Technical Support Document for Two Total Maximum Daily Loads for Indicator Bacteria in the Oyster Creek Watershed

Assessment Units: 1109_01 and 1110_01

Oyster Creek at Hwy 288, Dunbar Park, Lake Jackson, TX

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Abbreviations

AU	assessment unit
AVMA	American Veterinary Medical Association
CAFO	concentrated animal feeding operation
cfs	cubic feet per second
cfu	colony forming units
CGP	construction general permit
DAR	drainage-area ratio
DMR	discharge monitoring report
ECHO	Enforcement and Compliance History Online
E. coli	*Escherichia coli*
EPA	United States Environmental Protection Agency
EIH	Environmental Institute of Houston
Eq	equation
FDC	flow duration curve
GIS	geographic information system
GIWW	Gulf Intracoastal Waterway
H-GAC	Houston-Galveston Area Council
km	kilometer
LA	load allocation
LDC	load duration curve
MCM	minimum control measures
MGD	million gallons per day
mi^2	square mile
mL	milliliter
MOS	margin of safety
MS4	municipal separate storm sewer system
MSGP	multi-sector general permit
NEIWPCC	New England Interstate Water Pollution Control Commission
NHDPlus	National Hydrologic Dataset Plus
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
SWMP	stormwater management program
SWQM	surface water quality monitoring
SWQMIS	Surface Water Quality Monitoring Information System
TCEQ	Texas Commission on Environmental Quality
TDCJ	Texas Department of Criminal Justice
TMDL	total maximum daily load
TPDES	Texas Pollutant Discharge Elimination System
TPWD	Texas Parks and Wildlife Department
TWRI	Texas Water Resources Institute

UA	urbanized area
U.S.	United States
USCB	United States Census Bureau
USGS	United States Geological Survey
WLA	wasteload allocation
WWTF	wastewater treatment facility

Section 1. Introduction

1.1. Background

Section 303(d) of the federal Clean Water Act requires all states to identify waters that do not meet, or are not expected to meet, applicable water quality standards. States must develop a total maximum daily load (TMDL) for each pollutant that contributes to the impairment of a water body included on a state's 303(d) list of impaired waters. The Texas Commission on Environmental Quality (TCEQ) is responsible for ensuring that TMDLs are developed for impaired surface waters in Texas.

A TMDL is like a budget—it determines the amount of a particular pollutant that a water body can receive and still meet applicable water quality standards. TMDLs are the best possible estimates of the assimilative capacity of the water body for a pollutant under consideration. A TMDL is commonly expressed as a load with units in mass per period of time but may be expressed in other ways.

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

TCEQ first identified a bacteria impairment within the above tidal portion, assessment unit (AU) 1110_01, of Oyster Creek in the 2006 Texas Water Quality Inventory and 303(d) List (TCEQ, 2008), now called the Texas Integrated Report. A bacteria impairment within the tidal portion, AU 1109_01, of Oyster Creek was later determined in the 2012 Texas Integrated Report (TCEQ, 2013). The bacteria impairments have been identified in each subsequent edition through the Environmental Protection Agency (EPA) approved 2022 Texas Integrated Report (TCEQ, 2022a).

This document will consider two bacteria impairments in two AUs of the Oyster Creek watershed. The impaired water bodies and identifying AU numbers are shown below:

- Oyster Creek Tidal, AU 1109_01
- Oyster Creek Above Tidal, AU 1110_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 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). *Escherichia coli* (*E. coli*) and Enterococcus are members of the fecal coliform bacteria group and are used in the state of Texas as the fecal indicator bacteria in freshwater bodies and tidal water bodies, respectively.

On Feb. 7, 2018, TCEQ adopted revisions to the *Texas Surface Water Quality Standards* (TCEQ, 2018a) and on May 19, 2020, 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 *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.

Oyster Creek is both a tidal (AU 1109_01) and freshwater stream (AU 1110_01) and has a primary contact recreation 1 use. The associated criterion for *E. coli* is a geometric mean of 126 cfu per 100 mL. The associated criterion for Enterococci is a geometric mean of 35 cfu per 100 mL.

1.3. Report Purpose and Organization

The Oyster Creek 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 presence of fecal 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 146.7-square mile Oyster Creek watershed comprises three water bodies, Oyster Creek Tidal (Segment 1109), Oyster Creek Above Tidal (Segment 1110) and an unclassified waterbody, Upper Oyster Creek Above Tidal (1110A) (Figure 1). The approximate 95-mile creek originates at the confluence with Middle Oyster Creek in southeastern Fort Bend County and travels southward through central Brazoria County before turning southeastward at the city of Lake Jackson. From there, Oyster Creek meanders and broadens across the Texas coastal plain before terminating at the Gulf Intracoastal Waterway (GIWW) near the cities of Brazosport and Surfside Beach. The GIWW inland of Follets Island, travels southwestward toward the Freeport Channel or northeastward toward the Drum Bay-Christmas Bay complex of West Galveston Bay where there are connections to the Gulf of Mexico.

Prior to extensive human activity, Oyster Creek’s length was much longer, having originated in northeast Fort Bend County in the vicinity of the town of Fulshear. Oyster Creek has since seen significant hydrologic modifications. Modifications to the northern portions of Oyster Creek, outside of the TMDL project area, near Interstate 69 in the City of Sugarland connect Oyster Creek to the Brazos River, except during severe rainfall storm events. The modifications were first made to impound Oyster Creek using a diversion dam 1.1 mile upstream of State Highway 6. This diversion allowed for the ponding of irrigation water pumped from the Brazos River to support sugarcane production. The waters are now being used for amenity lakes in commercial and residential applications. As the waters no longer connect to the lower reaches of Oyster Creek, this portion is known as Upper Oyster Creek (Segment 1245). A separate diversion canal was completed in 1998 at McKeever Road to prevent the flooding of the Sienna subdivision. This water body is known as Middle Oyster Creek (Segment 1258) (H-GAC, 2007).

Modifications to Oyster Creek have also taken place in the TMDL project area. A flood protection levy was constructed on the west bank of Oyster Creek Tidal (1109_01) around the town of Oyster Creek. The levy is used to protect the town and heavy industries to the west of Oyster Creek from storm surges. The completion of the levy cut off a major oxbow found in the town of Oyster Creek and stormwater from the town is now routed directly to the GIWW.

A diversion canal with a pump station was sited at a saltwater dam at the southern terminus of Oyster Creek Above Tidal, near Highway 288 and Dunbar Park in Lake Jackson. Water from the Brazos River is stored at the 12,000 acre-feet Harris Reservoir, northwest of the town of Holiday Lakes and gravity fed to Oyster Creek during times of drought for industrial and residential use (Breeding, 2021). A planned expansion is underway for an additional 49,000 acre-feet reservoir sited north of the Harris

Reservoir. The reservoir and pump station are owned and operated by Dow Chemical Co. (Dow, 2020).

The unclassified water body, Upper Oyster Creek Above Tidal (1110A) (Figure 1), begins in Sienna, which is a community within the City of Missouri City extraterritorial jurisdiction, at the point where Middle Oyster Creek becomes a canal and turns west. It is about a two-mile reach of Oyster Creek that flows through the community of Sienna and ends at the beginning of Oyster Creek Above Tidal (Segment 1110).

The segment, Oyster Creek Above Tidal (1110), is approximately 67.88 miles in length and travels mostly south from Upper Oyster Creek Above Tidal (1110A) to the City of Lake Jackson where it terminates at the confluence with Oyster Creek Tidal (Segment 1109). Segment 1110 has a watershed area of 123.1 square miles, including Upper Oyster Creek Above Tidal (1110A). The Oyster Creek Above Tidal watershed contains all or portions of six cities, towns, and villages: Rosharon, Bonney, Holiday Lakes, Angleton, Bailey’s Prairie, and Lake Jackson.

The segment Oyster Creek Tidal (1109) begins in the City of Lake Jackson and traverses about 25 miles southeastward to the confluence with the GIWW. The tidal segment has a watershed area of 23.6 square miles. Other cities that are found in the Oyster Creek Tidal watershed include Clute and Richwood.

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

- Segment 1109 Oyster Creek Tidal – From the confluence with the Intracoastal Waterway in Brazoria County to a point 100 meters (110 yards) upstream of Farm to Market Road (FM) 2004 in Brazoria County.
    - AU 1109_01 – From the confluence with the Intracoastal Waterway in Brazoria County to a point 100 meters (110 yards) upstream of FM 2004 in Brazoria County.
- Segment 1110 Oyster Creek Above Tidal – From a point 100 m (110 yards) upstream of FM 2004 in Brazoria County to a point 4.3 kilometers (km) (2.7 miles) upstream of Scanlan Road in Fort Bend County.
    - AU 1110_01 – From a point 100 m (110 yards) upstream of FM 2004 in Brazoria County upstream to the Styles Bayou confluence.
    - AU 1110_02 – From Styles Bayou upstream to an unnamed tributary [2.9 km (1.8 miles) downstream of FM 1462].
    - AU 1110_03 – From an unnamed tributary [2.9 km (1.8 miles) downstream of FM 1462] upstream to a point 4.3 km (2.7 miles) upstream of Scanlan Road in Fort Bend County.
- Unclassified Waterbody 1110A Upper Oyster Creek Above Tidal – From a point 4.3 km (2.7 miles) upstream of Scanlan Road in Fort Bend County upstream to

the confluence with Middle Oyster Creek approximately 325 m south of McKeever Road in Fort Bend County.

  - AU 1110A_01 – From a point 4.3 km (2.7 miles) upstream of Scanlan Road in Fort Bend County upstream to the confluence with Middle Oyster Creek approximately 325 m south of McKeever Road in Fort Bend County.

Future references to Segment 1110 will incorporate analysis for Upper Oyster Creek Above Tidal (1110A), unless otherwise mentioned, due to its small size. Due to the hydrologic modifications discussed previously, H-GAC has modified the National Hydrologic Dataset Plus (NHDPlus, USGS, 2021) to delineate the watershed boundaries for use in this report. Modifications include the removal of the aforementioned town of Oyster Creek from the watershed that was included in the NHDPlus version of the watershed.

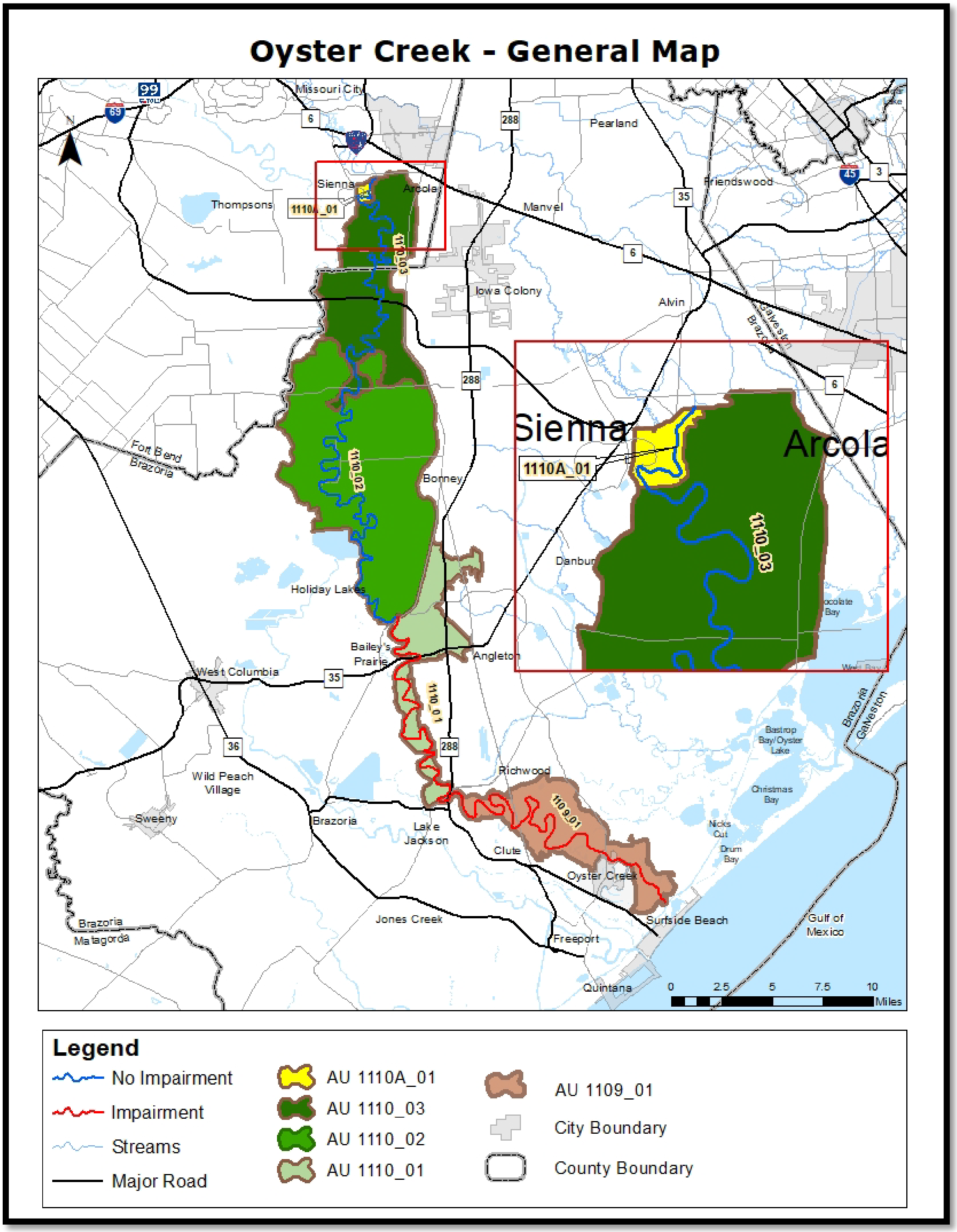

Figure 1. Overview map of the Oyster Creek watershed

2.2. Review of Routine Monitoring Data

2.2.1. Analysis of Bacteria Data

The EPA-approved 2022 Texas Integrated Report lists AU 1109_01 as impaired for primary contact recreation 1 use due to high levels of Enterococci bacteria (TCEQ, 2022a). The AU has been listed since 2012. TCEQ's assessment found the geometric mean for Enterococci within this AU to be 59.87 cfu/100 mL, above the standard of 35 cfu/100 mL (Table 1).

The 2022 Texas Integrated Report lists AU 1110_01 as impaired for primary contact recreation 1 use due to elevated levels of *E. coli* bacteria (TCEQ, 2022a). The AU has been listed since 2006. TCEQ assessment found the geometric mean for *E. coli* within this AU to be 239.33 cfu/100 mL, which is above the standard of 126 cfu/100 mL (Table 1).

Additionally, the 2022 Texas Integrated Report lists AU 1110_02 as a concern for primary contact recreation 1 use due to elevated levels of *E. coli* bacteria (TCEQ, 2022a). While the geometric mean for this AU, 170 cfu/100 mL, is above the geometric mean standard of 126 cfu/100mL, there is an insufficient number of samples (17) to classify this AU as impaired (Table 1).

Table 1. 2022 Texas Integrated Report summary

Water Body Name	AU	Parameter	Data Date Range	TCEQ SWQM[a] Station	No. Samples	Geometric mean (cfu/100mL)
Oyster Creek Tidal	1109_01	Enterococci	12/01/13-11/30/20	11485, 11486	47	59.87
Oyster Creek Above Tidal	1110_01	*E. coli*	12/01/13-11/30/20	11489	26	239.33
Oyster Creek Above Tidal	1110_02	*E. coli*	12/01/13-11/30/20	11491	17	170.72

[a] surface water quality monitoring

H-GAC obtained ambient *E. coli* and Enterococci data from TCEQ's Surface Water Quality Monitoring Information System (SWQMIS) between 2004 and 2020. The data represented the routine ambient bacteria and other water quality data collected for the project area by the TCEQ Regional Office and TCEQ's Clean Rivers Program.

The data were collected at four TCEQ SWQM stations, two in Segment 1110, 11491 and 11489, and two in Segment 1109, 11486 and 11485 (Figures 2 and 3). TCEQ SWQM station locations and general descriptions are as follows (TCEQ, 2022b):

- TCEQ SWQM Station 11485 (29.011110, -95.327770) in AU 1109_01 is on the west bank of Oyster Creek Tidal, 78m downstream from FM 523.
- TCEQ SWQM Station 11486 (29.059504, -95.449617) in AU 1109_01 is on Oyster Creek Tidal at That-Way Drive 0.5 miles below FM 2004 in the city of Lake Jackson.
- TCEQ SWQM Station 11489 (29.125555, -95.481390) is on the east bank of Oyster Creek Above Tidal 15m downstream from Walker Street/Brazoria County Road 290, southeast of Bailey’s Prairie in AU 1110_01.
- TCEQ SWQM Station 11491 (29.199587, -95.516047) is south of Holiday Lakes on Oyster Creek at Sims Road/Brazoria County Road 30 in AU 1110_02.

Data for TCEQ SWQM Station 11485 was available for the period of 2004 through 2019 (Table 2) with a bacteria geometric mean of 20.78 cfu/100 mL. Data was collected for a shorter timeframe at TCEQ SWQM Station 11486 with a bacteria geometric mean of 189.43 cfu/100 mL. The 2022 Texas Integrated Report assessment combines these two station’s data to perform the assessment. Given the geometric means calculated above, the bacteria data from TCEQ SWQM Station 11486 is driving the impairment.

A review of the historic data for TCEQ SWQM Station 11489 for the period of 2004 through 2020 returned a geometric mean of 238.75 cfu/100 mL (Table 2). TCEQ SWQM Station 11491 has only been monitored since 2017 and yields a geometric mean of 165.35 cfu/100 mL.

