are within the Cotton Bayou watershed. Numerous CGP authorizations were found in the Cotton Bayou watershed. Areas authorized under the CGP within the Cotton Bayou watershed but outside of the USCB urbanized area covered a total of 278.9 acres.

Table 8. TPDES MS4 Permits

Regulated Entity	Authorization Type	TPDES Permit No./EPA ID
City of Mont Belvieu	Phase II MS4	General Permit (TXR040000)/ TXR040499
Chambers County	Phase II MS4	General Permit (TXR040000)/ TXR040438
Texas Department of Transportation	Combined Phase I and II MS4	WQ0005011000/TXS002101

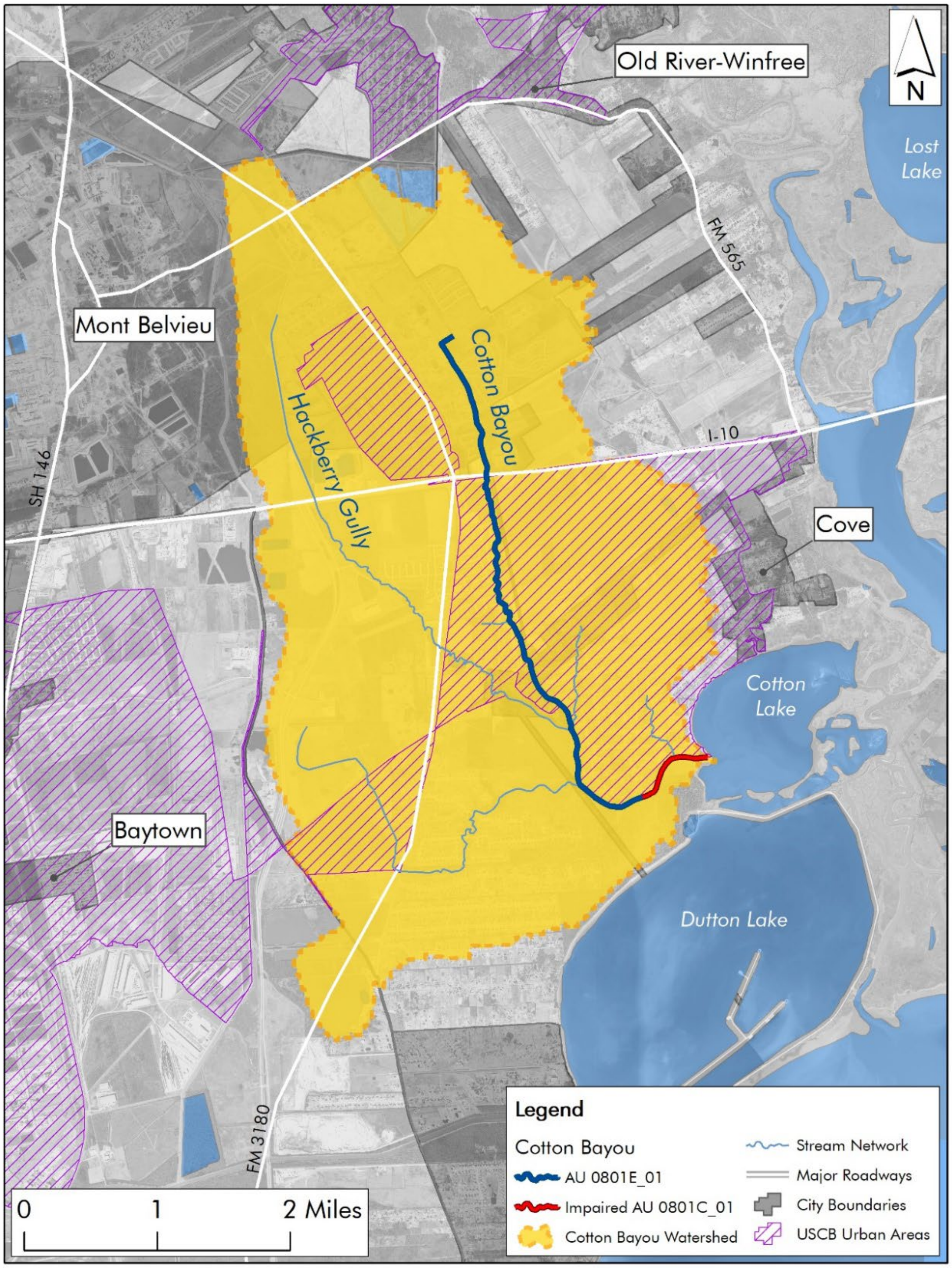

Figure 8. Regulated stormwater areas based on Phase I and Phase II MS4 permits as defined by the urbanized area

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 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. Between 2016 and 2019, nine SSO events were reported. The most common cause cited was equipment failure (e.g., loss of power to lift stations, pump failure) followed by severe weather. Annual SSO volume totaled 1,000 gallons in 2016, 2,943 gallons in 2018, and 1,250 gallons in 2019. No SSOs were reported in 2017.

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 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 Animals

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

Most avian and mammalian wildlife including invasive species are difficult to estimate, as long-term monitoring data or literature values indicating historical baselines are lacking. However, the White-Tailed Deer Program of the Texas Parks and Wildlife Department (TPWD) estimates deer populations for their Resource Management Units. In the ecoregion surrounding Cotton Bayou, TPWD deer population estimates recorded from 2008 through 2019 average one deer for every 216.7 acres (TPWD, 2020). By applying this factor to the acreage in the Cotton Bayou watershed, the deer population is estimated to be 48.

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 water resources. Considering these factors, in addition to insights from local stakeholders, feral hog population estimates were:

- 8.9 per square mile in low intensity development
- 12.7 per square mile in developed open space, barren land, and cropland
- 16.4 per square mile in pasture/grassland, forest/shrubs, and wetlands
- no hogs in other developed areas or open water

Using these assumptions, the total feral hog population of the Cotton Bayou watershed is estimated to be 207. The bacteria contribution from feral hogs and wildlife could not be determined based on existing information.

