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

Segments: 1304 and 1304A

Assessment Units: 1304_01 and 1304A_01

Caney Creek Above Tidal at FM 457 Matagorda County (photo courtesy of Environmental Institute of Houston)

August 2019

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Segments: 1304 and 1304A

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Prepared for
Total Maximum Daily Load Program
Texas Commission on Environmental Quality
MC–203
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List of Acronyms and Abbreviations

AA	authorized agents
AMLE	Adjusted Maximum Likelihood Estimation
AU	assessment unit
cfs	cubic feet per second
cfu	colony forming units
CAFO	concentrated animal feeding operation
CRP	Clean Rivers Program
DAR	drainage area ratio
DMR	discharge monitoring report
E. coli	*Escherichia coli*
EIH	Environmental Institute of Houston
FDC	flow duration curve
FG	future growth
FIB	fecal indicator bacteria
H-GAC	Houston-Galveston Area Council
ICWW	Intracoastal Waterway
I/I	Inflow and Infiltration
I-Plan	implementation plan
IR	Texas Integrated Report of Surface Water Quality
LA	load allocation
LDC	load duration curve
LR	load regression
MGD	million gallons per day
mi	mile
ml	milliliter
MOS	margin of safety
MSGP	multi-sector general permit
MS4	municipal separate storm sewer system
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
OSSF	on-site sewage facility
ppt	parts per thousand
QAPP	Quality Assurance Project Plan
SAS	Statistical Analysis Software
SSO	sanitary sewer overflow
SWQMIS	Surface Water Quality Monitoring Information System
TCEQ	Texas Commission on Environmental Quality
TMDL	total maximum daily load
TPDES	Texas Pollutant Discharge Elimination System
TSD	technical support document
TSSWCB	Texas State Soil and Water Conservation Board

TSWQS	Texas Surface Water Quality Standards
TWDB	Texas Water Development Board
USGS	United States Geological Survey
USEPA	United States Environmental Protection Agency
WLA	wasteload allocation
WWTF	wastewater treatment facility

Section 1.
Introduction

1.1 Background

Clean water is an important element to all living things. The Houston-Galveston Area Council (H-GAC) Clean Rivers Program (CRP) service area covers four river basins (Figure 1) and part of a fifth, Bays and Estuaries. The basins contain 16,000 miles of streams and shoreline providing a network of valuable habitat and ecosystem services for southeast Texas. This network joins freshwater streams to productive coastal estuaries and connects us to nature and to each other. Clean water is a foundation for the region's economy, contributing $4 billion annually through ecotourism, oyster harvesting, and commercial fishing.

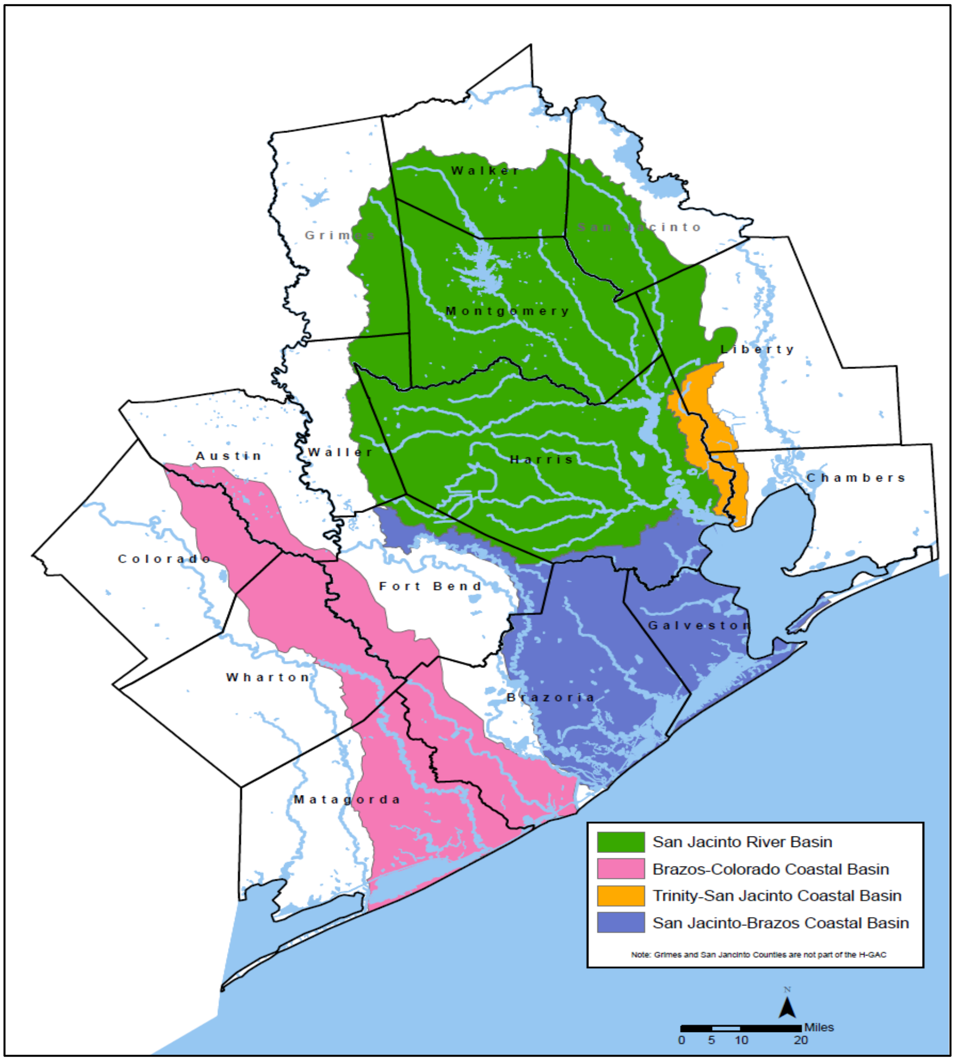


Figure 1. Four Texas river basins within the H-GAC Clean Rivers Program service boundary for southeast Texas

However, more than 80 percent of stream miles within the region fail to meet state water quality standards or screening criteria for one or more parameters. Expanding development and continuing population growth, aging and poorly-maintained infrastructure, and certain types of land management techniques strain the health of waterways if proper best practices are not in use or established.

H-GAC was tasked by the Texas Commission on Environmental Quality (TCEQ) to prepare the Caney Creek technical support document (TSD) as part of the targeted basin approach to the Brazos-Colorado Coastal Basin, Basin 13 (Figure 2). This approach seeks to characterize water quality problems, particularly bacteria, identify opportunities for public and stakeholder involvement, and recommend potential management approaches to begin to address bacteria impairments found in the Basin. Portions of Caney Creek and its major tributary, Linnville Bayou, were found to not meet state water quality standards for contact recreation due to elevated levels of indicator bacteria.

1.2 Water Quality Standards

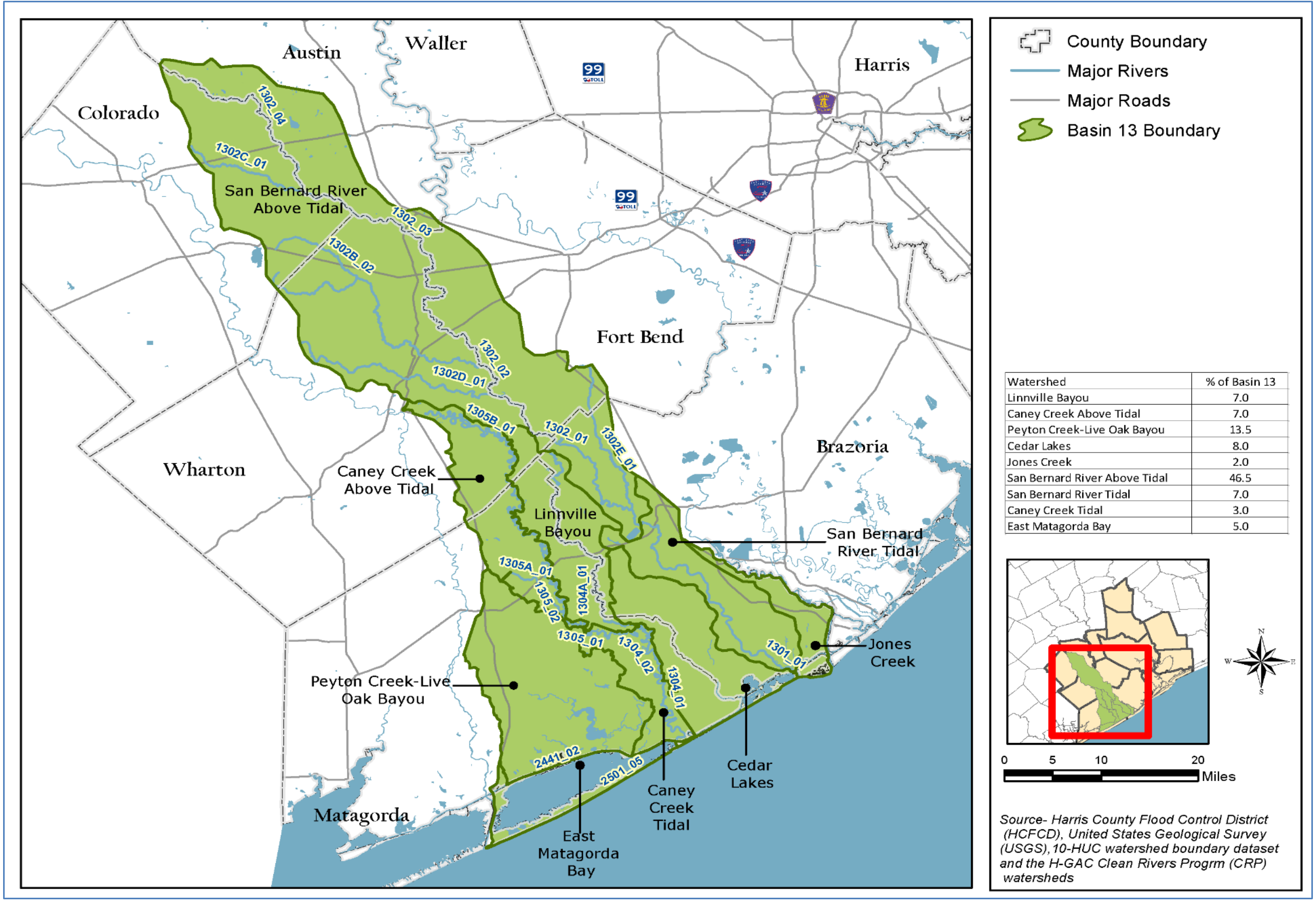
Section 303(d) of the federal Clean Water Act requires all states to identify waters that do not meet, or are not expected to meet, applicable water quality standards. States must develop a total maximum daily load (TMDL) for each pollutant that contributes to the impairment of a listed waterbody. The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

The TCEQ conforms to the requirements of the Clean Water Act Sections 305(b) and 303(d) by producing the Texas Integrated Report of Surface Water Quality (IR) every two years. The report assesses the state’s waters to determine if they meet state water quality standards. Those waterbodies, often referred to as segments, that do not meet water quality standards are included on the 303(d) list as impaired.

The TCEQ established water quality standards to protect the public’s health and use, and support aquatic life, while sustaining economic development. The standards set explicit goals for the quality of streams, lakes, rivers, and bays throughout the region.

Water quality standards identify appropriate uses for the state’s surface waters, including aquatic life, recreation, and sources of public drinking water. Criteria are established to evaluate these uses, including dissolved oxygen, temperature, pH, dissolved minerals, toxic substances, and bacteria.

These state standards are codified as state rules under Title 30, Chapter 307 of the Texas Administrative Code. The standards are written by the TCEQ under the authority of the Clean Water Act and the Texas Water Code. The U..S. Environmental Protection Agency (USEPA) approves the Texas Surface Water Quality Standards (TSWQS).



Watershed	% of Basin 13
Linnville Bayou	7.0
Caney Creek Above Tidal	7.0
Peyton Creek-Live Oak Bayou	13.5
Cedar Lakes	8.0
Jones Creek	2.0
San Bernard River Above Tidal	46.5
San Bernard River Tidal	7.0
Caney Creek Tidal	3.0
East Matagorda Bay	5.0

Source- Harris County Flood Control District (HCFCD), United States Geological Survey (USGS), 10-HUC watershed boundary dataset and the H-GAC Clean Rivers Progrm (CRP) watersheds

Figure 2. Basin 13 Boundary, including Caney Creek Tidal (1304), Linville Bayou (1304A), and Caney Creek Above Tidal (1305)

The TSWQS (TCEQ, 2010) are designed to:

- 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; and
- provide a basis on which TCEQ regulatory programs can establish reasonable methods to implement and attain the state's goals for water quality.

The TCEQ encourages public participation in the development and revision of the water quality standards through participation on the TSWQS Advisory Work Group.

1.3 Contact Recreation and Bacteria

Water quality professionals are challenged to ensure the region's waterbodies meet state water quality standards. Elevated bacteria concentrations represent the most common impairment in Texas.

Bacteria are used as indicators for risk of illness during contact recreation (e.g. swimming and water skiing) from ingestion of water. The state and the EPA use *Escherichia coli (E. coli)* (fresh water) and Enterococci (salt water) as fecal indicator bacteria (FIB) as they both are found in human and animal intestines and feces and are easily assessed and predictive of human health risk (Byappanahalli et al., 2012). The presence of FIB in waters suggests that human and animal wastes may be reaching the assessed waters due to inadequately treated wastewater, agriculture, and animal sources.

On June 30, 2010, the TCEQ adopted the Texas Surface Water Quality Standards (TSWQS), approving the categorical levels of recreational use and their associated criteria (TCEQ, 2010). Recreational criteria are based on FIB rather than direct measurements of pathogens. Criteria are expressed as the number of bacteria per 100 milliliters (mL) of water (in terms of colony-forming units (cfu), or other applicable reporting measures.) The 2010 TSWQS have been revised several times with the latest revisions being adopted by the TCEQ on February 7, 2018. The TSWQS related to recreational use based on revisions through 2018 are as follows:

Recreational use consists of four categories for freshwater (TCEQ, 2010):

I. Primary Contact Recreation – activities that are presumed to involve a significant risk of ingestion of water (e.g., swimming, wading by children, water skiing, diving, tubing, surfing, and the following whitewater activities: kayaking, canoeing, and rafting). Classified segments are designated for primary contact recreation 1 unless sufficient site-specific information demonstrates that elevated concentrations of FIB frequently occur due to sources of pollution that cannot be reasonably controlled by existing regulations; wildlife sources of bacteria are unavoidably high; there is limited aquatic recreational potential; or primary or secondary contact recreation is considered unsafe for other reasons such as ship and barge traffic. The geometric mean for this criterion *E. coli* is 126 most probable number (CFU) per 100 mL. The single sample criterion is 399 CFU per 100 mL in fresh water.

II. 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. The *E. coli* geometric mean criterion for fresh water is 630 CFU per 100 mL.
III. 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.
IV. 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. This category has a geometric mean criterion for *E. coli* of 2,060 CFU per 100 mL.

Recreational use consists of three categories for saltwater (TCEQ, 2018a):

I. Primary Contact Recreation 1 – the geometric mean criterion for enterococci is 35 CFU per 100 mL. The single sample criterion is 130 CFU per 100 mL.
II. Secondary Contact Recreation 1 – A secondary contact recreation 1 use for tidal streams and rivers can be established on a site-specific basis if justified by a use-attainability analysis and the water body is not a coastal recreation water as defined by the Beaches Environmental Assessment and Coastal Health Act of 2000 (Beach Act). The geometric mean criterion for enterococci is 175 CFU per 100 mL.
III. Noncontact recreation – a noncontact recreation use for tidal streams and rivers can be established on a site-specific basis if justified by the use-attainability analysis and the water body is not a coastal recreation water as defined by the Beach Act. The geometric mean criterion for enterococci is 350 CFU per 100 mL.

1.4 Total Maximum Daily Load Program

As mentioned, the development of an impaired water bodies list satisfies federal Clean Water Act requirements under Section 303(d) by identifying waters that do not meet, or are not expected to meet, applicable water quality standards. States must develop a TMDL for each pollutant that contributes to the impairment of a listed water body. The 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 pollutant that a water body can receive and still meet its applicable water quality standards. TMDLs are the best possible estimates of assimilative capacity of the water body for the pollutant under consideration. A TMDL is commonly expressed as a load with units of mass per unit of time but may be expressed in other ways. In addition to the TMDL, an implementation plan (I-Plan) is developed, which is a description of the regulatory and voluntary management measures necessary to improve water quality and restore full use of the water body.

The TMDL Program is a major component of Texas's 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 primary objective of the TMDL Program is to restore and maintain the beneficial uses–such as drinking water supply, recreation, support of aquatic life, or fishing–of impaired or threatened water bodies.

1.5 Houston-Galveston Area Council

H-GAC, an established Council of Governments and regional planning agency for the Gulf Coast State Planning Region, has more than 35 years of regional environmental planning and public outreach experience. H-GAC is designated as the lead agency responsible for regional water quality assessment for the San Jacinto River Basin, Trinity-San Jacinto Coastal Basin, San Jacinto-Brazos Coastal Basin, Brazos-Colorado Coastal Basin, and Bays and Estuaries (Figure 1). H-GAC coordinates the CRP in these basins.

The Texas Clean Rivers Act requires river authorities to prepare written water quality assessment reports for their respective basins and present the reports to the governor, TCEQ, Texas State Soil and Water Conservation Board (TSSWCB), and Texas Parks and Wildlife Department. The Act also established the Texas Clean Rivers Program, funded by fees paid by wastewater discharge permittees and water rights holders.

The CRP, under the direction of the TCEQ, requires continuous assessment of ambient water quality to identify key issues and develop management strategies statewide. The data and information provided by the state's CRP partners form the backbone supporting the State's IR. Results from the CRP process help set the agenda for all other water quality management programs; including monitoring, standards development, permitting, enforcement, public outreach, and field investigation and research.

1.6 Caney Creek Watershed

The TCEQ first identified bacteria impairments within the Caney Creek watershed in 2002, and in each subsequent edition of the IR for Clean Water Sections 305(b) and 303(d) (formerly called the Texas Water Quality Inventory and 303(d) List) through 2016. At the time of drafting this report, the draft 2018 IR was released for public comment and relevant portions of the unofficial document will be referenced (TCEQ, 2019a).

Water bodies, such as Caney Creek, are generally divided into one or more segments based on hydrologic features. This document will consider bacteria impairments found in two Caney Creek segments (one tidal segment and one an unclassified nontidal segment). Classified segments are denoted by four-digit numerical numbers. Caney Creek is classified as 1304 and 1305 (Figure 3).

In certain cases, a segment or a portion of a segment will be listed as unclassified due to that portion not being defined in the TSWQS. The unclassified portion will be tied to the classified segment it is hydrologically connected to using the same four-digit numerical number with a letter designation (e.g. 1304A - Linnville Bayou).

Segments are further broken down into one or more assessment units (AU). An AU is defined as the “smallest geographic area of use support reported in the assessment” (TCEQ, 2015). The complete list of water bodies and their identifying AU for study in this report are shown below:

1) Caney Creek Tidal: 1304_01, 1304_2, 1304A_01, 1304A_02 and 1304A_03; and
2) Caney Creek Above Tidal: 1305_01, 1305_02, 1305_03, 1305A_01, 1305A_02 and 1305B_01.

When presented as the Caney Creek watershed or simply Caney Creek, the term will generally refence all segments and the AUs that make up the segments. This report will refer to the segments as either Caney Creek Tidal and Caney Creek Above Tidal or as 1304 and 1305. In addition, while TCEQ does not classify Linnville Bayou as a segment, due to its comparable size, Linnville Bayou will be treated like a segment in this report by name or as 1304A. This is particularly important for the TMDL calculations presented in Section 4.

The AUs will be used in describing individual impairments or specific characteristics not found in the other AUs. The assessments are based on nine monitoring stations found in the AUs. Two impairments based on the draft 2018 IR require a TMDL. The impaired AUs are 1304_01 and 1304A_01, highlighted red on Figure 3. There are three AUs that are listed with FIB concerns, 1304_02, 1305_02 and 1305B_01, highlighted in yellow on Figure 3. More detail will be discussed in Section 2 concerning the assessments and monitoring data. The bacteria loadings calculated in this document will be used by Caney Creek stakeholders to create an I-Plan and/or watershed protection plan to address the impaired AUs with the goal to reduce bacteria and support contact recreation in the Caney Creek watershed.