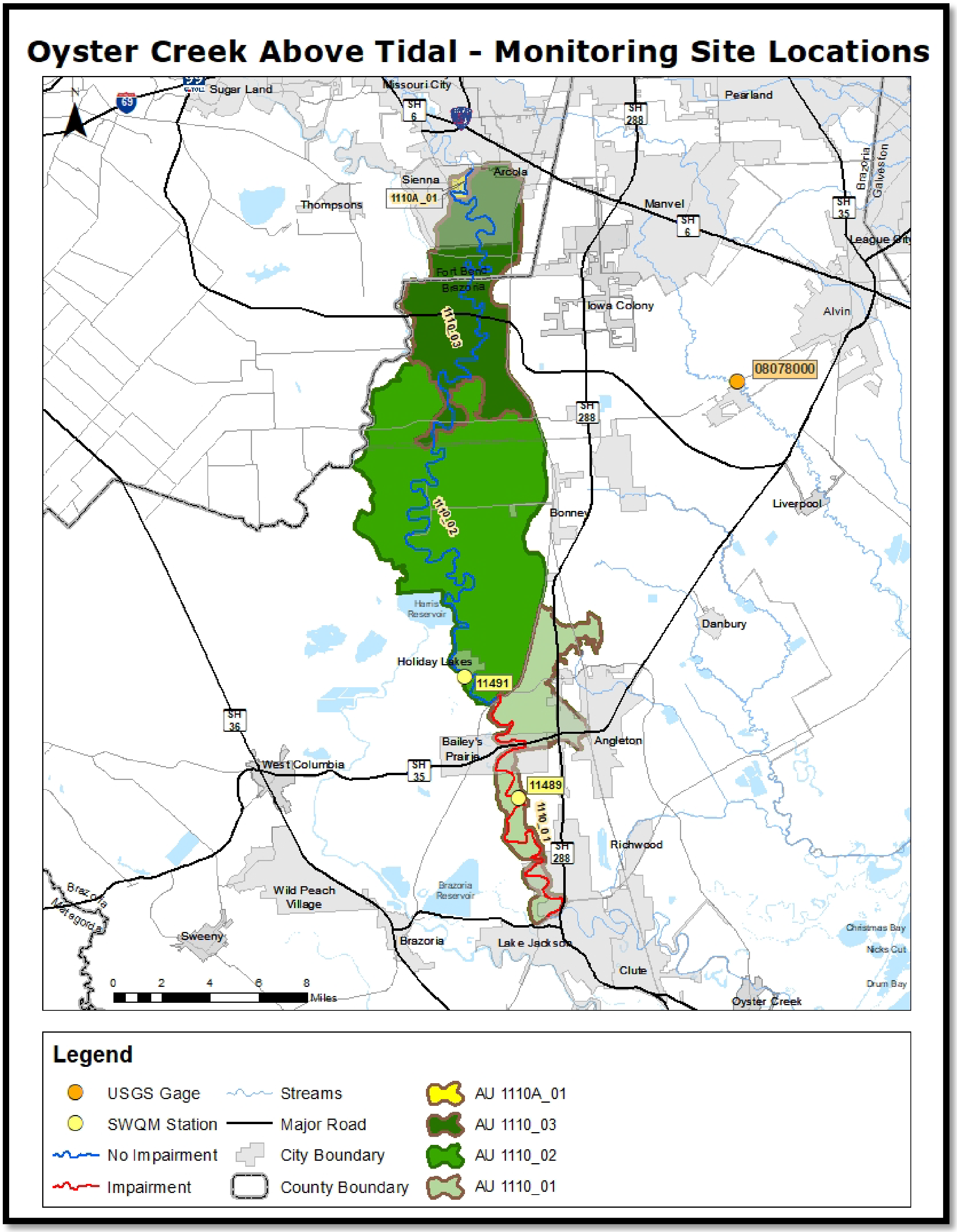

Figure 2. Active monitoring stations in Oyster Creek Above Tidal

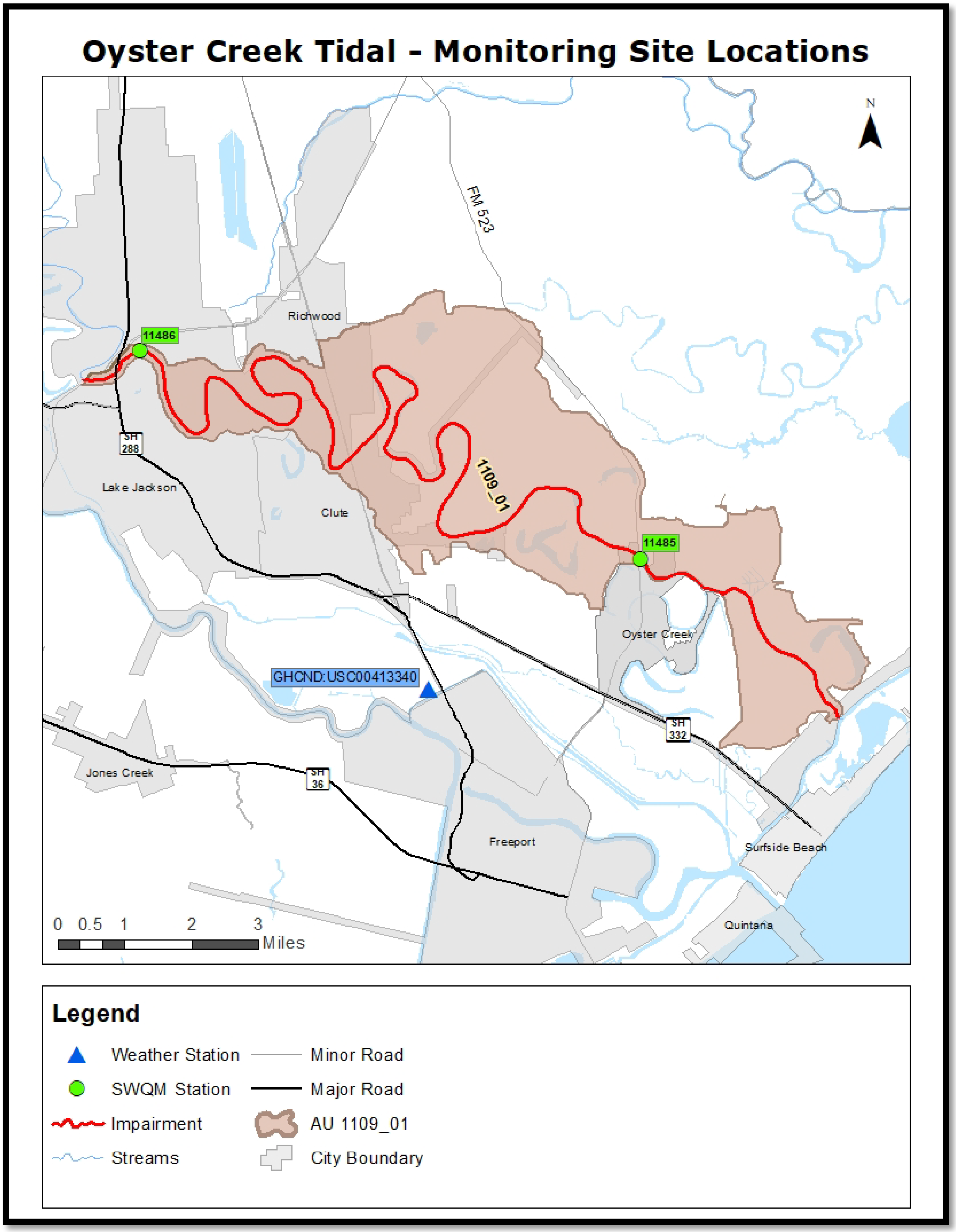

Figure 3. Active monitoring stations in Oyster Creek Tidal

Table 2. Historic fecal indicator bacteria data

SWQM Station	AU	Parameter	Data Date Range	No. Samples	Geometric mean (cfu/100 mL)
11485	1109_01	Enterococci	03/30/04 - 12/18/19	55	20.78
11486	1109_01	Enterococci	02/08/08 - 10/15/20	52	189.43
11489	1110_01	*E. coli*	01/07/04 - 02/04/20	66	238.75
11491	1110_02	*E. coli*	02/02/17 - 10/14/20	18	165.35

Daily streamflow records are an essential component of TMDL development. Daily streamflow will be discussed in Section 3 in greater detail. In February 2017, a gaging station was established at TCEQ SWQM Station 11491 by the Environmental Institute of Houston (EIH), the University of Houston at Clear Lake, in AU 1110_02 (Figure 2).

As historical daily streamflow records were limited, H-GAC obtained the daily flow records from the U.S. Geological Survey (USGS) streamflow gage 08078000 (Figure 2), on Chocolate Bayou Above Tidal (Segment 1108).

2.3. Climate and Hydrology

Precipitation and temperature data for the period of 2004 through 2020 were retrieved from the National Climatic Data Center for Freeport (GHCND: USC00413340, Figure 3) (NOAA, 2022). Temperatures and precipitation in the Oyster Creek watershed are consistent with subtropical coastal areas.

Average precipitation for the watershed is 47.78 inches per year (Table 3). This dataset includes measurements recorded during the statewide drought that peaked in 2011, when the measured annual rainfall was only 20.81 inches. The wettest year for this period was 2016, with 73.38 inches. Mean monthly precipitation ranged from a minimum of 2.27 inches in February to a maximum of 6.46 inches in September with a monthly average of 3.98 inches (Figure 4). The driest months typically occur in late winter or early spring. The wettest periods occur in summer and early fall, during hurricane season, where rainfall near or above 20 inches in a month is common.

Table 3. Average annual rainfall recorded at a gage near the Oyster Creek watershed

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

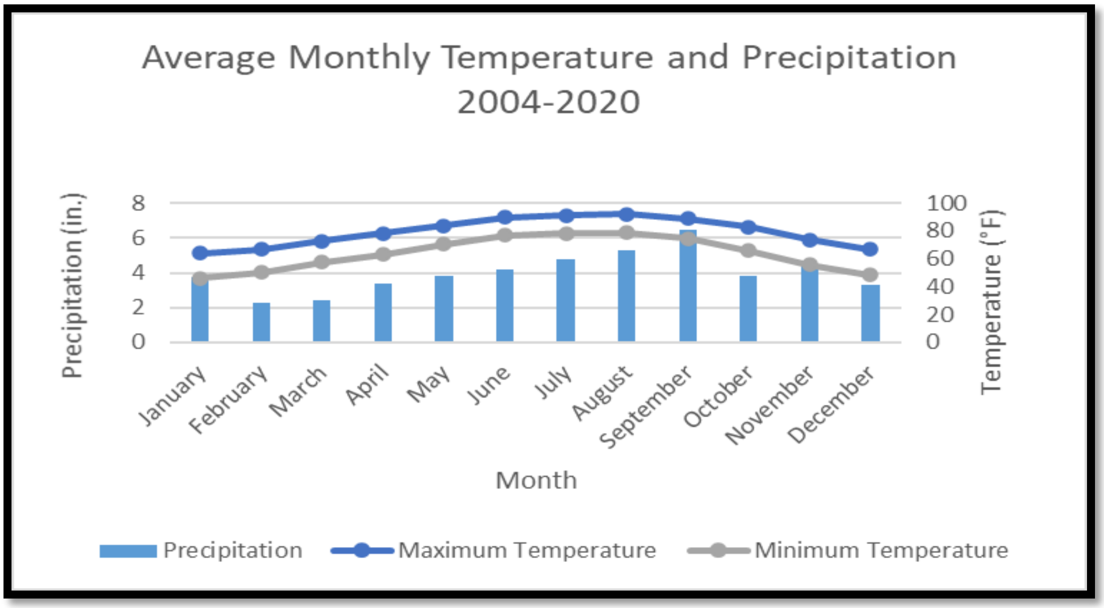

Figure 4. Average monthly temperature and precipitation

Temperatures in the region are consistent with that of a coastal subtropical region. Average annual minimum and maximum temperatures are 63.91 °F and 79.30 °F, respectively. Figure 4 includes maximum and minimum average monthly temperatures. As shown, December and January are the coolest months with the lowest monthly average minimum temperatures, 48.61 °F and 46.26 °F, respectively. July and August are the hottest months with the highest average maximum temperatures, 91.34 °F and 92.35 °F, respectively.

2.4. Population and Population Projections

H-GAC, through its Regional Growth Forecast, routinely assesses the region's population and develops population projections (H-GAC, 2021a). The most recent analysis was based on the U.S. Census Bureau (USCB) 2020 Decadal Census (USCB, 2020, H-GAC, 2021b). Oyster Creek Above Tidal subwatershed had a population of 26,611 in 2020 (Table 4). The Oyster Creek Tidal subwatershed had a population of 12,376 in 2020. The population in the Oyster Creek watershed is not evenly distributed. Most of the population can be found in the upper watershed in Sienna and in the lower portion of the watershed in the cities of Angleton and Lake Jackson.

The population within the Oyster Creek watershed is projected to increase in the future. The population in the Oyster Creek Tidal subwatershed is projected to increase to 21,222, an increase of 71.48% by 2050 (H-GAC, 2021a). The population growth in the Oyster Creek Above Tidal subwatershed is estimated to reach 43,579 in 2050, a 63.76% increase over 2020. More on how H-GAC prepares population projections is described in Appendix A.

Table 4. Population changes in the Oyster Creek watershed

Subwatershed	2020	2050	% Change
Oyster Creek Tidal	12,376	21,222	71.48%
Oyster Creek Above Tidal	26,611	43,579	63.76%
Total	38,987	64,801	66.21%

2.5. Land Cover

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

In 2021, H-GAC used LANDSAT imagery to categorize the Houston-Galveston region into 10 classes of land cover (H-GAC, 2020). The definitions for the 10 land cover types are as follows:

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

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

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

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

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

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

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

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

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

The Oyster Creek watershed covers 93,883.40 total acres with 15,086.60 acres in the Oyster Creek Tidal subwatershed and 78,796.80 acres in the Oyster Creek Above Tidal subwatershed (Table 5, Figures 5 and 6).

Pasture/Grasslands makes up the largest single land cover type at 44.95% in the Oyster Creek watershed, 27.05% and 48.38% in Oyster Creek Tidal and Oyster Creek Above Tidal subwatersheds, respectively (Table 5). Wetlands make up the second largest land cover type at 18.57% in the Oyster Creek watershed, 32.90% and 15.83% in Oyster Creek Tidal and Oyster Creek Above Tidal subwatersheds, respectively.

Developed land cover (which includes High Intensity, Medium Intensity, Low Intensity and Open Space Development land cover types) makes up the third largest land cover type in the Oyster Creek watershed at 13.92% when combined (Table 5). However, it is not distributed evenly across the watershed with greater development found proportionally in the Oyster Creek Tidal subwatershed at 26.04%, whereas development land cover types only make up 11.60% of the Oyster Creek Above Tidal subwatershed.

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 improvements to the State Highway 288 corridor, the Oyster Creek watershed has shown evidence of this trend and is expected to continue to expand development in the coming years, particularly in the northern portion of the watershed.

Table 5. Oyster Creek watershed land cover types

Land Cover Type	Oyster Creek Tidal (acres)	Oyster Creek Tidal (% acres)	Oyster Creek Above Tidal (acres)	Oyster Creek Above Tidal (% acres)	Total (acres)	Total (% acres)
High Intensity Development	104.60	0.69%	165.10	0.21%	269.70	0.29%
Medium Intensity Development	557.40	3.69%	1,125.00	1.43%	1,682.40	1.79%
Low Intensity Development	1,425.20	9.45%	2,435.00	3.09%	3,860.20	4.11%
Open Space Development	1,841.40	12.21%	5,413.30	6.87%	7,254.70	7.73%
Barren Lands	84.10	0.56%	19.40	0.02%	103.50	0.11%
Forest/Shrubs	942.80	6.25%	7,665.60	9.73%	8,608.40	9.17%
Pasture/Grasslands	4,080.30	27.05%	38,124.30	48.38%	42,204.60	44.95%
Cultivated Croplands	74.70	0.50%	9,678.90	12.28%	9,753.60	10.39%
Wetlands	4,963.90	32.90%	12,473.00	15.83%	17,436.90	18.57%
Open Water	1,012.20	6.71%	1,697.20	2.15%	2,709.40	2.89%
Total	**15,086.60**	**100.00%**	**78,796.80**	**100.00%**	**93,883.40**	**100.00%**