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.

In Table 9, estimates of livestock in the Cotton Bayou watershed are shown. These estimations were calculated by applying a ratio of suitable land cover area (pasture and grassland) within the watershed land area compared to suitable land cover area within the county to numbers from the 2017 Census of Agriculture for Chambers County performed by the USDA (USDA NASS, 2019). This calculation assumes equal distribution of livestock and farm operations in pasture and grassland land cover types. These livestock numbers are not used to develop an allocation of allowable bacteria loading to livestock.

Table 9. Estimated livestock populations

AU	Cattle and Calves	Hogs and Pigs	Goats and Sheep	Horses
0801C_01	437	1	19	15

Fecal matter from dogs and cats is transported to water bodies by runoff in both urban and rural areas and can be a potential source of bacteria loading. Table 10 summarizes the estimated number of dogs and cats in the TMDL watershed. Pet population estimates were calculated as the estimated number of dogs (0.614) and cats (0.457) per household according to data from the American Veterinary Medical Association 2017-2018 U.S. Pet Statistics (AVMA, 2018). The number of households in the watershed was estimated using 2018 H-GAC Regional Growth Forecast data. The actual contribution and significance of bacteria loads from pets reaching the water bodies of the watershed is unknown.

Table 10. Estimated households and pet populations

AU	Households	Dogs	Cats
0801C_01	3,037	1,865	1,388

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 drainfield of a septic system. Reed, Stowe, and Yanke LLC (2001) provide information on estimated failure rates of OSSFs for different regions of Texas. The Cotton Bayou watershed is within the Region IV area, which has a reported failure rate of about 12%, providing insights into expected failure rates for the area.

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

Within the Cotton Bayou watershed, 439 permitted OSSFs have been documented (Figure 9). To estimate unpermitted OSSFs in the Houston-Galveston area known OSSF locations, county parcel data, and WWTF service boundaries were used to search H-GAC's geographic information database of potential locations. This search revealed another 350 OSSFs to add to the 439 permitted systems for a total of 789 units.

OSSFs can be a source of fecal waste when not sited or functioning properly, especially when they are close to waterways. Many factors including soil type, design, age, and maintenance can influence the likelihood of an OSSF failure. By applying the estimated 12% failure rate to the number of OSSFs estimated in the watershed area, 95 are projected to be failing.

2.7.2.4. Bacteria Survival and Die-off

Bacteria are living organisms that survive and die. Certain enteric bacteria can survive and replicate in organic materials if appropriate conditions prevail (such as warm temperature). Fecal organisms from improperly treated effluent can survive and replicate during their transport in pipe networks, and they can survive and replicate in organic-rich materials such as improperly treated compost and sewage sludge (or biosolids).

While the die-off of indicator bacteria has been demonstrated in natural water systems due to the presence of sunlight and predators, the potential for their 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.