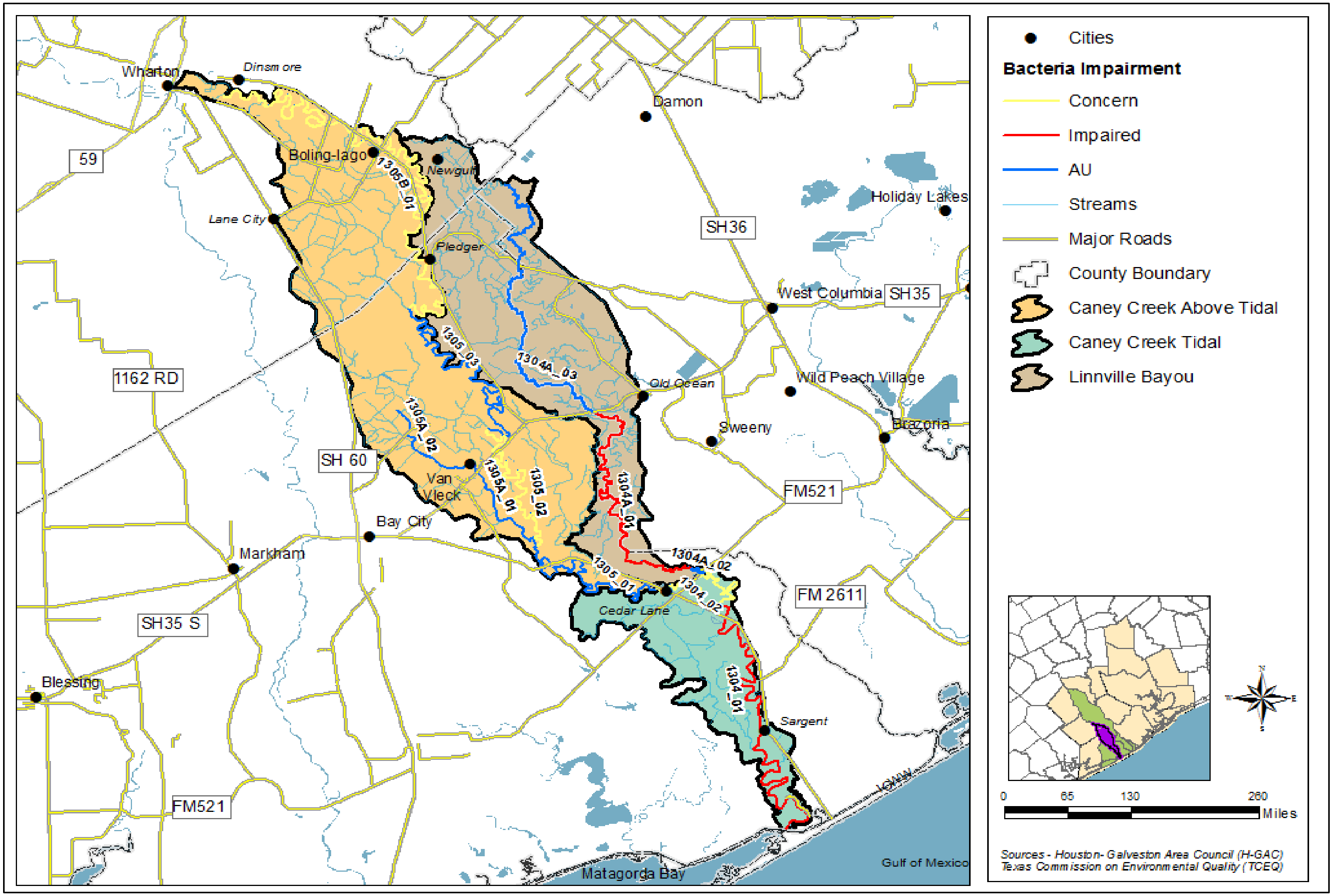


Figure 3. Caney Creek watershed with segments, assessment units and impairments delineated

1.7 Report Purpose and Organization

The TMDL project, including the TSD, for the Caney Creek watershed was initiated through a contract between the TCEQ and H-GAC. The tasks of this project to be performed by H-GAC include:

1. acquiring existing (historical) data and information necessary to support assessment activities;
2. performing the appropriate activities necessary to allocate bacteria loadings; and
3. assisting the TCEQ in preparing the TMDL.

Using historical bacteria and flow data, this portion of the project was to:

1. review the characteristics of the watershed and explore the potential sources of bacteria for the impaired segments;
2. develop an appropriate tool for development of bacteria TMDLs for the impaired segments; and
3. submit the draft and final TSD for the impaired segments.

The purpose of this report is to provide technical documentation and supporting information for developing the fecal bacteria TMDLs for the Caney Creek watershed. This report contains:

- information on historical data;
- watershed properties and characteristics;
- summary of historical bacteria that confirm the State of Texas 303(d) listings of impairment due to the presence of FIB;
- development of load duration curves; and
- application of the load duration curve approach for the pollutant load allocation process.

Section 2.
Historical Data Review and Watershed Properties

2.1 Description of Study Area

The Caney Creek watershed lies in southeast Texas. The 303 square mile study area includes parts of three Texas counties: Brazoria, Matagorda and Wharton. The watershed is included within the Houston-The Woodlands, TX Combined Statistical Area (US Census Bureau, 2012)).

Historically, Caney Creek, once named Canebrake Creek due to dense native bamboo, arose one mile south of the town of Matthews in Colorado County and ran 155 miles to the coast (Handbook of Texas, 2010). The Colorado River, in the past, traversed the course of Caney Creek. Now the portion of Caney Creek above the City of Wharton is mostly remnant oxbows and intermittent pools. During floods, floodwater from the Colorado will sometimes cross into the Caney Creek watershed due to the creek's proximity to the Colorado near the town of Glen Flora.

For water quality assessments, the state has determined that the 130-mile creek originates in southeastern Wharton County in the City of Wharton. It initially begins as an intermittent stream traveling generally southeastward to the Matagorda County line. By the time it reaches the county line, Caney Creek has become a perennial stream meandering southeastward through eastern Matagorda County before terminating south of the town of Sargent near the Gulf Coast Intracoastal Waterway (ICWW). Water from Caney Creek is then transported southwestward in the ICWW to a point where the ICWW connects to East Matagorda Bay. At that point East Matagorda Bay and the ICWW are connected to the Gulf of Mexico at Brown Cedar Cut, a man-made channel through the Matagorda Peninsula.

The Caney Creek watershed comprises two classified segments, Caney Creek Tidal (1304) and Caney Creek Above Tidal (1305), and three unclassified segments, 1304A, 1305A and 1305B (Figure 3). The tidal segment begins near the town of Cedar Lane and FM 457 and traverses 36 miles southeastward to the confluence with the ICWW (H-GAC, 2016a). The tidal segment has a watershed area of 44 square miles. The tidal segment is broken in to two distinct AUs, 1304_01 and 1304_02. Three small towns or villages can be found in the tidal segment: Sargent, Hawkinsville and Cedar Lane.

1304A is a freshwater tributary to Caney Creek Tidal and has a watershed area of 100 square miles. Linnville Bayou begins in southeastern Wharton County near the town of Newgulf as an intermittent stream and travels for approximately 20.3 miles, much of it as the border between Matagorda and Brazoria counties, before terminating into Caney Creek Tidal (AU 1304_02) in Matagorda County. 1304A is broken into three AUs: 1304A_01, 1304A_02, and 1304A_03. Towns and villages in 1304A include Old Ocean and Newgulf.

Caney Creek Above Tidal begins at the confluence with Waterhole Creek and travels 51 miles before terminating at the tidal boundary just south of the town of Cedar Lane (Figure 3, H-GAC, 2016a). The above tidal segment comprises a watershed area of 78 square miles. 1305 is broken into three AUs: 1305_01, 1305_02, and 1305_03. The above tidal includes towns and villages: Allenhurst, Ashwood, Caney and Sugar Valley.

Two unclassified segments are tributaries to 1305, 1305A and 1305B. 1305A is named Hardeman Slough. Hardeman Slough begins just above the town of Van Vleck and has a watershed area of 27 square miles. 1305A is comprised of two AUs, 1305A_01 and 1305A_02. 1305B consists of only one AU, 1305B_01 and begins as the headwaters of Caney Creek in the City of Wharton. 1305B traverses 43 miles southeastward as an intermittent stream before becoming the segment 1305 at the confluence with Waterhole Creek. 1305B has an area of 54 square miles and includes the all or a portion of the cities, town and villages: Wharton, Boling, Iago, Lane City and Pledger.

The 2018 Texas Water Quality IR (TCEQ, 2019a) provides the following segment and AU descriptions for the water bodies considered for this document:

- Segment 1304 (AU 1304_01 and 1304_02) – Caney Creek Tidal: From the confluence with the Intracoastal Waterway in Matagorda County to a point 1.9 km (1.2 miles) upstream of the confluence of Linville Bayou in Matagorda County.
    - 1304_01 – From the downstream end of segment to the confluence with Dead Slough;
    - 1304_02 – From the confluence with Dead Slough to the upstream end of segment.
- 1304A (AU 1304A_01, 1304A_02, and 1304A_03) – Linville Bayou (unclassified waterbody): From the confluence with Caney Creek in Matagorda County upstream to a point 0.7 km above SH 35 in Brazoria/Matagorda Counties.
    - 1304A_01 – Intermittent stream with perennial pools from a point 1.1 km above the confluence with Caney Creek in Matagorda County upstream to a point 0.1 km above SH 35 in Brazoria/Matagorda counties;
    - 1304A_02 – From the confluence with Caney Creek to a point 1.1 km above the confluence with Caney Creek in Matagorda County; and
    - 1304A_03 – From a point 0.1 km above SH 35 to a point 0.7 km above SH 35 in Brazoria/Matagorda Counties.
- Segment 1305 (AU 1305_01, 1305_02, and 1305_03) – Caney Creek Above Tidal: From a point 1.9 km (1.2 mi) upstream of the confluence of Linnville Bayou in Matagorda County to the confluence of Water Hole Creek in Matagorda County.
    - 1305_01 – From the downstream end of the segment to the confluence with Hardeman Slough;

  - 1305_02 – From the confluence with Hardeman Slough to the confluence with Snead Slough;
  - 1305_03 – From confluence with Snead Slough in Matagorda County to the upper end of the segment at the confluence with Water Hole Creek in Matagorda County.
- 1305A (AU 1305A_01 and 1305A_02) – Hardeman Slough (unclassified waterbody): From the confluence with Caney Creek to 0.3 km upstream of Matagorda County Rd 110.
  - 1305A_01 – Perennial stream from the confluence with Caney Creek upstream to the confluence with an unnamed tributary approximately 1.9 km downstream of FM 3156 near the City of Van Vleck; and
  - 1305A_02 – From approximately 1.9 km downstream of FM 3156 near the City of Van Vleck to 0.3 km upstream of County Rd 110.
- 1305B (AU 1305B_01) – From the confluence with Water Hole Creek in Matagorda Co. (at the upper end of Segment 1305) to the headwaters approximately 43 miles at Old Caney Rd. in Wharton Co.
  - 1305B_01 – From the confluence with Water Hole Creek in Matagorda Co. (at the upper end of Segment 1305) to the headwaters approximately 43 miles at Old Caney Rd. in Wharton Co.

The unclassified segments 1305A and 1305B will be analyzed for the remainder of this report, unless otherwise mentioned, as part of the Caney Creek Above Tidal watershed. This is due in part to their relatively small size and similar watershed characteristics with 1305.

2.2 Watershed Climate and Hydrology

Precipitation and temperature data for the period of 1972 thru 2017 was retrieved from the National Climatic Data Center for the Cities of Freeport and Wharton (NOAA. 2017). Average precipitation for the watershed is between 45 and 47 inches per year (Table 1). Evaporation rates can reach up to 60 inches per year during drought conditions.

Table 1. Average annual rainfall recorded at gauges located near Caney Creek, 1972-2017

STATION	STATION_NAME	LATITUDE	LONGITUDE	Average Annual Rainfall (in)
GHCND: USC00413340	FREEPORT 2 NW TX US	28.9845	-95.3809	46.8
GHCND: USC00419655	WHARTON TX US	29.31778	-96.08472	45.1

Average monthly precipitation (Figure 4) ranges from slightly under three to slightly over seven inches (NOAA. 2017). Rainfall occurs throughout the year with February and March seeing the least amount of rainfall while the summer months typically see the greatest rainfall due to tropical disturbances. September stands out with the highest average rainfall, as that month corresponds with the height of the hurricane season. Average monthly air temperature ranges from slightly above 50 ºF in the winter to slightly below 90 ºF in the summer months (Figure 4).

Only the Freeport Station, USC00413340, is presented in Figure 6 as the Wharton Station did not provide consistent monthly temperature readings over the period of record.

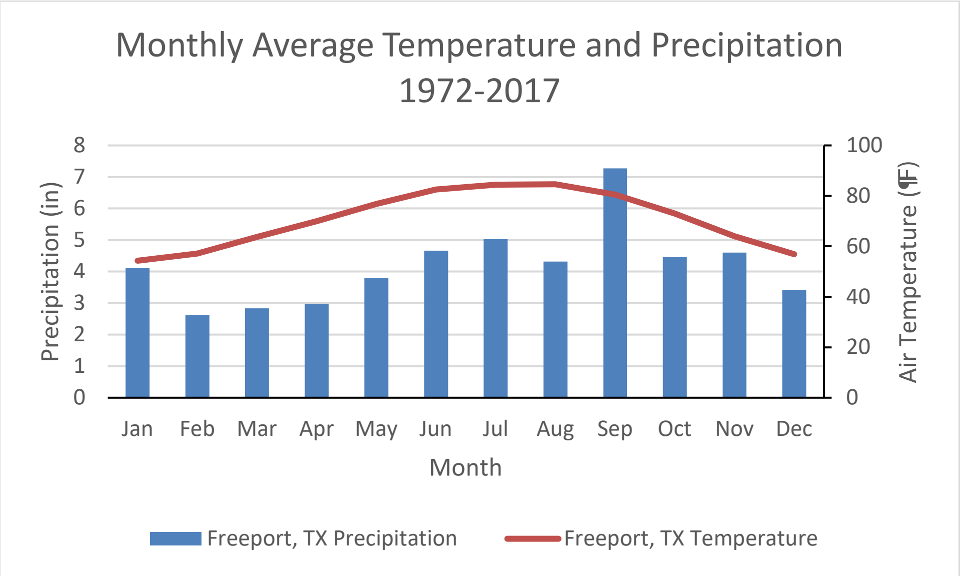


Figure 4. Average monthly precipitation and temperature recorded near Caney Creek between 1972 and 2017

Topography ranges from just under 100 feet at Old Caney Road in Wharton County near the City of Wharton to sea level at the ICWW. The source water for Caney Creek is mostly from rainfall runoff. Much of the upper watershed in Wharton County is intermittent due to a lack of base flows. Downstream, base flows are maintained by limited return flows from a few permitted sources and from irrigated row crop and sod farms. The creek and its tributaries are generally sluggish due to the gentle 0.04 percent sloping relief (Snowden, 1989) found on the coastal plain. Riparian vegetation is still common along portions of the sinuous creek and remnant oxbows, particularly in Linnville Bayou. The above tidal segment consists of woody vegetation along its banks with upland areas opened to pasture, farms and coastal prairies. As the above tidal portion of the creek cedes to the tidal reach the creek broadens as it reaches the ICWW.

Typical soil types in the region include fine, poorly draining alluvial clays, clay-based silts and loams, with dispersed areas of sandy substrate resulting from subtropical climate and fluvial geologic characteristics (Figure 5). Agriculture production is the primary economic driver in the watershed. The soils were considered fertile enough to grow rice, sugar cane and cotton in the past (Handbook of Texas, 2010). In addition to row crops like sorghum, cotton and corn, sod farming is also a major farmed product in the watershed (Figure 6). The primary mineral resources within the region include small oil and gas fields and sand and gravel extraction (Figure 7).

2.3 Watershed Population and Population Projections

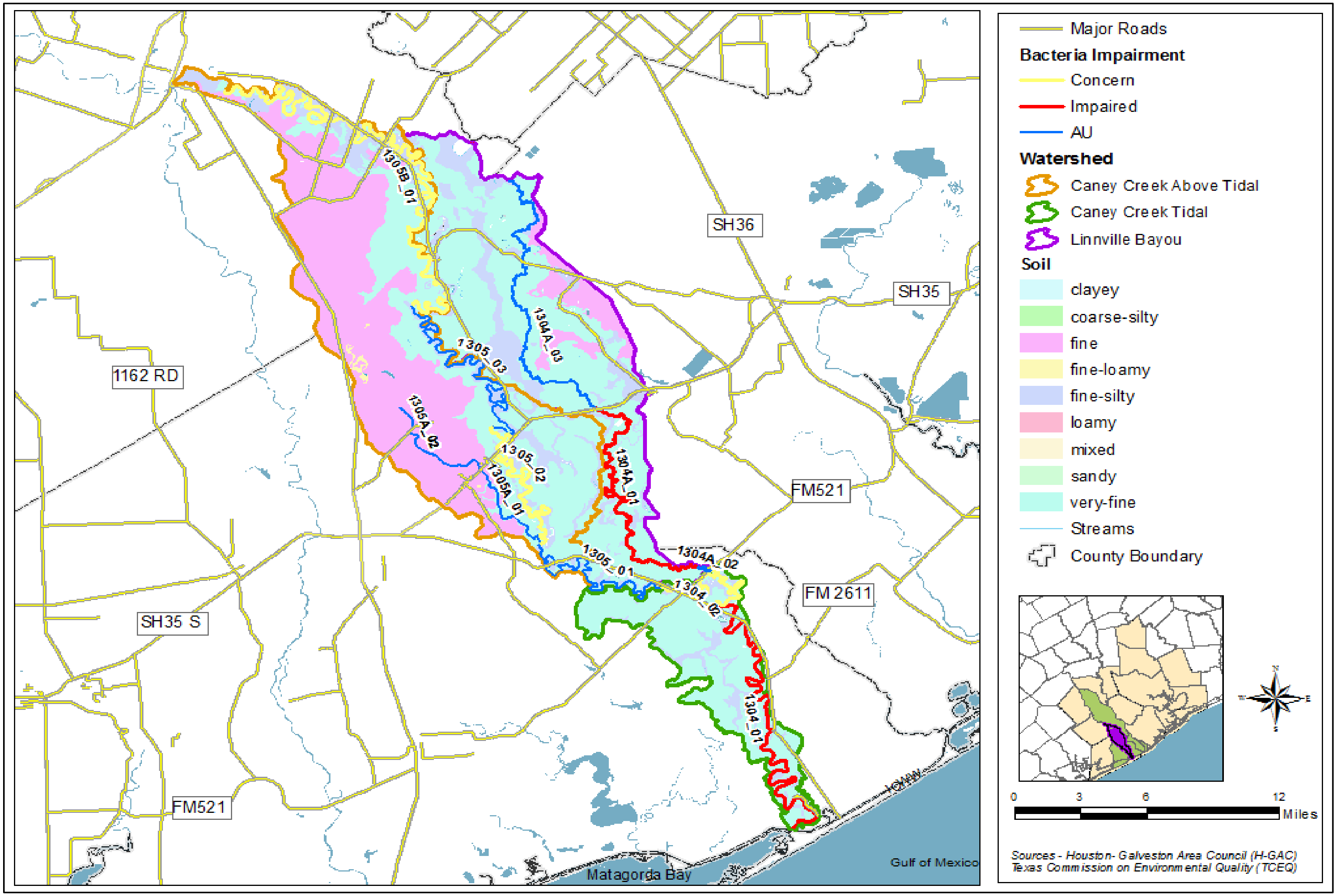
Caney Creek Above Tidal had a population of 7,597 in 2016 (Table 2). Caney Creek Tidal had a population of 438 and Linnville Bayou had a population of 912. The population of the Caney Creek watershed is projected to increase in the future.

To determine the change in population, data from the Texas Water Development Board's (TWDB, 2018) 2017 County Population Projection was reviewed. Brazoria, Matagorda and Wharton County are, in 2070, anticipated to grow by 80 percent, 14 percent and 24 percent, respectively. Those projected rates were then applied to the current population based on the proportional area each county makes up within each watershed segment to determine the population in 2070. Projected 2070 populations were then added for each proportional area for the watershed segment and new population change rates were developed. The change rate was then used to develop the TMDL load calculation found in Section 4. The Caney Creek watershed is anticipated to grow by 21 percent by 2070, with much of that growth in the Brazoria County portion of Linnville Bayou.

Table 2. Population statistics for current and future between 2016 and 2070

WATERSHED	Y2016	Y2070	% Change
Caney Creek Tidal	438	501	14.38
Linnville Bayou	912	1,321	44.85
Caney Creek Above Tidal	7,597	8,964	17.99
Total	8,947	10,786	20.55

A large petrochemical facility, Phillips 66 Co. refinery and Chevron – Phillips Chemical Co. are located on Hwy. 35 in Old Ocean on the eastern bank of Linnville Bayou. The facility is a major employment center for the watershed.