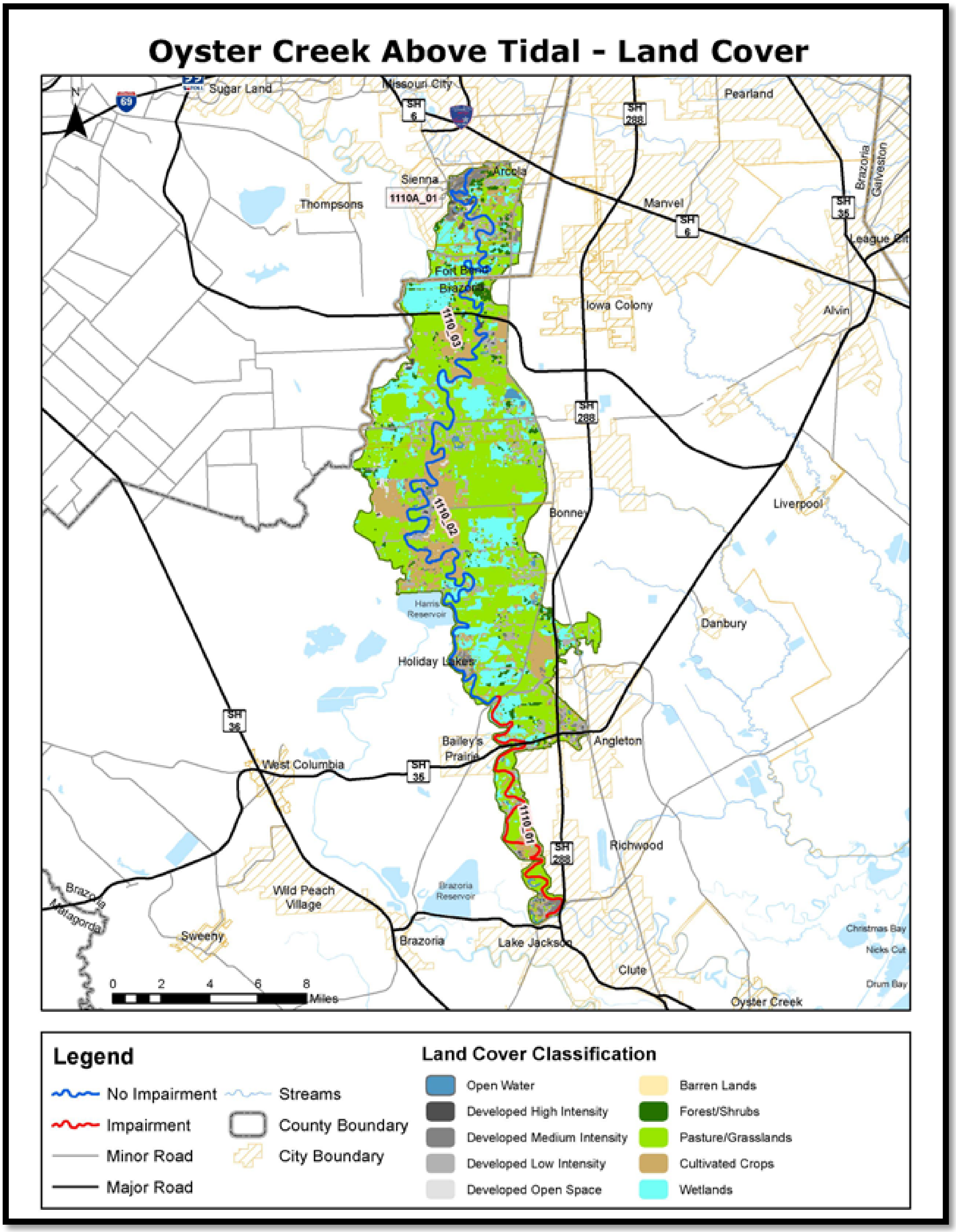

Figure 5. Land cover in the Oyster Creek Above Tidal subwatershed

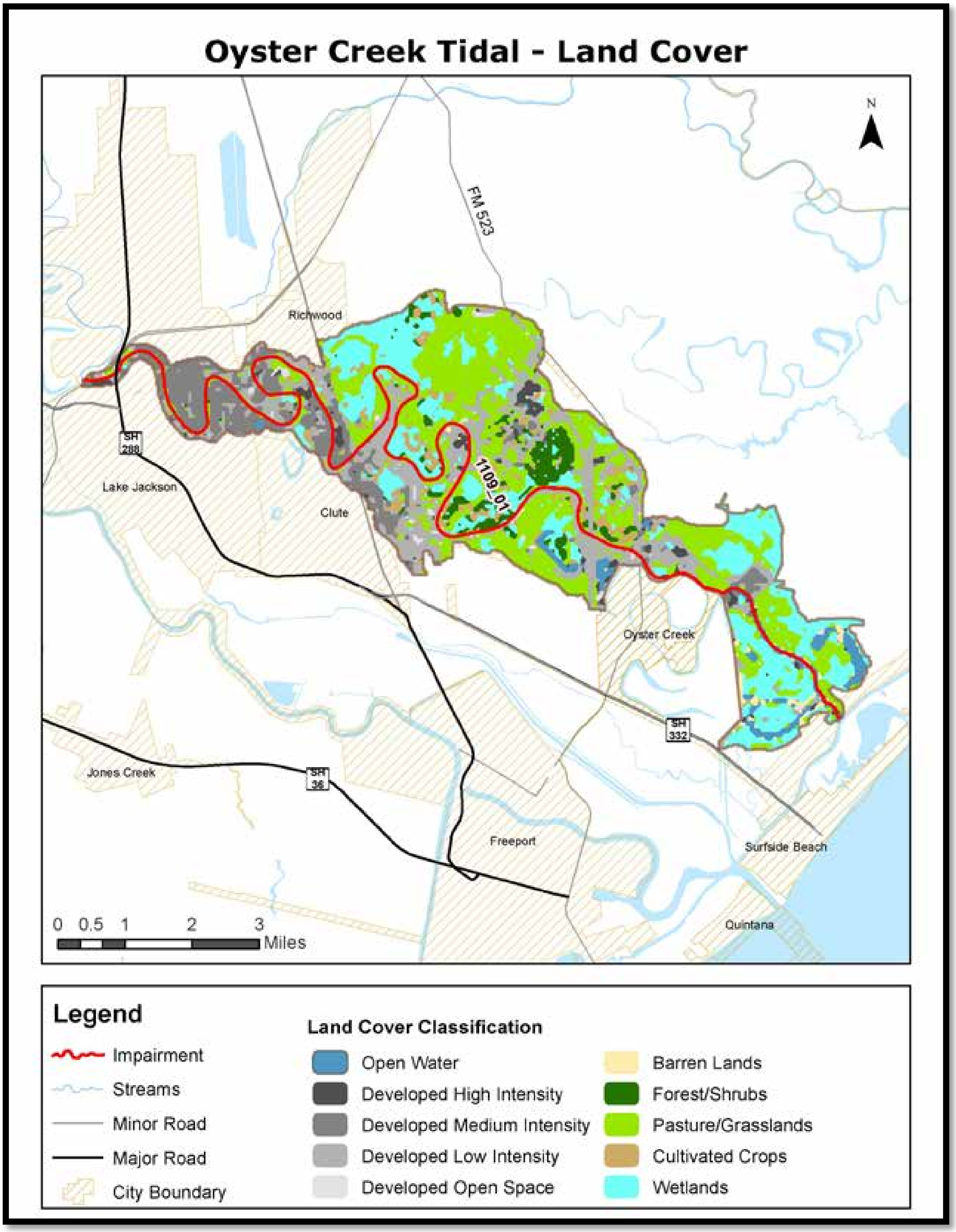

Figure 6. Land cover in the Oyster Creek Tidal subwatershed

2.6. Soils

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

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

The predominant soil group within the Oyster Creek watershed is Group D at 74.25%, which is typical of Texas coastal areas which are made up of slow draining alluvial clays (Table 6, Figure 7 and 8). The second largest soil group is that of Group B at 18.44%. These soils are consistent with alluvial silt and loam deposits laid down by rivers and common in stream banks and adjacent to oxbows. Oxbows are a common occurrence in the Oyster Creek watershed.

Table 6. Hydrologic soil groups

Hydrologic Group	Oyster Creek Tidal (acres)[a]	Oyster Creek Tidal (% acres)	Oyster Creek Above Tidal (acres)[a]	Oyster Creek Above Tidal (% acres)	Total (acres)[a]	Total (% acres)
A	0.00	0.00%	153.96	0.20%	153.96	0.16%
B	3,207.17	21.26%	14,109.56	17.91%	17,316.73	18.44%
C	1.46	0.01%	3,155.07	4.00%	3,156.53	3.36%
C/D	1,355.61	8.99%	2,193.38	2.78%	3,548.99	3.78%
D	10,522.49	69.75%	59,185.59	75.11%	69,708.08	74.25%
Total	**15,086.73**	**100.00%**	**78,797.56**	**100.00%**	**93,884.29**	**100.00%**

[a] Acreage for the TMDL watersheds differ from previously listed totals in the report due to calculations that included different sources for data.

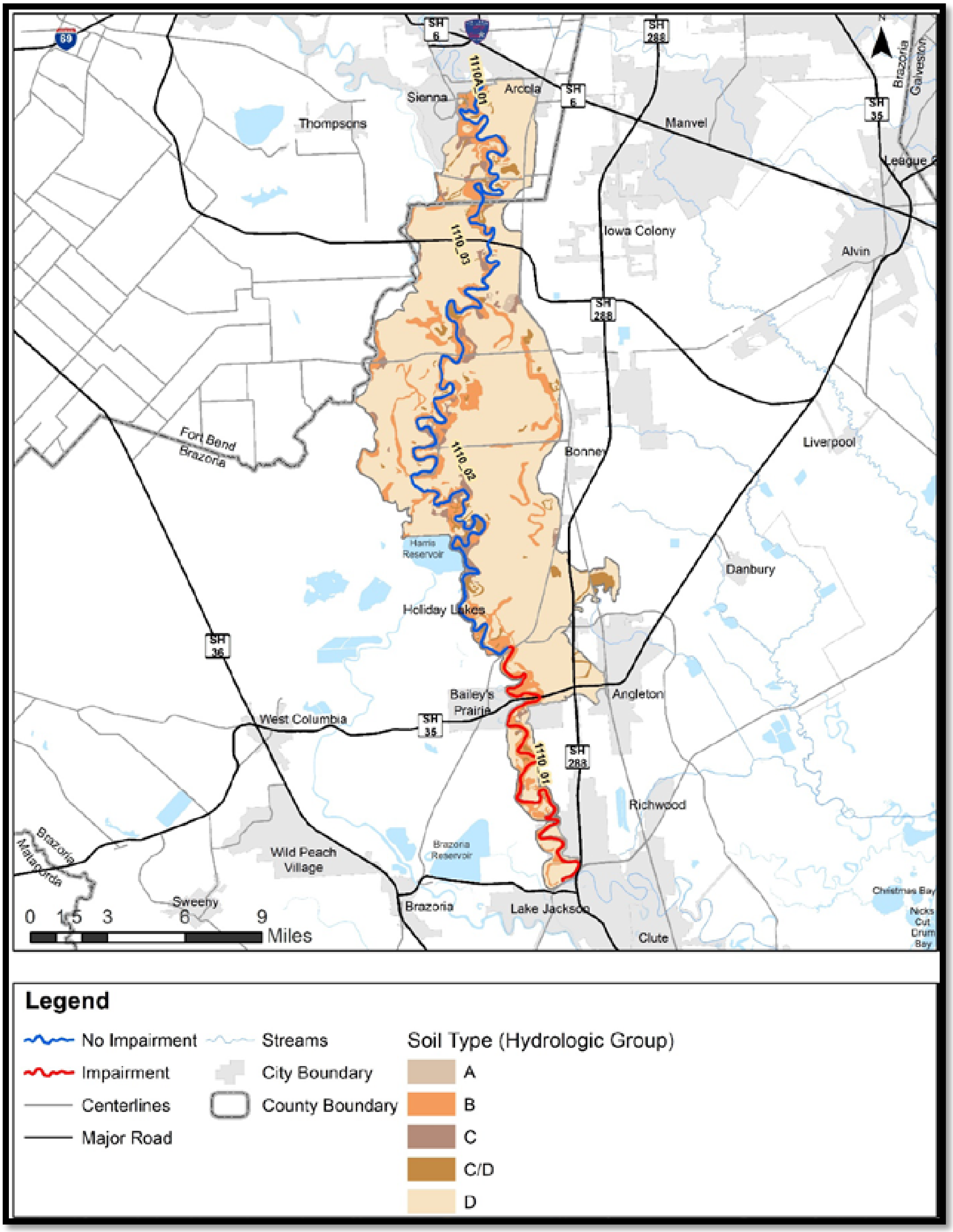

Figure 7. Hydrologic soil groups in the Oyster Creek Above Tidal subwatershed

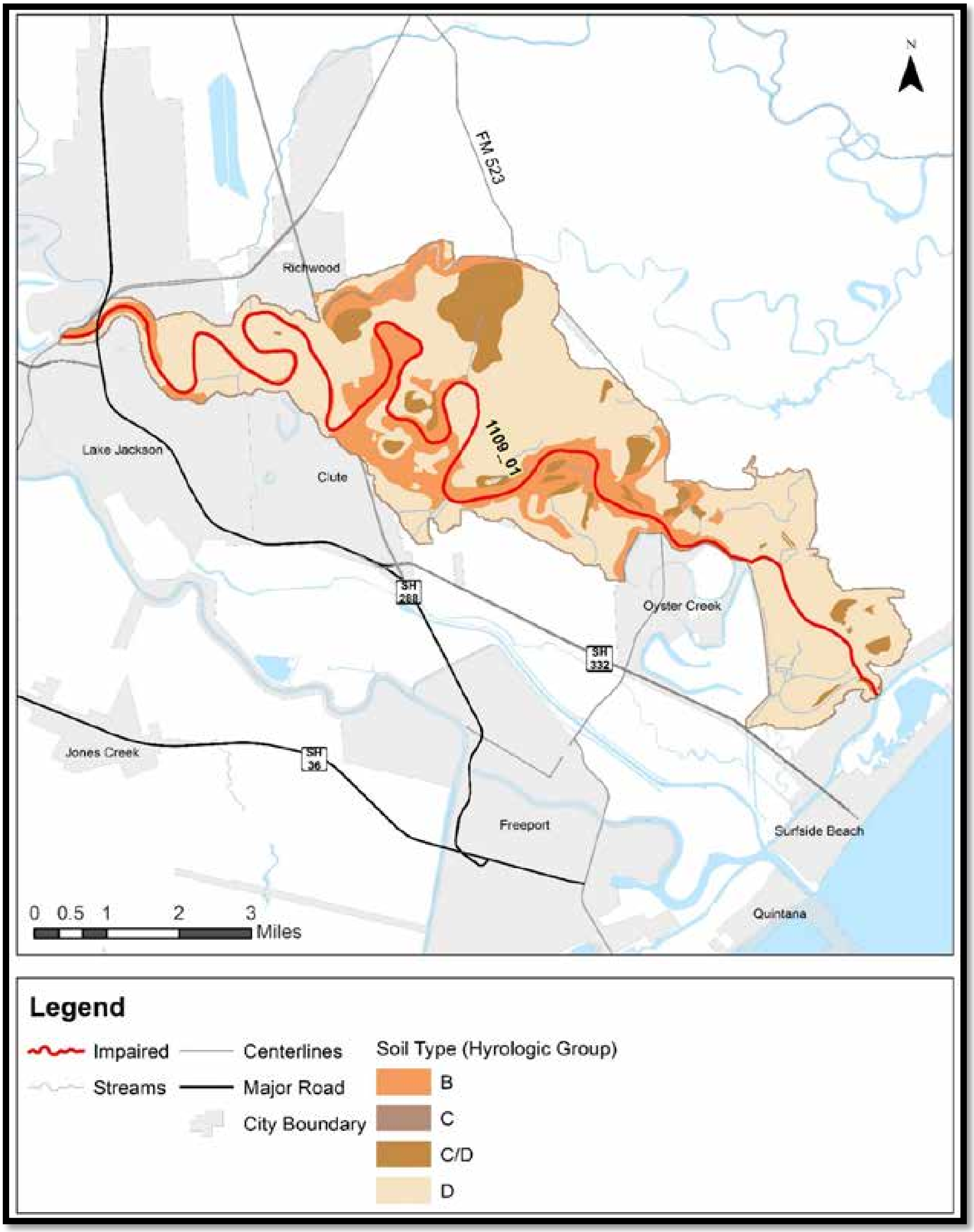

Figure 8. Hydrologic soil groups in the Oyster Creek Tidal subwatershed

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 domestic and industrial WWTF outfalls, SSOs, and stormwater discharges from regulated construction sites, industrial sites, and municipal separate storm sewer systems (MS4s).

2.7.1.1. Domestic and Industrial Wastewater Treatment Facilities

As of May 2022, seven wastewater permits were within the Oyster Creek watershed, discharging through eight permitted outfalls (Table 7, Figures 9 and 10). Five of the discharge permits have bacteria limits and the remaining two discharge permits do not have bacteria limits, which will be excluded from further analysis (TCEQ, 2022c).

The permit held by the Texas Department of Criminal Justice (TDCJ) Terrell Unit (WQ0002952000) was removed from further analysis as the cannery is permitted for industrial wastewater and does not include fecal bacteria. However, the effluent is discharged to a pond and may include bacteria through vegetable wash-water that during high rainfall events or flooding may be released to Oyster Creek.

The Dow Chemical Company Stratton Ridge Plant Site holds a permit (WQ0004429000) for the discharge of stormwater into the watershed. This facility will be included in the stormwater allocation analysis and is not included here.

Additionally, the Oyster Creek watershed includes WWTFs that are not included in the wasteload allocation analysis as they discharge outside of the TMDL watershed. Sienna MUD Number 1 (WQ0014612001) and Fort Bend County MUD 131 (WQ0014197001) operate WWTFs in the watershed but the treated effluent is discharged outside of the watershed to channels of Middle Oyster Creek (Segment 1258). In 2018, the TDCJ Scott

Unit (WQ0010829001) permit expired as their wastewater effluent was tied into the City of Lake Jackson WWTF. The Lake Jackson WWTF (WQ0010047001) discharges outside of the watershed to the Brazos River (Segment 1201). The City of Clute WWTF (WQ0010044001) also discharges outside of the watershed to Old Brazos River Channel (Segment 1111). These WWTFs are not included in the WWTF analysis; however, the sanitary sewer lines run through the watershed and should be considered a potential source under sanitary sewer overflows (SSOs).

The five permittees identified for the wasteload allocation analysis hold bacteria limits in their permits and discharge to Oyster Creek Tidal or Oyster Creek Above Tidal. One facility, Commodore Cove (WQ0010798001), is found near the town of Oyster Creek in AU 1109_01 (Figure 10). Two facilities, Oyster Creek WWTF (WQ0010548004) and Beechwood WWTF (WQ0012113001) are located near the City of Angleton in AU 1110_01 (Figure 9). TDCJ Terrell Unit WWTF (WQ0013804001) can be found in AU 1110_02. The last facility, TDCJ Darrington Unit WWTF (WQ0010743001) is found in AU 1110_03. These five WWTFs were used in calculating the TMDL allocations found in Section 4.

WWTF permit requirements require self-reporting in the form of Discharge Monitoring Reports (DMRs). The DMRs are submitted to the state and EPA. EPA’s Enforcement and Compliance History Online (ECHO, EPA, 2022) was reviewed June 6, 2022, to ascertain the compliance history of the five WWTFs. The current compliance history, 2019 through 2022, suggests that there are no violations for *E. coli* according to the EPA for all five WWTFs. However, a review of the overall compliance history did note *E. coli* and Enterococci permit violations for reports with exceedances above permit limits at three of the five, Commadore Cove Improvement District WWTF, Beechwood WWTF, and TDCJ Terrell Unit WWTF.

Based on this review, WWTFs would not be considered a major source of fecal indicator bacteria to the watershed. However, preventing or limiting future exceedances should be one goal of this plan as releases of untreated and partially treated human sources of fecal indicator bacteria, even episodically, are a public health concern.