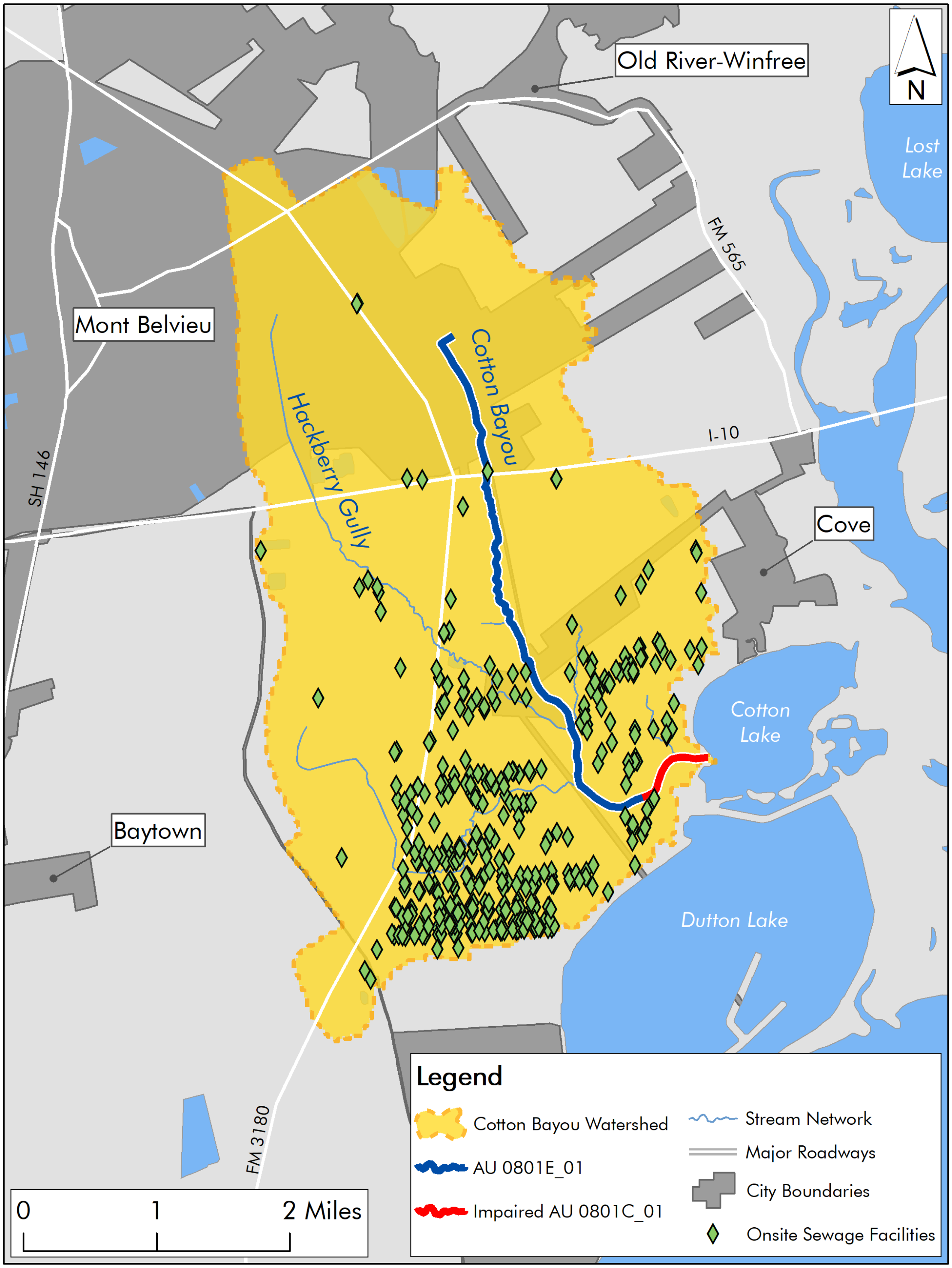

Figure 9. Permitted OSSFs in the TMDL watershed

Section 3. Bacteria Tool Development

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

3.1. Tool Selection

The LDC method allows for the estimation of existing and allowable loads by using the cumulative frequency distribution of streamflow and measured pollutant concentration data (Cleland, 2003). In addition to estimating stream loads, this method allows for the determination of the hydrologic conditions under which impairments are typically occurring. This information can be used to identify broad categories of sources (point and nonpoint) that may be contributing to the impairment.

Texas and other states have successfully used the LDC method to develop TMDLs accepted by the regulatory community due to the method's simplicity and ability to address information limitations commonly found with bacteria TMDLs. The LDC is now 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).

3.2. Data Resources

Except for daily streamflow, Cotton Bayou Tidal data resource availability was sufficient to perform modified LDC analysis in 0801C_01. To do this, daily streamflow, fecal indicator bacteria, and salinity data are required. Streamflow will be discussed further below to address this data limitation.

All the required ambient water quality data (Enterococci and salinity) were adequately available through SWQMIS for 2006 to 2020. The SWQMIS database serves as the repository for TCEQ surface water quality data for the state of Texas. All data used for these analyses were collected under a TCEQ-approved Quality Assurance Project Plan. Data 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 TCEQ SWQM Station 18697 were combined into a working data set for modified LDC development.

Historically, United States Geological Survey (USGS) gage 08067248 corresponded to TCEQ SWQM Station 18697 but has not actively produced flow measurements since 2007. Contextually, this data is important for quantifying what flows have been observed at this station in the past and how they compare to current flows measured on USGS gages on nearby streams. These comparisons led to the selection of USGS gage 08067525 on Goose Creek in Baytown, Texas, as a proxy for modeling stream flow comparable to that of Cotton Bayou. Modeled flow data was further adjusted using a ratio of drainage area upstream of the Goose Creek USGS gage to drainage area upstream of TCEQ SWQM Station 18697 on Cotton Bayou Tidal to be more reflective of the conditions unique to the Cotton Bayou watershed. These methods are based on the more stringent data requirements of other formal watershed-based planning efforts and are therefore sufficient for the conceptual nature of this analysis.

3.3. Method for Developing Flow Duration and Load Duration Curves

To develop the modified flow duration curve (FDC) and LDC, the previously discussed data resources were used in the following sequential steps.

- Step 1: Determine the hydrologic period of record to be used in developing the modified FDC.
- Step 2: Determine the stream location for which modified FDC and LDC development is desired.
- Step 3: Develop daily streamflow record at desired location.
    - Step 3.1: Develop regression of salinity to streamflow for stream location.
    - Step 3.2: Incorporate daily tidal volumes into streamflow record.
- Step 4: Develop FDC at the desired stream location, segmented into discrete flow regimes.
- Step 5: Develop allowable bacteria LDC at the same stream location based on the relevant criteria and the data from the FDC.
- Step 6: Superimpose historical bacteria data on the allowable bacteria LDC.

Cleland (2003) and EPA (2007) explain the LDC method. Find more information about the modified LDC method 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

A period of 14 years between October 2006 and October 2020 was observed to cover a comparable timeframe to the one referenced in the Watershed Characterization Report (H-GAC, 2020) updated by one year. This period covers both drought and flood years as referenced in Section 2.3.

3.3.2. Step 2: Determine Desired Stream Location

Data from TCEQ SWQM Station 18697 will be used to develop the TMDL for 0801C_01. SWQM Station 18697 is within the impaired AU and is actively monitored for Enterococci. However, because there are no established USGS gages in the Cotton Bayou watershed, USGS gage 08067525 on Goose Creek in Baytown, Texas was used as a proxy for modeling stream flow comparable to that of Cotton Bayou (Figure 10).