Sources - Houston- Galveston Area Council (H-GAC)
Texas Commission on Environmental Quality (TCEQ)

Figure 5. Soils found in Caney Creek watershed consist mostly of poorly-drained clay and clay-based fines

Figure 6. Sod farm on CR 1301 north of Boling-Iago

Figure 7. Oil pump jack east of Boiling-Iago on CR442

2.4 Review of Caney Creek Tidal and Above Tidal Routine Monitoring Data

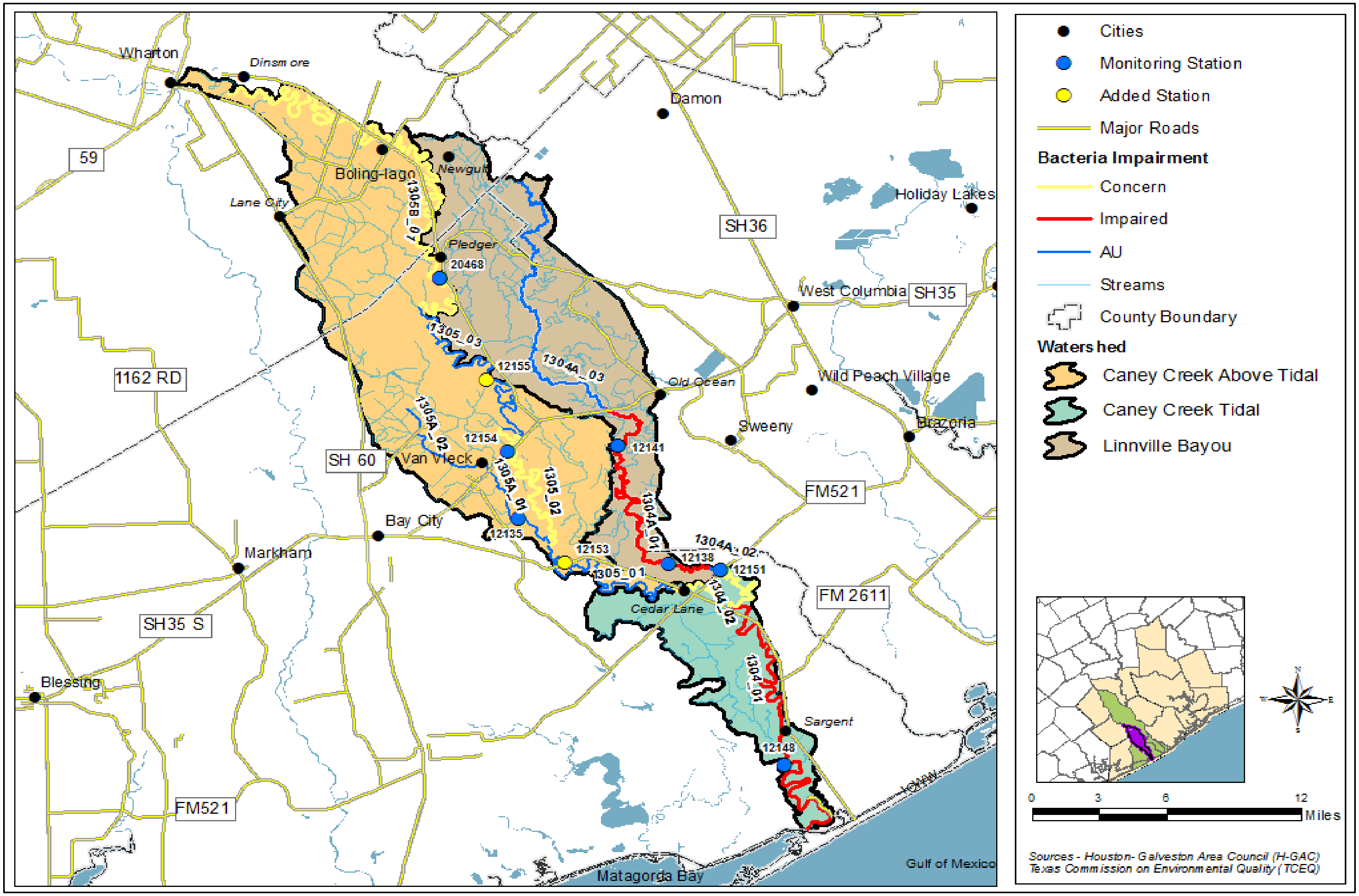
2.4.1 Data Acquisition

Ambient *E. coli* and enterococci data were obtained from the TCEQ Surface Water Quality Monitoring Information System (SWQMIS). The data represented the routine ambient bacteria and other water quality data collected for the project area by the TCEQ and TCEQ's CRP for the study area. The data are collected at nine stations: two in 1304, station identification numbers (SID) 12148 and 12151, two in 1304A, SIDs 12138 and 12141; three in 1305, SIDs 12153, 12154, 12155, one in 1305A, SID 12135 and one in 1305B, SID 20468 (Figure 8).

2.4.2 Analysis of Bacteria Data

The draft 2016 Texas IR lists the AU 1304_01 and 1304A_01 as impaired for contact recreation use due to high levels of FIB bacteria (TCEQ, 2019b). 1304_01 has been listed as nonsupport (NS) since 2006 and 1304A_01 was listed as NS in 2010. AU 1304_02 has been identified with a use concern (CN). A review of the 2016 IR for 1304_01 and 1304A_01 shows the bacteria geometric means as relatively stable at 54.25 CFU/100mL (Enterococcus) and 176.97 CFU/100mL (*E.coli*), respectively (Table 3). 1304_02 has an Enterococcus geometric mean to 81.67 CFU/100mL. The geometric mean for 1304_02 is based on only a few samples, insufficient to assess for an impairment.

AU 1305_02 in Caney Creek Above Tidal has an *E. coli* bacteria geometric mean of 122.91 CFU/100mL according to the draft 2016 IR. The AU was assessed as fully supporting (FS) the contact recreation use. This was an improvement over previous assessments that had listed this AU as NS. 1305B_01 carries a CN for FIB with an *E.coli* geometric mean of 1,136.15 CFU/100mL on just 6 samples, insufficient to assess for an impairment. The remaining assessment units, 1304A_02, 1304A_03, 1305_01, 1305_03, 1305A_01, 1305A_02 were not evaluated for bacteria concentrations in the 2016 IR by the TCEQ and are currently presumed to meet the state's contact recreation standards.



Sources - Houston-Galveston Area Council (H-GAC)
Texas Commission on Environmental Quality (TCEQ)

Figure 8. SWQM station locations in segments 1304, 1304A, and 1305

Table 3. 2016 Integrated Report Summary for the Caney Creek watershed

Name	**Assessment Unit**	**Parameter**	**Data Date Range**	**No. Samples**	**Geomean**	**Status**
Caney Creek Tidal	1304_01	Enterococcus	12/1/2007 - 11/30/2014	52	54.25	NS
Caney Creek Tidal	1304_02	Enterococcus	12/1/2007 - 11/30/2014	4	81.67	CN
Linnville Bayou	1304A_01	*E. coli*	12/1/2007 - 11/30/2014	11	176.97	NS
Caney Creek Above Tidal	1305_02	*E. coli*	12/1/2007 - 11/30/2014	26	122.91	FS
Caney Creek Above Tidal	1305B_01	*E. coli*	12/1/2007 - 11/30/2014	6	1136.15	CN

(NS – nonsupport, CN – use concern, FS – fully supporting)

At the time of drafting this report, the TCEQ's draft 2018 IR was available for public comment on the TCEQ website (TCEQ, 2019a). A review of the most recent period for 1304_01 and 1304A_01 shows the bacteria geometric means as relatively stable at 61.54 CFU/100mL (Enterococcus) and 164.59 CFU/100mL (*E. coli*), respectively (Table 4). The AUs remain impaired for FIB and have been assessed as NS for contact recreation use. In 1304_02, the Enterococcus geometric mean is 72.07.67 CFU/100mL, and the AU continues to maintain a CN due to FIB.

AU 1305_02, in the draft 2018 IR has been changed from being listed as FS contact recreation use to being listed with a CN due to FIB. The *E.coli* geometric mean for 1305_02 is 143.68 (Table 4). 1305B_01 continues to be listed with a CN for FIB with an E.coli geometric mean of 1,165.53 CFU/100mL. This geometric mean is based on a small sample size of 5 samples. The assessment unit, 1305A_01 was assessed in the draft 2018 IR. Based on the *E.coli* geometric mean of 86.15, the AU's contact recreation use was assessed with no concern (NC). The remaining assessment units, 1304A_02, 1304A_03, 1305_01, 1305_03, 1305A_02 were not evaluated for bacteria concentrations in the 2016 IR by the TCEQ and are currently presumed to meet the state's contact recreation standards.

Table 4. Draft 2018 Integrated Report Summary for the Caney Creek watershed

Name	Assessment Unit	Parameter	Data Date Range	No. Samples	Geomean	Status
Caney Creek Tidal	1304_01	Enterococcus	12/1/2009 - 11/30/2016	42	61.54	NS
Caney Creek Tidal	1304_02	Enterococcus	12/1/2009 - 11/30/2016	12	72.07	CN
Linnville Bayou	1304A_01	*E. coli*	12/1/2009 - 11/30/2016	16	164.59	NS
Caney Creek Above Tidal	1305_02	*E. coli*	12/1/2009 - 11/30/2016	24	143.68	CN
Caney Creek Above Tidal	1305A_01	*E. coli*	12/1/2009 - 11/30/2016	11	86.15	NC
Caney Creek Above Tidal	1305B_01	*E. coli*	12/1/2009 - 11/30/2016	5	1,165.53	CN

(NS – nonsupport, CN – use concern, NC – no concern)

More recent bacteria monitoring data was retrieved from TCEQ SWQIMS through December 2018. Table 5 presents the calculated bacteria geometric mean for SWQM bacteria data collected between 2012 and 2018 for segments 1304, 1304A, 1305, 1305A and 1305B. The seven-year period was picked to correspond with the duration of each IR. The draft 2018 report reviewed in Table 4 ended the data period in 2016. The review presented with Table 5 covering a similar seven-year period but shifts the period by two years. This period will be reflected in the 2020 IR when it is completed. Additionally, Table 5 uses the segments rather than individual AUs, as previous reviews of the IRs provided. Table 6 will pick up the discussion on individual AUs. The segments are presented here as pictorially representing the trend in geometric means, Figure 9. A pictorial representation cannot be easily done using AUs, due to a lack of enough data to characterize each AU.

The data were reviewed, and trends were developed (Table 5 and Figure 9). Data collected for a seven-year period between 2012 and 2018 continues to support the impairment findings in segments 1304 and 1304A, with geometric means of 57.7 (Enterococcus) and 147.8 (*E. coli*), respectively (Table 5). Segment 1305 as presented in the draft 2018 report has improved to the point that TCEQ has changed the segment from impaired to a CN. That can be seen in Table 5 as segment 1305 has a seven-year geometric mean of 134.5 CFU/100mL (*E. coli*). Segment 1305A has an *E. coli* geometric mean below the standard. Segment 1305B as discussed previously, has a high geometric mean in Table 5, 521.5 CFU/100mL (*E. coli*), but there remains an insufficient number of data records to assess. Figure 9 presents Table 5 pictorially as a rolling seven-year geometric trend for each segment in the Caney Creek watershed.

Table 5. Seven-year bacteria geomean for both segment using SWQM bacteria data collected between 2011-2018

Name	**Segment**	**Parameter**	**Data Date Range**	**No. Samples**	**Geomean**
Caney Creek Tidal	1304	Enterococci	01/12/2012 - 10/25/2018	49	57.7
Linnville Bayou	1304A	*E. coli*	01/12/2012 - 10/25/2018	25	147.8
Caney Creek Above Tidal	1305	*E. coli*	01/12/2012 - 10/25/2018	46	134.5
Harderman Slough	1305A	*E. coli*	11/19/2013 – 10/18/2018	21	68.8
Unclassified Stream to Caney Creek	1305B	*E. coli*	01/12/2012 – 08/22/2017	11	521.5

The geometric means presented in Figure 9 are given as a ratio of the mean to the standard by dividing the mean by the appropriate assessment criterion, either 35 CFU/100mL for Enterococcus or 126 CFU/100mL for *E. coli*. The standard as presented in Figure 9 is the standard divided by itself for both tidal and above tidal criterion and presented as a constant of the value 1. The geometric mean for each segment continues to demonstrate slight elevated FIB levels in all but one of the segments. It is notable again that segment 1305B is an outlier here with much higher values.

One recommendation made in a previous Basin 13 report (H-GAC, 2016b) was to collect *E. coli* data from 1305_01 and 1305_03 to better understand FIB in the segment. The seven-year data 2012-2018 presented in Table 6 reflects that new data collected by the Environmental Institute of Houston at stations 12153 and 12155. A continuous flow level height gauge was installed at 12153 to assist with development of load duration curves (LDC) in the watershed. LDCs will be discussed in Section 3.

FIB appears to improve moving downstream from 1305B_01 to 1305_01, 521.5 CFU/100mL at 1305B_01 to 55.5 CFU/100mL at 1305_01. *E. coli* at AU 1305_02 still appears to be elevated with a geometric mean of 153.3 CFU/100mL. However, as reviewed above, based on the most recent draft 2018 IR, the AU was changed to a listing of CN for FIB. The AU will need to be observed to track future FIB trends. Enterococci data for 1304_01 supports the impaired listing with a geometric mean of 58.5 CFU/100mL when compared with the 35 CFU/100mL Enterococcus standard. 1304A_01 has a current seven-year of *E.coli* data resulting in 196.6

CFU/100mL. 1304A_02 is currently a historic station, as there are only two data points across the seven-year period.

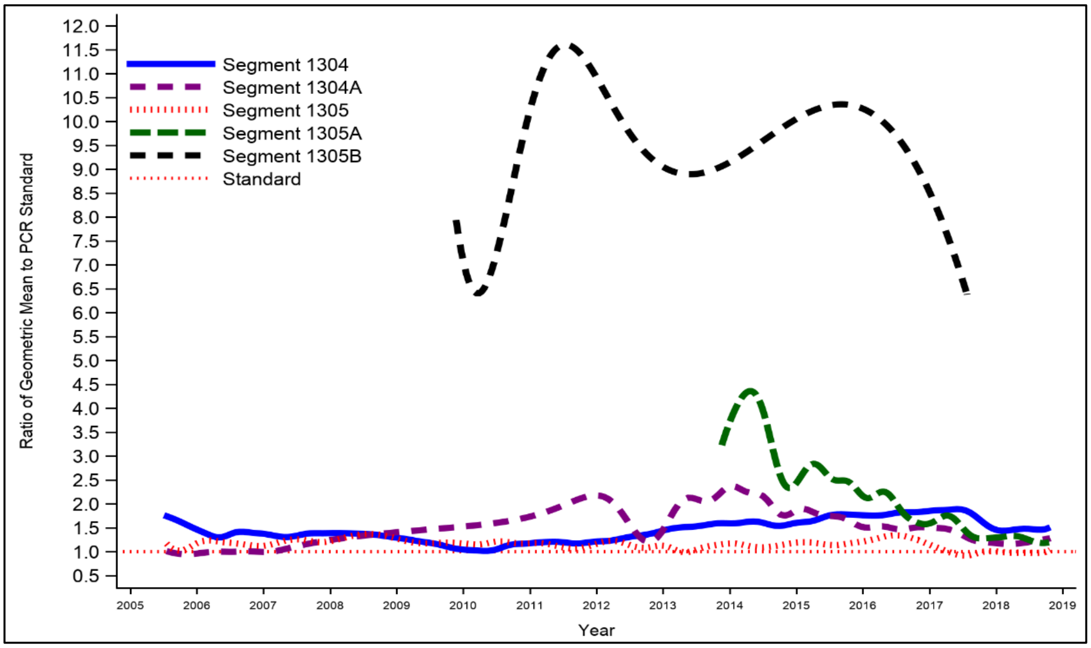


Figure 9. Rolling seven-year geometric mean trend for segments in the Caney Creek watershed

Table 6. Seven-year FIB geometric mean for 1304 and 1305, 2012-2018

AU	SID	Indicator	Earliest Date	Most Recent Date	Samples	Geometric Mean
1304_01	12148	Enterococci	1/12/2012	10/25/2018	29	58.5
1304_02	12151	Enterococci	11/19/2013	10/18/2018	20	56.6
1304A_01	12141	*E. Coli*	1/12/2012	10/25/2018	23	196.6
1304A_02	12138	*E. Coli*	4/8/2014	7/26/2017	2	5.6
1305_01	12153	*E. Coli*	2/2/2017	10/18/2018	10	55.5
1305_02	12154	*E. Coli*	1/12/2012	10/25/2018	27	153.3
1305_03	12155	*E. Coli*	2/2/2017	8/22/2017	9	243.1
1305A_01	12135	*E. Coli*	11/19/2013	10/18/2018	21	68.8
1305B_01	20468	*E. Coli*	1/12/2012	8/22/2017	11	521.5

2.5 Land Cover and Land Uses

The National Oceanic and Atmospheric Administration (NOAA) describes land cover data as physical land types such as forests, wetlands, agriculture, impervious surfaces, and other land and water types, while land use documents how people are using the land for development, conservation, or mixed uses. (NOAA, 2017).

The project area is 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 the Colorado River meander across the project area in the past, 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.

2.5.1 Land Cover

H-GAC acquired land satellite imagery, LandSat 8, taken in 2015. The imagery was analyzed by H-GAC in 2017 for ten land cover types following protocols adapted from NOAA's Coastal Change Analysis Program (H-GAC, 2017). The definitions for the ten land cover types are as follows:

1. High Intensity Development - Contains significant land area that is covered by concrete, asphalt, and other constructed materials. Vegetation, if present, occupies < 20 percent of the landscape. Constructed materials account for 80 to 100 percent of the total cover. This class includes heavily built-up urban centers and large constructed surfaces in suburban and rural areas with a variety of land uses.
2. Medium Intensity Development - Contains area with mixture of constructed materials and vegetation or other cover. Constructed materials account for 50 to 79 percent of the total area. This class commonly includes multi- and single-family housing areas, especially in suburban neighborhoods, but may include all types of land use.
3. 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 percent of total area. This subclass commonly includes single-family housing areas, especially in rural neighborhoods, but may include all types of land use.
4. 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 percent of total land cover.
5. Cultivated Crops - Contains areas intensely managed to produce annual crops. Crop vegetation accounts for greater than 20 percent of total vegetation. This class also includes all land being actively tilled.
6. 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 percent of total vegetation.
    b. Grassland/Herbaceous - Contains areas dominated by graminoid or herbaceous vegetation, generally greater than 80 percent of total vegetation. These areas are not subject to intensive management such as tilling but can be utilized for grazing.
7. 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 percent of total cover.
    b. Unconsolidated Shore - Includes material such as silt, sand, or gravel that is subject to inundation and redistribution due to the action of water. Substrates lack vegetation except for pioneering plants that become established during brief periods when growing conditions are favorable.

8. Forest/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 percent of total vegetation cover. More than 75 percent 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 percent of total vegetation cover. More than 75 percent 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 percent of total vegetation cover. Neither deciduous nor evergreen species are greater than 75 percent 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 percent of total vegetation. This class includes tree shrubs, young trees in an early successional stage, or trees stunted from environmental conditions.
9. Open Water - This is a composite class that contains open water and both palustrine and estuarine aquatic beds.
    a. Open Water - Include areas of open water, generally with less than 25 percent cover of vegetation or soil.
    b. Palustrine Aquatic Bed - Includes tidal and non-tidal wetlands and deep-water habitats in which salinity due to ocean-derived salts is below 0.5 percent 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 percent.
    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 percent 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 percent.
10. Wetlands - This is a composite class that contains all the palustrine and estuarine wetland land types.
    a. Palustrine Forested Wetland - Includes tidal and non-tidal wetlands dominated by woody vegetation greater than or equal to five meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean derived salts is below 0.5 percent. Total vegetation coverage is greater than 20 percent.
    b. Palustrine Scrub/Shrub Wetland - Includes tidal and non-tidal wetlands dominated by woody vegetation less than five meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent. Total vegetation coverage is greater than 20 percent. Species present could be true shrubs,

young trees and shrubs, or trees that are small or stunted due to environmental conditions.

c. Palustrine Emergent Wetland (Persistent) - Includes tidal and non-tidal wetlands dominated by persistent emergent vascular plants, emergent mosses or lichens, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent. Total vegetation cover is greater than 80 percent. 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 percent. Total vegetation coverage is greater than 20 percent.
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 percent. Total vegetation coverage is greater than 20 percent.
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 percent and that are present for most of the growing season in most years. Total vegetation cover is greater than 80 percent. Perennial plants usually dominate these wetlands.

The Caney Creek watershed covers 193,653 acres: 28,200, 64,041 and 101,412 acres in 1304, 1304A and 1305, respectively (Table 7, Figure 10). The four developed land cover classes, High Intensity, Medium Intensity, Low Intensity and Open Space Development were combined into a single class for Table 7 and Figure 10 to simplify the presentation. Each development class makes up a relatively small fraction of the land cover within the Caney Creek watershed. The four developed land cover classes will be discussed separately. Pasture/Grassland makes of the single largest land classification at 35 percent, 37 percent and 40 percent within Segments 1304, 1304A and 1305 respectively (Table 7). In 1304 and 1304A, Wetland and Forest/Shrub classes make up the next two major classes at or slightly above 25 percent of the land cover for each class. For Segment 1305, Cultivated Crop (26 percent) and Wetland (18 percent) make up the next two land cover types.