Table 7. Permitted domestic and industrial WWTFs

Subwatershed	AU	TPDES/NPDES[a] Number	Permittee	Facility Name	Facility Type[b]	Outfall Number	Bacteria Limit	Average Daily Discharge (MGD)[c]	Full Permitted Discharge (MGD)
Oyster Creek Tidal	1109_01	WQ0010798001/ TX0025283	Commodore Cove Improvement District	Commodore Cove Improvement District WWTF	WW	1	35 (Enterococci)	0.02	0.06
Oyster Creek Tidal	1109_01	WQ0004429000/ TX00124915	The Dow Chemical Company	Stratton Ridge Plant Site Salt Dome Operations	SW	001, 002	n/a	n/a	Intermittent and Flow Variable
Oyster Creek Above Tidal	1110_01	WQ0010548004/ TX0056316	City of Angleton	Oyster Creek WWTF	WW	1	126 (*E. coli*)	1.85	3.6
Oyster Creek Above Tidal	1110_01	WQ0012113001/ TX0079260	Undine Texas Environmental, LLC	Beechwood WWTF	WW	1	126 (*E. coli*)	0.02	0.1
Oyster Creek Above Tidal	1110_02	WQ0013804001/ TX0115169	TDCJ	Terrell Unit WWTF	WW	1	126 (*E. coli*)	1.54	2.0
Oyster Creek Above Tidal	1110_02	WQ0002952000/ TX0103896	TDCJ	TDCJ Terrell Cannery	IW	1	n/a	n/a	0.25
Oyster Creek Above Tidal	1110_03	WQ0010743001/ TX0031585	TDCJ	TDCJ Darrington WWTF	WW	1	126 (*E. coli*)	0.68	0.8

[a] NPDES: National Pollutant Discharge Elimination System

[b] WW= domestic wastewater treatment plant, IW= industrial wastewater, SW= stormwater

[c] MGD: million gallons per day

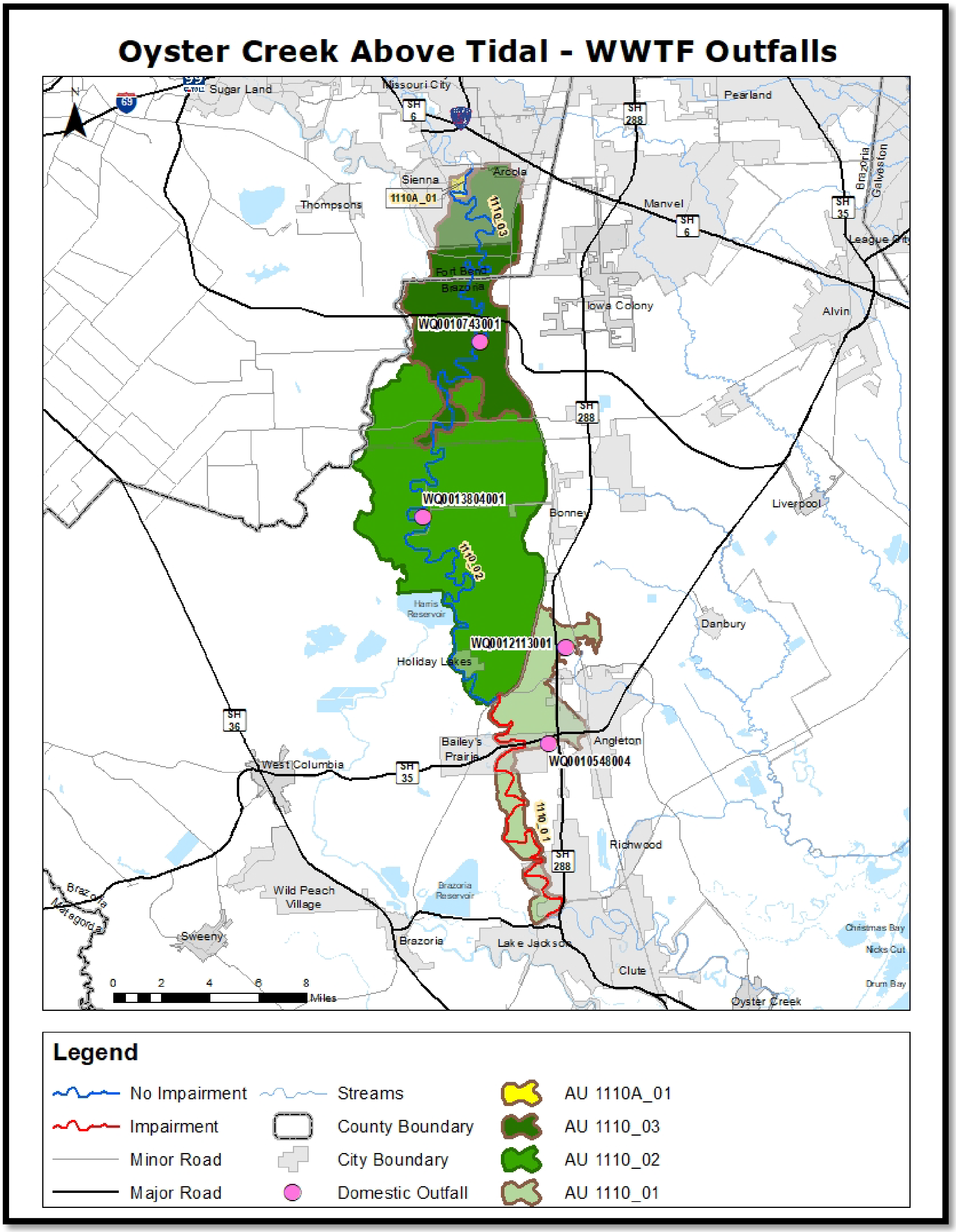

Figure 9. Oyster Creek Above Tidal wastewater outfalls

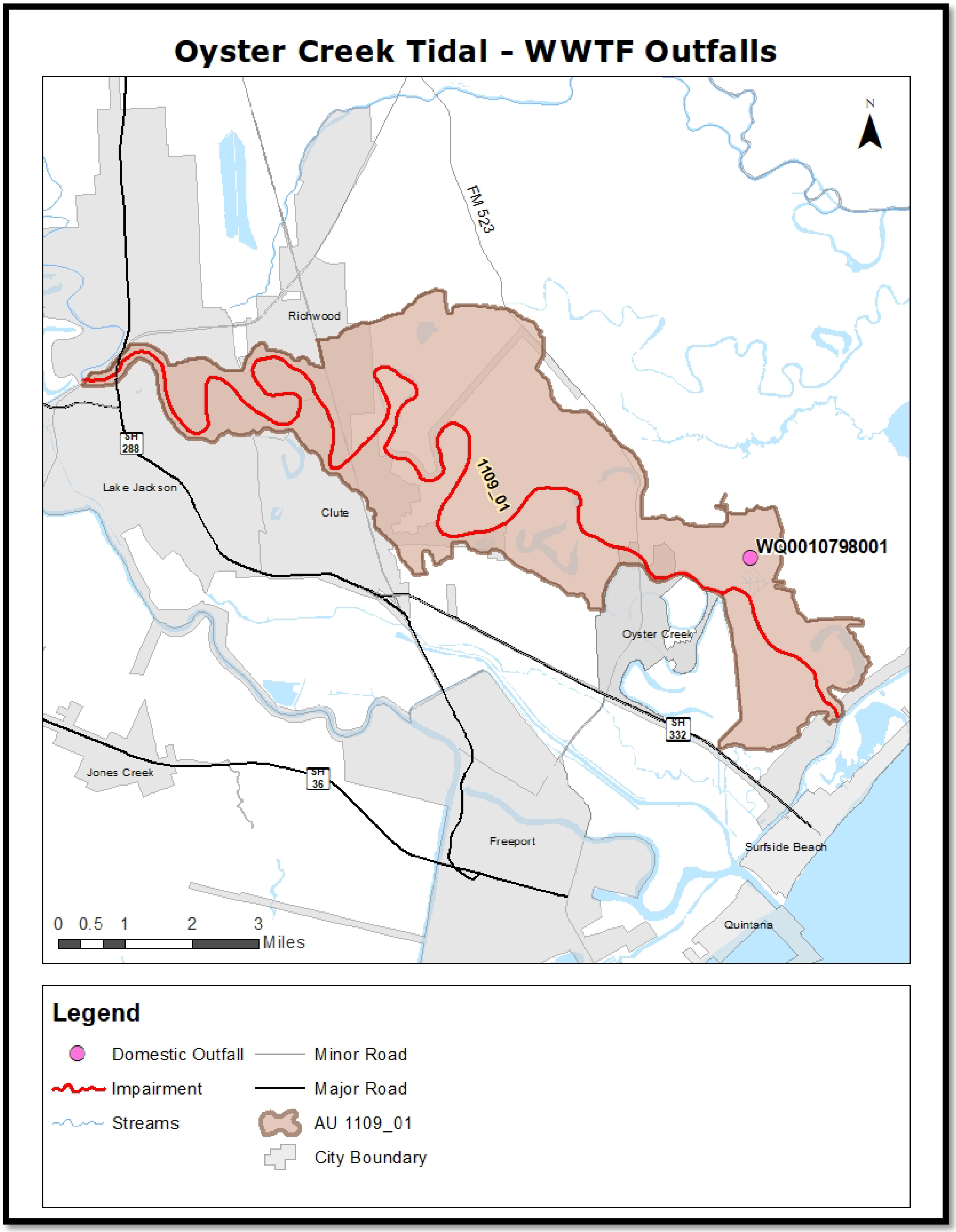

Figure 10. Oyster Creek Tidal wastewater outfall

2.7.1.2. 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 permits (TCEQ, 2022d) in the Oyster Creek watershed as of May 2022 found one concrete production facility within the Oyster Creek Tidal subwatershed (Segment 1109). This facility does not have bacteria reporting requirements or limits in their authorization. The effluent is assumed to contain inconsequential amounts of indicator bacteria; therefore, it was unnecessary to allocate a bacteria load to this facility. The concrete production facility is authorized to discharge stormwater, thus it will be considered in the stormwater allocation analysis (Table 8). No other active wastewater general permit authorizations were found.

Table 8. Concrete production facility

Subwatershed	AU	Permit	Permitee Name	County	City	Estimated Acreage
Oyster Creek Tidal	1109_01	TXG112022	Gulf Coast Concrete and Shell	Brazoria	Freeport	3.8

Three concentrated animal feeding operations (CAFOs) general permit authorizations were found in the Oyster Creek Above Tidal (Segment 1110) subwatershed (Table 9). CAFOs generate concentrated fecal and nutrient wastes but are not authorized to discharge wastewater except under chronic or catastrophic rainfall or catastrophic conditions. CAFOs are required to contain these wastes onsite in ponds. The ponds are allowed to dry out and any solids that could include fecal bacteria and nutrients are then disposed of by land application for crop and sod farming. The CAFOs, with appropriate control measures, would not be considered a source of discharge to the water body. However, containment failures, particularly during heavy rainfall and flooding conditions, do happen and could potentially cause releases of fecal wastes into the TMDL watershed. CAFOs in the Oyster Creek watershed were not used in the allocation analysis since they are not authorized to discharge wastewaters and are not expected to contribute bacteria loadings to the water bodies.

Table 9. Concentrated animal feeding operations

Subwatershed	AU	Permit	Name	County	City
Oyster Creek Above Tidal	1110_01	TXG920521	TDCJ Wayne Scott Unit	Brazoria	Angleton
Oyster Creek Above Tidal	1110_02	TXG920523	TDCJ Ramsey Unit	Brazoria	Rosharon
Oyster Creek Above Tidal	1110_03	TXG920526	TDCJ Darrington Unit	Brazoria	Rosharon

Except for the concrete production plant, no attempt was made to allocate bacteria loads from the remaining general permit types. For the concrete production facility, acreage was estimated by reviewing county appraisal parcel data and/or importing the location information associated with the authorization into a geographic information system (GIS) and measuring the facility boundaries. Once calculated, the area for the permit was used for development of the stormwater allocations in Section 4.

2.7.1.3. TPDES Regulated Stormwater

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

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

TPDES MS4 Phase I and II rules require municipalities and certain other entities in urbanized areas (UA) to obtain permit coverage for their stormwater systems. A regulated MS4 is a publicly owned system of conveyances and includes ditches, curbs, gutters, and storm sewers that do not connect to a wastewater collection system or treatment facility. Phase I permits are individual permits for large and medium-sized communities with populations of 100,000 or more based on the 1990 U.S. Census, whereas the Phase II General Permit regulates other MS4s within a USCB defined UA.

The purpose of an MS4 permit is to reduce discharges of pollutants in stormwater to the "maximum extent practicable" by developing and implementing a stormwater management program (SWMP). The SWMP describes the stormwater control practices that the regulated entity will implement, consistent with permit requirements, to minimize the discharge of pollutants. MS4 permits require that SWMPs specify the best management practices to meet several minimum control measures (MCMs) that, when implemented in concert, are expected to result in significant reductions of pollutants discharged into receiving water bodies. Phase II MS4 MCMs include 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 the following general permits:

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

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

A review of active permits covering MS4s in the TCEQ Central Registry found that there are 31 active MS4 Phase II permit authorizations and one combined Phase I/II MS4 permit (WQ0005011000) within the Oyster Creek watershed (Table 10). Data from the

USCB covering UAs was used to map potential MS4 coverage area for the watershed and to determine the likely area under the MS4 Phase II permit (USCB, 2010). Approximately 6,632.99 acres or 6.85% are under a stormwater permit in the Oyster Creek watershed. Of this total, 3,582.09 acres and 3,050.90 acres were found in the Oyster Creek Above Tidal and Oyster Creek Tidal subwatersheds, respectively (Figures 11 and 12).

Table 10. Permitted MS4s

Segments	TPDES Permit No./ NPDES ID	Regulated Entity	County	City
1109/1110	WQ0005011000	Texas Department of Transportation	Fort Bend/ Brazoria	N/A
1109/1110	TXR040139	City of Clute	Brazoria	Clute
1109/1110	TXR040140	City of Lake Jackson	Brazoria	Lake Jackson
1109/1110	TXR040141	City of Richwood	Brazoria	Richwood
1109/1110	TXR040142	Velasco Drainage District	Brazoria	N/A
1109/1110	TXR040154	Brazoria County	Brazoria	N/A
1110	TXR040136	City of Angleton	Brazoria	Angleton
1110	TXR040137	Angleton Drainage District	Brazoria	Angleton
1110	TXR040298	City of Missouri City	Fort Bend	Missouri City
1110	TXR040292	First Colony MUD 9	Fort Bend	Missouri City
1110	TXR040045	Fort Bend County	Fort Bend	N/A
1110	TXR040316	Fort Bend County MUD 23	Fort Bend	Fresno
1110	TXR040519	Fort Bend County MUD 24	Fort Bend	Fresno
1110	TXR040295	Fort Bend County MUD 26	Fort Bend	Missouri City
1110	TXR040293	Fort Bend County MUD 42	Fort Bend	Missouri City
1110	TXR040579	Fort Bend County MUD 46	Fort Bend	Missouri City
1110	TXR040290	Fort Bend County MUD 47	Fort Bend	Missouri City
1110	TXR040363	Fort Bend County MUD 49	Fort Bend	Missouri City
1110	TXR040297	Fort Bend County MUD 115	Fort Bend	Missouri City
1110	TXR040296	Meadowcreek MUD	Fort Bend	Missouri City
1110	TXR040219	Blue Ridge West MUD	Fort Bend	Missouri City
1110	TXR040383	Fort Bend County Drainage District	Fort Bend	Sugar Land
1110	TXR040359	Quail Valley Utility District	Fort Bend	Missouri City
1110	TXR040360	Thunderbird Utility District	Fort Bend	Missouri City
1110	TXR040361	Palmer Plantation MUD1	Fort Bend	Missouri City
1110	TXR040362	Palmer Plantation MUD2	Fort Bend	Missouri City
1110	TXR040513	Sienna Management District	Fort Bend	Missouri City
1110	TXR040514	Sienna LID	Fort Bend	Missouri City

Segments	TPDES Permit No./ NPDES ID	Regulated Entity	County	City
1110	TXR040515	Sienna MUD 1	Fort Bend	Missouri City
1110	TXR040516	Sienna MUD 2	Fort Bend	Missouri City
1110	TXR040517	Sienna MUD 3	Fort Bend	Missouri City
1110	TXR040518	Sienna MUD 10	Fort Bend	Missouri City

MSGPs were reviewed in TCEQ's Central Registry in May 2022 for active permits within the Oyster Creek Tidal and Oyster Creek Above Tidal subwatersheds (TCEQ, 2022d). A total of seven active MSGPs were found within the Oyster Creek watershed, four in the Oyster Creek Tidal subwatershed and three in the Oyster Creek Above Tidal subwatershed. To eliminate the possibility of over counting the stormwater permit area, only the area of MSGPs outside of UAs are included. Three of the four MSGPs in the Oyster Creek Tidal subwatershed were found to have boundaries outside the UA for a total of 2,511.73 acres (Figure 12).

All three MSGPs found within the Oyster Creek Above Tidal subwatershed are outside the UA, totaling 173.88 acres (Figure 11). The total Oyster Creek watershed area under MSGPs was estimated at 2,685.61 acres. It was previously noted that permit TX00124915 refers to an individual industrial wastewater permit for two stormwater outfalls. As this permit is for stormwater, the permit is included here with the MSGPs. The acreages were estimated by reviewing county appraisal parcel data and/or importing the location information associated with the authorization into GIS and measuring the facility area.

CGP authorizations are required when one acre or more of land is disturbed during construction. Construction activities found in the Oyster Creek watershed can change over time and the permit data found via the TCEQ Central Registry are only considered accurate for the date that the data was accessed. In May 2022, review of TCEQ Central Registry for a period of 2016 through 2021 found a yearly average of 66 active construction activities, 18 in the Oyster Creek Tidal subwatershed and 48 in the Oyster Creek Above Tidal subwatershed.

A permit field for construction activities retrieved from TCEQ Central Registry records "Area Disturbed." Due to the variable nature of these permits, the acres recorded serve here as a representative estimate. The disturbed areas are summed to estimate the amount of the watershed area under a stormwater construction permit at any given time. For the 66 permits found, there was a total annual estimated area of 2,992.26 acres under a construction permit, 384.105 acres in the Oyster Creek Tidal subwatershed and 2,608.15 acres in the Oyster Creek Above Tidal subwatershed. A final step was taken to remove those construction activities found within the UA to prevent over counting. After that step, the estimated construction activity within the Oyster Creek watershed was estimated at 1,163.15 acres, 152.3 acres in the Oyster

Creek Tidal subwatershed and 1,010.85 acres in the Oyster Creek Above Tidal subwatershed.