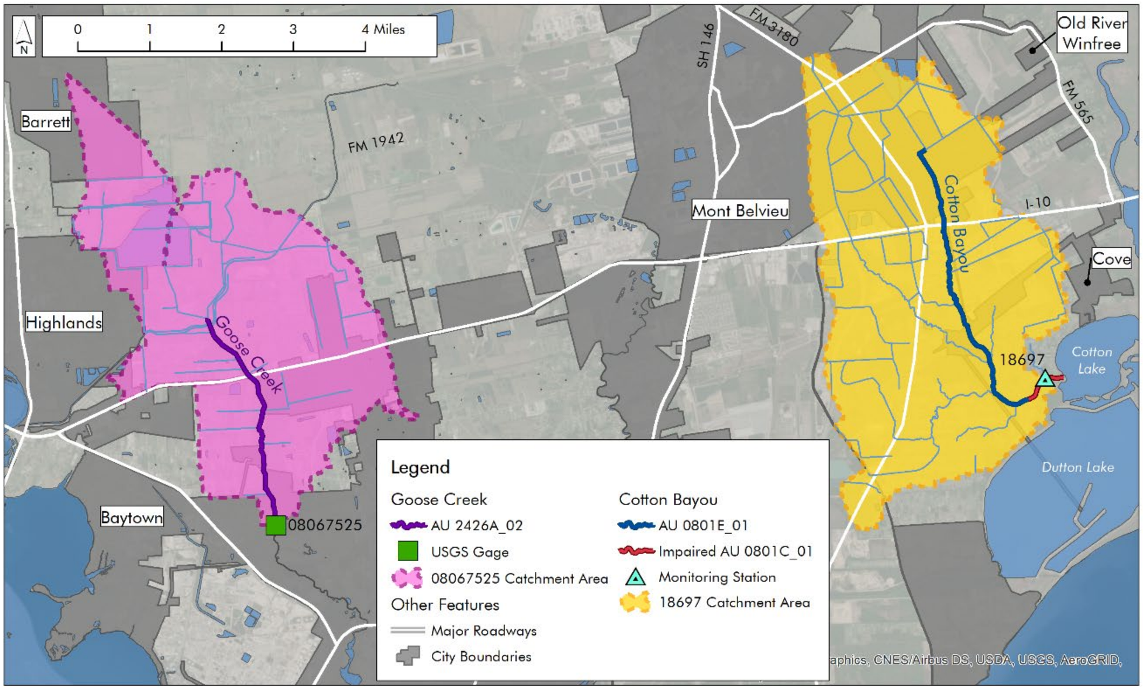

Figure 10. Drainage area comparison for USGS Gage 08067525 and TCEQ SWQM Station 18697

3.3.3. Step 3: Develop Daily Streamflow Record at Desired Location

Flow data from the USGS gauge 08067525 on Goose Creek were “naturalized” by correcting the additions of WWTF discharges, and withdrawals of upstream water rights diversions. As used in this document, naturalized flow is referring to the flow without the additions of permitted discharges and withdrawals from water rights, *i.e.*, the flow that would occur in response to precipitation, evapotranspiration, near-surface geology, soils, land covers of the watershed, and other factors. The naturalized daily streamflow records were developed from extant USGS records.

Two permitted outfalls were identified upstream of USGS gage 08067525. For the 14-year hydrologic period selected for this analysis, WWTF discharge data was available from October 2015 to September 2020. The overall mean DMR reported discharge from each of the WWTF outfalls was subtracted from the daily gauge streamflow records. This resulted in an adjusted streamflow records with the point source discharge influence being removed.

Next, water right consumptions (*i.e.*, the balance between diverted amount and returned flow amount) were researched using the Texas Water Rights Viewer (TCEQ, 2022d). There is one diversion point within the catchment area of the Goose Creek USGS gauge, but it is authorized to divert water from the San Jacinto River (Lake

Houston) to be stored for industrial, municipal, and irrigation use. There is no water diversion from Goose Creek recorded, therefore, no water rights adjustments were applied in flow naturalization.

The daily, freshwater flow values at the station on Cotton Bayou Tidal were calculated based on the adjusted flow values of USGS gage 08067525 and the drainage-area ratio (DAR) method. To compute the DAR, the drainage area above USGS gage 08067525 was compared with the area of the Cotton Bayou watershed contributing to TCEQ SWQM Station 18697 (Table 11). This DAR is then applied to the adjusted daily streamflow measurements from USGS gage 08067525 to determine the estimated daily flow value at 18697.

Table 11. DAR calculations for Cotton Bayou Tidal

Station	Area (acres)	DAR
USGS 08067525	8,777.25	--
TCEQ SWQM 18697	10,219.38	1.16

Following application of the DAR, the most recent five-year average daily flows from WWTFs within the TMDL watershed (Table 7) were added to the streamflow record to account for the estimated actual flow at the monitoring station.

3.3.3.1. Step 3.1: Develop Salinity to Streamflow Regression

FDCs and LDCs are graphs that visualize the percentage of time during which a value of flow or load is equaled or exceeded. The difference in the modified LDC from the traditional approach is the application of salinity in development of the FDC to account for tidal flux in the water body. To develop the modified LDC, quarterly Clean Rivers Program (CRP) Enterococci and salinity measurements from 2006 to 2020 were acquired. Due to the tidal nature of the stream, there were no daily flow records to estimate the daily loads of bacteria. As a surrogate, derived daily flow measurements were used.

Salinity observations (from CRP monitoring) taken at TCEQ SWQM Station 18697 were combined with adjusted daily freshwater flow values based on the date of the observation. The top and bottom 5% were considered outliers and eliminated from further calculations. Salinity records in parts per thousand (ppt) were then plotted against the natural log flow values in a scattered plot (Figure 11). A salinity to streamflow regression was developed for TCEQ SWQM Station 18697. 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 in a day (Equation 1).