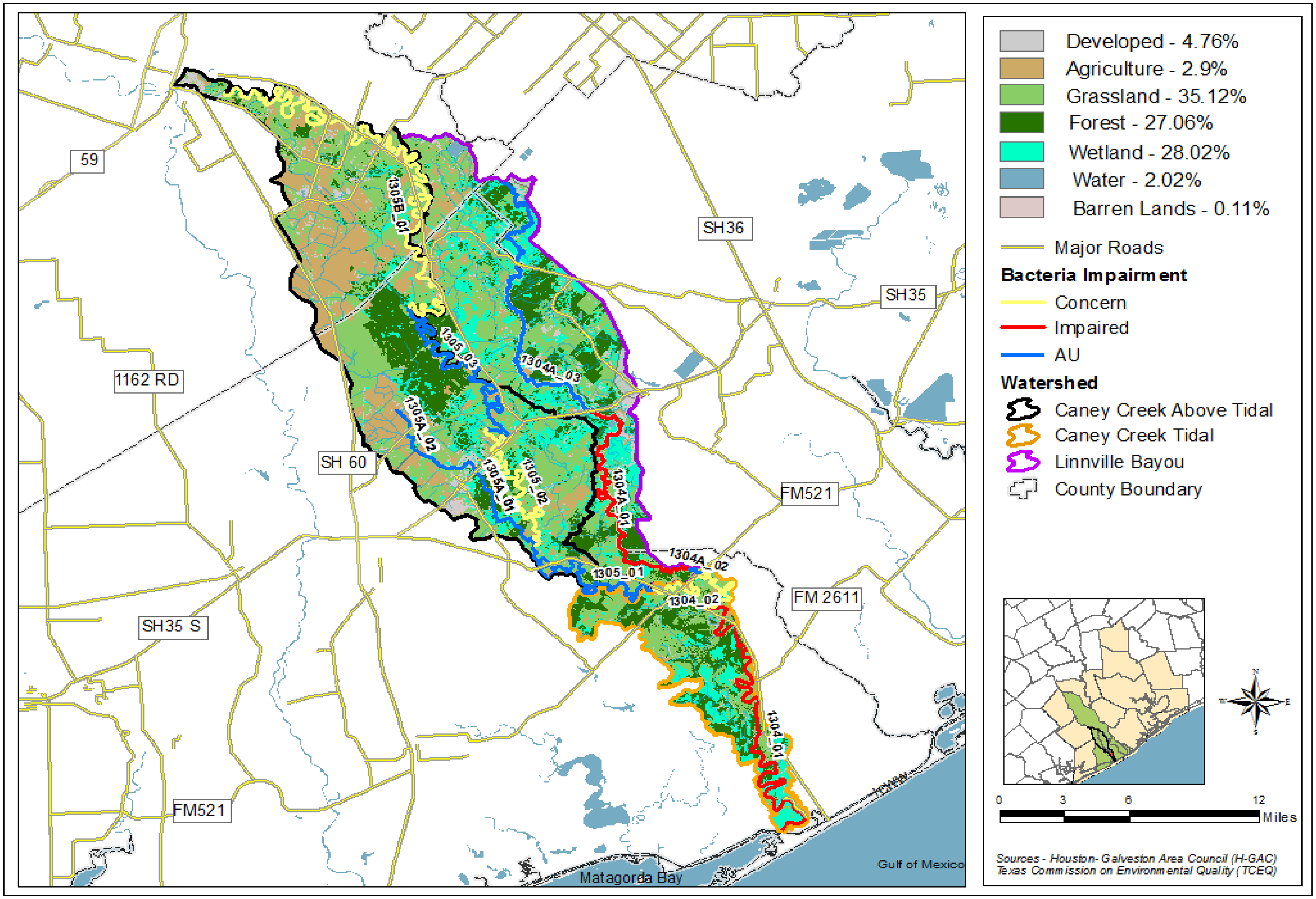
As mentioned, the develop land uses make up a small percentage of the land cover classification within 1304, 1304A and 1305, at 4.76 percent, 5.55 percent, and 6.42 percent, respectively. When the four developed land uses High, Medium, Low Intensity and Open Space (Table 8) are compared individually, the data shows that most of the development is either classed as Open Space or Low Intensity with a high of 98.7 percent after combining both classes in 1304 to 89.7 percent in 1305. Low Intensity and Open Space development in 1304A falls between the two other segments at 92.7 percent. The opposite gradient is found when observing High Intensity and Medium Intensity development where 10.3 percent of both classes can be found in 1305 while only 1.3 percent found in 1304. For High and Medium Intensity classes, 1304A, again falls into the middle at 7.3 percent. It is worth noting that in 1304A, the High Intensity class is the larger of the two classes due to the large industrial complex found within the AU at Old Ocean.

Table 7. Land cover types found in 1304, 1304A and 1305

Land Cover	1304		1304A		1305		Total	
Class Type	Area (Acres)	% Total	Area (Acres)	% Total	Area (Acres)	% Total	Area (Acres)	% Total
Developed	1,343.60	4.76%	3,551.19	5.55%	6,513.98	6.42%	11,408.77	5.89%
Cultivated Crops	817.43	2.90%	4,169.14	6.51%	26,481.25	26.11%	31,467.82	16.25%
Pasture/Grasslands	9,904.68	35.12%	23,429.63	36.59%	40,842.56	40.27%	74,176.87	38.30%
Barren Lands	31.36	0.11%	275.53	0.43%	240.21	0.24%	547.10	0.28%
Forest/Shrubs	7,631.67	27.06%	15,963.73	24.93%	9,369.39	9.24%	32,964.79	17.02%
Open Water	570.03	2.02%	356.27	0.56%	111.87	0.11%	1,038.17	0.54%
Wetland	7,901.17	28.02%	16,295.97	25.45%	17,852.63	17.60%	42,049.77	21.71%
Total	**28,199.94**	**100.00%**	**64,041.46**	**100.00%**	**101,411.89**	**100.00%**	**193,653.29**	**100.00%**

Table 8. Developed Land Classification broken further into High, Medium and Low Intensity and Open Space Development for 1304, 1304A and 1305

Developed Cover	1304		1304A		1305		Total	
Class Type	Area (Acres)	% Total	Area (Acres)	% Total	Area (Acres)	% Total	Area (Acres)	% Total
High Intensity	0.45	0.03%	159.10	4.48%	401.60	6.17%	561.15	4.92%
Medium Intensity	16.98	1.26%	99.62	2.81%	267.86	4.11%	384.46	3.37%
Low Intensity	421.23	31.35%	1,559.95	43.93%	3,101.36	47.61%	5,082.54	44.55%
Open Space	904.94	67.35%	1,732.52	48.79%	2,743.16	42.11%	5,380.62	47.16%
Total	**1,343.60**	**100.00%**	**3,551.19**	**100.00%**	**6,513.98**	**100.00%**	**11,408.77**	**100.00%**



Sources - Houston-Galveston Area Council (H-GAC)
Texas Commission on Environmental Quality (TCEQ)

Figure 10. Land cover in segments 1304, 1304A, and 1305

2.6 Potential Sources of Fecal Indicator Bacteria

A common approach to analyze potential FIB sources is to review regulated and unregulated sources in the watershed. Pollution sources that are regulated have permits under the Texas Pollutant Discharge Elimination System (TPDES) and the National Pollutant Discharge Elimination System (NPDES).

Unregulated sources, often considered nonpoint sources, are those where the pollutant originates from diffuse locations and is usually carried to surface waters by rainfall runoff. Nonpoint sources are not regulated by a permit. Examples of unregulated sources include wildlife, on-site sewage treatment facilities (OSSFs), and byproducts of agriculture production.

2.6.1 Regulated Sources

Wastewater treatment facilities (WWTFs) and stormwater discharges from industries, construction, and municipal separate storm sewer systems (MS4s) are examples of regulated sources permitted under the TPDES and NPDES programs.

2.6.1.1 Domestic and Industrial Wastewater Treatment Facilities

There are five distinct permittees in the Caney Creek watershed that maintain wastewater discharge permits for 9 wastewater outfalls (Table 9, Figure 11), based on the USEPA’s Integrated Compliance Information System (ICIS), TCEQ’s Central Registry and TCEQ’s Outfall Data Layer, last reviewed on May 1, 2019. All permits were in either Segment 1304A or 1305. No permits were found in segment 1304. However, the outfall permit WQ0014177001 has been included in Figure 11 as the service area for the permittee, Caney Creek Municipal Utility District, is within the 1304_01 watershed, though the outfall discharges to the ICWW in Basin 24. The permittee’s service area includes the collection system and the WWTF, both are potential FIB sources through sanitary sewer overflows, spills and equipment malfunction.

Two permittees in 1304A, WQ0000721000 (Phillips 66 Co.) and WQ0005147000 (Chevron Phillips Chemical Co.), do not have bacteria limits in their permit. Both companies are located at the Old Ocean chemical refining area in Linnville Bayou watershed. As neither discharges an appreciable amount of FIB, their outfalls will be excluded from further analysis.

The remaining three permittees (Table 10) are domestic WWTFs which hold bacteria limits in their permits. One facility is found near Boling in 1305B_01. The other two are located near Van Vleck in 1305A_01 (Figure 12). The maximum permitted discharge flows in million gallons per day (MGD) from each facility were recorded for use in development of the TMDL loading calculation.

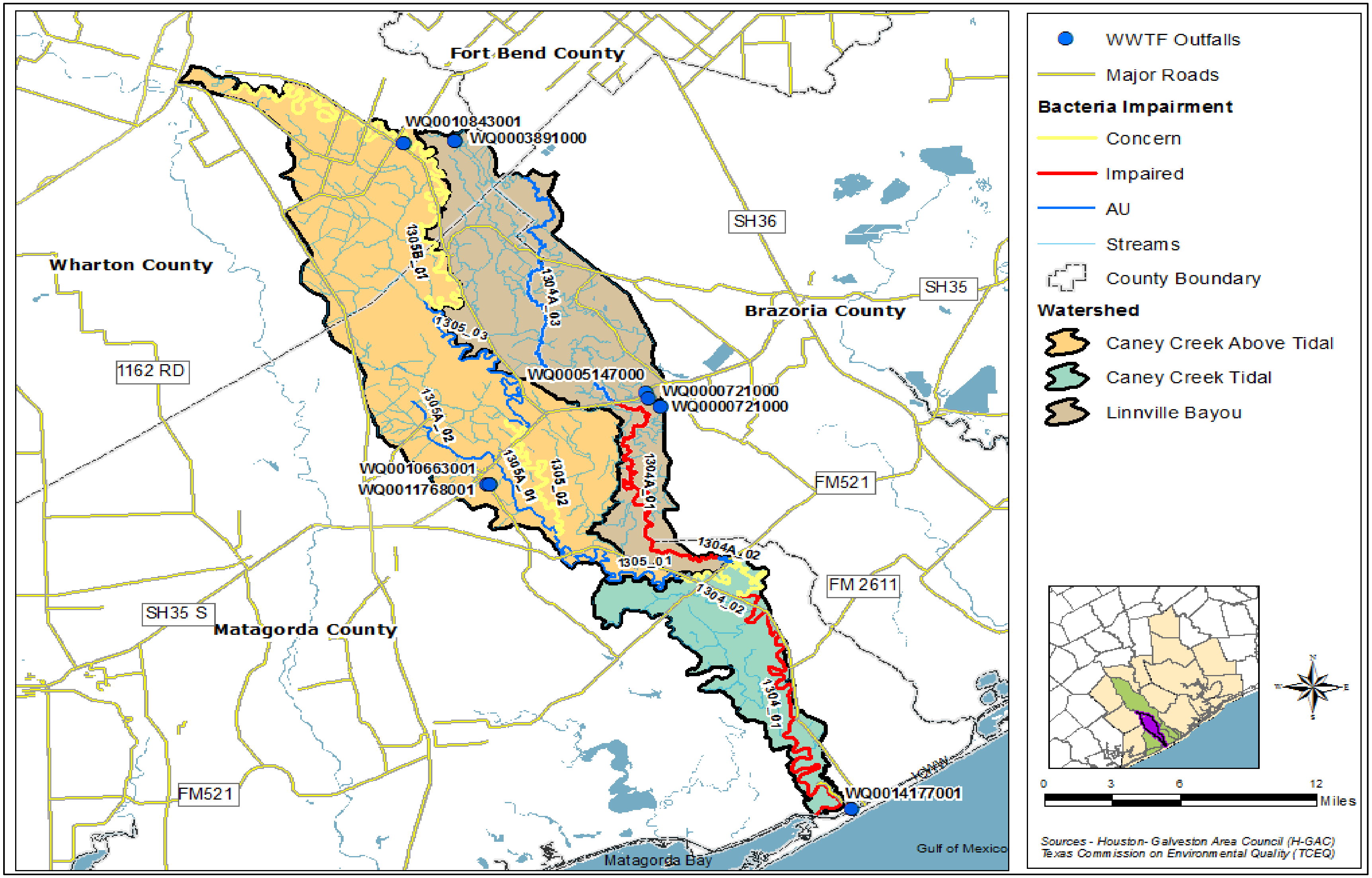
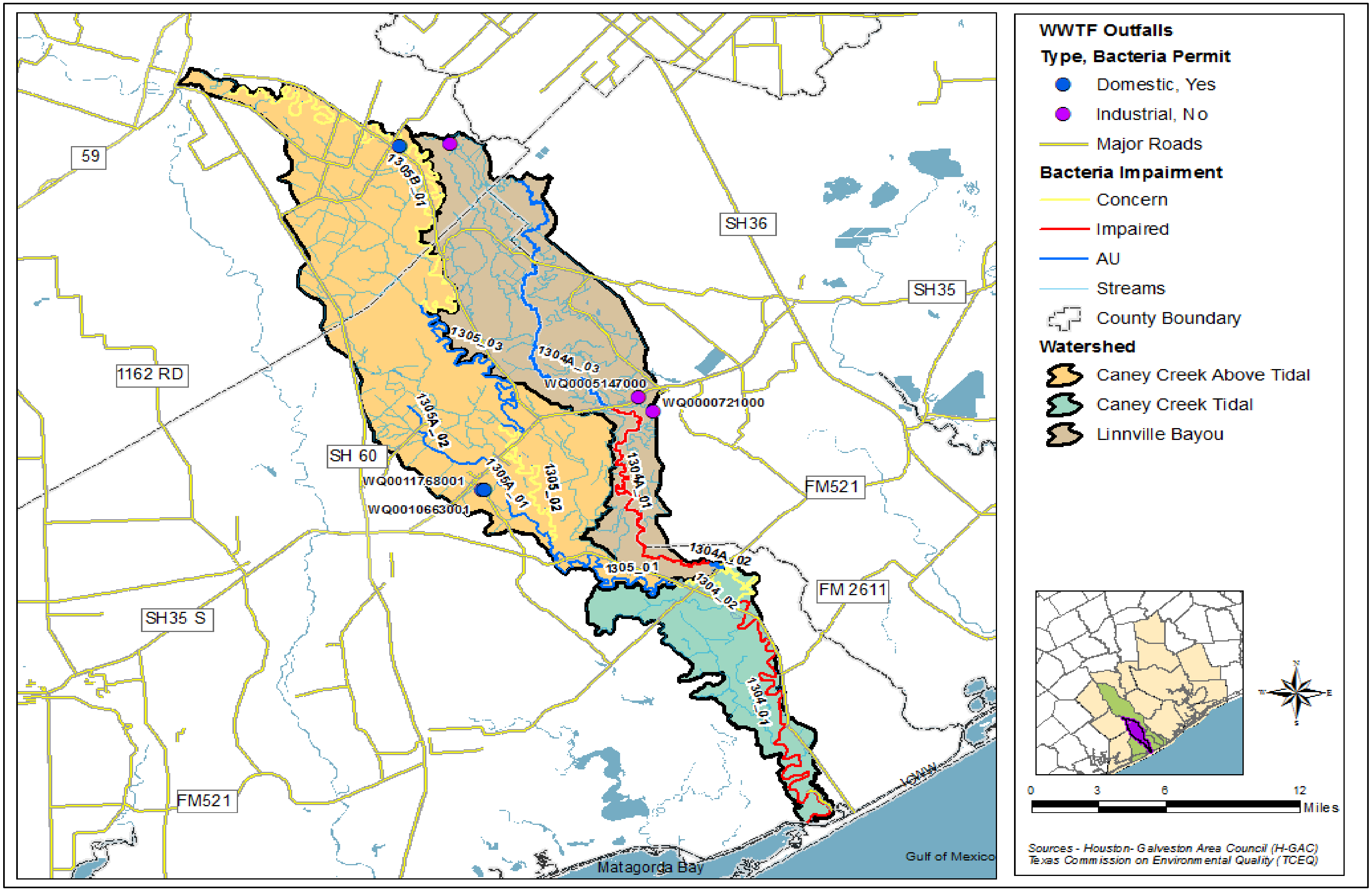


Figure 11. Location of WWTF outfalls in segments 1304, 1304A, and 1305

Table 9. Five wastewater dischargers, with eight permitted outfalls found in 1304, 1304A, and 1305

Segment	TPDES Permit Number	NPDES Permit Number	Permittee	Outfall Number	Bacteria Limits	Permitted Discharge (MGD)
1304A	WQ0000721000	TX00007536	PHILLIPS 66 CO	2, 6, 10, 13	No	Continuous/Flow Variable
1304A	WQ0005147000	TX00135917	CHEVRON PHILLIPS CHEMICAL COMPANY LP	1, 3	No	Intermittent/Flow Variable
1305	WQ0010663001	TX00024155	MATAGORDA COUNTY WCID 6	1	126 (*E. coli*)	0.193
1305	WQ0010843001	TX00033910	BOLING MWD	1	126 (*E. coli*)	0.133
1305	WQ0011768001	TX00070297	MASSEY JIMMIE WAYNE	1	126 (*E. coli*)	0.01



Sources - Houston- Galveston Area Council (H-GAC)
Texas Commission on Environmental Quality (TCEQ)

Figure 12. Domestic and industrial outfalls found in 1304, 1304A and 1305

WWTF permittees are required to sample their effluent for FIB concentrations and report the results to the state in their Discharge Monitoring Reports (DMRs). The reports are available from the state and USEPA (ICIS) for review. Analysis of the permittee's DMRs are provided in Table 11. The permittees reported that they did not exceed the bacteria geometric mean of 126 CFU/100mL for the reporting period. One facility, WQ0010843001, was found to have exceeded the Daily Maximum/Grab (399 CFU/100 mL) for three percent of samples reported in their DMRs for the reporting period.

2.6.1.2 Sanitary Sewer Overflows

Sanitary sewer overflows (SSOs) are unauthorized discharges that must be addressed by the responsible party, either the TPDES permittee or the owner of the collections system that is connected to the permitted system. SSOs in dry weather most often result from blockages in the sewer collection pipes caused by tree roots, grease, and other debris. Inflow and infiltration (I/I) are typical sources of SSOs under conditions of high flow in the WWTF system due to rainfall infiltration during storm events. Blockages in the line may exacerbate the I/I problem.

A review of SSOs reported to TCEQ Region 12 by permit holders in Caney Creek found only one SSO reported for the period of 2012-2018. WQ0014177001 in AU 1304_01, reported on 5/27/2012 one SSO due to a blockage in the collection system. This SSO released an estimated 3,000 gallons of untreated sewage.

2.6.1.3 Dry Weather Discharges/Illicit Discharges

In addition to stormwater, regulated entities under TPDES and NPDES permits must identify and correct dry weather discharges/illicit discharges that contribute effluent to the MS4 but have not been approved via permit or result from emergency firefighting activities. Examples of illicit discharges to the storm sewer include home sanitary pipes connected directly to the storm sewer, cross connections between municipal sanitary sewer and the storm sewer, leaking sanitary sewer leaching into storm sewer, and failing OSSFs leaking into the storm sewer.

2.6.1.4 TPDES General Wastewater Permits

The TCEQ regulates certain types of facilities that process wastewater, some of which potentially contain FIB. General wastewater permit types include:

- TXG110000 – concrete production facilities;
- TXG130000 – aquaculture production facilities;
- TXG340000 – petroleum bulk stations and terminals;
- TXG670000 – hydrostatic test water discharges;
- TXG830000 –petroleum fuel or petroleum substances;
- TXG920000 – concentrated animal feeding operations; and
- WQG200000 – livestock manure compost operations.

Table 10. Three WWTFs found in 1305 with their full permitted discharge rate

SEGMENT	TPDES_NUM	PERMITTEE	Monitored Bacteria	Full Permitted Discharge (MGD)
1305	WQ0010663001	MATAGORDA COUNTY WCID 6	126 (*E. coli*)	0.193
1305	WQ0010843001	BOLING MWD	126 (*E. coli*)	0.133
1305	WQ0011768001	MASSEY JIMMIE WAYNE	126 (*E. coli*)	0.010
Total				**0.336**

Table 11. Compliance history including FIB limits, monitoring frequency, bacteria reported and exceedance percentage for WWTFs

TPDES ID	Facility/ Permittee Name	Parameter	Geometric Mean Limit	Daily Maximum/ Grab	Monitoring Frequency	Percent Exceedance, Geometric Mean	Percent Exceedance, Daily Maximum/Grab	Data Date Period
WQ0010663001	MATAGORDA COUNTY WCID 6	*E. coli*	126	399	Monthly	0	0	8/2014 - 12/2017
WQ0010843001	BOLING MWD	*E. coli*	126	399	Monthly	0	3	10/2010 - 12/2017
WQ0011768001	MASSEY JIMMIE WAYNE	*E. coli*	126	399	Quarterly	0	0	11/2010 - 12/2017

A review of active general permit coverage via TCEQ's Central Registry (TCEQ, 2018) for the Caney Creek watershed as of January 31, 2018, found one concentrated animal feeding operation (CAFO) in Caney Creek Above Tidal (Table 12, Figure13).

Table 12. One CAFO found within segment 1305

Segment ID	Permit	Type	County	City	Lat	Lon	Estimated Area (acres)	Wastewater generated (acre-feet)
1305	TXG921286	WHARTON COUNTY FOODS LLC	WHARTON	BOLING	29.23083	95.9667	1060	321.28

CAFOs are required to contain wastes onsite and 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 can cause releases of fecal wastes to segment 1305.

Figure 13. Wharton County Foods on CR 442 between the towns of Boling and Lane City

No other active general wastewater permit facilities or operations were found. No attempt was made to allocate bacteria loads to wastewater dischargers from the remaining general permit types.

2.6.1.5 TPDES General Stormwater Permits

Land-based sources not attributed to WWTFs, their conveyance systems, or to general wastewater fall into two categories: regulated and unregulated stormwater. Regulated stormwater, as it sounds, is permitted by the state under TPDES and is considered a point source by the state. Stormwater from unregulated areas is considered a nonpoint source and will be discussed under unregulated sources in Section 2.6.2. Discharges of stormwater from a Phase II urbanized area, industrial facility, construction site, or other facility involved in certain activities are required to be covered under the following TPDES general permits:

- TXR040000 – stormwater Phase II MS4 general permit for urbanized areas;
- TXR050000 – stormwater multi-sector general permit (MSGP) for industrial facilities;
- TXR150000 – stormwater from construction activities disturbing more than one acre;
- TXG110000 – concrete production facilities; and
- TXG340000 – petroleum bulk stations and terminals.