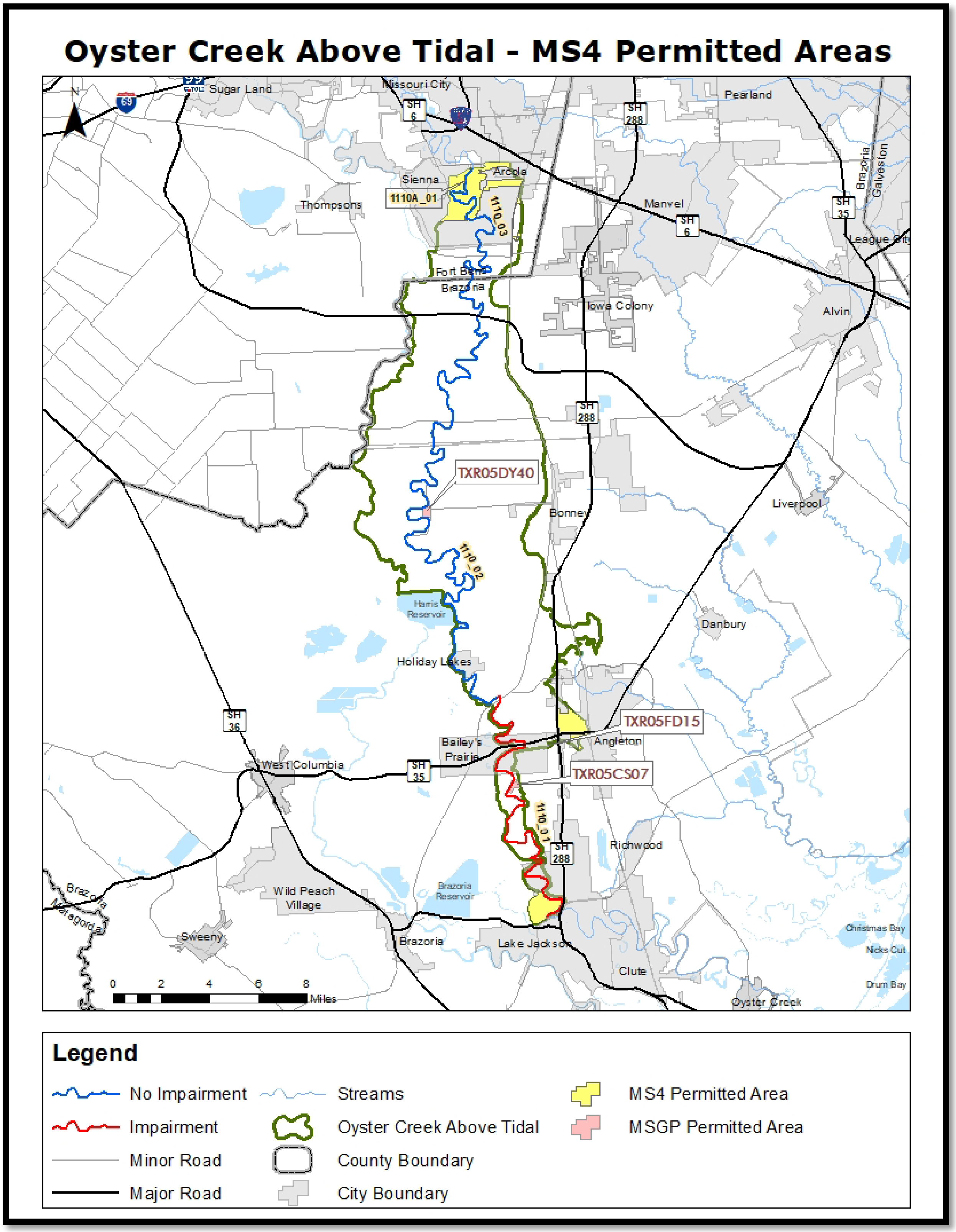

Figure 11. MS4 and MSGP permit areas within the Oyster Creek Above Tidal subwatershed

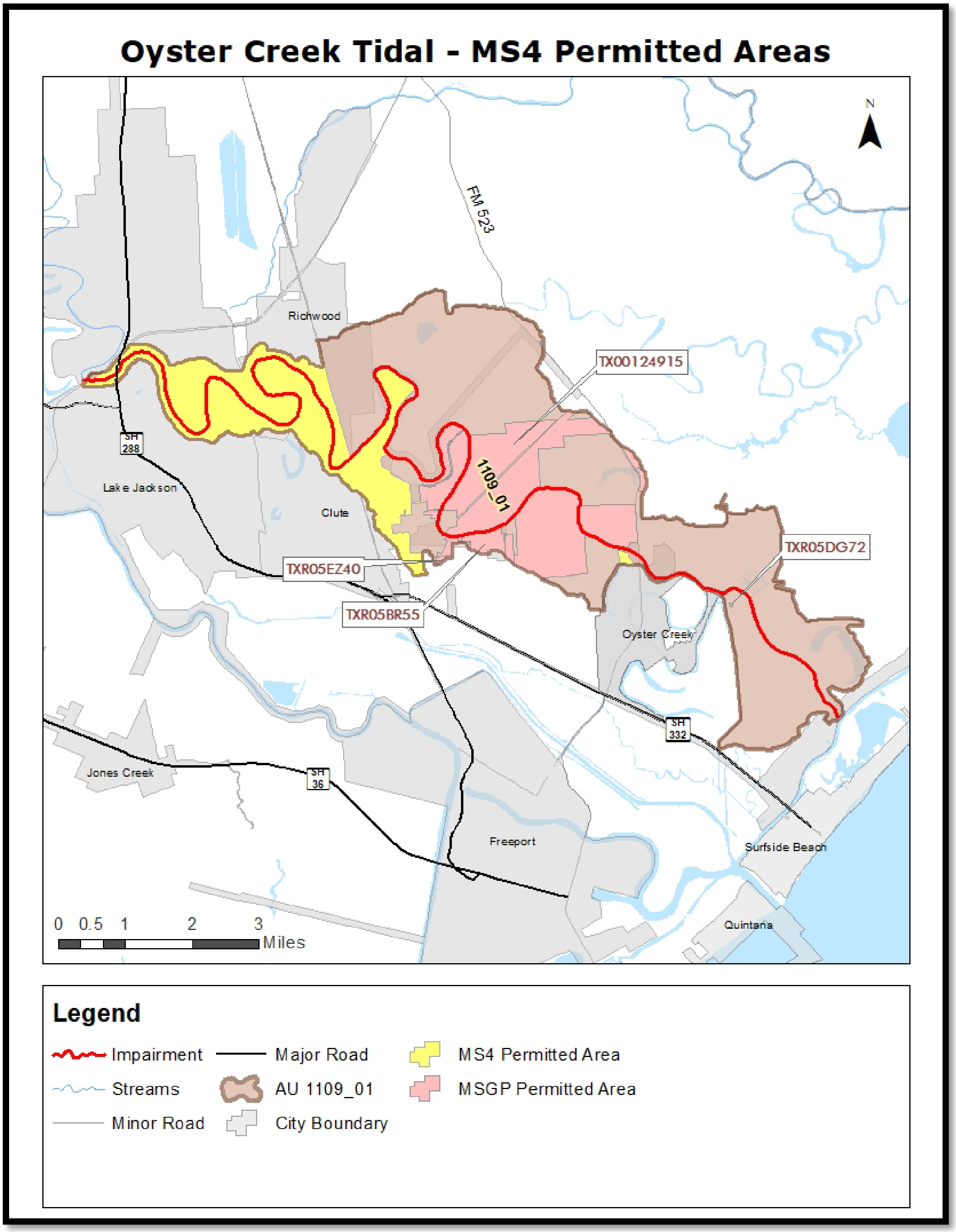

Figure 12. MS4 and MSGP permit areas within the Oyster Creek Tidal subwatershed

2.7.1.4. Sanitary Sewer Overflows

SSOs are unauthorized discharges that must be addressed by the responsible party, either the TPDES permittee or the owner of the collection system that is connected to the permitted system. These overflows in dry weather most often result from blockages in the sewer collection pipes caused by tree roots, grease, and other debris. Inflow and infiltration are typical sources of SSOs under conditions of high flow in the WWTF system. Blockages may worsen the inflow and infiltration problem. Other causes, such as collapsed sewer line, may occur under any condition.

SSO data are reported to TCEQ Region 12 by permit holders in Oyster Creek. TCEQ provided the SSO data for analysis in March 2022 (TCEQ, 2022e). Municipalities report 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 Oyster Creek covered the period of Jan. 1, 2016, through Dec. 31, 2021. A combined total of 91 SSOs were reported by five permit holders with collection systems within the Oyster Creek watershed (Table 11). The reported untreated effluent released to the Oyster Creek watershed for the period of record was estimated at 241,321 gallons or an average of 2,651.88 gallons per reported SSO. For the six-year period, 2021 had the most reported SSOs with 42 and the least number were reported in 2019. The greatest single cause attributed to SSOs was due to infiltration and inflow, this was reported to cause 36 SSOs. The second and third highest causes reported were due to power outages and equipment failure, 18 and 12 SSOs, respectively.

Table 11. Summary of Reported SSOs

Year	SSO Number	SSO Volume
2016	14	56,395
2017	12	3,915
2018	14	4,025
2019	3	116,200
2020	6	1,947
2021	42	58,839
Total	91	241,321

2.7.1.5. Dry Weather Discharges/Illicit Discharges

Pollutant loads can enter water bodies from MS4 outfalls that carry authorized sources as well as illicit discharges under both dry- and wet-weather conditions. The term “illicit discharge” is defined in TPDES General Permit TXR040000 for Phase II MS4s as “Any discharge to a municipal separate storm sewer that is not entirely composed of stormwater, except discharges pursuant to this general permit or a separate authorization and discharges resulting from emergency firefighting activities.” Illicit discharges can be categorized as either direct or indirect contributions. Examples of illicit discharges identified in the *Illicit Discharge Detection and Elimination Manual: A Handbook for Municipalities* (NEIWPCC, 2003) include:

Direct Illicit Discharges:

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

Indirect Illicit Discharges:

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

2.7.2. Unregulated Sources

Unregulated sources of bacteria are generally nonpoint. Nonpoint source loading enters the impaired water body through distributed, nonspecific locations, which may include urban runoff not covered by a permit. Potential sources, detailed below, include wildlife, feral hogs, various agricultural activities, agricultural animals, urban runoff not covered by a permit, failing 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. 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 Oyster Creek, TPWD deer population estimates recorded from 2008 through 2020 average 0.03957 deer for every acre, regardless of land cover type (TPWD, 2020). By applying this factor to the acreage in the Oyster Creek watershed, the white-tailed deer population is estimated at 3,715 (Table 12).

Table 12. Estimated deer population

Subwatershed	Area (acres)	Estimated Deer Population
Oyster Creek Tidal	15,086.60	597
Oyster Creek Above Tidal	78,796.80	3,118
Total	**93,883.40**	**3,715**

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. Considering these factors, feral hog populations were estimated to be 8.9 hogs per square mile in Barren Lands, Cultivated Crops, and Low Intensity Development. An estimated 16.4 hogs per square mile is applied to Open Space Development, Forest/Shrubs, Pasture/Grasslands, and Wetland land cover types. Under these assumptions, the total number of feral hogs were estimated to have a total population of 2,126 within the Oyster Creek watershed (Table 13). The *E. coli* contribution from feral hogs and wildlife could not be determined based on existing information.

Table 13. Estimated feral hog population

Subwatershed	Low Quality (acres)	Feral Hogs	High Quality (acres)	Feral Hogs	Total
Oyster Creek Tidal	1,584.00	22	11,828.40	303	325
Oyster Creek Above Tidal	12,133.30	169	63,676.20	1,632	1,800
Total	**13,717.30**	**191**	**75,504.60**	**1,935**	**2,126**

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. There are three permitted CAFOs in the Oyster Creek watershed, which were discussed under the regulated sources section. Animals housed within the CAFOs are not included here.

In Table 14, estimates of livestock in the Oyster Creek watershed are shown. Livestock numbers from the 2017 Census of Agriculture are provided at the county level for Brazoria and Fort Bend counties, collected by the USDA (USDA, 2019). The county livestock numbers were distributed equally across livestock and farm operations in emergent wetland, shrub/scrub, and pasture/grasslands land cover types within the county. To determine the number of livestock within each subwatershed, the number of livestock to acre was calculated for each county and then that stocking rate was applied to the watershed based on the proportion of the county found within the watershed. Livestock numbers are not used to develop the TMDL loading allocation.

Table 14. Estimated livestock populations

Area Name	Area (Acres)	Cattle and Calves	Hogs and Pigs	Sheep and Goats	Equine	Poultry
Brazoria County	438,990	68,515	3,811	4,832	4,522	123,578
Fort Bend	196,715	31,605	54	983	2,027	2,796
Oyster Creek Tidal	7,060	1,102	61	78	73	1,988
Oyster Creek Above Tidal	38,200	6,015	235	352	394	7,690
Total	**45,260**	**7,117**	**296**	**430**	**467**	**9,678**

Fecal bacteria from dogs and cats are transported to streams by runoff in both urban and rural areas and can be a potential source of bacteria loading. Table 15 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 (AVMA) 2017-2018 U.S. Pet Statistics (AVMA, 2018). The number of households in the watershed was estimated using the H-GAC's Regional Forecast analysis of the USCB 2020 decadal census data, with the average household size of 2.71 (USCB, 2020). The actual contribution and significance of bacteria loads from pets reaching the water bodies of the watershed is unknown.

Table 15. Estimated households and pet populations

Subwatershed	Estimated Households	Dogs	Cats
Oyster Creek Tidal	4,569	2,805	2,088
Oyster Creek Above Tidal	9,823	6,032	4,489
Total	**14,392**	**8,837**	**6,577**

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, it has been reported that less than 0.01% of fecal coliforms originating in household wastes move further than 6.5 feet down gradient of the drainfield of a septic system (Weiskel *et al.*, 1996). Reed, Stowe, and Yanke LLC (2001) provide information on estimated failure rates of OSSFs for different regions of Texas. The TMDL watershed is within the Region IV area, which has a reported failure rate of about 12%, providing insights into expected failure rates for the area.

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

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

There are 1,390 registered OSSFs in the Oyster Creek watershed, 69 in the Oyster Creek Tidal subwatershed and 1,321 in the Oyster Creek Above Tidal subwatershed (Table 16, Figures 13 and 14).

In addition to permitted systems, there are OSSFs that are not registered. Nonregistered OSSF locations were estimated using H-GAC’s geographic information database of potential OSSF locations (H-GAC, 2022b) in the Houston-Galveston area using known OSSF locations, 911 addresses, and WWTF service boundaries. Using H-GAC’s estimate of nonregistered OSSFs, there are likely another 2,144 total OSSFs; 253 in the Oyster Creek Tidal subwatershed and 1,891 in the Oyster Creek Above Tidal subwatershed (Table 16, Figures 13 and 14).

Table 16. Registered and nonregistered OSSFs

Subwatershed	Registered	Nonregistered	Total
Oyster Creek Tidal	69	253	322
Oyster Creek Above Tidal	1,321	1,891	3,212
Total	**1,390**	**2,144**	**3,534**

OSSFs can be an appreciable source of fecal waste when not sited or functioning properly, especially when they are close to waterways. Many factors including soil type, design, age, and maintenance can influence the likelihood of an OSSF failure. By applying the estimated 12% failure rate to the 3,534 OSSFs estimated within the TMDL watershed (Table 16), 424 OSSFs 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.

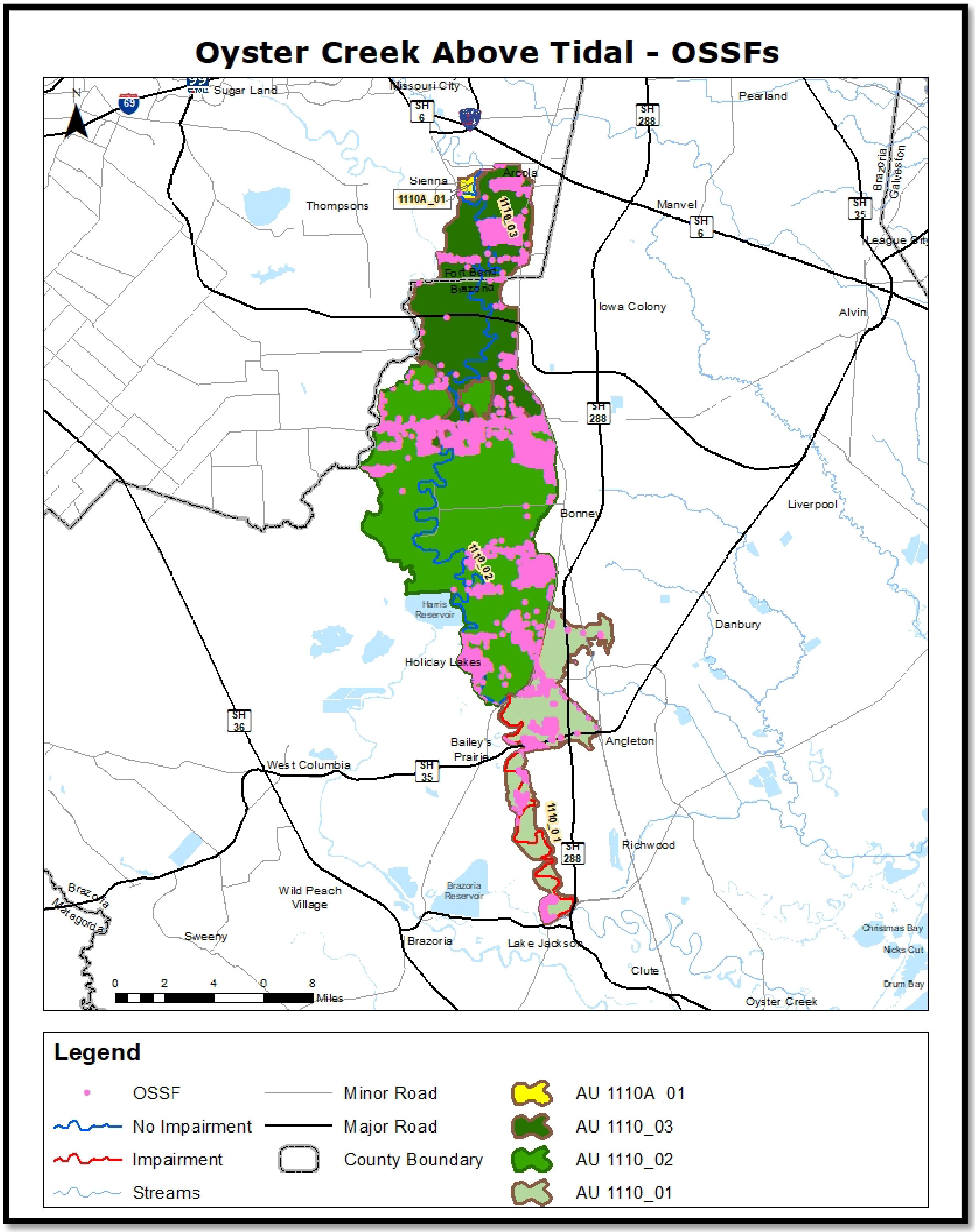

Figure 13. Estimated OSSF locations within the Oyster Creek Above Tidal subwatershed