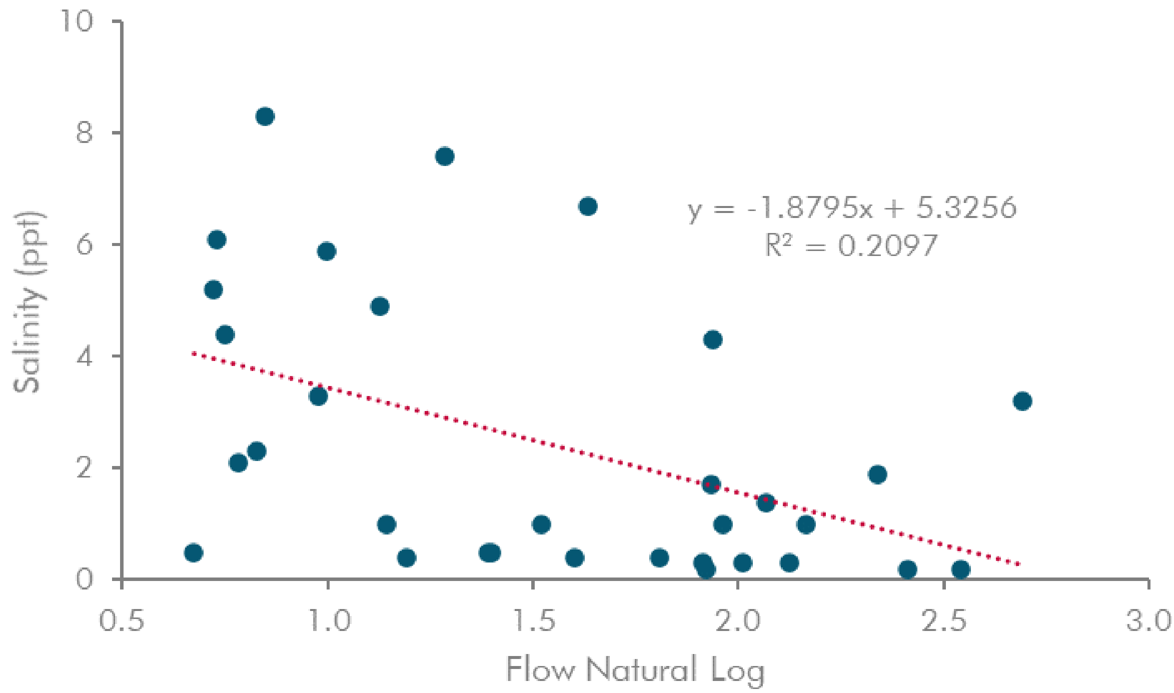

Figure 11. Regression scatter plot of salinity versus daily streamflow

Salinity (ppt) = (-1.8795 * derived flow) + 5.3256 (Equation 1)

3.3.3.2. Step 3.2: Incorporate Daily Tidal Volumes into Streamflow Record

The regression equations developed previously were then used to compute the total daily flow volume including both fresh and saline water. The process requires manipulation of the following mass balance equation for salinity at the tidally influenced stations:

$$(V_r + V_s) * S_t = V_r * S_r + V_s * S_s \quad \text{(Equation 2)}$$

Where:

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 = 0 ppt

S_s = salinity of seawater (assumed to be 35 ppt)

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

$$V_s = (V_r / (S_s/S_t - 1)) \qquad \text{(Equation 3)}$$

for S_t greater than background salinity, otherwise $V_s = 0$

Where S_t was computed for each day of the streamflow record using the station specific regression equation (Equation 1) and the estimated actual daily streamflow (V_r), as input to the equation. The calculation of S_t allowed V_s to be computed from Equation 3.

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:

$$V_t = V_r + V_s \qquad \text{(Equation 4)}$$

3.3.3.3 Step 3.3: Adjust for WWTF Flows

After accounting for tidal influence, flows were further adjusted by subtracting out the most recent five-year average daily flows from WWTFs within the TMDL watershed (Table 7). As a final step, full permitted flows including future growth (FG) flows (calculated in Section 4.7.4) were added to account for the probability that additional flows from WWTF discharges may occur because of population increases.

3.3.4. Steps 4 through 6: Flow Duration and Load Duration Curves

A modified FDC is a graph that visualizes the percentage of time during which a value of flow is equaled or exceeded. To develop a modified 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 percent 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 Enterococci (geometric mean of 35 cfu/100 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.

The resulting curve represents the maximum daily allowable loadings for the geometric mean criterion. The next step was to plot the measured Enterococci data on the developed LDC using the following steps:

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

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

3.4. Flow Duration Curve for the TMDL Watershed

In Figure 12, the modified FDC for TCEQ SWQM Station 18697 is shown. The curve is separated into five flow regimes including high flows (0-10%), moist conditions (10-40%), mid-range flows (40-60%), dry conditions (60-90%), and low flows (90-100%). For reference, the Enterococci geometric mean criterion curve (load at 35 cfu/100 mL) and the Enterococci single sample criterion curve (load at 130 cfu/100 mL) are also included on the FDC.

3.5. Load Duration Curve for the TMDL Watershed

In Figure 13, the modified LDC for TCEQ SWQM Station 18697 is shown. The figure includes the FDC, the Enterococci geometric mean criterion curve (load at 35 cfu/100 mL), the Enterococci single sample criterion curve (load at 130 cfu/100 mL), the existing load curve, the existing geometric mean load by flow regime (single points), and individual bacteria samples.