The permits for MS4s, MSGPs, and construction pertain only to stormwater. Concrete production facilities and petroleum bulk stations and terminals are also potential dischargers of wastewater under TPDES General Wastewater Permits. There were no concrete production or petroleum bulk stations and terminals found in either segment.

The TCEQ Central Registry (2018) was reviewed on June 8, 2018 for stormwater permits. No permits were found that pertain to Phase II MS4 for the Caney Creek watershed. There were 4 construction activities, two in 1304A, one in 1305 and one in 1305A, with active stormwater construction permits (Table 13). Construction permits are required when one acre or more of land is disturbed during construction. Construction activities found in the Caney Creek watershed can change, were construction has wrapped up at some locations while new areas are being cleared and prepped for construction. The permit data found at TCEQ is only considered accurate for the date the data was accessed.

Acreages are recorded in “Area Disturbed” field permit authorization found in the Water Quality General Permits and Registration Search hosted by TCEQ (TCEQ Central Registry, 2018). Due to the variable nature of these permits, the acres recorded serve only as a representative estimate, after summing up all disturbed areas, of the watershed area under a stormwater construction permit at any given time. The estimated disturbed area for 1304A, 1305 and 1305A was found to be 345, 1, and 1,194 acres, respectively. The construction permit acreages were recorded for use in development of the TMDL in Section 4.

MSGPs were reviewed in the TCEQ Central Registry in 2018 for active permits in segments 1304, 1304A and 1305. A total of six MSGPs are active in 1304A and 1305A (Table 14). Three were found in 1304A and three in 1305A. Acreages were estimated by reviewing county appraisal parcel data and/or importing the location information associated with the authorization into GIS and measuring the disturbed area. The total estimated acreage for 1304A and 1305A is 1935 and 678 acres, respectively. It should be noted that permits TXR05BI93 and TXR05DO16 both refer to the same permittee, Phillips 66 and therefore only the acreage for one of the permits was used. Once calculated, the area for each permit was saved for development of the TMDL in Section 4.

Table 13. Permitted stormwater construction site found in segments 1304A and1305

AU	Permit	Type	County	City	Lat	Lon	Estimated Area (acres)
1304A	TXR15157L	S & B Engineers And Constructors, Ltd.	Brazoria	Old Ocean	29.34437	-95.4537	235
1304A	TXR15ZE76	Zachry Industrial, Inc.	Brazoria	Old Ocean	29.05783	-95.764	110
1305A	TXR150014583	Tenaris Bay City, Inc.	Matagorda	Bay City	28.99827	-95.9017	1,193
1305	TXR15161K	Bass Construction Co., Inc.	Wharton	Iago	29.27996	-95.9618	1

Table 14. MSGPs found in 1304A and 1305

Segment ID	Permit	Type	County	City	Lat	Lon	Estimated Area (acres)
1304A	TXR05BI93*	Phillips 66 Company	Brazoria	Old Ocean	29.07333	-95.7528	1,057
1304A	TXR05DJ65	Chevron Phillips Chemical Company LP	Brazoria	Sweeny	29.075	-95.7467	878
1304A	TXR05DO16*	Phillips 66 Company	Brazoria	Old Ocean	29.07333	-95.7528	0
1305A	TXR05DE75	DD Fluids, LLC	Matagorda	Van Vleck	29.00694	-95.9006	5
1305A	TXR05DH28	Tenaris Bay City, Inc.	Matagorda	Bay City	28.9972	-95.8951	667
1305A	TXR05Y292	Varichem International, Inc.	Matagorda	Van Vleck	29.0063	-95.9025	6

**TXR05BI93 and TXR05DO16 refer to the same company. No acres were assigned to TXR05DO16 to avoid double counting.*

2.6.2 Unregulated Sources

Unregulated sources of FIB are often considered nonpoint sources because they come from diffuse sources rather than a single source. OSSFs, certain agricultural activities, land application fields, urban runoff not covered under a permit, and pet wastes are examples of unregulated sources.

2.6.2.1 On-site Sewage Facilities

Away from municipal centers where more centralized public wastewater treatment is common, rural and low-density suburban residences and stand-alone commercial and industrial businesses within the county or a city's extra territorial jurisdiction are more likely to use owner-operated OSSFs, often referred to as septic systems. When functioning properly and sited correctly, much like WWTFs, OSSFs contribute little if any FIB.

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

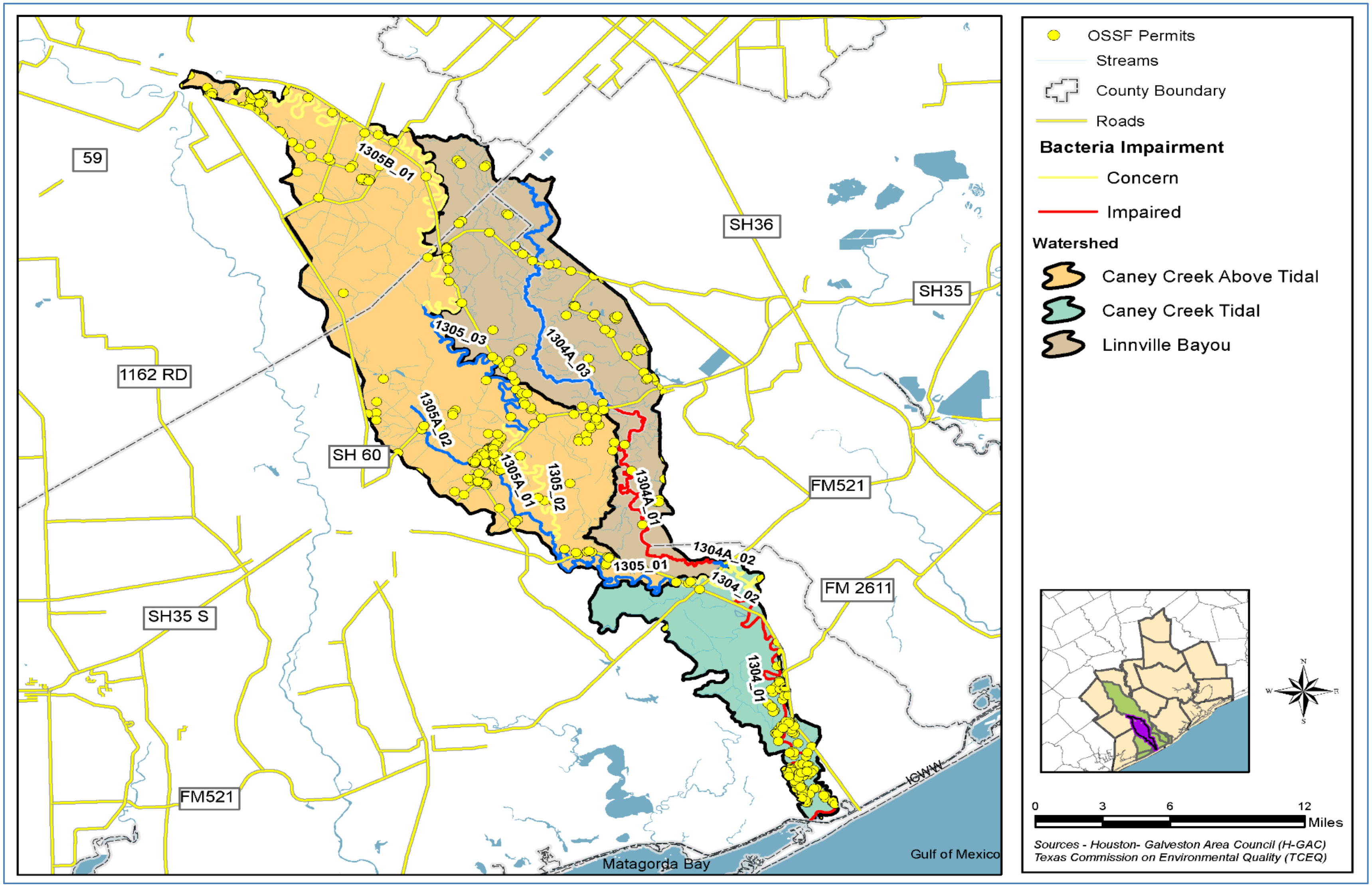
In addition to permitted systems, there is a larger number of systems that are unpermitted or grandfathered. These systems are difficult to identify and enumerate. In other parts of H-GAC's region, H-GAC uses appraisal district parcel data and know areas of permitted OSSFs to ascertain unpermitted systems. For much of Caney Creek, H-GAC does not have parcel data. H-GAC communicated with Texas A&M AgriLife and TCEQ regarding unpermitted and grandfathered OSSFs for Coastal Texas, including Brazoria and Matagorda Counties.

Permitted OSSFs are presented in Figure 14. There are 514 permitted OSSFs in the Caney Creek watershed: 139 in 1304, 65 in 1304A and 310 in 1305 (Table 15). Using AgriLife's estimate of unregistered and grandfathered OSSFs, there are likely another 3,276 OSSFs: 1,293, 372, and 1,611 in 1304, 1304A and 1305 respectively. Note this does not include the Wharton County portion of 1304A or 1305, as Texas AgriLife did not estimate OSSFs in that county.

Table 15. Permitted and Grandfathered OSSFs in 1304, 1304A and 1305

Segment	Permitted OSSF	Grandfathered OSSF	Total
Caney Creek Tidal	193	1,293	1,486
Linnville Bayou	65	372	437
Caney Creek Above Tidal	310	1,611	1,921
Total	568	3,276	3,844

The Reed, Stowe & Yanke (2001) study suggests that there is a 12 percent failure rate for OSSFs in Texas. That rate, derived from survey responses received from the AAs, falls in line with EPA's guidance on failure rates nationally of 10 to 20 percent (H-GAC, 2005). Appling the 12 percent failure rate to 3,844 systems, an estimated 461 systems are failing in Caney Creek.



Sources - Houston- Galveston Area Council (H-GAC)
Texas Commission on Environmental Quality (TCEQ)

Figure 14. Permitted OSSFs found in 1304, 1304A and 1305

2.6.2.2 Agriculture

Agriculture production remains a large economic base for segments 1304,1304A, and 1305. Agriculture is a nonpermitted activity that potentially contributes FIB during production. FIB from agriculture can reach waterbodies from runoff from livestock grazing lands and land applications of manure as fertilizer during crop production, and direct deposition from livestock with access to the creek.

Figure 11 and Table 7 presented the current state of two agriculture land cover types, Cultivated Cropland and Pasture/Hay. Agriculture makes up between 38% and 66% of the land cover when analyzed for 1304, 1304A, and 1305.

Table 16 contains Brazoria, Matagorda, and Wharton County livestock figures for 2012, compiled by the US Department of Agriculture Census of Agriculture (USDA, 2012). A stocking rate for each county was developed by analyzing county land cover data and selecting the Pasture/Grassland for the county. Data for segments 1304, 1304A, and 1305 were developed using a proportional stocking rate for the county and multiplying it times the area for each segment's Pasture/Grassland found within each County.

Table 16. Estimated livestock figures for Brazoria County, Matagorda and Wharton Counties, and 1304, 1304A and 1305

Watershed	Pasture/Grassland Area (Acres)	Cattle and Calves	Hogs and Pigs	Sheep and Lambs	Equine	Poultry
Brazoria	262,112	78,907	4,218	1,435	4,572	6,033
Matagorda	240,492	53,283	47	304	1,141	1,261
Wharton	256,621	57,168	131	395	1,687	242
Caney Creek Tidal	9,904.68	2,194	2	13	47	52
Linnville Bayou	23,429.63	5,804	127	63	215	244
Caney Creek Above Tidal	40,842.56	9,069	13	56	224	144

(USDA Census of Agriculture.)

2.6.2.3 Pets

Pets are another common unregulated source of FIB in urban and rural settings. Dense urban areas present a particularly unique setting for pet bacteria contributions. Dog parks, pet walks, and large feral populations of dogs and cats increase the likelihood that FIB is potentially significant. Connected impervious surfaces direct rainfall runoff to storm sewers with little natural landscape area treatment. In more rural settings like Caney Creek, pets remain a source, but are not considered a major source.

Estimated rates of dog and cat ownership per household have been developed and can be applied to generate an estimate of the number of dogs and cats found in the Caney Creek watershed. Using the rates of 0.614 and 0.457 for dog and cat ownership for each household (AVMA, 2018) and 2016 estimate of 185 households in segment 1304, 357 in 1304A, and 3,003 in 1305 (US Census, 2014), there is an estimated dog population of 114, 219 and 1,844 in 1304, 1304A, and

1305 respectively. There is an estimated cat population of 85, 163 and 1,372 in 1304, 1304A and 1305 respectively (Table 17).

Table 17. Estimated population households, dogs and cats in 1304, 1304A and 1305.

Segment	Estimated Households	Dogs	Cats
Caney Creek Tidal	185	114	85
Linnville Bayou	357	219	163
Caney Creek Above Tidal	3,003	1,844	1,372
Total	3,545	2,177	1,620

2.6.2.4 Wildlife

FIB can also come from wildlife such as mammals and birds as bacteria are common in the intestines of all warm-blooded animals. Most types of wildlife are attracted to the water, increasing the likelihood of direct deposition of bacteria into the water, and for FIB to be picked up off adjacent land during rainfall events.

While wildlife inhabits all parts of Caney Creek, areas that remain undeveloped are key reservoirs for wildlife. Development accounts for less than 6% of the Caney Creek watershed (Figures 11 and Table 7), leaving large areas available for wildlife use.

Feral hogs, a nonnative, invasive species, are unique in their ability to adapt to a variety of habitats and their high reproductive rates. Feral hogs have been identified as a large contributor to FIB due to their desire to wallow in mud and spend time in water to escape the summer heat.

Feral hog density rates suggest that there are between 1.33 and 2.45 hogs per square mile in areas with suitable habitat (Texas AgriLife Extension, 2012). The lower rate would apply to the least favorable habitat (i.e. barren land) while the higher rate would apply to areas of higher suitability. High and medium density developed areas are not considered in the calculation. Applying both rates to suitable habitat in 1304, 1304A and 1305 the population of hogs range from a low of 59 to 109 feral hogs in 1304 to a high of 209 to 386 in 1305 (Table 18).

Table 18. Feral hog estimate populations in 1304, 1304A and 1305. (1 square mile = 640 acres)

Watershed	Suitable Area (Acres)	Suitable Area (Sq. Mile)	Feral Hog Population
Caney Creek Tidal	28,182.51	44.04	59-108
Linnville Bayou	63,782.74	99.66	133-244
Caney Creek Above Tidal	100,742.43	157.41	209-386

2.6.2.5 Bacteria Survival and Die-off

Potential sources for FIB have been examined in previous sections. It is well understood that FIB in the water column in natural systems die off, decreasing concentrations due to the presence of sunlight, predators, and competition for available nutrients. Recent research has also made clear that FIB can survive outside of warm-blooded hosts in the organic films found on pipes and upper sediment layers of streambeds (Brinkmeyer et. al, 2014). Less clear is the understanding of FIB regrowth and any potential relationship with pathogenic bacteria. As these are considered in-stream processes, they were not used in the development of bacteria source loading estimates for the three segments in this report.

Section 3.
Bacteria Tool Development

3.1 Introduction

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

3.2 Model Selection

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

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

The LDC method allows for the estimation of existing and allowable loads by utilizing the cumulative frequency distribution of streamflow and measured pollutant concentration data. Texas and other states have successfully used the LDC method to develop TMDLs which have been accepted by the regulatory community due to the method's simplicity and ability to address information limitations commonly found with bacteria TMDLs. The LDC has become recommended as part of a three-tiered approach by the appointed bacteria task force driven by the TCEQ and the TSSWB (TWRI, 2007). More recently, Texas began using modified LDCs for TMDLs in tidal waters with the Mission and Aransas Bay TMDL (Hauck et al, 2013) and Tres Palacios Creek Tidal TMDL (Hauck et al, 2015). The LDC has limitations, as it will not fully quantify individual source contributions of all point and nonpoint loads, nor is it capable of assessing load reductions provided by specific bacteria reduction management measures. It is recommended here as it provides a simple means for determining the loading value across moisture conditions and can be broadly used to indicate sources of bacteria (e.g. point source and non-point source.)

3.2.1 Data Resources

Data resource availability was sufficient for segments in Caney Creek and Linnville Bayou, to perform LDCs and modified LDCs in segment 1304 and 1304A respectively, with the exception of daily streamflow. To complete LDCs, daily streamflow, FIB, and in the case of tidally influenced waters, salinity is required. Streamflow will be discussed further below to address this data limitation.

All the required water quality data (*E. coli,* Enterococci, and salinity) were adequately available through SWQMIS for the period of 2004 to 2017. 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 (QAPP). Qualified data (data added to SWQMIS with “qualifier” codes that identify quality, sampling, or other problems that may render the data unsuitable) were excluded from the download. All data for all stations, collected from January 1, 2004, through December 31, 2017, were combined into a working data set for LDC development (Table 19).

3.2.1.1 Stream Flow data generation

Daily stream flow records are an essential component of LDC development. Lack of availability of daily stream flow data for the period of 2004 to 2018 in the main stream was an issue in Caney Creek. However, there is one recently established stream gauge station (SID 12153) by the Environmental Institute of Houston (EIH) at the segment 1305_01 that measures stream depths in 15-minute intervals. The stream flow records for this gauge station are developed by generating a flow curve based on a relationship between observed flow and the gauged depths. The flow was generated for the period of February 14, 2017, to December 31, 2018, through EIH.

Table 19. Bacteria geomean for both segments for SWQM bacteria data collected between 2004 and 2018

AU	SID	Indicator	Earliest Date	Most Recent Date	Samples	Geometric Mean
1304_01*	12148	Enterococci	1/7/2004	10/25/2018	105	47.8
1304_02	12151	Enterococci	4/20/2004	10/18/2018	28	53.7
1304A_01	12141	*E. Coli*	1/7/2004	10/25/2018	38	205
1304A_02	12138	*E. Coli*	4/8/2014	7/26/2017	2	5.6
1305_01	12153	*E. Coli*	2/2/2017	10/18/2018	10	55.5
1305_02	12154	*E. Coli*	1/7/2004	10/25/2018	58	147.4
1305_03	12155	*E. Coli*	2/2/2017	8/22/2017	9	243.1
1305A_01	12135	*E. Coli*	11/19/2013	10/18/2018	21	68.8
1305B_01	20468	*E. Coli*	11/23/2009	8/22/2017	15	664.6

**Include data from station ID 12149, an historic station with 18 samples collected between 2009 and 2012*

Meanwhile, the daily flow records from the United States Geologic Survey (USGS) streamflow gauge SID 08162600, located in Tres Palacios watershed Segment 1502 (near Midfield, TX) was used along with EIH flow records to derive daily stream flow at Caney Creek for the intended LDC period of 2004 to 2018. The USGS gauge station at the Tres Palacios watershed was selected for several reasons. Tres Palacios is one of the closely located streams to Caney Creek that comparatively consists of similar land cover composition, weather patterns, and watershed activities such as agriculture and industries. Also, the sizes of two catchment areas of the USGS station and SID 12153 are also relatively similar (Table 20).

Table 20. Catchment area comparison between Caney Creek at Station ID 12153 and Tres Palacios at USGS 08162600

Catchment	Area Sq. Miles
USGS ID 08162600	154.6
SID 12153	130.26

The USGS gauge records were "Naturalized" by correcting the additions of WWTF discharges, and withdrawals of upstream water rights diversions. As used herein, naturalized flow is referring to the flow without the additions of permitted discharges and withdrawals from water tights, 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.

Only one outfall, permitted to discharge to the Tres Palacios, was found above the USGS flow gauge ID 08162600. The estimated daily DMR reported discharge for the time-period of 2004-2018 from the WWTF outfall (Table 21) was subtracted from the daily gauge streamflow records. This resulted in an adjusted streamflow records with the point source discharge influence being removed.

Table 21. Average DMR reported discharge of the outfall upstream of USGS gauge 08162600

TPDES ID	NPDES ID	Permittee	Average Daily Flow (MGD)
WQ0010844001	TX0021474	City of El Campo	1.0316

Next, 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 calculated daily average consumption values from all the water rights were added back into the adjusted streamflow records, resulting in an adjusted streamflow records with upstream water right diversion influence being removed.

The EIH-generated flow curve at the SID 12153 was converted into daily values by correlating monthly measured flow at the station with the 15-minute height recordings. To find a relationship between daily flow patterns between the two streams, Caney Creek and Tres Palacios, a linear regression model was built between the two flow records. For this purpose of the regression model, only the flow records from February 14, 2017, to December 31, 2018, from both the watersheds were considered. The linear regression estimation was performed using SAS statistical software package. Based on the estimated regression relationship, the daily flow values for the SID 12153 in Caney Creek for the period of January 1, 2004, to December 31, 2018, were derived.

The daily, fresh water flow values at the other stations in Caney Creek were calculated based on the derived flow values of SID 12153 and drainage area ratio (DAR) method. To compute the Area Ratio, the area above the SID 12153 was compared with the watershed contributing to the monitoring station. In the case of SID 12151, the contributing watershed includes the area between SIDs 12151 and 12153, in addition to the area contributing to SID 12153. DAR can be found in Table 22.

Table 22. Drainage Area Ratio for stations in 1304, 1304A and 1305

Location	Area Sq. Miles	DAR
SID 12135	24.94	0.19
SID 12155	74.68	0.57
SID 12154	99.67	0.77
SID 12141	57.58	0.44
SID 12138	99.86	0.77
SID 12153	130.26	1
SID 12151	262.68	2.02
SID 12148	299.45	2.3

Once the DARs are known, freshwater flow values can be generated at each station. As an example, the flow values at SID 12153 were multiplied by 2.02 to obtain the fresh water flow at station SID 12151.