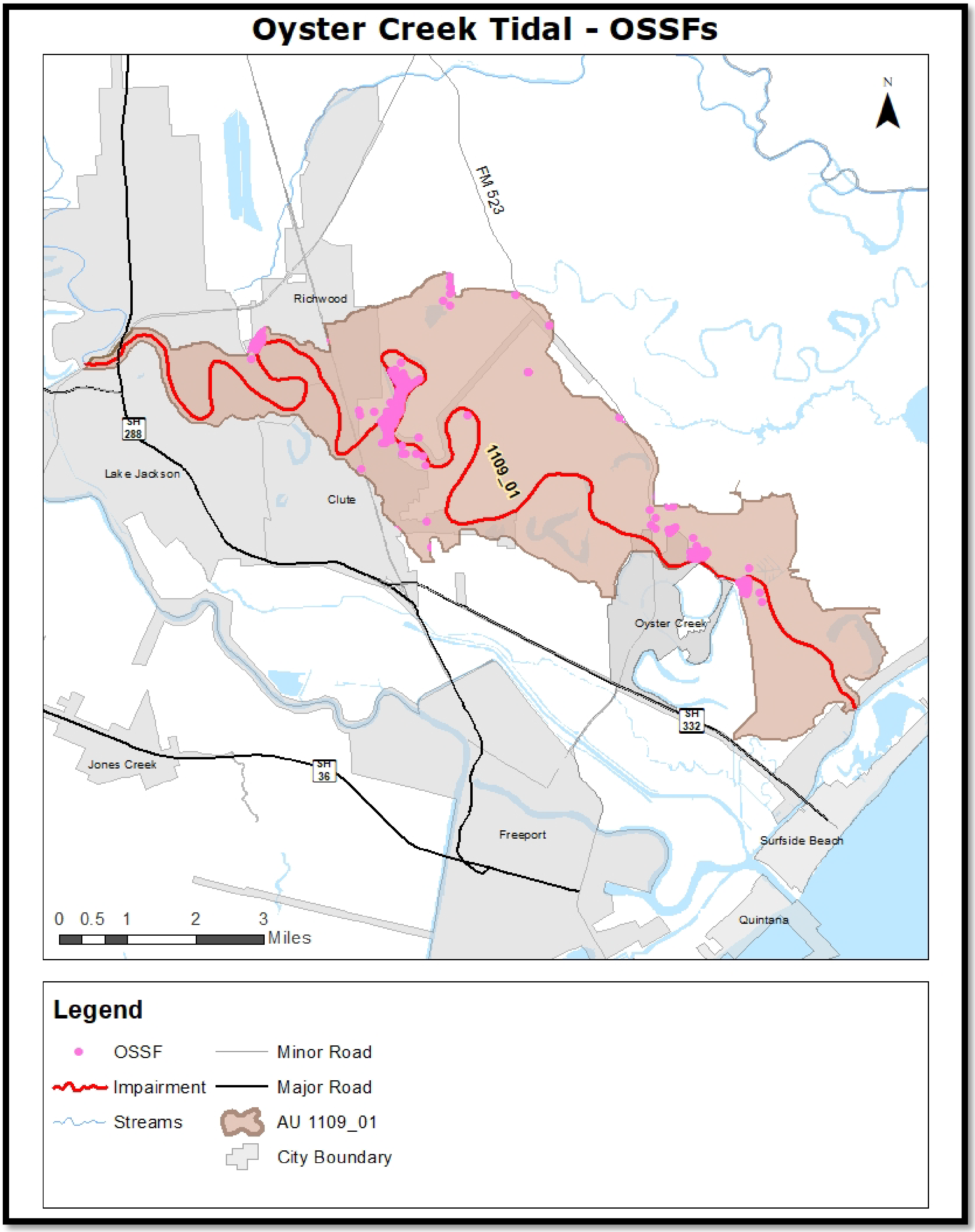

Figure 14. Estimated OSSF locations within the Oyster Creek Tidal subwatershed

Section 3. Bacteria Tool Development

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

3.1. Tool Selection

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

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

3.2. Data Resources

With the exception of daily streamflow, Oyster Creek data resource (i.e., fecal indicator bacteria data) availability was sufficient to perform LDC analysis in Oyster Creek Above Tidal. Salinity data is needed to address tidal inflow to complete LDCs in Oyster Creek Tidal in addition to daily streamflow and fecal indicator bacteria. Streamflow will be discussed further below to address this data limitation.

All required water quality data (*E. coli*, Enterococci, and salinity) that were available through SWQMIS for Jan. 1, 2004 to Dec. 31, 2020, were reviewed and were determined sufficient for completing LDCs. SWQMIS is a database that serves as the repository for TCEQ surface water quality data for the state of Texas. All data used for these analyses were collected under a TCEQ-approved quality assurance project plan. Data with "qualifier" flags associated with potential data quality problems were excluded from the download. All data were combined into a working data set for LDC development (Table 2).

Daily streamflow records are an essential component of LDC development. Lack of available daily streamflow data for the period of 2004 to 2020 were an issue in Oyster Creek for both AUs, 1109_01 and 1110_01. In February 2017, a gaging station was established at TCEQ SWQM Station 11491 by EIH in AU 1110_02 that measures the gage height every 15 minutes. To convert the gage heights to streamflow, a flow rating curve was developed using monthly field measured flows and heights. The streamflow records were available for the period of Feb. 17, 2017 to Dec. 31, 2020 through EIH (EIH, 2022).

The daily flow records from the USGS flow gage 08078000, on Chocolate Bayou Above Tidal (Segment 1108) was also used to derive daily streamflow at Oyster Creek for the intended LDC period of 2004 to 2020. This USGS gage was selected for several reasons. Chocolate Bayou watershed is close to the Oyster Creek watershed and it has a similar drainage area (Table 17, Figure 15), land cover composition, weather patterns and watershed land use activities, such as agriculture and industries.

Table 17. Catchment area comparison

Waterbody	Station Number	Catchment Area (mi^2)
Chocolate Bayou	08078000	77.54
Oyster Creek	11491	100.77

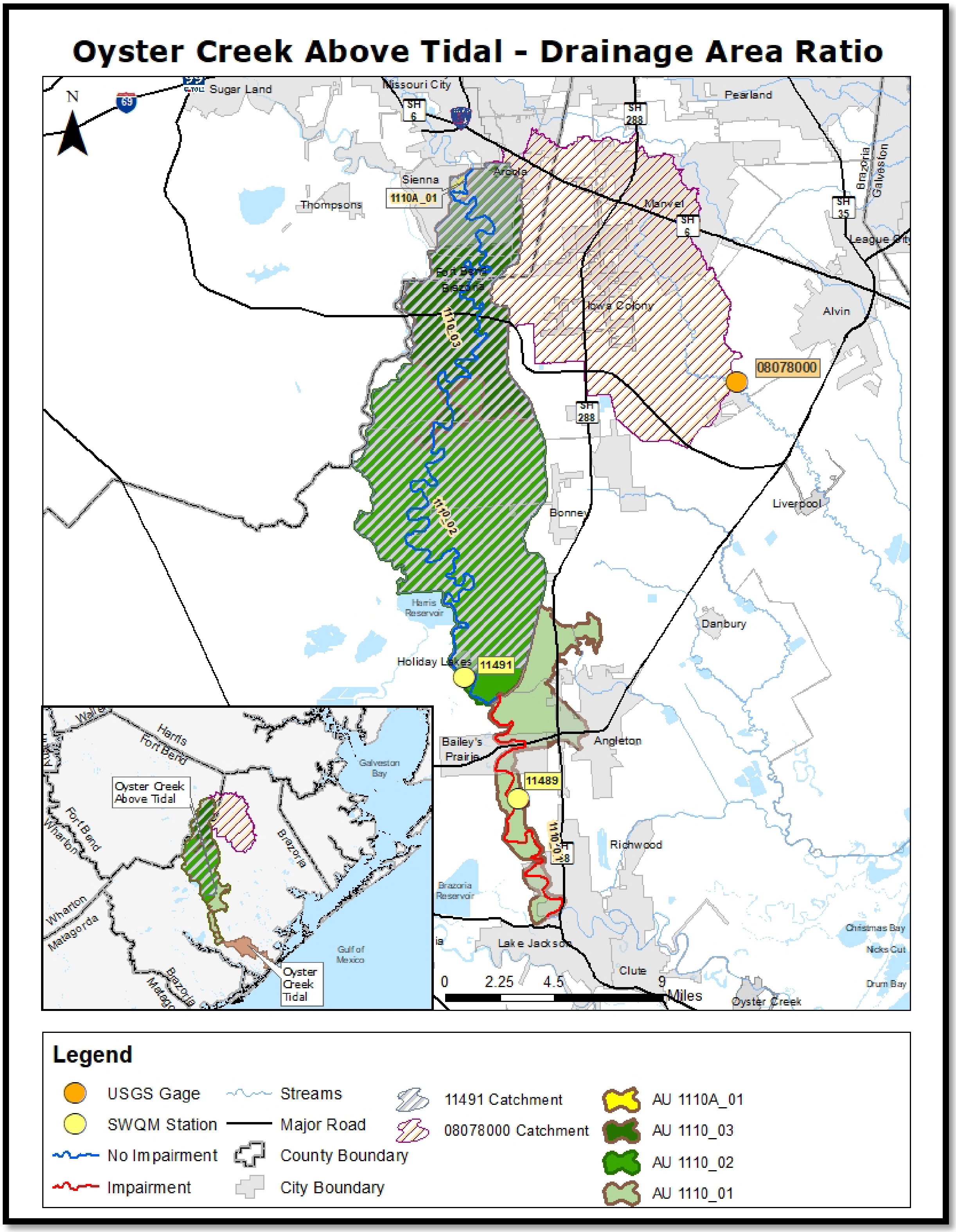

Figure 15. Catchment area comparison

3.3. Methodology for Flow Duration and Load Duration Curve Development

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

- 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 regression of salinity to streamflow for AU 1109_01.
    - Step 4.2: Incorporate daily tidal volumes into streamflow record for AU 1109_01.
- 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

Daily streamflow at TCEQ SWQM Station 11491 monitored by EIH in AU 1110_02 that measures the gage height every 15 minutes was used. To convert the gage heights to streamflow, a flow rating curve was developed using monthly field measured flows and heights. The streamflow records were available for the period of Feb. 13, 2017 to Dec. 31, 2020 through EIH.

To extend the period of record, the daily flow data from USGS gage 08078000 (USGS, 2019), located on Chocolate Bayou Above Tidal (Segment 1108) was used in conjunction with TCEQ SWQM Station 11491 to derive daily streamflow at Oyster Creek for the intended LDC period of 2004 to 2020.

3.3.2. Step 2: Determine Desired Stream Location

Data from USGS gage 08078000 and TCEQ SWQM Station 11491 will be used to develop the TMDLs for AU 1110_01 and AU 1109_01. TMDLs will be developed for station locations within the impaired AUs, TCEQ SWQM stations 11489 in AU 1110_01 and 11486 in AU 1109_01. It should be noted that TCEQ SWQM Station 11486 is not the station located the furthest downstream in AU 1109_01. However, a review of the data at TCEQ SWQM Station 11485, the most downstream station, shows that the impairment is being driven by data collected at TCEQ SWQM Station 11486 (Table 2).

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 Oyster Creek were calculated based on the daily freshwater flow regression between USGS gage 08078000 and the EIH gage at TCEQ SWQM Station 11491 and the DAR method. The DAR method involves multiplying a known 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 location of the known flow. TCEQ SWQM Station 11491 was used as the location of known flow.

To compute the DAR, the drainage area above TCEQ SWQM Station 11491 was compared with the total drainage area contributing to each monitoring station downstream. As an example, to calculate the DAR for TCEQ SWQM Station 11489, the total drainage area includes the area between TCEQ SWQM stations 11489 and 11491 and all of the drainage area contributing to TCEQ SWQM Station 11491. The cumulative drainage watershed area is then divided by TCEQ SWQM Station 11491’s watershed area. DAR values for all stations can be found in Table 18.

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

Where:

Y = streamflow for the ungaged TCEQ SWQM station

X = regression streamflow for TCEQ SWQM Station 11491

A_x = drainage area for TCEQ SWQM Station 11491

A_y = drainage area for the ungaged SWQM station

Table 18. Drainage-area ratios for stations in the Oyster Creek watershed

AU Watershed	TCEQ SWQM Station	Drainage Area (mi^2)	Cumulative Drainage Area (mi^2)	DAR
1110_02	11491	100.77	100.77	NA
1110_01	11489	17.03	117.80	1.17
1109_01	11486	5.18	122.98	1.22
1109_01	11485	17.68	140.66	1.40

Once the DARs are known, freshwater flow values can be generated at each station using equation (Eq.) 1. As an example, the flow values at TCEQ SWQM Station 11491 were multiplied by 1.17 to obtain the freshwater flow at TCEQ SWQM Station 11489. Additional steps are taken for tidal AUs. This will be explained in 3.3.4.

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

To derive the Oyster Creek daily streamflow, the streamflow for Chocolate Bayou must be “naturalized” by correcting for 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 extant USGS records.

The estimated average daily DMR reported discharges for 2017 – 2021 from all the WWTF outfalls upstream of the USGS gage location (Table 19) were subtracted from the daily gage streamflow records. This resulted in an adjusted streamflow record with point source discharge influences removed.

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

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

The water right consumptions (i.e., the balance between diverted amount and returned flow amount) were adjusted from the point source removed streamflow discharge records. The water rights diversion and return flow data were downloaded from the TCEQ Water Right Permitting and Availability Section’s Water Rights Viewer (TCEQ, 2022f). There were three water rights diversions 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 from Chocolate Bayou.

The Harris Reservoir should be mentioned at this point as it presents a major modification to flow second to the alteration that removed the upper portions of the Oyster Creek watershed. For the purposes of this discussion, the reservoir is used during times of drought as a source of fresh water. The reservoir releases water for domestic and industrial use, passing TCEQ SWQM stations 11491 and 11489. The supplied flow is removed via a pumping station prior to the saltwater barrier erected at Hwy 288. The flow was not removed from developing naturalized flow at TCEQ SWQM Station 11491 as it has a similar impact on flow at TCEQ SWQM Station 11489.

During high rainfall, the Harris Reservoir will contribute to the system as overflow, but this would be considered normal tributary flow.

Using the DAR method to address differences in watershed size between Chocolate Bayou and Oyster Creek above TCEQ SWQM Station 11491 (Table 18), a linear regression was made using Statistical Analysis Software between the daily streamflow at the EIH stream gage with the USGS Chocolate Bayou stream gage. Based on the estimated regression relationship, the daily streamflow values for Oyster Creek at TCEQ SWQM Station 11491 for the period of Jan. 1, 2004, to Dec. 31, 2020 were derived.

The derived daily streamflow for the EIH gage at TCEQ SWQM Station 11491 was then "naturalized." A similar procedure was used to remove WWTF daily discharges and return any water withdraws not returned to Segment 1110's subwatershed. Table 7 provides the estimated average daily DMR reported discharges for the time-period of 2017 – 2021 from the two permitted outfalls upstream of the EIH gage location, TCEQ SWQM Station 11491, TDCJ Darrington Unit WWTF (WQ0010743001) and TDCJ Terrell Unit WWTF (WQ0013804001).

The daily freshwater flow values at the other SWQM stations in Oyster Creek were then calculated based on the "naturalized" derived flow values of TCEQ SWQM Station 11491 and using the DAR method. Once the daily streamflow estimates are made using the DAR step a final procedure is performed to develop the daily streamflow record at each location. The WWTFs full permitted flow and Future Growth component as determined by future WWTF flow are added to the generated streamflow record at each location.

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

The modified FDC and LDC approach was attempted for AU 1109_01 as the AU is considered a tidal waterbody (ODEQ, 2006). 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 segment. Segment 1109 contains two TCEQ SWQM stations: 11486 and 11485. While an LDC was created for TCEQ SWQM Station 11485, for development of the TMDL in Section 4, only TCEQ SWQM Station 11486 will be used, as it best represents the impairment as Table 2 presented.

To develop the modified LDC, Enterococci and salinity measurements from 2004 to 2020 were acquired. There were no daily streamflow records available to estimate the daily loads of bacteria. Derived daily flow measurements from SWQM station 11491 were used, as discussed in the previous section.

At this point in developing the daily flow, salinity values were evaluated. After a review of salinity for TCEQ SWQM Station 11486, the values were found to be too low for tidal inflows to negatively influence LDC development. Constructing a modified LDC was dropped for this station and the steps for nontidal water bodies were followed as described in Section 3.3.5.

For TCEQ SWQM Station 11485, the modified LDC steps were followed. Daily flow records were generated and related to the salinity of the stream at TCEQ SWQM Station 11485 in the following steps:

Available Enterococci and salinity measurements from 2004 to 2020 were acquired or derived as presented previously. Each salinity measurement was matched with its corresponding calculated daily freshwater flow. The salinity records were then plotted against the log-transformed flow values in a scattered plot (Figure 16).

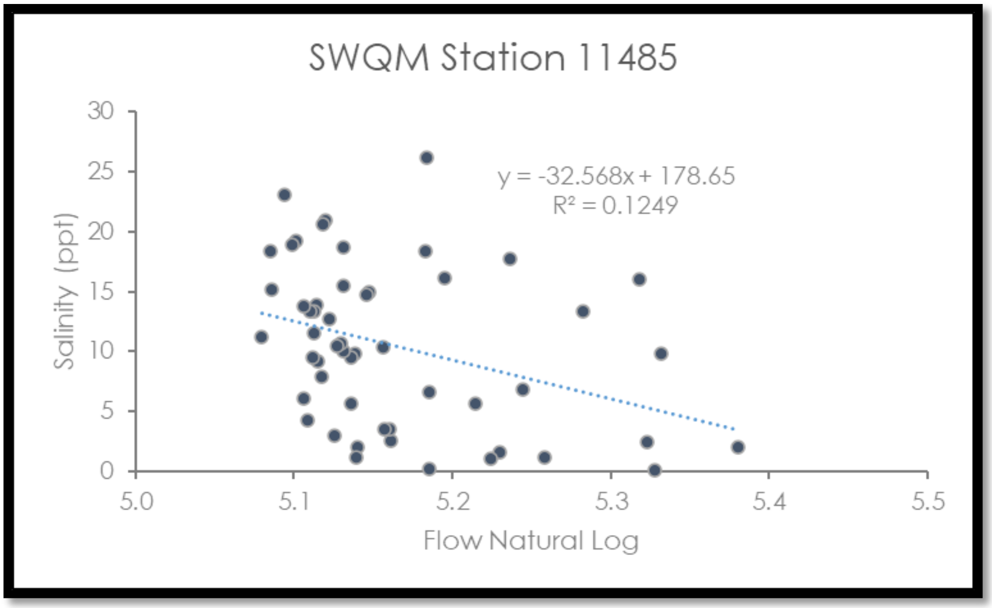

Figure 16. Regression scatter plot for TCEQ SWQM Station 11485

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

The equation for TCEQ SWQM Station 11485:

$$\hat{Y} = b_0X_1 + b_1 \qquad \text{(Eq. 2)}$$

$\hat{Y}$ = Salinity (parts per thousand (ppt))

X_1 = Log-transformed Flow (cubic feet per second (cfs))

b_0 = Slope of the linear regression line = -32.568

b_1 = Intercept = 178.65

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:

$$(V_r + V_s) * S_t = V_r * S_r + V_s * S_s \qquad \text{(Eq. 3)}$$

V_r = volume of daily freshwater (river) flow

V_s = volume of daily seawater flow

S_t = salinity in river (ppt)

S_r = background salinity of upstream river water (ppt); assumed = 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:

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

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 equations of Step 4 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 4.