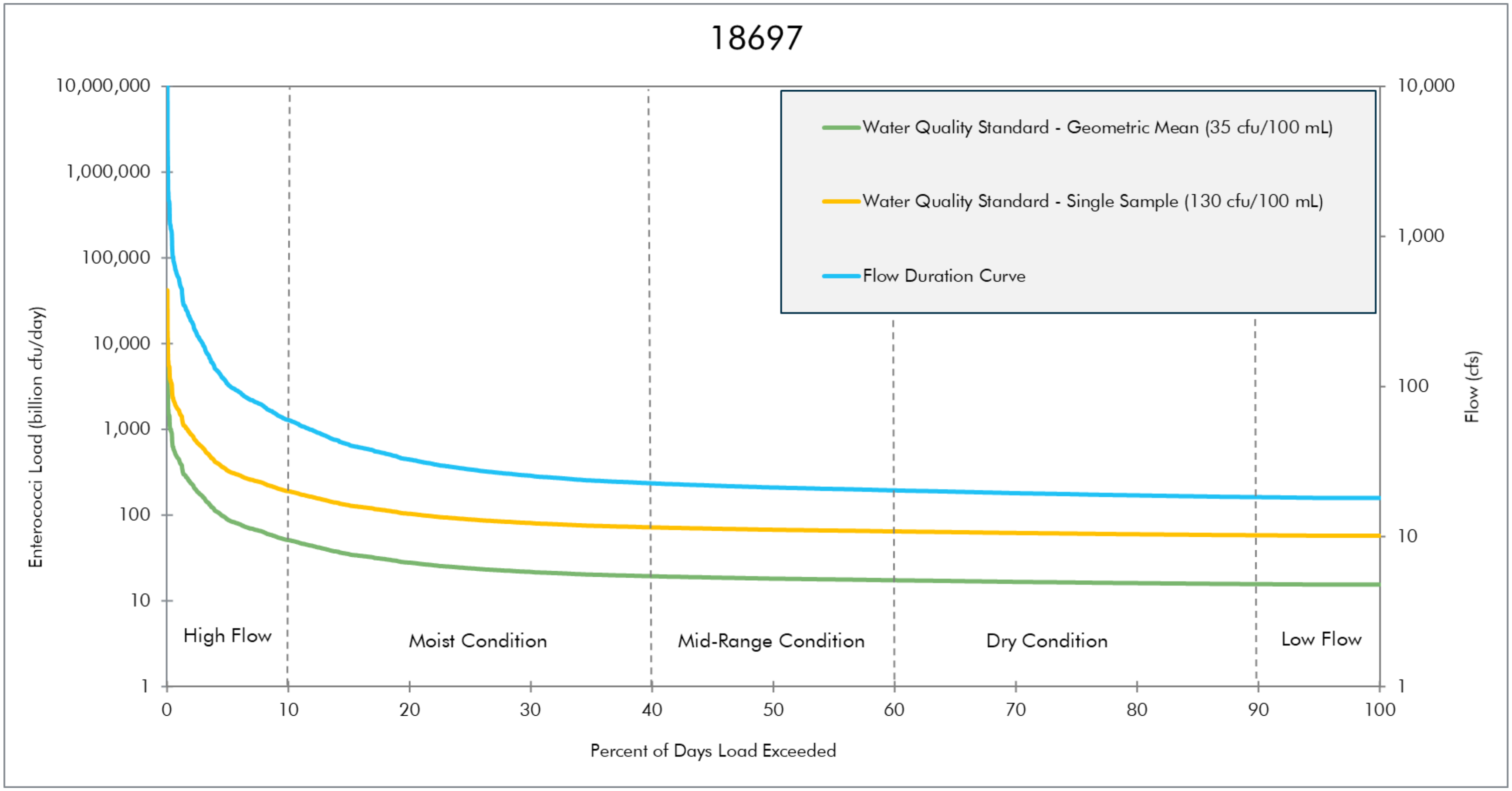

Figure 12. Modified FDC for TCEQ SWQM Station 18697

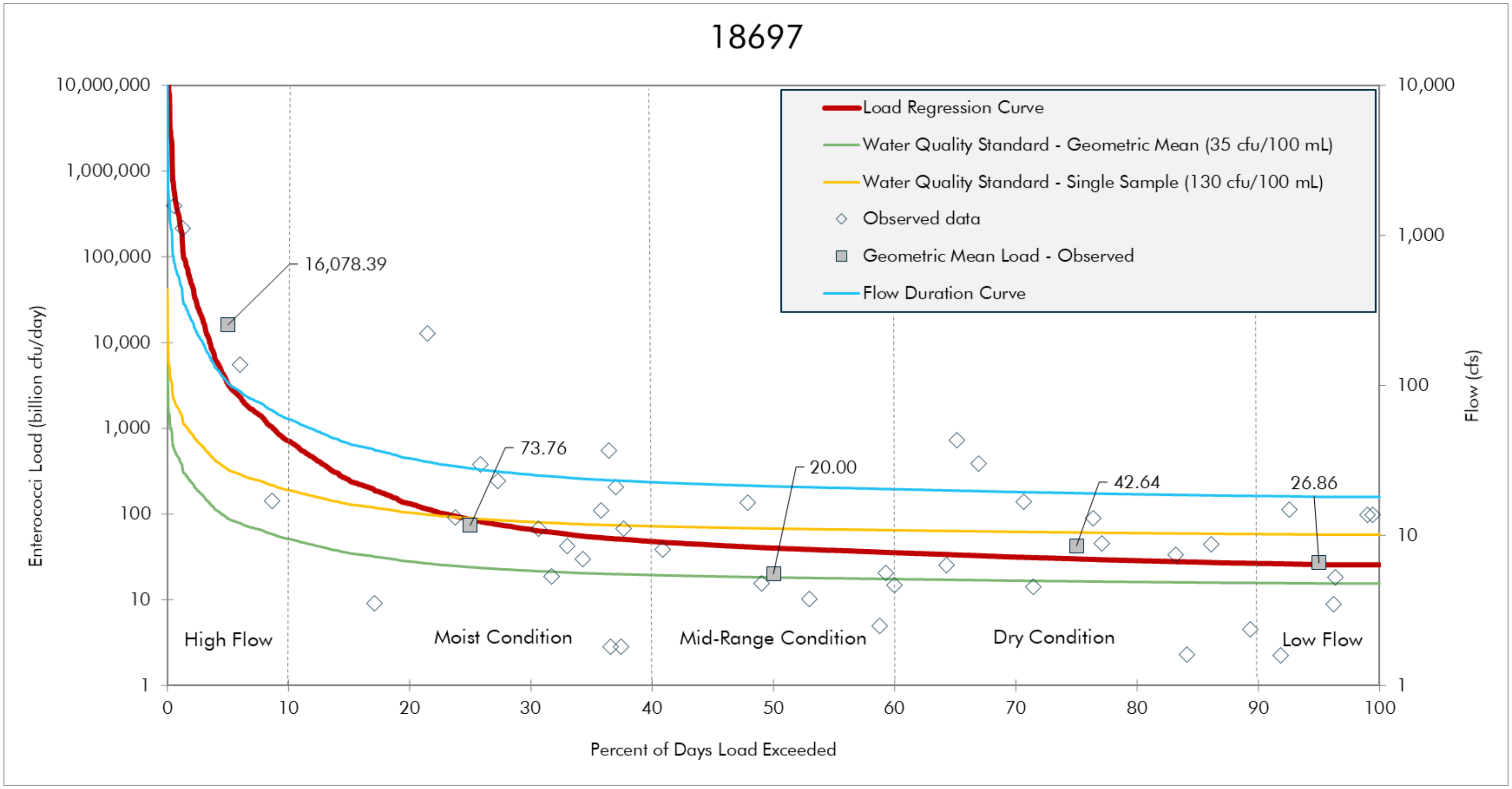

Figure 13. Modified LDC for TCEQ SWQM Station 18697

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 Enterococci below the geometric mean criterion of 35 cfu/100 mL, which is protective of the primary contact recreation 1 use in tidal water bodies.