3.2.2. Allocation Tool Selection

Following the review of available data and derived data, including streamflow, FIB, historical DMRs, and in the case of tidal segments, salinity, and considering the expanded use of LDCs in TMDL development, particularly in the case of modified LDCs in tidal waters in Texas (Hauck et. al, 2013 and 2015), the LDC method was chosen for segments 1304, 1304A, and 1305.

In developing the LDCs, the standard LDC approach (USEPA, 2007) along with Load Estimation (LoadEst) technique (Runkel et.al., 2004) was followed for the station in the above tidal segments (1304A and 1305) of Linnville Bayou and Caney Creek (Section 3.3). There were six coordinated monitoring stations that have collected water quality data in the above tidal segment of the watershed. They were; SIDs 20468, 12155, 12154, 12135, 12153, and 12141. Due to inadequate availability of water quality data, the SIDs 20468, 12155 and 12153 were not selected in developing LDCs. These stations did not consist of enough data to run a regression analysis in developing the Load Regression curve. Therefore, the LDC were developed only for the SIDs 12154, 12135, and 12141.

While SID 12141 represented an AU that is impaired, LDCs were also made for SIDs 12135 and 12154. As the impaired AU, 1304_02 is downstream of 1304A and 1305 the TMDL load calculations for 1304A_01 and 1305_02 will be used as tributary loads to segment 1304. The LDC for 12154 can be used to inform stakeholders regarding the FIB concern listing. In addition, there was sufficient data at SID 12135 to develop a LDC. While a TMDL is not needed to address an impairment in 1305_02 or 1305A_01, the five percent exceedance value can still be used to calculate a loading value and add the tributary influence to segment 1304. This is necessary as 1305_01 lacked sufficient data to develop a LDC.

For the stations at the tidal segment of the stream, 1304, the modified LDC method was used (Section 3.4). The modified LDC method has been developed to apply LDCs to tidal waters where downstream flows are mingled with tidal flows generated from diurnal changes in sea levels. There are two coordinated monitoring stations in the tidal segment. They are SIDs 12151 and 12148. Both stations were selected for LDC development. While a modified LDC was not need for SID 12151, as it represents an AU that is not considered impaired, the LDC can be used to inform stakeholder on present use concerns for the AU. The LDC can also be used to calculate a loading value and add the tributary's influence on 1304_01, an impaired AU.

3.3 Methodology for Flow Duration & Load Duration Curve Development

The initial steps in developing LDCs are to gather the previously discussed sets of data and select appropriate stream locations, typically monitoring stations. The preferable location is the most downstream-positioned station in the segment, close to the terminating boundary. In the case of 1305 and 1304A, above mentioned three stations (SIDs 12154, 12135, and 12141) were selected to develop LDC. Data records for streamflow, FIB *(E. coli),* and other records needed for TMDL development, WWTF DMRs, segment watershed area, permitted flows, and future growth flows were gathered from the previously mentioned sources.

3.3.1 Flow Duration Curve Development

The first step in developing an LDC is the development of flow duration curve (FDC) to identify the ranges of flow regimes. The observed flow records, that were calculated using the approach mentioned in 3.2.2.1 were arranged in descending order and ranked from 1 to N. Then the flow exceedance frequency (x-value of each point) was estimated by calculating the historical exceedance frequency of the measured flow. In other words, the percent of historical observations that equal or exceed the measured flow using the following formula, where F is the frequency of occurrence (expressed as percent of time a flow value is equaled or exceeded), R is the rank, and N is the number of observations.

$$F = 100 * \frac{R}{N+1} \qquad \text{(Equation 1)}$$

The sorted flow rate was plotted against the exceedance probability in a semi-log curve to generate the flow duration curve (Figure 16). A common way to look at the duration curve is by dividing it into five zones based on percent of exceedance, representing high flows (1-10% exceedance), moist conditions (10-40% exceedance), mid-range flows (40-60% exceedance), dry conditions (60-90% exceedance), and low flows (90-100% exceedance) (USEPA, 2007). In our LDC developments, we adopted the US EPA guide to determine flow regimes in all LDCs in this study.

3.3.2 Load Duration Curve Development

The monitored bacteria concentrations were first paired with flow data in the FDC; then the daily loads of bacteria were estimated using the following formula, where the conversion factor is 24,465,715.2:

Daily Load (CFU/day) = Bacteria concentration (in CFU/100mL) * flow (cfs) *

conversion factor (Equation 2)

Calculated daily loads were then added to the FDC semi-log plot as a scatter-plot diagram. Other than the monitored bacteria daily load points, there are two other curves generally added to an LDC. First is the load regression (LR) curve. The LR curve shows the general trend of the monitored constituents based on a regression analysis. This curve helps to identify whether the constituent load is below or above the TMDL. Furthermore, it is useful in estimating the load reduction needed to maintain an unimpaired water body in each flow regime. The other important information in an LDC is the standard curve, which shows the allowable maximum daily limit of constituent loading while maintaining an unimpaired stream (Figure 15).

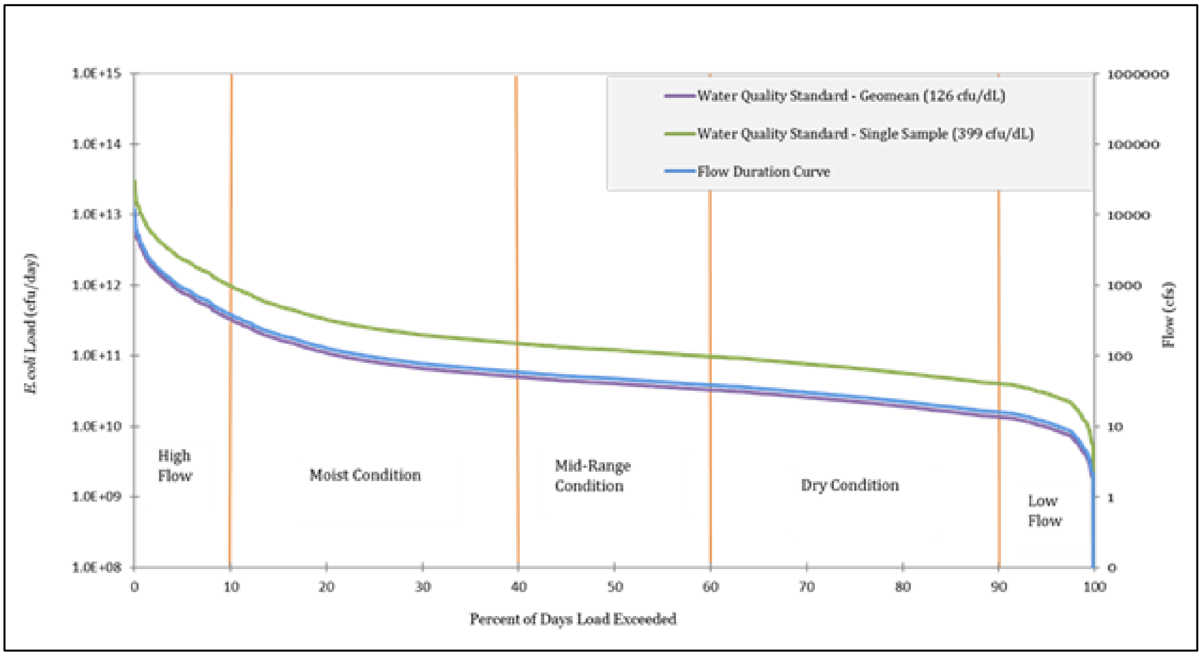


Figure 15. FDC, standard geometric mean, and single sample grab curves

3.3.3 Load Regression Curve Development

The LR curve developed in this study is based on USGS's LoadEst methodology (Runkel et.al., 2004). The LoadEst program is a FORTRAN based stand-alone program that generates the regression model for estimating the stream load of a specific constituent at a location. The calibration and estimation procedure in LoadEst are based on three statistical estimation methods: Adjusted Maximum Likelihood Estimation (AMLE), Maximum Likelihood Estimation, and Least Absolute Deviation. In this study, we used AMLE to correct the first-order bias and to estimate the instantaneous load of bacteria.

The AMLE equation is given as:

$$\mathrm{Ln(Load)} = a0 + a1\ \mathrm{LnQ} \qquad \text{(Equation 3)}$$

Where:

Load = constituent load [kg/d]

LnQ = Ln(Q) - center of Ln(Q)

After the model was set up and the calibration, header, and estimation files were generated with appropriate information, the LoadEst program was run for the constituents. Using the regression formula generated from LoadEst analysis, the LR curve was developed based on the daily flow values and added to the semi-log plots that include FDC and observed loading data.

3.3.3 Water Quality Standard Curve

Generally, an LDC consists of one or two water quality standard or allowable maximum daily load curves. In this analysis, we have included two standard lines to represent geomean and single sample standards. The criterion for each standard line is given as:

E. coli:

Geomean: 126 CFU/100 mL

Single Sample: 399 CFU/100 mL

Enterococci:

Geomean: 35 CFU/100 mL

Single sample: 130 CFU/100 mL

The daily load for standard lines were estimated based on following formula:

$$\text{TMDL (counts/day)} = \text{criterion} * \text{flow (cfs)} * \text{unit conversion factor} \qquad \text{(Equation 4)}$$

3.3.5 Above Tidal Load Duration Curve Review

Figure 17 brings the LDC together with the components: FDC, geometric mean and single-sample standard curves, observed data, and the LR curve. The LDCs were developed for SIDs 12154, 12135, and 12141 (Figure 16, 17, and 18). At this point the LDC is used to develop TMDL load reduction calculations which will be presented in the next section of this report for 1305. Using the flow regime of 0-10% High Flows, 10-40% Moist Conditions, 40-60%

Intermediate Conditions, 60-90% Dry Conditions and 90-100% high flow, the LDCs can be viewed as periods where the bacteria load meets the standard (i.e. the LR curve is below the geometric mean) and periods where it exceeds the standard (i.e. the LR curve is above the geometric mean). Geometric mean load values (Average Load) using the FIB data were generated for each flow regime (Figure 16, 17, and 18).

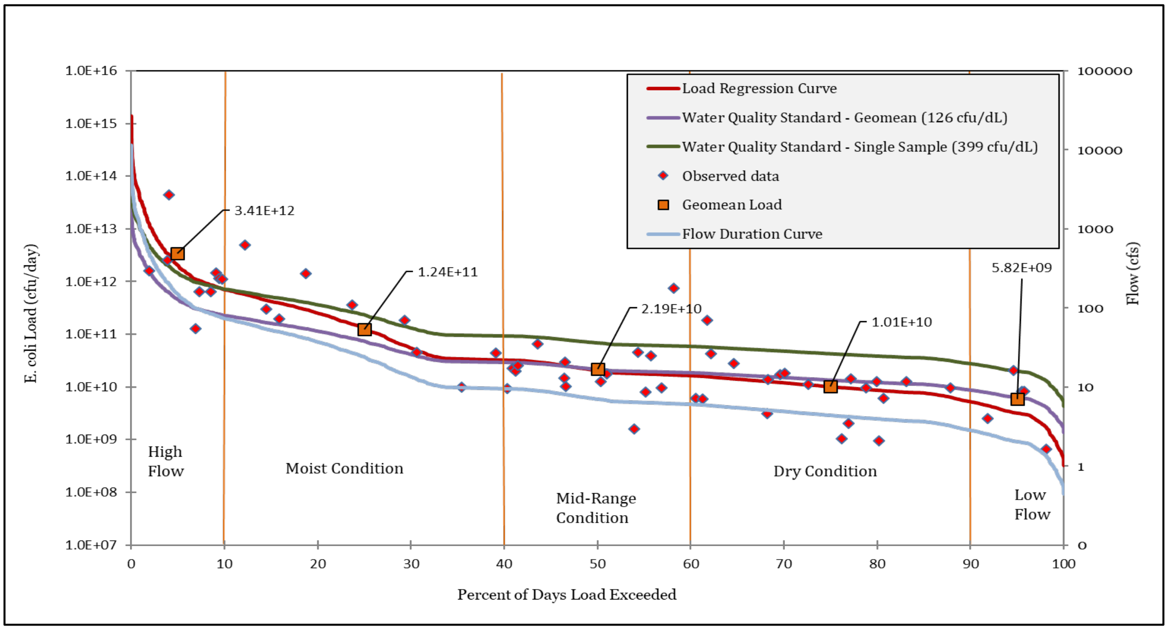


Figure 16. LDC for SID 12154 in 1305_02

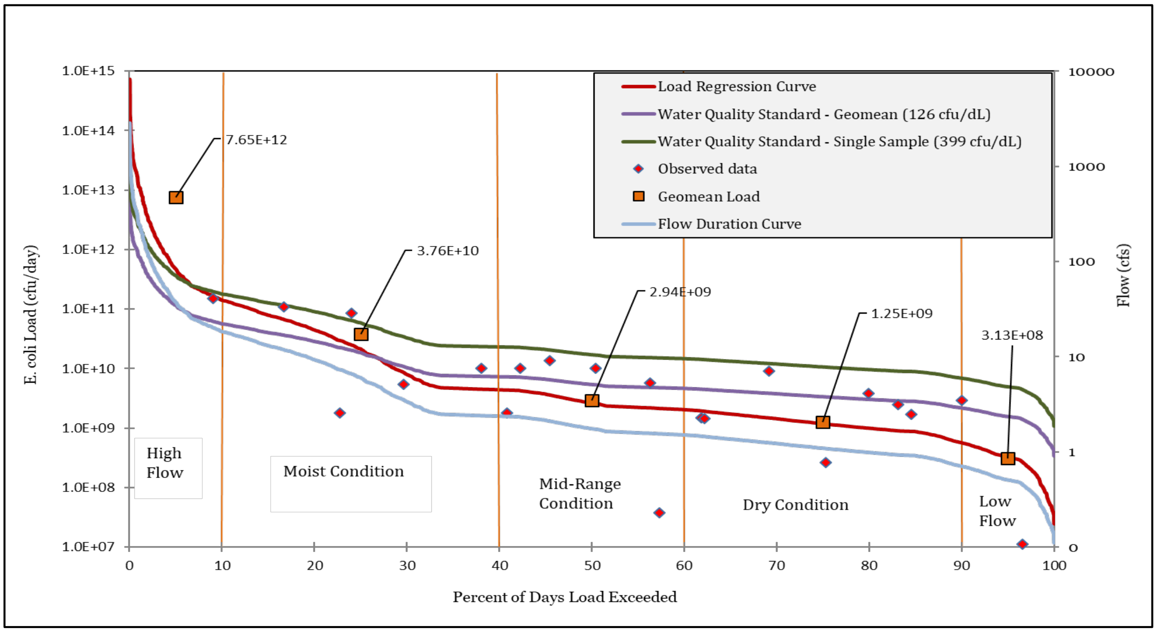


Figure 17. LDC for SID 12135 in 1305A_01

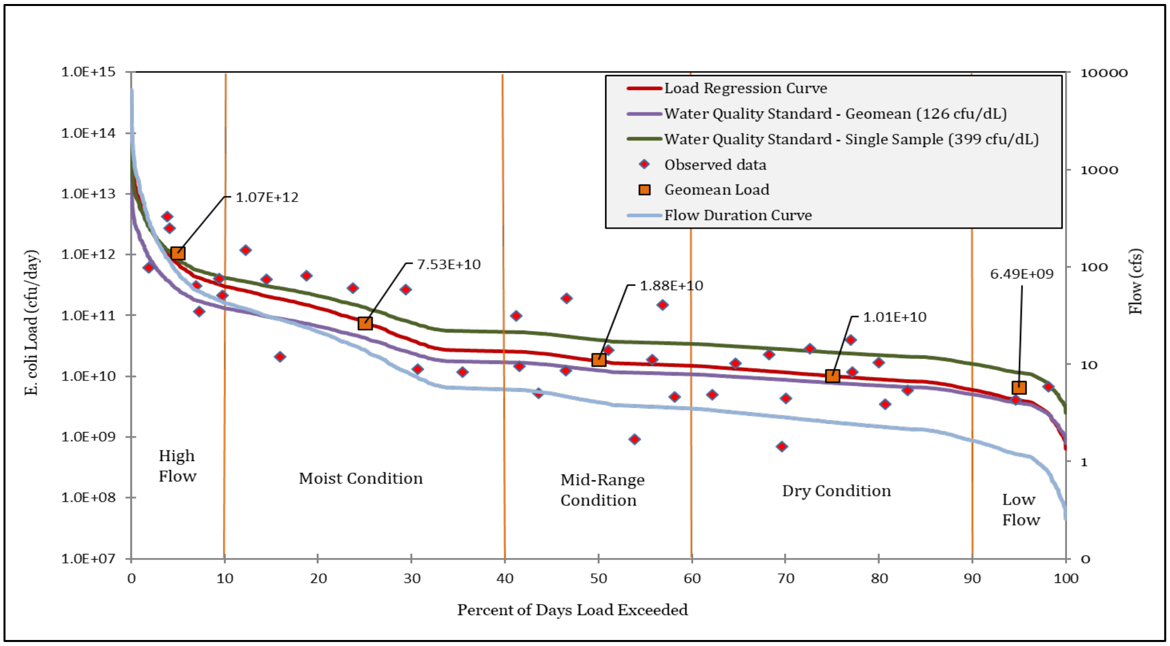


Figure 18. LDC for SID 12141 in 1304A_01

Additionally, individual observed data can be contrasted with the single-sample standard curve to determine the relation of either above or below the single-sample standard during certain flow regimes. This can be useful as mentioned in calculating load reductions during TMDL development but can also be useful in visually depicting reduction requirements to the public and conveying whether dry weather conditions or wet weather conditions present the biggest challenge in meeting the standard (e.g. dry weather inputs from WWTFs or wet weather sources such as stormwater).

Reviewing the LDC for SID 12154 in Figure 16, LR curve begins well above the geometric mean standard curve at high flows and begins to approach the standard during moist conditions. The LR curve eventually crosses the standard during mid-range conditions. This would suggest that potentially nonpoint sources from stormwater are driving FIB above the standard at this station. This can be contrasted with the impaired AU’s SID 12141 in Figure 18, where the LR curve begins above the standard curve and remains above the standard through nearly all the LDC flow conditions until very late in the low flow condition. This would suggest the potential for both nonpoint sources (those in high and moist condition flows) and point sources (those more typically present during dry and low flow conditions).

3.4 Modified LDC Development

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. In addition to salinity, the FIB is now Enterococci, used to indicate the potential for pathogens in tidal waters. 1304 contain two monitoring stations, SIDs 12148 and 12151 in 1304_01 and 1304_02, respectively, and the LDCs were developed for the two stations.

To develop the modified LDCs, quarterly CRP Enterococci and salinity measurements from 2004 to 2018 were acquired. Due to the tidal nature of the stream, there were no daily flow records to estimate the daily loads of bacteria. As a surrogate, derived daily flow measurements at each station was used. Daily flow records were generated and related to the salinity of the stream in the next step.

3.4.1 Salinity vs. Flow Regression Analysis

The next step is to combine salinity observations (from CRP monitoring) taken at each station with adjusted daily fresh water flow values based on the date of the observation. The top and bottom five percent were considered outliers and eliminated from further calculations. The salinity records were then plotted against the base 10 LOG flow values in a scattered plot (Figure 19).

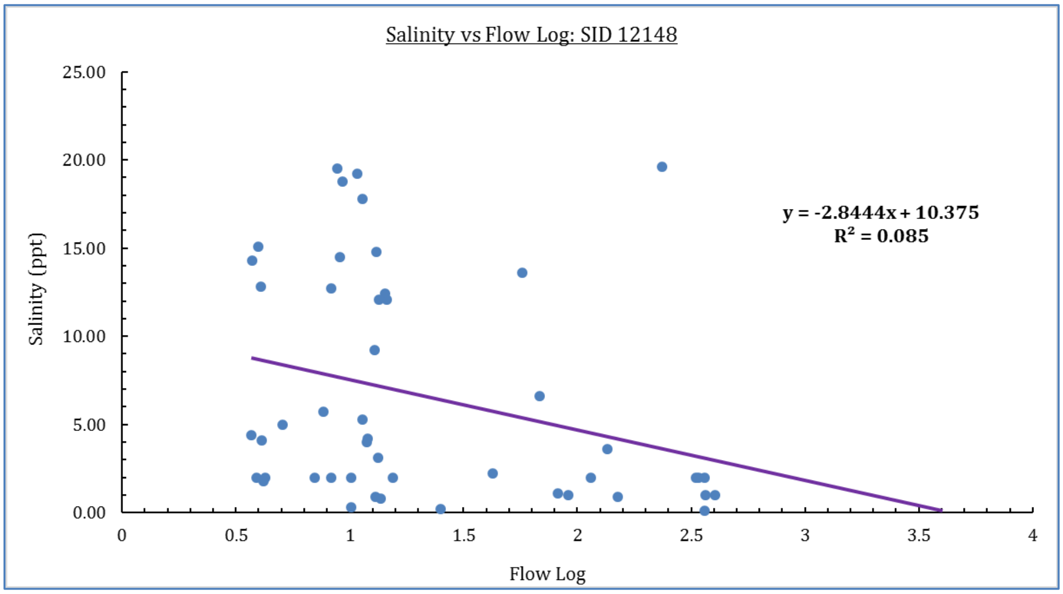


Figure 19. Regression scatter plot of salinity vs. flow values

A linear regression curve and the curve-fitting equation were estimated to develop a daily freshwater flow-measured salinity relation. Using the linear regression equation in each station, daily salinity time series were generated with respect to the derived daily flow values.