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

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

From this point the development of FDCs and LDCs follows the same process as found in Section 3.3.5.

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

FDCs and LDCs are graphs that visualize the percentage of time during which a value of flow or load is equaled or exceeded. To develop the FDC for the 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 (Figure 16).

Further, when developing an LDC:

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

The resulting curve represents the maximum daily allowable loadings for the geometric mean criterion (Figure 17).

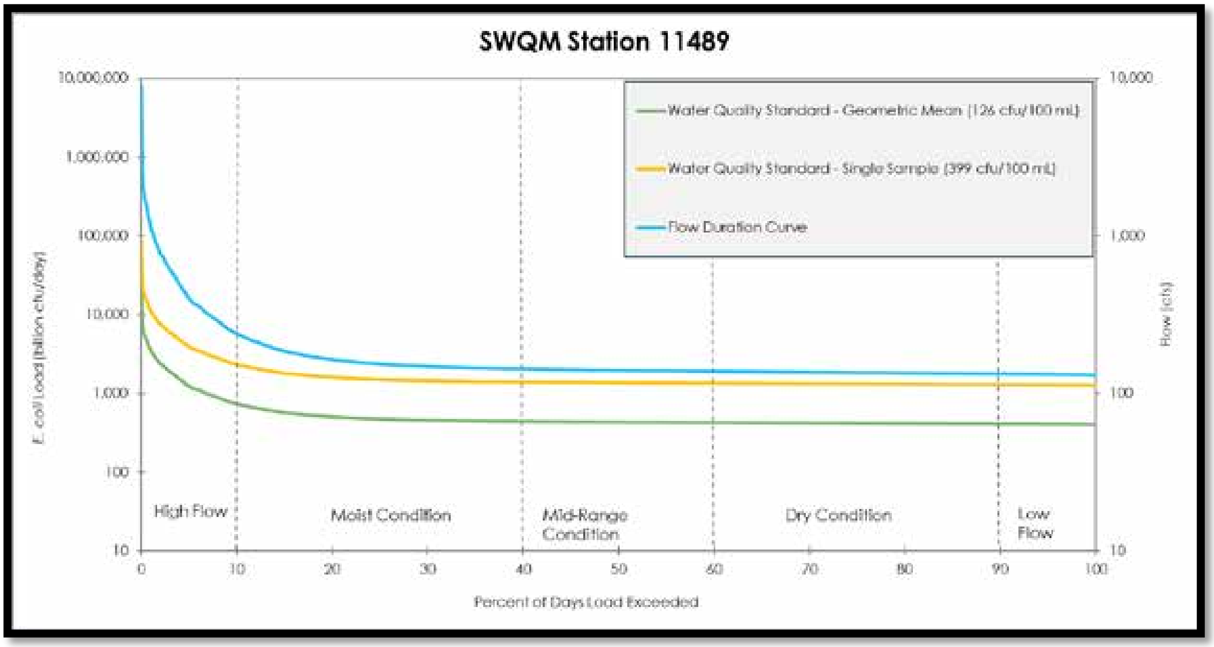

Figure 17. FDC for TCEQ SWQM Station 11489

The next step is to plot the measured fecal indicator bacteria data on the developed FDC using the following steps:

- Compute the daily loads for each sample by multiplying the measured Enterococci or *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 TCEQ SWQM station the load for each measurement at the exceedance percentage for its corresponding streamflow.

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

3.4. Flow Duration Curves

Figure 17 provides the FDC for TCEQ SWQM Station 11489. The curve is separated into five flow regimes including high flows (0–10%), moist conditions (10–40%), mid-range flows (40–60%), dry conditions (60–90%), and low flows (90–100%). For reference, the *E. coli* geometric mean criterion curve (load at 126 cfu/100 mL) and the *E. coli* single sample criterion curve (load at 399 cfu/100 mL) are included on the FDC.

Figure 18 is the FDC for TCEQ SWQM Station 11486. For this FDC the standard criterion curves have changed to loads using the Enterococci geometric mean criterion of 35 cfu/100 mL and the single sample criterion of 130 cfu/100 mL.

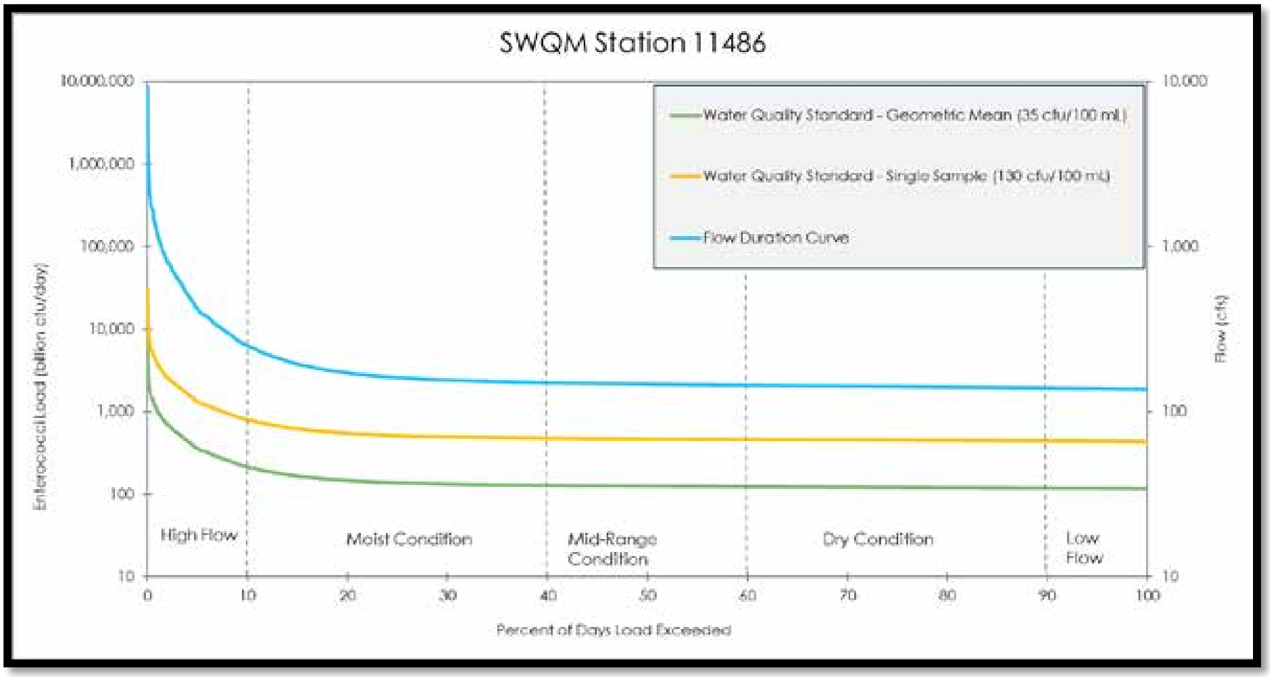

Figure 18. FDC for TCEQ SWQM Station 11486

Figure 19 is the modified FDC for TCEQ SWQM Station 11485 using the Enterococci standard criterion loads.

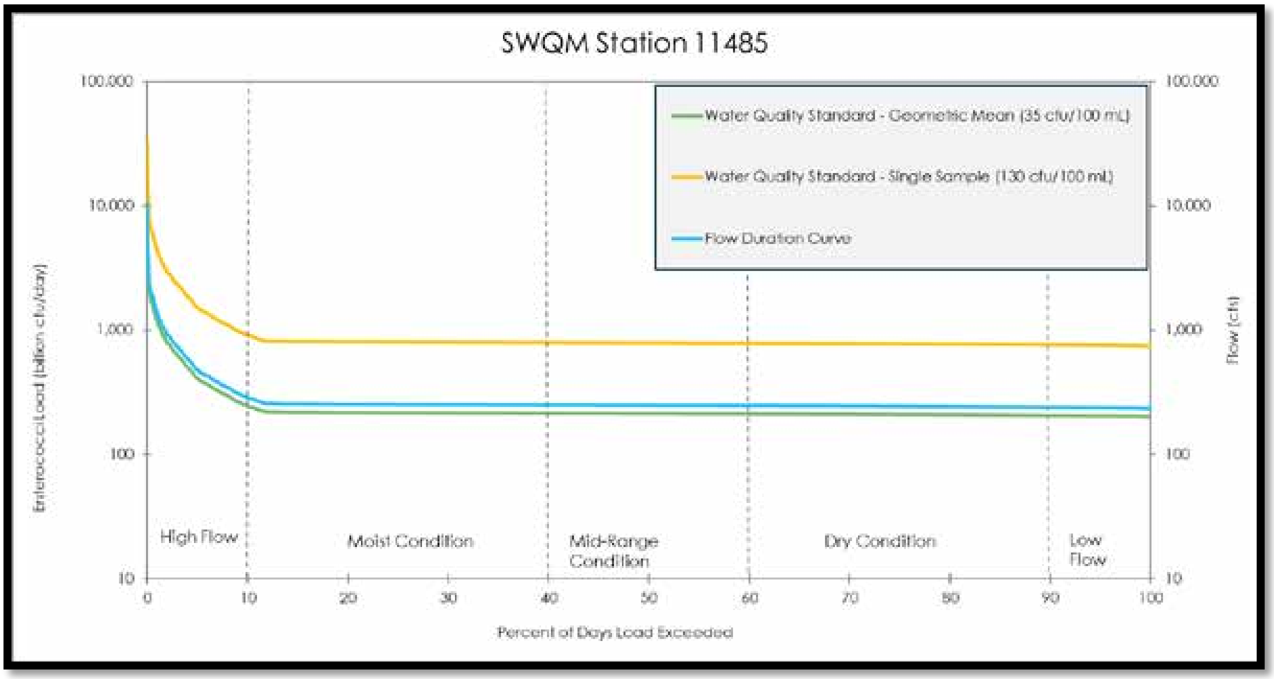

Figure 19. FDC for TCEQ SWQM Station 11485

3.5. Load Duration Curves

Figures 20, 21, and 22, present LDCs for TCEQ SWQM stations 11485, 11486, and 11489, respectively. The figures include the FDC, the geometric mean criterion curves, the single sample criterion curve, the existing load regression curve, the observed bacteria geometric mean load by flow regime (single points), and individual observed bacteria data points.

The LDC for TCEQ SWQM Station 11485 confirms that the contact recreation impairment is driven by the elevated fecal bacteria load found at TCEQ SWQM Station 11486 (Figure 20). The load regression curve quickly falls below the geometric mean curve early in the high flow condition. Here most of the individual bacteria source inputs are found below the standard curve as evidenced by the geometric means calculated within each flow regime.

Looking at the LDCs for TCEQ SWQM stations 11486 and 11489 show the load regression curve above the geometric mean curve throughout the duration of all flow regimes for both stations (Figures 21 and 22). For TCEQ SWQM Station 11486, the load regression curve is significantly above the standard curve in all flow regimes. The LDCs suggest that the impairments are potentially influenced by both dry and wet weather bacteria sources at both stations. Most of the individual bacteria data points for TCEQ SWQM stations are above the geometric mean standard curve, most prominently in the high and moist conditions but also in the dry conditions, again indicative of wet and dry weather bacteria source inputs.

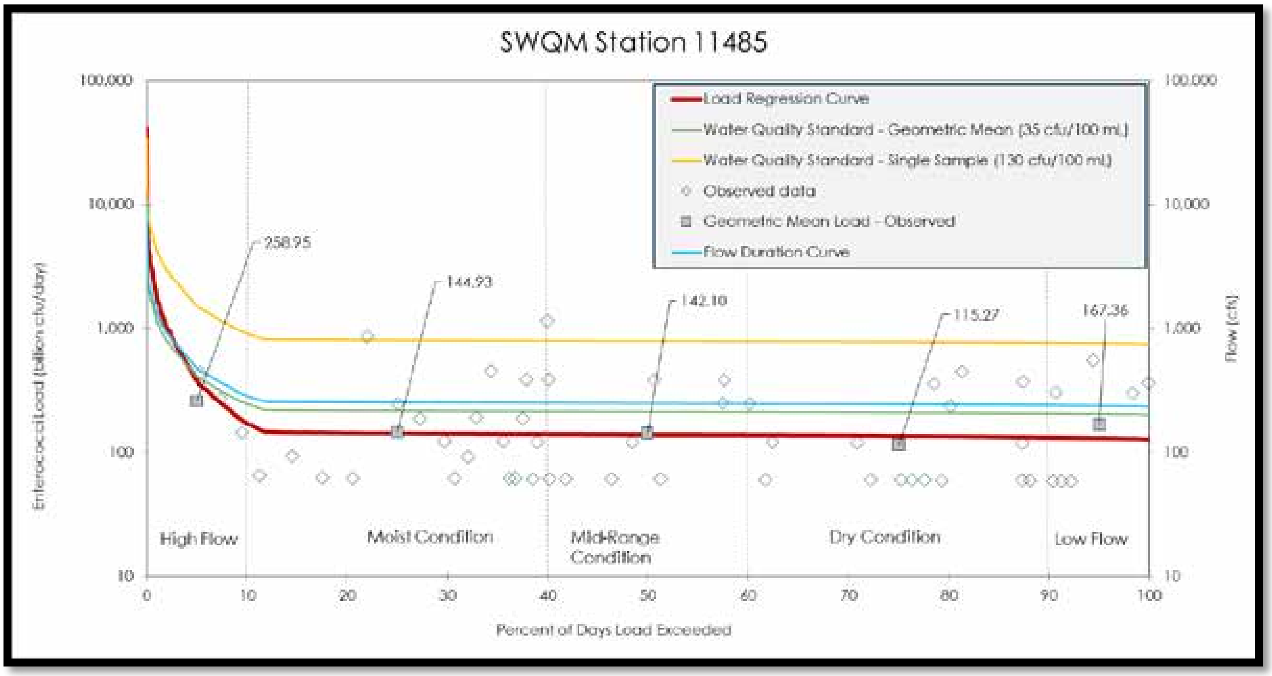

Figure 20. Modified LDC for TCEQ SWQM Station 11485 in Oyster Creek Tidal

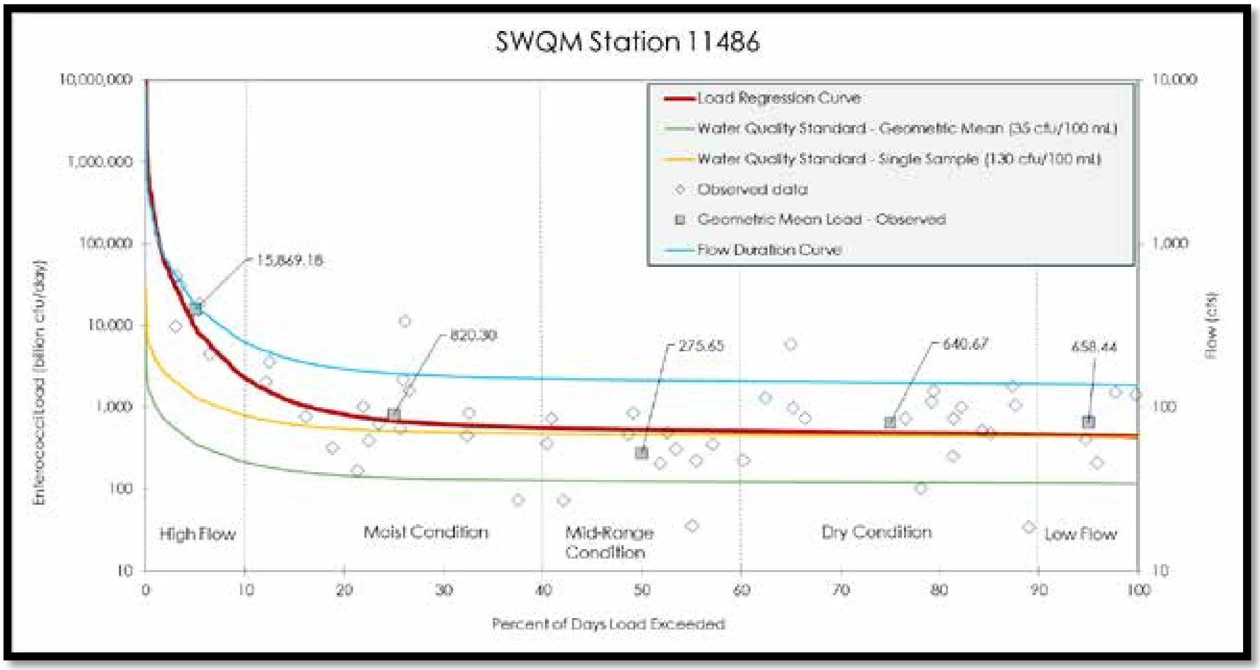

Figure 21. Modified LDC for TCEQ SWQM Station 11486 in Oyster Creek Tidal

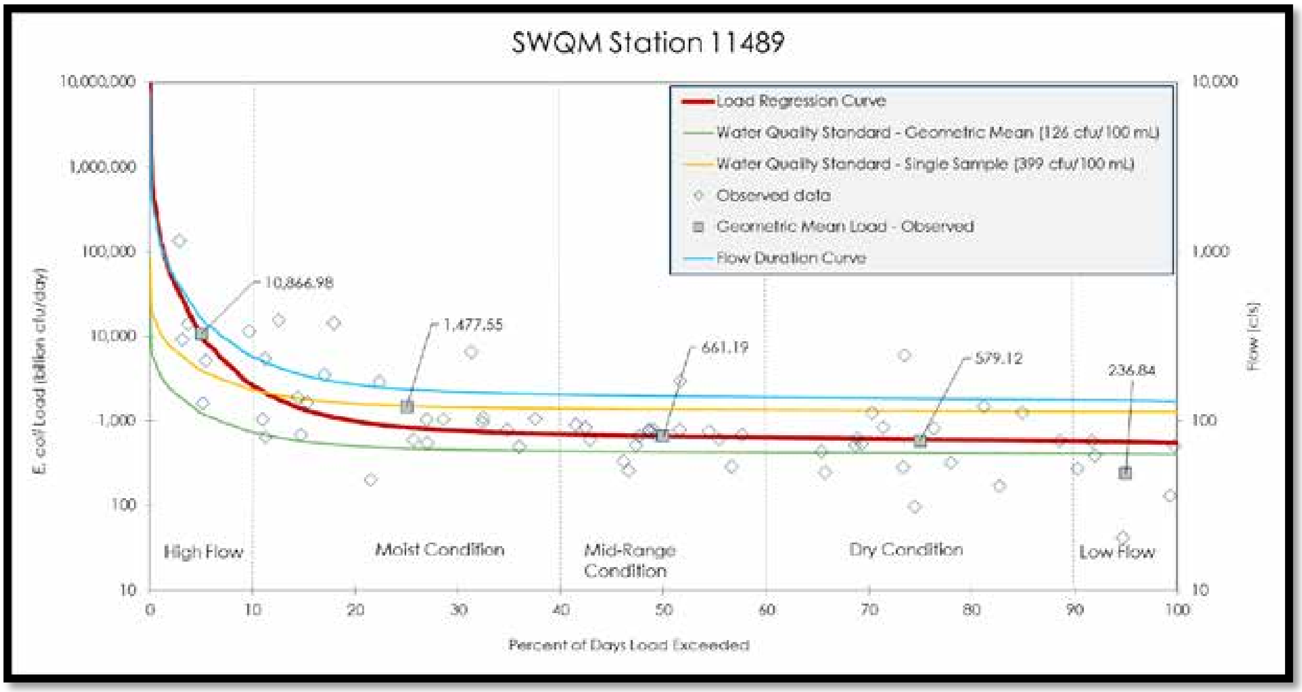

Figure 22. LDC for TCEQ SWQM Station 11489 in Oyster Creek Above Tidal

Section 4. TMDL Allocation Analysis

This section contains the bacteria TMDL allocation for the two impaired Oyster Creek AUs. The allocation is based on the LDCs for AU 1110_01 and AU 1109_01, which were described in Section 3.