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 (40 CFR) Section 130.7(c)(1)]. To evaluate potential seasonal difference, ambient monitoring data for Cotton Bayou Tidal was grouped into a cool season (November-March) and a warm season (May-September). Data collected in April and October was excluded, assuming those months are transitions between the two seasons. There was no discernable difference observed comparing seasons using a Wilcoxon Rank Sum test.

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 size, 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 them from the land surface and the volume of runoff decreases following the rain event.

LDCs were used to examine the relationship between instream water quality and the source of indicator bacteria loads. Inherent to the use of LDCs as the mechanism of linkage analysis is the assumption of a direct relationship between pollutant load sources (regulated and unregulated) and instream loads. Further, this one-to-one relationship was 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 in the environment is also a weakness of this method.

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

At TCEQ SWQM Station 18697, the load regression curve modeled from observed data exceeds the curve representing the geometric mean maximum in all flow conditions (Figure 13). However, the large reductions needed in higher flow conditions relative to lower flow conditions can indicate the influence of nonpoint sources as major contributors to bacteria exceedance at this site. While reduction strategies targeting improvement of nonpoint source pollutants may have greater impacts at this site, improvements to both point and nonpoint source loading will positively affect the watershed.

4.5. Margin of Safety

The margin of safety (MOS) is used to account for uncertainty in the analysis performed to develop the TMDL and thus provides a higher level of assurance that the 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 TMDL covered by this report incorporates an explicit MOS of 5%.

4.6. Load Reduction Analysis

According to analyses of the geometric means of observed bacteria data compared to water quality standards for primary contact recreation 1 activities, bacteria concentrations in the bayou are above the water quality criterion at all levels of flow. Bacteria reductions are needed at all flows, with the highest reductions required in the high flow and moist conditions flow regimes. This indicates that nonpoint source load pressures 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 LDC results indicated potential point source influence on bacteria loads in dry and low flow conditions.

Based on these results, potential reduction targets for Enterococci loads at each flow condition are detailed in Table 12.

Table 12. Percentage reduction calculations for TCEQ SWQM Station 18697

Flow Regime	Geometric mean (cfu/100 mL)	Percent Reduction Required
High Flow	3,332.81	98.95%
Moist Conditions	117.54	70.22%
Mid-Range Conditions	38.88	9.98%
Dry Conditions	91.19	61.62%
Low Flow	60.62	42.26%

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 (Equation 5)

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 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 LDC for the TCEQ SWQM station within the watershed (Figure 13). As discussed in more detail in Section 3, the bacteria LDC was developed by multiplying each flow value along the FDC by the Enterococci criterion (35 cfu/100 mL) and by the conversion factor used to represent maximum loading in cfu/day. Effectively, the "allowable load" displayed in the LDC at 5% exceedance (the median value of the high flow regime) is the TMDL.

TMDL (cfu/day) = Criterion * Flow (cfs) * Conversion Factor (Equation 6)

Where:

Criterion = 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 Enterococci that the impaired water body can receive daily was determined using Equation 6 based on the median value within the high flow regime of the FDC (or 5% flow exceedance value) for the TCEQ SWQM station (Table 13).

Table 13. Summary of allowable loading calculation

Load units expressed as billion cfu/day Enterococci

AU	5% Exceedance Flow (cfs)	5% Exceedance Load (cfu/day)	TMDL (Billion cfu/day)
0801C_01	104.133	8.92E+10	89.169

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:

$$MOS = 0.05 * TMDL \quad \text{(Equation 7)}$$

Using the TMDL value for the AU provided in Table 13, the MOS may be readily computed by proper substitution into Equation 7 (Table 14).

Table 14. MOS calculation

Load units expressed as billion cfu/day Enterococci

AU	TMDL[a]	MOS
0801C_01	89.169	4.458

[a] TMDL from Table 13.

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}).

$$WLA = WLA_{WWTF} + WLA_{SW} \quad \text{(Equation 8)}$$

4.7.3.1. Wastewater

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

$$WLA_{WWTF} = Target * Flow * Conversion\ Factor \quad \text{(Equation 9)}$$

Where:

Target= 35 cfu/100 mL for Enterococci

Flow = full permitted flow (MGD)

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

Using this equation, each WWTF's allowable loading was calculated using the permittee's full permitted flow. All WWTFs in the Cotton Bayou watershed occur in the above tidal reach, 0801E_01. To account for the contribution of upstream WWTFs for use in calculating TMDLs in the impaired tidal reach, 0801C_01, loadings for 0801E_01 replace 126 cfu/100 mL, the freshwater criterion, with 35 cfu/100mL, the tidal criterion. Table 15 presents the WLA for each WWTF and the resulting total allocation for the AU within the TMDL watershed.

Table 15. WLAs for TPDES-permitted facilities

Load units expressed as billion cfu/day Enterococci

AU	TPDES Permit No.	NPDES Permit No.	Permittee	Full Permitted Flow (MGD)[a]	Enterococci WLA_{WWTF}
0801E_01	WQ0011109001	TX0085961	Tiki Leasing Company, Ltd.	0.032	0.042
0801E_01	WQ0011449001	TX0066656	Aqua Texas, Inc.	0.90	1.192
0801E_01	WQ0014807001	TX0053317	City of Mont Belvieu	3.0	3.975
0801E_01	WQ0015245001	TX0135348	3180 Maverick Investments, LLC	0.015	0.020
0801E_01	WQ0015887001	TX0140333	Chambers County Improvement District No. 3	0.80	1.060
0801E_01	WQ0016031001	TX0141631	Parkland Development LLC	0.2	0.265
Total				4.947	6.554

[a] Full Permitted Flow from Table 7.