For example: the equation for the SID 12148:

Salinity (parts per thousand (ppt)) = (-2.8444*derived flow at 12148) + 10.375
(Equation 5)

The resulting equation developed for each station was then used to calculate the volume of seawater flowing through the station cross section over the period of a day.

3.4.2 Total Water Volume Estimation at the Station

The regression equations developed previously were then used to compute the total daily flow volume including both fresh and saline water. Sea water volume was estimated based on the measured salinity values using the following mass balance formula:

$$(V_s = V_r / (S_s/S_t - 1)) \qquad \text{(Equation 6)}$$

Where,

Vs = Seawater Flow,

Vr = Daily Freshwater Flow,

Ss = Salinity of Seawater = 35 ppt,

St = Estimated Salinity in Stream

The total flow at the station (i.e. sea water and freshwater) was estimated using formula;

$$Vt = Vr + Vs \qquad \text{(Equation 7)}$$

Where,

Vt = Total flow

Vr = Daily freshwater flow

Vs = Seawater flow

3.4.3 Modified Flow Duration Curve Development

The modified FDC was then developed following similar procedures for creating an FDC in the above tidal segments. Daily flows (Vt) were ranked from highest to lowest. Then the percent of days each flow was exceeded (exceedance value) is calculated, (rank ÷ (number of data points + 1) * 100). The resulting exceedance value is plotted against the flow value.

3.4.3 Completed Modified LDC

Using statistical analysis software (SAS), Enterococci observation, and total river flow values were combined based on the observation date. Like the approach used in above tidal segments for *E. coli*, the LR curves were developed for Enterococci at the tidal stations using the LoadEst approach. All the FDC, LR curve, observed data points, and standard curves were plotted in a semi-log plot to complete the LDC. Figures 20, and 21 illustrate the modified LDCs for tidal SIDs 12151 and 12148, respectively.

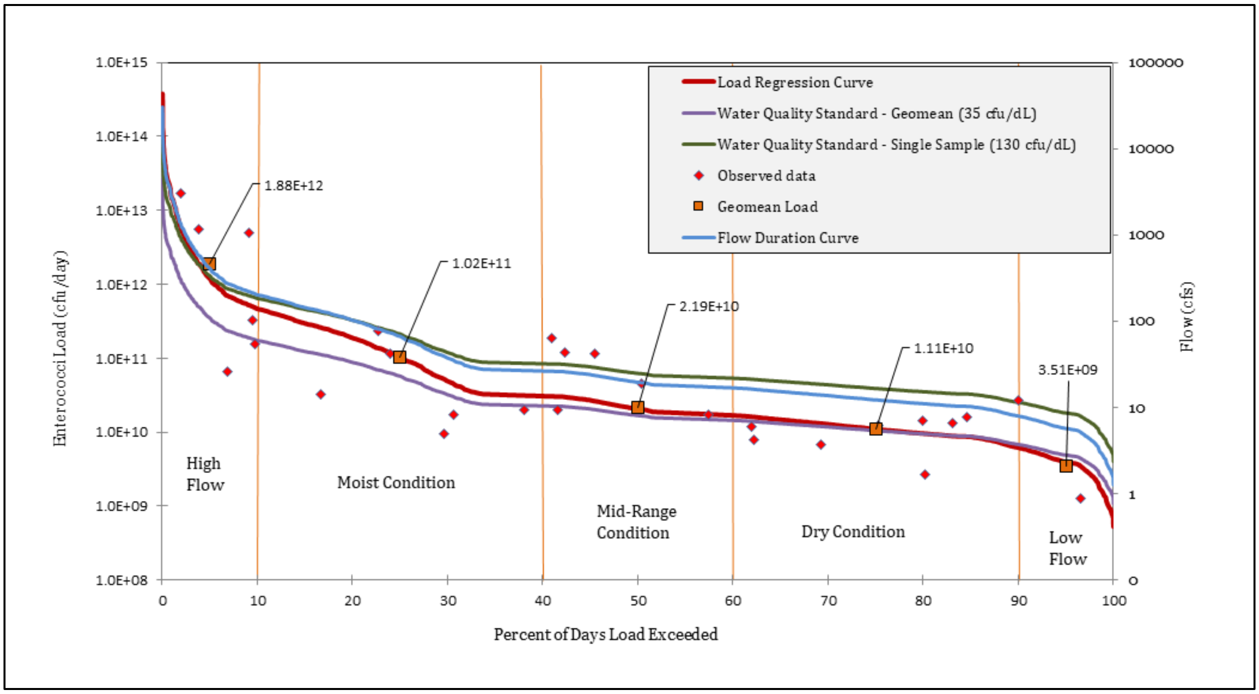


Figure 20. Modified LDC for SID 12151 in 1304_02

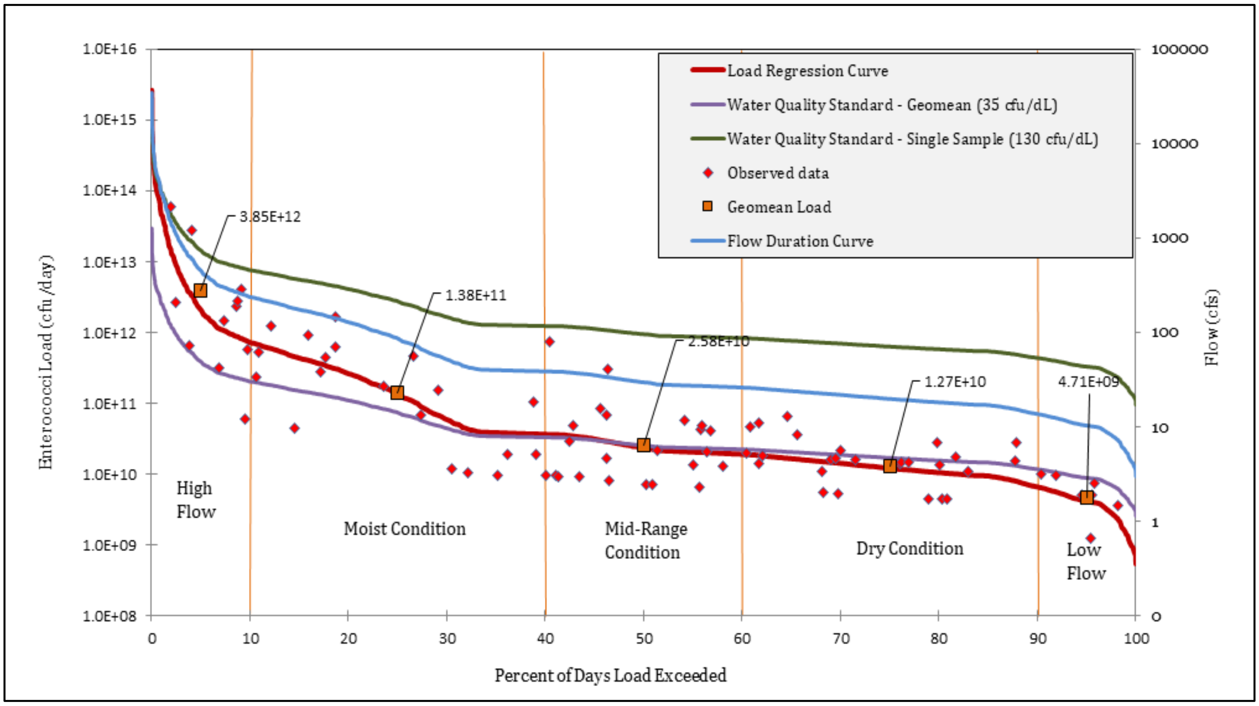


Figure 21. Modified LDC for SID 12148 in 1304_01

3.4.4 Tidal Load Duration Curve Review

The tidal LDCs can be reviewed in a similar fashion to the review of the above tidal LDCs. Here both tidal curves, presented as Figure 20 and 21, behave similarly. Looking at SID 12148 LDC for the impaired AU 1304_01, the LR curve is observed well above the standard curve during high flow events. The LR curve approaches the standard curve during the later stages of the moist condition regime. The LR curve then follows along the standard curve before crossing during the middle part of the mid-range conditions. This pattern would suggest nonpoint sources during wet weather events are driving the impairment in this AU.

Section 4.
TMDL Allocation Analysis

This section contains the bacteria TMDL allocation for two segments 1304 and 1304A. The allocation is based on two developed LDCs prepared for 1304_01 and 1304A_01. Additionally, LDCs were prepared for 1305_02, 1305A_01 and 1304_02. The process for developing LDCs was described in section three.

The LDC method (modified LDC included) provided a flow-based approach to determine necessary reductions in bacteria loadings and allowable loadings within 1304 and 1304A. The method uses frequency distributions to assess a bacteria criterion over the historical range of flows, providing a means to determine maximum allowable loading and load reductions necessary to support the primary contact recreation use.

Nine monitoring stations provided ambient FIB data for analysis which were reviewed in this report (Figure 9). In segment 1305, there are five station, SIDs 12153 (1305_01), 12154 (1305_02), 12155 (1305_03), 12135 (1305A_01) and 20468 (1305B_01). There are two stations in 1304A_01, SIDs12141 and 12138. 12138 is a discontinued station and ambient monitoring is no longer collected. In 1304 there are two stations for the segment, SIDs 12148 (1304_01) and 12151 (1304_02). For the TMDL allocation, traditionally only the furthest downstream station in an AU is used. It provides the point that includes most of the AU's watershed for analysis and is therefore typically the most representative of conditions for the entire AU.

Of the five stations in segment 1305 only two, SIDs 12154 and 12135, had sufficient data to complete a LDC. When sufficient data is available a TMDL can be completed for each AU and the calculated load added to the downstream AU (TCEQ, 2016). The calculated loads from 1305_02 and 1305A_01 were used to develop the load at 1304_02. Additionally, the LDC and calculated load for 1305_02 will be used to inform stakeholders about the FIB use concern in the AU and during TMDL I-Plan development.

SID 12141 found in 1304A Linnville Bayou contained sufficient data to develop a LDC. The impairment in 1304A_01 was evaluated using the LDC developed for SID 12141 and a TMDL load allocation was made.

Segment 1304 contains two monitoring stations, SIDs 12148 and 12151. The LDC developed for SID 12151 (1304_02) will be used to develop the TMDL load allocation for the AU. While 1304_02 is not considered impaired, it does have a use concern for contact recreation. The LDC will be used to explain the use concern with watershed stakeholders and TMDL I-Plan development. In addition, a TMDL load allocation was completed for 1304_02 as the resulting load will be used in calculating the TMDL for 1304_01 along with the LDC developed for SID 12148. As 1304_02 is downstream of 1304A and 1305 the TMDL load calculations for 1304A_01 will be used as tributary loads to segment 1304. In addition, there was sufficient data at SIDs 12154 and 12135 to develop a LDC. While a TMDL was not needed to address an impairment at both stations, the five percent exceedance value can still be used to calculate a load allocation value and add segment 1305's influence to segment 1304.

4.1 Endpoint Identification

To develop a bacteria TMDL load allocation, a target must be identified for the load to meet. Both segments were assigned primary contact recreation use. The criterion that the TMDL will target is the numerical standard assigned to the designated use by TCEQ. The numeric standard was developed using FIB, which while not necessarily pathogenic in themselves are indicative of the potential for pathogenic viral, bacterial, or protozoan contaminants emanating from warm-blooded organisms. For 1304, enterococci are the FIB, and has a contact recreation criterion of 35 CFU/100mL for tidal waters. For nontidal waters including 1304A, TCEQ set the contact recreation standard using the FIB *E. coli* at a concentration not to exceed 126 CFU/100mL (TCEQ, 2015).

4.2 Seasonality

Federal regulations (40 CFR §130.7(c)(1)) require TMDLs to account for seasonal variation in watershed conditions and pollutant loadings (USEPA, 1992). To evaluate potential seasonal difference, ambient monitoring data for Caney 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 variety of statistical analyses (e.g. Wilcoxon rank analysis, ANOVA/Kruskal-Wallis).

4.3 Linkage Analysis

The ability to use LDCs in developing the TMDL load allocation requires linking sources of loading with instream water quality as measured by ambient monitoring. By doing so, the development of management measures through a future implementation plan can be designed, with the goal of reaching the desired water quality standards.

A review of the LDC method and partition of the graph into flow regimes allows for gross analysis of sources. During low flows and dry conditions, contribution of bacteria can typically be attributed to point sources and direct fecal deposition to the water body. The ambient bacteria concentration at these flows will fluctuate as the magnitude from contributing sources changes. During storm events, runoff over land picks up deposited sources, nonpoint sources, and begins to contribute to the loading of the stream. With sufficiently sized storms, the runoff contribution greatly outpaces the input from point sources. These events are captured on the LDC in the wet and high flow regime which captures elevated levels of both permitted sources and nonpermitted sources. Typically, the bacteria concentration rises as runoff first reaches the water body. This "first flush" of bacteria is generally attenuated over time as the bacteria has been washed off the land and runoff decreases following the rain event.

One assumption the link between bacteria sources and the concentration found in the stream. It is generally assumed that there is a one-to-one relationship between the two which is factored into the LDC. When using the LDC to develop the load allocation, that one-to-one relationship is still assumed. This is important when the load is applied to potential sources (e.g. WWTFs, areas of the watershed under stormwater regulation and, the remaining allocation apportioned to nonregulated sources).

4.4 LDC and Modified LDC

In developing the TMDL allocation, the LDC method is used to examine the relationship between ambient conditions with wide categorical sources of FIB. LDCs, including modified versions, provides a simple statistical interpretation of water quality problems and can be easily explained to stakeholders. Data, streamflow, and ambient water quality are generally available, and the method does not require the more complex processes that models typically use. Regulatory agencies support the use of LDCs in development of TMDL load allocations, and the method has been used successfully in the state of Texas (Hauck et. al, 2013).

The developed TMDL load allocation that follows for both segments use the median, five percent exceedance, contact recreation criteria in the high flow regime. In doing so for the LDC, this is where the point sources and nonpoint sources, as noted earlier, are more pronounced and demonstrate the greatest departure from the standard criteria. The five percent exceedance value is important for the modified LDC as salt water intrusion is considered absent from the streamflow. The modified LDC will then function more like the standard LDC and eliminates the need to address the complex dynamic of tidal flows.

LDCs are often created as they are simple to develop and are easy to present to watershed stakeholders. Breaking the graph into flow regimes provides insight into potential bacteria source loadings. Generally, if high bacteria concentrations are measured in a water body at low to median flow in the absence of runoff events, the main contributing sources are likely to be point sources. During ambient flows, these constant inputs to the system will increase pollutant concentrations depending on the magnitude and concentration of the sources. As flows increase in magnitude, the impact of point sources is typically diluted, and would therefore be a smaller part of the overall concentrations.

4.5 Margin of Safety

The margin of safety (MOS) accounts for uncertainty present during the development of the TMDL. The MOS allows for a level of assurance that the TMDL goal will be met (USEPA, 1992). The MOS can be either incorporated in the process by using conservative assumptions when developing the allocation or by explicitly reserving a portion of the TMDL load allocation for MOS with the remainder used for allocations (USEPA, 1992). The TMDL in this report incorporates an explicit MOS of five percent.

4.6 Load Reduction Analysis

It was mentioned that at different points on the LDC, certain loading sources may contribute more to the bacteria concentration. It is potentially useful then to look at direct load reduction by comparing the geometric mean of the load within each flow regime to that of the average standard value of corresponding flow regime. The calculation is made by subtracting the geometric mean by the appropriate standard criteria and then dividing by the geometric mean (Table 23). It generally follows that the highest load reductions would be found in the high flow conditions where nonpoint and point sources would be present.

Table 23. Load reduction percentages for five flow conditions in 1304, 1304A and 1305 based on LDC.

		1304_01		**1304A_01**	
		Enterococci		***E. coli***	
		35 MPN/100mL		***126 MPN/100 mL***	
Flow Condition	**Exceedance Range**	**Geometric Mean (MPN/100mL)**	**Required Percent Reduction**	**Geometric Mean (MPN/100mL)**	**Required Percent Reduction**
High Flow	(0-10%)	239.64	85.39%	356.93	64.70%
Moist	(10-40%)	64.92	46.09%	228.62	44.89%
Mid-Range	(40-60%)	33.62	0.00%	181.01	30.39%
Dry	(60-90%)	25.97	0.00%	163.89	23.12%
Low Flow	(90-100%)	17.24	0.00%	151.42	16.79%

4.7 Pollutant Load Allocation

A TMDL represents the maximum amount of a pollutant a stream can receive in a single day and still meet water quality standards. The pollutant load allocation for the selected scenarios can be expressed by the equation:

$$\text{TMDL} = \text{WLA} + \text{LA} + \text{FG} + \text{MOS} \qquad \text{(Equation 8)}$$

Where:

TMDL = total maximum daily load
WLA = waste load allocation, a term that includes all permitted sources
LA = load allocation, a term that expresses all non-regulated sources
FG = future growth, potential for future growth of permitted sources
MOS = margin of safety load

Federal regulation, 40 CFR, §130.2(1) states that TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measure. FIB in TMDLs are expressed as CFU/day, representing the maximum one-day load the stream can assimilate while still attaining the standards for surface water quality.

4.7.1 Segment Level TMDL Computations

It was previously mentioned that to develop the TMDL loading allocation for both segments, the five percent exceedance value of the highest flow regime for the standard criterion would be used. This value would only be taken from the LDC created for monitoring station representing the segment as discussed previously. As discussed in Section 3, the standard curve for the FIB criterion was created by multiplying the flow value developed from the FDC with the criterion (126 cfu/100mL or 35 cfu/100mL) and the conversion factor. This effectively creates a daily maximum loading value in cfu/day.

By selecting the five percent exceedance value as the allowable load, the TMDL is set by the equation:

TMDL (cfu/day) = Criterion * Flow (cfs) * Conversion factor (Equation 4)

Where:

Criterion = either 35 cfu/100mL; 126 cfu/100mL
Conversion Factor (to get billion cfu/day) = 0.0244657152

Using the five percent load duration exceedance, the TMDL values are provided in Table 24.

Table 24. TMDL calculation at the 5% exceedance flow in the High Flow condition

AU	Bacteria Indicator	Criterion (CFU/100 mL)	5% Exceedance Flow (cfs)	5% Exceedance Load	TMDL (Billion CFU/day)
1304_01	Enterococci	35	452.76	3.88E+11	387.70
1304_02*	Enterococci	35	410.83	3.52E+11	351.79
1304A_01	*E. coli*	126	87.15	2.69E+11	268.66
1305_02*	*E. coli*	126	149.61	4.61E+11	461.19
1305A_01*	*E. coli*	126	37.40	1.15E+11	115.30

**Daily loads created for 1305_02, 1305A_01, and 1304_02 to determine loadings for 1304_01.*

4.7.2 Margin of Safety

As discussed in Section 4.5, the MOS is applied explicitly to the TMDL load allocation. The MOS is therefore expressed by the equation:

MOS = 0.05 * TMDL (Equation 9)

Where:

MOS = margin of safety load
TMDL = total maximum daily load

An additional step must be taken to account for upstream loading from Caney Creek Above Tidal and Linnville Bayou on Caney Creek Tidal (TCEQ, 2016). Each computation will discuss accounting for the tributary contribution. Here a load allocation, LA_{trib} is calculated for 1305_02, 1305A_01 and 1304A_01 by completing the TMDL allocation procedures for each AU at the 5% exceedance value but replacing the freshwater criterion, 126 CFU/100 mL for the tidal criterion, 35 CFU/100 mL. LA_{trib} is then the sum of all three AUs and used in calculating the 1304_02 TMDL. LA_{trib} for 1304_01 is the load allocation (LA) developed from calculating the TMDL for 1304_02.

To calculate MOS when accounting for an upstream contribution, LA_{trib} is subtracted from the TMDL prior to multiplying by 0.05. For the AUs, the TMDL, LA_{trib} (if needed) and MOS values are presented in Table 25.

Table 25. MOS calculation based on TMDL calculated at the 5% exceedance flow

AU	Bacteria Indicator	TMDL[a] (Billion CFU/day)	LA_{trib}[b] (Billion CFU/day)	MOS (Billion CFU/day)
1304_01	Enterococci	387.70	341.37	2.32
1304_02	Enterococci	351.79	216.62	6.76
1304A_01	*E. coli*	268.66	_	13.43
1305_02	*E. coli*	461.19	_	23.06
1305A_01	*E. coli*	115.30	_	5.76

[a] TMDL from Table 24

[b] LA_{trib} for 1304_01 is LA taken from 1304_02 on Table 31. 1304_02 is from the sum of LA on Table 31 from 1304A_01, 1305_02 and 1305A_01, however 126 CFU/100mL is replaced with 35 CFU/100mL for all calculations.

4.7.3 Wasteload Allocation

Developing the WLA requires calculating two pieces of information: the wasteload that is allocated to TPDES permitted wastewater treatment facilities (WLA_{wwtf}) and the waste load that is allocated to regulated stormwater dischargers (WLA_{sw}). The equation is:

$$WLA = WLA_{wwtf} + WLA_{sw} \qquad \text{(Equation 10)}$$

4.7.3.1 WLA_{wwtf}

To calculate the WLA_{wwtf} requires developing a daily waste load allocation for TPDES permitted facilities. The full-permitted daily flow of each WWTF in the segment is multiplied by the accepted criterion for the segment, the conversion factor, and reduced to account for the MOS. This calculation is expressed by:

$$WLA_{wwtf} = Criterion*Flow*Conversion\ Factor \qquad \text{(Equation 11)}$$

Where:

Criterion = 35 CFU/100 mL for enterococci; 126 CFU/100mL for *E. coli*
Flow = full permitted flow (MGD)
Conversion Factor (to get billion cfu/day) = 0.037854118

Using Equation 11, each TPDES 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 segment. The criterion was applied based on the FIB designated for the segment. To account for the contribution of upstream WWTFs for use in calculating TMDLs in 1304, WLA_{trib} sums up loadings for segment 1305 but replaces 126 CFU/100 mL, the freshwater criterion, with 35 CFU/100mL, the tidal criterion.