4.1. Endpoint Identification

All TMDLs must identify a quantifiable water quality target that indicates the desired water quality condition and provides a measurable goal for the TMDL. The TMDL endpoint also serves to focus the technical work needed and as a criterion against which to evaluate future conditions. Please note that some calculations completed in this section have been rounded and may not lead to the exact final amounts listed in the text, tables, or figures.

The endpoint for the TMDLs are to maintain the concentration of Enterococcus below the geometric mean criterion of 35 cfu/100ml in AU 1109_01, and to also maintain the concentration of *E. coli* below the geometric mean criterion of 126 cfu/100ml in AU 1110_01. Both criteria listed above are protective of the primary contact recreation 1 use in saltwater and freshwater, respectively (TCEQ, 2018a).

4.2. Seasonal Variation

Seasonal variations occur when there is a cyclic pattern in streamflow and, more importantly, in water quality constituents. TMDLs must account for seasonal variation in watershed conditions and pollutant loading, as required by federal regulations [Title 40, Code of Federal Regulations, Chapter 1, Part 130, Section 130.7(c)(1) (or 40 CFR 130.7(c)(1))] (EPA, 1991). To evaluate potential seasonal difference, ambient monitoring data for Oyster Creek 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 of the data.

4.3. Linkage Analysis

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

Generally, if high bacteria concentrations are measured in a water body at low to median flows in the absence of runoff events, the main contributing sources are likely to be point sources and direct deposition (such as direct fecal deposition into the water body). During ambient flows, these inputs to the system will increase pollutant concentrations depending on the magnitude and concentration of the sources. As flows increase in 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 fecal bacteria from the land surface and the volume of runoff decreases following the rain event.

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

4.4. Load Duration Curve Analysis

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

The weaknesses of this method include the limited information it provides about the magnitude or specific origin of the various sources. Information gathered about point and nonpoint sources in the watershed is limited. The general difficulty in analyzing and characterizing Enterococcus or *E. coli* 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 both TCEQ SWQM stations, 11486 and 11489, the load regression curve modeled from observed data exceeds the curve representing the geomean maximum in all flow conditions including into the low-flow conditions (Figures 21 and 22). The LDC for

TCEQ SWQM Station 11489 exhibits a load that approaches the standard in the low flow condition, while the LDC for TCEQ SWQM Station 11486 remains well above the standard curve through all conditions. This indicates that both nonpoint sources and point sources are driving the bacteria impairments in both Oyster Creek Above Tidal, AU 1110_01 and Oyster Creek Tidal, AU 1109_01. Reduction strategies should target improvement of point and nonpoint source pollutants to have a positive effect on the watershed.

4.5. Margin of Safety

The margin of safety (MOS) is used to account for uncertainty in the analysis performed to develop the TMDL and thus provides a higher level of assurance that the 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 a MOS.

The TMDL covered by this report incorporates an explicit MOS of 5%.

4.6. Load Reduction Analysis

According to LDC analyses, bacteria loads in the water bodies are well above the Surface Water Quality Standards criteria at nearly all levels of flow. Bacteria reductions in excess of 65% are needed throughout the water bodies at moist and high flow conditions (Table 20). 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, with elevated levels across nearly all flow regimes, point sources should also be considered as targets for improvement.

Based on these results, potential reduction targets for loads at each flow condition are detailed in Table 20. While the LDC for TCEQ SWQM Station 11489 showed the load approaching the standard curve, it never quite reaches it. Table 20 looks at the observable data geometric means within each flow condition. In this case, TCEQ SWQM Station 11489 meets the standard in the low flow condition.

Table 20. Potential fecal indicator bacteria reductions needed by AU

AU	Flow Condition	Exceedance Range	Fecal Indicator Bacteria	Criterion (cfu/100mL)	Geometric Mean (cfu/100mL)	Required Percent Reduction
1109_01	High Flow	(0-10%)	Enterococci	35	1,284.14	97.27%
1109_01	Moist	(10-40%)	Enterococci	35	197.74	82.30%
1109_01	Mid-Range	(40-60%)	Enterococci	35	76.67	54.35%
1109_01	Dry	(60-90%)	Enterococci	35	185.12	81.09%
1109_01	Low Flow	(90-100%)	Enterococci	35	195.57	82.10%
1110_01	High Flow	(0-10%)	*E. coli*	126	1,012.75	87.56%
1110_01	Moist	(10-40%)	*E. coli*	126	358.39	64.84%
1110_01	Mid-Range	(40-60%)	*E. coli*	126	192.19	34.44%
1110_01	Dry	(60-90%)	*E. coli*	126	174.26	27.70%
1110_01	Low Flow	(90-100%)	*E. coli*	126	73.27	0.00%

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:

$$\text{TMDL} = \text{WLA} + \text{LA} + \text{FG} + \text{MOS} \qquad \text{(Eq. 6)}$$

Where:

TMDL = total maximum daily load

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

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

FG = loadings associated with future growth from potential regulated facilities

MOS = margin of safety load

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

4.7.1. Assessment Unit-Level TMDL Calculations

The bacteria TMDLs for the water bodies were developed as pollutant load allocations based on information from the LDCs for the SWQM stations within the watersheds. As discussed in more detail in Section 3, the bacteria LDC was developed by multiplying each flow value along the FDC with the criterion (126 cfu/100mL or 35 cfu/100mL, respectively) and 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 (Eq. 7)

Where:

Criterion = 35 cfu/100 mL (AU 1109_01) or 126 cfu/100 mL (AU 1110_01)

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

The allowable loading of *E. coli* or Enterococci that the impaired water body can receive on a daily basis was determined using Equation 7 based on the median value within the high regime of the FDC (or 95% flow exceedance value) for the TCEQ SWQM station (Table 21).

Table 21. TMDL calculations at the 5% exceedance flow

AU	Indicator Bacteria	Criterion (cfu/100 mL)	5% Exceedance Flow (cfs)	5% Exceedance Load (cfu/day)	TMDL (Billion cfu/day)
1109_01	Enterococci	35	664.877	5.69E+11	569.334
1110_01	*E. coli*	126	403.715	1.24E+12	1,244.524

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 (Eq. 8)

Where:

MOS = margin of safety load

TMDL = total maximum daily load

Using the value of TMDLs provided in Table 21, the MOS may be readily computed by proper substitution in Eq. 8 (Table 22).

Table 22. MOS calculations

Load units expressed as billion cfu/day

AU	Indicator Bacteria	Criterion (cfu/100 mL)	TMDL[a]	MOS
1109_01	Enterococci	35	569.334	28.467
1110_01	*E. coli*	126	1,244.524	62.226

[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}).

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

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 (126 cfu/100mL for freshwater and 35 cfu/100mL for saltwater) is used as the WWTF target to provide instream and downstream load capacity. Thus, WLA_{WWTF} is expressed in the following equation:

$$WLA_{WWTF} = \text{Target} * \text{Flow} * \text{Conversion Factor} \qquad \text{(Eq. 10)}$$

Where:

Target = 35 cfu/100 mL (AU 1109_01) or 126 cfu/100 mL (AU 1110_01)

Flow = full permitted flow (MGD)

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

Using Equation 10, each WWTF's allowable loading was calculated using each facility's full permitted flow. The individual results were summed to arrive at a total allocated loading for each AU. The criterion was applied based on the fecal indicator bacteria designated for the segment.

To account for the contribution of upstream WWTFs, WLA_{WWTF} for AU 1109_01 includes WWTF loading from AU 1110_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

Load units expressed as billion cfu/day

AU	TPDES No.	Permittee	Indicator Bacteria	Full Permitted Discharge (MGD)[a]	WLA_{WWTF} (Billion cfu/day *E. coli*)	WLA_{WWTF} (Billion cfu/day Enterococci)
1109_01	WQ0010798001	Commodore Cove Improvement District WWTF	Enterococci	0.06	_	0.079
			Total	0.06	_	8.691[b]
1110_01	WQ0010548004	Oyster Creek WWTF	*E. coli*	3.60	17.171	4.770
1110_01	WQ0012113001	Beechwood WWTF	*E. coli*	0.10	0.477	0.132
1110_02	WQ0013804001	TDCJ Terrell Unit WWTF	*E. coli*	2.00	9.539	2.650
1110_03	WQ0010743001	TDCJ Darrington Unit WWTF	*E. coli*	0.80	3.816	1.060
			Total	6.50	31.003	8.612

[a] Full permitted discharge from Table 7.

[b] The value for AU 1109_01 was calculated substituting the Enterococci criterion (35 cfu/100mL) for use in the WLA_{WWTF} for the upstream AUs WWTFs.

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 (WLA_{SW}). A simplified approach for estimating the WLA for these areas was used in the development of this TMDL due to the limited amount of data available, the complexities associated with simulating rainfall runoff, and the variability of stormwater loading.

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

$$WLA_{SW} = (TMDL - WLA_{WWTF} - FG - MOS) * FDA_{SWP} \quad \text{(Eq. 11)}$$

Where:

WLA_{SW} = sum of all regulated stormwater loads

WLA_{WWTF} = sum of all WWTF loads

FG = sum of future growth loads from potential regulated facilities

MOS = margin of safety load

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

The fractional proportion of the drainage area under the jurisdiction of stormwater permits (FDA_{SWP}) must be determined to estimate the amount of overall runoff load that should be allocated to WLA_{SW}. The term FDA_{SWP} was calculated based on the combined area under regulated stormwater permits. FDA_{SWP} is calculated by first totaling the area of each stormwater permit. The stormwater sources and how areas were estimated were discussed previously. Those area estimates were summed for each category and imported into Table 24. The stormwater categories are then summed up to determine the total area under stormwater jurisdiction in each segment.

Limiting the focus of Oyster Creek Tidal to that of the area above TCEQ SWQM Station 11486 requires adjusting the area under a stormwater permit to just the area above that station. The small watershed area above the station is completely within the City of Lake Jackson’s MS4 Phase II stormwater permit. No concrete production facilities, MSGP or construction activities are assigned to this portion of the watershed.

To arrive at the proportion, the area under stormwater jurisdiction is then divided by the total watershed area. FDA_{SWP} for Segment 1109 accounts for the upstream area contribution by adding the total of area under permit for the area above TCEQ SWQM Station 11486 with that of the entire Segment 1110 and dividing by the total watershed area above TCEQ SWQM Station 11486 (Table 24).

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

AU	Watershed Area[a] (Acres)	MS4 General Permit (Acres)	Industrial Stormwater (Individual and MSGP) (Acres)	Construction Activities (Acres)	Concrete Production Facilities (Acres)	Total Area of Permits[a] (Acres)	FDA_{SWP}
1109_01	78,694.40	3,582.09	173.88	1,010.85	0.00	4,766.82	0.061
1110_01	75,385.60	3,419.83	173.88	1,010.85	0.00	4,604.56	0.061

[a] Watershed Area and Total Area of Permits were calculated as the sum of those areas of the catchment above the TCEQ SWQM station within the AU and any contributing areas upstream of the AU.

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 complete the WLA_{SW}, a value for future growth (FG) is needed. FG is calculated based on future WWTF wasteload. The calculation for FG is presented in Section 4.7.4. The calculated FG is presented here for continuity. All the needed information to complete Equation 11 is known and presented along with the resulting WLA_{SW} in Table 25.

Table 25. Regulated stormwater calculations

Load units expressed as billion cfu/day

AU	Indicator Bacteria	TMDL[a]	MOS[b]	WLA_{WWTF}[c]	FG[d]	FDA_{swp}[e]	WLA_{sw}
1109_01	Enterococci	569.34	28.467	8.691	5.548	0.061	31.900
1110_01	*E. coli*	1,244.524	62.226	31.003	19.768	0.061	69.114

[a] TMDL from Table 21

[b] MOS from Table 22

[c] WLA_{WWTF} for 1109_01 is the sum for AU 1109_01 and *E. coli* values from AUs 1110_01, 1110_02, and 1110_03 from Table 23

[d] FG from Table 26

[e] FDA_{SWP} from Table 24

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 of the TMDL watershed was based on population projections and current permitted wastewater dischargers for the entire TMDL watershed. Recent population and projected population growth between 2020 and 2050 for the TMDL watershed are provided in Table 26. 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 2020 and 2050 to determine the estimated future flows.

Thus, the FG is calculated as follows:

$$FG = Criterion * (\%POP_{2020\text{–}2050} * WWTF_{FP}) * Conversion\ Factor \quad \text{(Eq. 12)}$$

Where:

Criterion = 35 cfu/100 mL (AU 1109_01) or 126 cfu/100 mL (AU 1110_01)

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

$\%POP_{2020\text{–}2050}$ = estimated percent increase in population between 2020 and 2050

Conversion factor = 3,785,411,780 mL/million gallons ÷ 1,000,000,000

The results are tabulated in Table 26. FG in Segment 1110 is also calculated using the tidal criterion, 35 cfu/100mL and is applied in AU 1109_01 to account for the effects of upstream growth on the AU.

Table 26. FG calculations

AU	Indicator Bacteria	Criterion (cfu/100mL)	% Population Change (2018-2050)	Full Permitted Discharge[a] (MGD)	FG Flow (MGD)	FG (Billion cfu/day)	FG[b] (Billion cfu/day)
1109_01	Enterococci	35	71.48%	0.06	0.043	0.057	5.548
1110_01	*E. coli*	126	63.76%	6.5	4.145	19.768	-

[a] Full permitted discharge from Table 23.

[b] FG in AU 1109_01 is the sum of FG values calculated for each WWTF in Segment 1110 using Enterococci criterion (35 cfu/100mL).

4.7.5. Load Allocations

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

$$LA = TMDL – WLA_{WWTF} - WLA_{SW} - FG – MOS \quad \text{(Eq. 13)}$$

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 calculations for LA are presented in Table 27.

Table 27. LA calculations

Load units expressed as billion cfu/day

AU	Indicator Bacteria	TMDL[a]	MOS[b]	WLA_{WWTF}[c]	WLA_{SW}[d]	FG[e]	LA
1109_01	Enterococci	569.334	28.467	8.691	31.900	5.548	494.728
1110_01	*E. coli*	1,244.524	62.226	31.003	69.114	19.768	1,062.413

[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

4.8. Summary of TMDL Calculations

Table 28 summarizes the TMDL calculation for the TMDL watersheds. 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 11486 and 11489. Allocations are based on the current geometric mean criterion for Enterococci or *E. coli* of 35 cfu/100 mL or 126 cfu/100 mL, respectively, for each component of the TMDL.

Table 28. TMDL allocation summary

Load units expressed as billion cfu/day

AU	Indicator Bacteria	TMDL[a]	MOS[b]	WLA_{WWTF}[c]	WLA_{SW}[d]	LA[e]	FG[f]
1109_01	Enterococci	569.334	28.467	8.691	31.900	494.728	5.548
1110_01	*E. coli*	1,244.524	62.226	31.003	69.114	1,062.413	19.768

[a] TMDL from Table 21

[b] MOS from Table 22

[c] WLA_{WWTF} from Table 23

[d] WLA_{SW} from Table 25

[e] LA from Table 27

[f] FG from Table 26

The final TMDL allocation (Table 29) needed to comply with the requirements of 40 CFR 130.7 include the FG component within the $WLA_{WWTF.}$

Table 29. Final TMDL allocation

Load units expressed as billion cfu/day

AU	Indicator Bacteria	TMDL	MOS	WLA_{WWTF}[a]	WLA_{sw}	LA
1109_01	Enterococci	569.334	28.467	14.239	31.900	494.728
1110_01	*E. coli*	1,244.524	62.226	50.771	69.114	1,062.413

[a] WLA_{WWTF} includes the FG component

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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 2050 populations in the TMDL Project watershed.

1. The H-GAC regional forecast team obtained USCB 2020 Decadal Census 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 2020 watershed populations using the H3M data for the portion of the H3M within the watershed assuming equal distribution.

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

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

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

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

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