4.7.3.2. Regulated Stormwater

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

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

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

$$WLA_{SW} = (TMDL - WLA_{WWTF} - FG - MOS) * FDA_{SWP} \quad \text{(Equation 10)}$$

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}; Table 16) must be determined to estimate the amount of overall runoff load that should be allocated to WLA_{SW}. The term FDA_{SWP} was calculated based on the combined area under regulated stormwater permits, as described in section 2.7.1.3.

Table 16. Basis of regulated stormwater area and computation of FDA_{SWP} term

Watershed	Total Area (acres)	Area Under MS4 as Defined by Urbanized Area (acres)	Area Authorized by the CGP Outside Urbanized Areas (acres)	FDA_{SWP}
Cotton Bayou	10,350.90	3,355.70	278.90	35.114%

The daily allowable loading of Enterococci assigned to WLA_{SW} was determined based on the combined area under regulated stormwater permits. To calculate the WLA_{SW} (Equation 10), the FG term must be known. The calculation for that term is presented in the next section, but the results will be included here for continuity. Table 17 provides the information needed to compute WLA_{SW}.

Table 17. Regulated stormwater WLA calculation

Load units expressed as billion cfu/day Enterococci

AU	TMDL[a]	MOS[b]	WLA_{WWTF}[c]	FG[d]	FDA_{SWP}[e]	WLA_{SW}[f]
0801C_01	89.169	4.458	6.554	8.700	35.114%	24.389

[a] TMDL from Table 13

[b] MOS from Table 14

[c] WLA_{WWTF} from Table 15

[d] FG from Table 18

[e] FDA_{SWP} from Table 16

[f] WLA_{SW} = (TMDL – WLA_{WWTF} – FG - MOS) *FDA_{SWP} (Equation 10)

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 takes into account 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 2018 and 2045 are provided in Table 5. The projected population percentage increase within the watershed 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 2018 and 2045 to determine the estimated future flows.

Thus, the FG is calculated as follows:

$$FG = Criterion * (WWTF_{FP} * POP_{2018\text{-}2045}) * Conversion\ Factor \quad \text{(Equation 11)}$$

Where:

Criterion = 35 cfu/100 mL

$POP_{2018\text{-}2045}$ = estimated percent increase in population between 2018 and 2045

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

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

The calculation results are shown in Table 18.

Table 18. FG calculation

AU	Full Permitted Flow (MGD)	% Population Increase (2018-2045)	FG (MGD)	FG (Enterococci Billion cfu/day)[a]
0801C_01	4.947	132.740%	6.5666	8.700

[a] FG = Criterion * $WWTF_{FP}$ * $POP_{2018-2045}$ * Conversion Factor (Equation 11)

4.7.5. Load Allocations

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

$$LA = TMDL - WLA_{WWTF} - WLA_{SW} - FG - MOS \qquad \text{(Equation 12)}$$

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 19.

Table 19. LA calculation

Load units expressed as billion cfu/day Enterococci

AU	TMDL[a]	MOS[b]	WLA_{WWTF}[c]	WLA_{SW}[d]	FG[e]	LA[f]
0801C_01	89.169	4.458	6.554	24.389	8.700	45.068

[a] TMDL from Table 13

[b] MOS from Table 14

[c] WLA_{WWTF} from Table 15

[d] WLA_{SW} from Table 17

[e] FG from Table 18

[f] LA = TMDL – WLA_{WWTF} – WLA_{SW} – FG – MOS (Equation 12)

4.8. Summary of TMDL Calculations

Table 20 summarizes the TMDL calculation for the watershed. The TMDL was calculated based on the median flow in the 0-10 percentile range (5% exceedance, high flow regime) for flow exceedance from the LDC developed for TCEQ SWQM Station 18697. Allocations are based on the current geometric mean criterion for Enterococci of 35 cfu/100 mL for each component of the TMDL.

Table 20. TMDL allocation summary

Load units expressed as billion cfu/day Enterococci

AU	TMDL[a]	MOS[b]	WLA_{WWTF}[c]	WLA_{SW}[d]	LA[e]	FG[f]
0801C_01	89.169	4.458	6.554	24.389	45.068	8.700

[a] TMDL from Table 13

[b] MOS from Table 14

[c] WLA_{WWTF} from Table 15

[d] WLA_{SW} from Table 17

[e] LA from Table 19

[f] FG from Table 18

The final TMDL allocation (Table 21) needed to comply with the requirements of 40 CFR 130.7 includes the FG component within the $WLA_{WWTF.}$

Table 21. Final TMDL allocation

Load units expressed as billion cfu/day Enterococci

AU	TMDL	MOS	WLA_{WWTF}[a]	WLA_{SW}	LA
0801C_01	89.169	4.458	15.254	24.389	45.068

[a] WLA_{WWTF} includes the FG component

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Appendix A. Method Used to Determine Population Projections

The following steps detail the method used to estimate the 2018 and projected 2045 populations in the Cotton Bayou watershed.

1. The H-GAC regional forecast team obtained 2018 American Community Survey data from the USCB 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 2018 watershed populations using the H3M data for the portion of the H3M within the watershed assuming equal distribution.
4. Obtained population projections for the year 2045 from the H-GAC regional forecast based on H3M data.
5. Developed population projections using H-GAC regional forecast data for the portion of the H3M within the watershed assuming equal distribution.
6. Subtracted the 2018 watershed population from the 2045 population projection to determine the projected population increase. Subsequently, the projected population increase was divided by the 2018 watershed population to determine the percent population increase for the Cotton Bayou watershed.