Table 26 presents the load allocations for each WWTF located in 1305 and sums the load allocations providing a total WLA_{wwtf} and WLA_{trib} in the segment. The two permittees, Phillips 66 Co and Chevron Phillips Chemical Co. are not included. WLA are not typically calculated when the flow is intermittent and variable.

Table 26. WLAwwtf calculation using the full permitted discharge for each WWTF in segment 1305

AU	TPDES_NUM	Permittee	Monitored Bacteria	Full Permitted Flow (MGD)	WLA_{wwtf} (Billion MPN/day)	WLA_{trib} (Billion MPN/day)
1305B_01	WQ0010843001	Boling MWD	126 (*E. coli*)	0.133	0.634	0.176
1305A_01	WQ0010663001	Matagorda County WCID 6	126 (*E. coli*)	0.193	0.921	0.256
1305A_01	WQ0011768001	Massey, Jimmie Wayne	126 (*E. coli*)	0.010	0.048	0.013
			Total	**0.336**	**1.603**	**0.445**

*WLA_{trib} calculated using 35 CFU/100 mL

4.7.3.2 WLA_{sw}

Stormwater sources, such as MS4s and construction sites as explained in 2.6.1.4 and 2.6.1.5, are also regulated and consider point sources. The WLA must account for these sources. There is little data (e.g. rainfall runoff from each stormwater source) to directly account for the WLA contribution from stormwater. To arrive at a simplified stormwater contribution, the percentage of area under the jurisdiction of stormwater permits was estimated to arrive at the WLAsw of the TMDL. To arrive at the WLA_{sw} the LA component must be explained. LA is the nonpoint source stormwater load, the difference between total watershed area and the portion that is under a stormwater permit. The standard TMDL equation, Equation 8, can be re-written to arrive at WLA_{sw} by developing a ratio component based on area.

The equation for the WLA_{sw} is the sum of all loads from regulated stormwater sources and is calculated:

$$WLA_{sw} = (TMDL - WLA_{wwtf} - FG - LA_{trib} - MOS) * FDA_{swp} \qquad \text{(Equation 12)}$$

Where:

WLA_{sw}= sum of all regulated stormwater loads
TMDL = total maximum daily load
WLA_{wwtf} = sum of all WWTF loads
FG = sum of future growth loads from potential permitted facilities
LA_{trib} = load allocation from upstream AUs, when necessary
MOS = margin of safety load
FDA_{swp} = fractional proportion of drainage area under jurisdiction of stormwater permits.

The FDA_{swp} must be calculated to arrive at the fractional proportion of the drainage area under jurisdiction of stormwater permits. FDA_{swp} is calculated by first totaling the area of each stormwater permit. The stormwater sources and how areas were estimated were discussed in Section 2.6.1.4 and 2.6.1.5. Those area estimates were summed for each category and imported into Table 27. The stormwater categories are then summed up to determine the total area under stormwater jurisdiction in each segment. To arrive at the proportion, the area under stormwater jurisdiction is then divided by the total watershed area. FDA_{swp} for 1304 accounts for the upstream area contributions by adding the total of area under permit for both 1304, 1304A and 1305 and dividing by the total watershed area of the upstream AUs.

Table 27. FDAswp calculated as a proportion of stormwater total permit area.

AU	Bacteria Indicator	Drainage Area* (Acres)	Multisector General Permit (Acres)	Construction Activities (Acres)	Total Area of Permits* (Acres)	FDA_{swp}
1304_01	Enterococci	193,653.30	0	0	4,152	2.14%
1304_02	Enterococci	173,149.59	0	0	4,152	2.40%
1304A_01	*E. coli*	64,041.46	1,935	345	2,280	3.56%
1305_02	*E. coli*	65,769.85	0	1	1	0.0015%
1305A_01	*E. coli*	17,113.03	678	1,193	1,871	10.93%

**Drainage Area and Total Area of Permits are calculated as the sum of those areas within the AU and any contributing areas upstream of the AU.*

To complete the WLA_{sw}, a value for future growth (FG) is needed. FG is calculated based on future WWTF waste loads. The calculation for FG is presented in Section 4.7.4. The calculated FG is used here to move forward with completing the calculation of WLA_{sw}. All the needed information to complete Equation 12 is known and presented along with the resulting WLA_{sw} in Table 28. LA_{trib} is used here to remove the nonpoint source contribution of 1305 and 1304A.

*Table 28. WLAsw calculation. *WLAwwtf is the sum of WLAwwtf and WLAtrib from table 25*

AU	Bacteria Indicator	TMDL[a] (Billion CFU/day)	WLA_{wwtf}[b] (Billion CFU/day)	FG[c] (Billion CFU/day)	LA_{trib}[d] (Billion CFU/day)	MOS[e] (Billion CFU/day)	FDA_{swp}[f]	WLA_{sw} (Billion CFU/day)
1304_01	Enterococci	387.70	0.45	0.15**	341.37	2.32	2.14%	0.93
1304_02	Enterococci	351.79	0.45	0.15**	216.62*	6.76	2.40%	3.07
1304A_01	*E. coli*	268.66	0.00	0.24	–	13.43	3.56%	9.08
1305_02	*E. coli*	461.19	0.63	0.11	–	23.06	0.0015%	0.007
1305A_01	*E. coli*	115.30	0.97	0.17	–	5.76	10.93%	11.85

[a] TMDL from Table 24

[b] WLA_{wwtf} from Table 26

[c] FG from Table 30 (**FG is the sum of FG and FGtrib)

[d] LA_{trib} taken from Table 31 (*Calculated using 35 CFU/100 mL for 1305 and 1304A)

[e] MOS from Table 25

[f] FDA_{swp} taken from Table 27

Now that the WLA_{sw} has been calculated using the term WLA, Equation 10 can be solved for and the results are presented in Table 29. As a reminder, there are no WWTFs in 1304 or 1304A. WLA_{wwtf} for 1304 is the tributary contribution using the tidal criterion from WWTF in 1305.

Table 29. WLA calculation

AU	Bacteria Indicator	WLA_{wwtf}[a] (Billion CFU/day)	WLA_{sw}[b] (Billion CFU/day)	WLA (Billion CFU/day)
1304_01	Enterococci	0.45	0.93	1.38
1304_02	Enterococci	0.45	3.06	3.51
1304A_01	E. coli	0.00	9.08	9.08
1305_02	E. coli	0.63	0.007	0.64
1305A_01	E. coli	0.97	11.85	12.82

[a] WLAwwtf from Table 26 (*WLAwwtf in 1304 is the value WLAtrib from table 26)

[b] WLAsw from Table 28

4.7.4 Future Growth

TMDLs require the loading allocation to account for future growth in the watershed population, infrastructure requirements, and development. While future populations can be estimated, accounting for future development and infrastructure requirements is more problematic. To account for future growth, the present relationship between current population and WWTF infrastructure is used as a surrogate with the understanding that future WWTFs will be needed and permitted flows will likely be proportional.

Population growth was presented in Section 2.3 and is used to arrive at projected changes in population. For the three WWTFs found in the two AUs 1305A_01 and 1305B_01, the full permitted flow was used in the development of FG.

Projecting future growth for this exercise in 1304A_01 is hindered by the absence of WWTFs. Linnville Bayou is projected to grow from a population of 912 in 2016 to that of 1321, a population increase of 409 by 2070 (TWDB, 2018 and H-GAC, 2017). To account for this 44.85% increase in population and the potential for future development that may require centralized waste water, an alternative approach was completed.

Texas Administrative Code §217.32 requires new WWTF to accommodate daily wastewater flow of 75-100 gallons per capita per day (TAC, 2008). Using the daily wastewater upper figure (100) and multiplying it by the estimated population change would produce a conservative future permitted flow and FG value. Conservatively rounding the population increase up to 500 individuals and multiplying by the higher daily wastewater flow capacity, results in a potential future WWTF with a permitted capacity of 0.05 MGD. Applying this new potential permitted flow with the projected future growth in permitted flows from WWTFs in 1305A_01 and 1305B_01, FG can be calculated.

The equation for FG is as follows:

$$FG = \text{Criterion} * [\%POP_{2016\text{-}2070} * WWTF_{fp}] * \text{Conversion Factor} \qquad \text{(Equation 13)}$$

Where:

Criterion = 35 CFU/100 mL for Enterococci; 126 CFU/100mL for *E. coli*
$\%POP_{2016\text{-}2070}$ = estimated % increase in population between 2018-2045
$WWTF_{fp}$ = full permitted discharge (MGD)
Conversion Factor (to get billion cfu/day) = 0.037854118

The results are tabulated in Table 30. FG in WWTFs in 1305 and 1304A_01 are also calculated using the tidal criterion, 35 CFU/100mL to apply to the tidal segment. Absent in situ WWTFs, FG in 1304_01 and 1304_02 becomes the FG_{trib}.

Table 30. FG calculation using rate of population change and full permitted WWTF discharge

AU	TPDES Permit Number	Permittee	% Population Change (2016-2070)	Full Permitted Flow (MGD)	Future Growth in Flow (MGD)	WLA_{wwtf} (Billion *E. coli* cfu/day)	WLA_{trib} (Billion Enterococci cfu/day)
1304A_01*	–	–	*44.85%*	–	0.05	0.239	0.066
1305B_01	WQ0010843001	Boling MWD	*17.99%*	0.133	0.024	0.114	0.032
1305A_01	WQ0010663001	Matagorda County WCID 6	*17.99%*	0.193	0.035	0.166	0.046
1305A_01	WQ0011768001	Massey, Jimmie Wayne	*17.99%*	0.010	0.002	0.009	0.002
			Total	**0.336**	**0.111**	**0.528**	**0.146**

*Hypothetical future, unnamed and without permit, WWTF in 1304A_01 with a projected future full permitted flow of 0.05 MGD.

4.7.5 Load Allocation

All the terms necessary to calculate the LA for loads from all non-regulatory sources that were described in Section 2 are now present. LA is expressed by the equation:

$$LA = TMDL – WLA – FG – MOS \qquad \text{(Equation 14)}$$

Where:

LA = allowable loads from unregulated sources within the segments
TMDL = total maximum daily load
WLA = sum of all WWTF loads and regulated stormwater loads
FG = sum of future growth loads from potential permitted facilities
MOS = margin of safety load

The LA calculations are presented in Table 31.

Table 31. LA for non-regulatory stormwater loading sources

AU	Indicator Bacteria	TMDL[a] (Billion CFU/day)	WLA[b] (Billion CFU/day)	FG[c] (Billion CFU/day)	MOS[d] (Billion CFU/day)	LA (Billion CFU/day)
1304_01	Enterococci	387.70	1.38	0.15	2.32	383.85
1304_02	Enterococci	351.79	3.51	0.15	6.76	341.38
1304A_01	*E. coli*	268.66	9.08	0.24	13.43	245.91
1305_02	*E. coli*	461.19	0.64	0.11	23.06	437.38
1305A_01	*E. coli*	115.30	12.82	0.17	5.76	96.54

[a] TMDL from Table 24
[b] WLA from Table 29
[c] FG from Table 30
[d] MOS from Table 25

4.8 Summary of TMDL Calculations

Table 32 summarizes the TMDL calculation for Caney Creek Tidal and Linnville Bayou. The calculations were made based on development of LDCs for each watershed using the median flow in 0-10 percentile range or 5% exceedance in the high-flow range for the furthest downstream SWQM station in the segment. Allocations are based on current geometric mean criterion set for 1304 and 1304A, 35 CFU/100mL or 126 CFU/100mL, respectively. TMDL load allocations were prepared for 1305_02, 1305A_01 and 1304_02 and presented in prior tables. The results of these calculations were used to prepare the TMDL load allocations for the impaired downstream AU, 1304_01. Table 32 presents only the TMDL load allocations for the impaired AUs.

Table 32. TMDL load allocation for segments 1304 and 1304A

AU	Indicator Bacteria	TMDL[a] (Billion CFU/day)	MOS[b] (Billion CFU/day)	WLA_{wwtf}[c] (Billion CFU/day)	WLA_{sw}[d] (Billion CFU/day)	LA[e] (Billion CFU/day)	FG[f] (Billion CFU/day)
1304_01	Enterococci	387.70	2.32	0.45	0.93	383.85	0.15
1304A_01	*E. coli*	268.66	13.43	0.00	9.08	245.91	0.24

[a] TMDL from Table 25
[b] MOS from Table 26
[c] WLA_{wwtf} from Table 27
[d] WLA_{sw} from Table 29
[e] LA from Table 32
[f] FG from Table 31

The final step is to comply with 40 CFR 130.7 includes combining the FG component with the WLA_{wwtf} from Table 32. Table 33 presents the TMDL with FG as part of the WLA_{wwtf}.

Table 33. TMDL load allocation for segments 1304 and 1304A, FG added to WLA_{wwtf} term

AU	Indicator Bacteria	TMDL (Billion CFU/day)	MOS (Billion CFU/day)	WLA_{wwtf} (Billion CFU/day)	WLA_{sw} (Billion CFU/day)	LA (Billion CFU/day)
1304_01	Enterococci	387.70	2.32	0.60	0.93	383.85
1304A_01	*E. coli*	268.66	13.43	0.24	9.08	245.91

Should the FIB criterion change due to revisions in the state's surface water quality standards, Appendix A presents equations for recalculating the allocations in Table 33. Figures 22 and 23 in Appendix A for AUs 1304_01 and 1304A_01, respectively, graphically demonstrate the relationships between the various load allocations and response to changes in criterion. The equations presented in Tables 35 and 36, assume a stable flow and no changes in current bacteria permit requirements for WWTFs, at either 126 CFU/100 mL or 35 CFU/100 mL.

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Appendix A.

Equations for Calculating TMDL Allocations for Changed Contact Recreation Standard

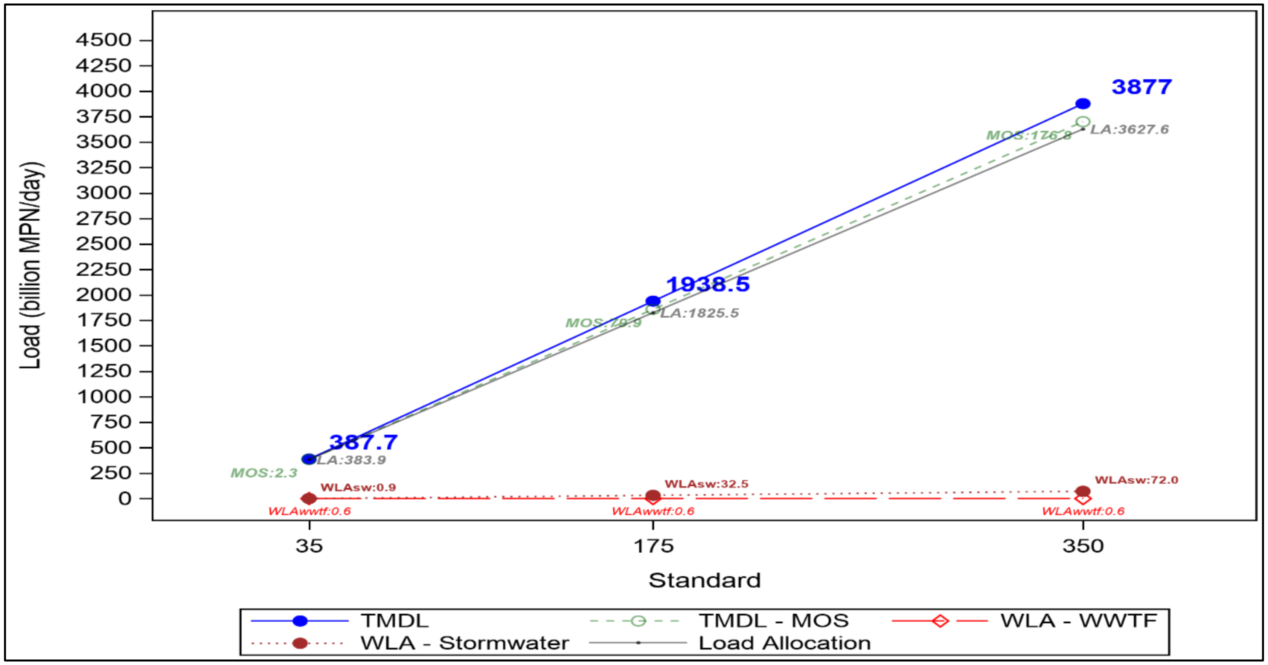

Figure A.22. Allocation loads for Caney Creek Tidal, 1304_01 as a function of water quality criteria

Table A.34. Equations for calculating new TMDL and allocations (in billion CFU/day Enterococci) for Caney Creek Tidal, 1304_01

TMDL=11.07706*Std	MOS=0.55385282*Std-17.068831	WLA$_{wwtf}$0.591493754	WLA$_{sw}$=0.225605*Std-6.96544322	LA=10.297599*Std+23.44278

Where:

Std = Revised contact recreation standard
MOS = Margin of safety
LA = Total load allocation (non-permitted source contributions)
WLA$_{wwtf}$ = Wasteload allocation (permitted WWTF load + future growth) [Note: WWTF load held at Primary Contact (35 CFU/100 mL) criteria]
WLA$_{sw}$ = Wasteload allocation (permitted stormwater)

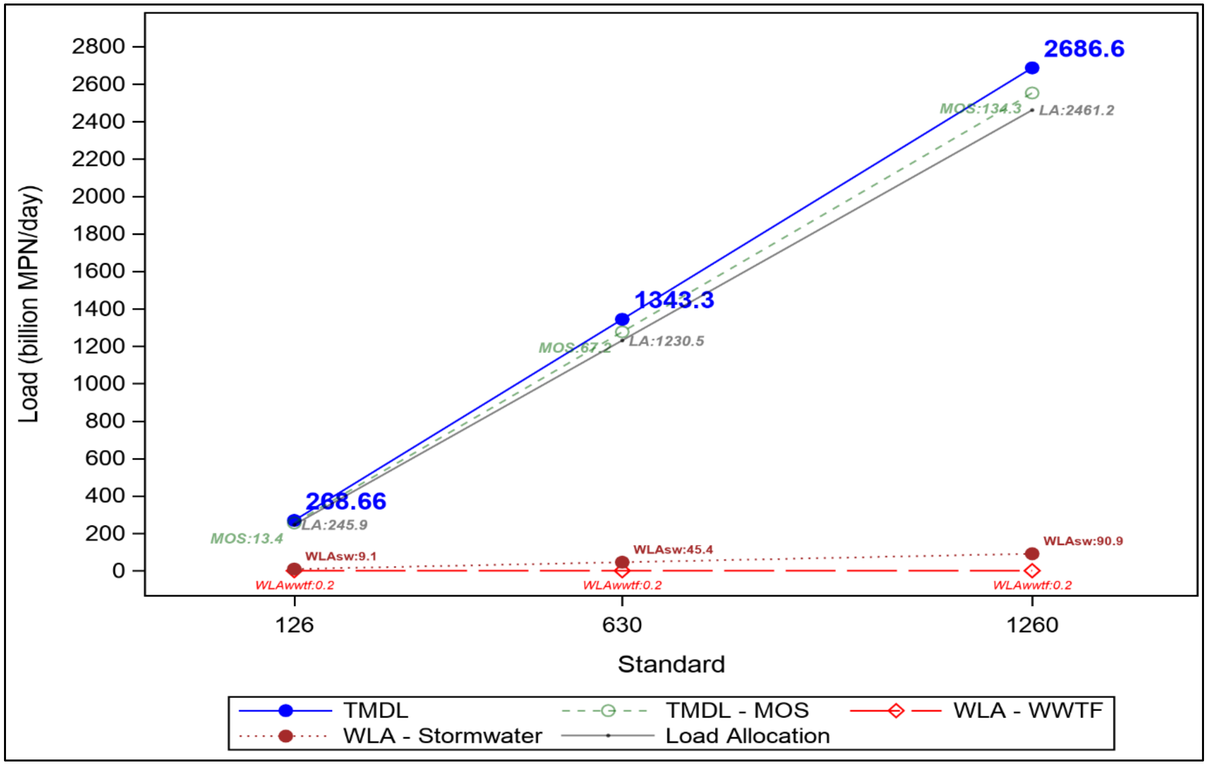

Figure A.23 - Allocation loads for Linnville Bayou, 1304A_01 as a function of water quality criteria

Table A.35. Equations for calculating new TMDL and allocations (in billion CFU/day E. coli) for Linnville Bayou, 1304A_01

TMDL=2.132208374*Std	MOS=0.106610419*Std	WLA_{wwtf} = 0.238480758	WLA_{sw}=0.0721151*Std-0.0084903	LA=1.9534827*Std-0.23

Where:

Std = Revised contact recreation standard
MOS = Margin of safety
LA = total load allocation (non-permitted source contributions)
WLA_{wwtf} = Wasteload allocation (permitted WWTF load + future growth) [Note: WWTF load held at Primary Contact (126 CFU/100 mL) criteria]
WLA_{sw} = Wasteload allocation (permitted stormwater)