Technical Support Document for Total Maximum Daily Loads for Indicator Bacteria in Adams Bayou, Cow Bayou, and Associated Tributaries

Segments 0508, 0508A, 0508B, 0508C, 0511, 0511B, 0511C, 0511E

Assessment Unit 0508_01, 0508_02, 0508_03, 0508_04, 0508A_01, 0508B_01, 0508C_01, 0511_01, 0511_03, 0511_04, 0511B_01, 0511C_01, 0511E_01

Adams Bayou at FM 3247

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Cover photograph taken March 18, 2016 from FM 3246 bridge over Adams Bayou

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Abbreviations and Acronyms

µS/cm	microsiemens per centimeter
AU	assessment unit
BMP	best management practice
cfs	cubic feet per second
cfu	colony forming units
DSLP	days since last precipitation
DAR	drainage area ratio
DMR	discharge monitoring report
DO	dissolved oxygen
ECHO	Enforcement & Compliance History Online
E. coli	Escherichia coli
EPA	United States Environmental Protection Agency
FDC	flow duration curve
FG	future growth
I&I	inflow and infiltration
ICIS	Integrated Compliance Information System
I-Plan	implementation plan
IH	Interstate Highway
LA	load allocation
LDC	load duration curve
ln	logarithm (natural)
MGD	million gallons per day
mL	milliliter
MOS	margin of safety
MPN	most probable number
MSGP	multi-sector general permit
MS4	municipal separate storm sewer system
NEIWPCC	New England Interstate Water Pollution Control Commission
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
ODEQ	Oregon Department of Environmental Quality
OSSF	onsite sewage facility
PCS	Permit Compliance System
ppt	parts per thousand
R^2	coefficient of determination
RMU	resource management unit
RSA	regulated stormwater area
SSO	sanitary sewer overflow

SWMP	Storm Water Management Program
SWQM	Surface Water Quality Monitoring
SWQMIS	Surface Water Quality Monitoring Information System
TCEQ	Texas Commission on Environmental Quality
TIAER	Texas Institute for Applied Environmental Research
TMDL	total maximum daily load
TPDES	Texas Pollutant Discharge Elimination System
TPWD	Texas Parks and Wildlife Department
TSWQS	Texas Surface Water Quality Standards
TWDB	Texas Water Development Board
TWRI	Texas Water Resources Institute
USCB	United States Census Bureau
USDA	United State Department of Agriculture
USGS	United States Geological Survey
WCID	water control and improvement district
WLA	waste load allocation
WWTF	wastewater treatment facility

Section 1
Introduction

1.1 Background

Section 303(d) of the federal Clean Water Act requires all states to identify waters that do not meet, or are not expected to meet, applicable water quality standards. These water bodies are known as impaired surface waters. States must develop a Total Maximum Daily Load (TMDL) for each pollutant that contributes to the impairment of a listed water body. The Texas Commission on Environmental Quality (TCEQ) is responsible for ensuring that TMDLs are developed for impaired surface waters in Texas.

The United States Environmental Protection Agency (EPA) defines a TMDL as “the maximum amount of a pollutant allowed to enter a waterbody so that the waterbody will meet and continue to meet water quality standards for that particular pollutant. A TMDL determines a pollutant reduction target and allocates load reductions necessary to the source(s) of the pollutant.”

A TMDL is like a pollution budget. They are the best possible estimates of the assimilative capacity of the water body for a pollutant under consideration. A TMDL is commonly expressed as a load with units of mass per period of time, but may be expressed in other ways. 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 TCEQ’s TMDL Program is a major component of Texas’ overall process for managing the quality of its surface waters. The program addresses impaired or threatened streams, reservoirs, lakes, bays, and estuaries (surface 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 surface water bodies in Texas.

TCEQ previously adopted TMDLs for bacteria, dissolved oxygen (DO), and pH in Adams Bayou, Cow Bayou, and their tributaries on June 13, 2007, and the (EPA) approved these TMDLs on August 28, 2007 (TCEQ, 2007). Since the adoption and approval of these TMDLs, a change from a segment-level approach to an assessment unit (AU)-level approach for TMDL development occurred. Several other pertinent changes, both in the way in which current TMDLs for bacteria are developed and in the environmental conditions in the watersheds of the impaired water bodies, have necessitated this update to the previously completed bacteria TMDLs. The update to the dissolved oxygen and pH TMDLs is described in a separate technical support document (Hauck *et al.* 2020).

This document will consider bacteria TMDLS for 8 water bodies (segments) and 13 assessment units (AUs). The complete list of water bodies and their identifying AU numbers are shown below:

1) Adams Bayou Tidal 0508_01, 0508_02, 0508_3, 0508_04;
2) Adams Bayou Above Tidal 0508A_01;
3) Gum Gully 0508B_01;
4) Hudson Gully 0508C_01;
5) Cow Bayou Tidal 0511_01, 0511_03, 0511_04;
6) Coon Bayou 0511B_01;
7) Cole Creek 0511C_01;
8) Terry Gully 0511E_01

By the end of 2006, TCEQ had developed draft TMDLs, on a segment basis, for these water bodies and released the TMDLs for public comment in February 2007. The final TMDLs, established on a segment basis, were adopted in June 2007. Also, while the original bacteria TMDLs adopted for Adams Bayou Tidal and Cow Bayou Tidal in 2007 avoided using fecal coliform as the indicator bacteria, the TMDLs for this tidally influenced segment were developed using *Escherichia coli (E. coli)* instead of Enterococci. Among TCEQ's motives for revising the TMDLs adopted in 2007 is a need to establish TMDLs for these water bodies on an AU basis and to ensure the correct indicator bacteria is applied to each water body.

1.2 Water Quality Standards

To protect public health, aquatic life, and development of industries and economies throughout Texas, water quality standards were established by TCEQ. The water quality standards describe the limits for indicators which are monitored in an effort to assess the quality of available water for specific uses. TCEQ is charged with monitoring and assessing water bodies, based on these water quality standards, and publishes the *Texas Integrated Report of Surface Water Quality* biennially.

The *Texas Surface Water Quality Standards* (TCEQ, 2010a; TSOS, 2018) are rules that:

- designate the uses, or purposes, for which the state's surface water bodies should be suitable;
- establish numerical and narrative goals for surface 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 surface water quality.

Standards are established to protect designated uses assigned to the state's surface water bodies. Typical uses include:

- domestic water supply
- categories of aquatic life use
- recreation categories and
- aquifer protection

Fecal indicator bacteria are used to assess the risk of illness during contact recreation (e.g., swimming) from ingestion of water. Both *E. coli* and Enterococcus spp. (Enterococci) are present in the intestinal tracts of humans and other warm-blooded animals. The presence of these bacteria in water may indicate the presence of other pathogens emanating from wastes that may be reaching water bodies from sources such as inadequately treated sewage, improperly managed animal waste from livestock, pets, aquatic birds, wildlife, and from failing septic systems (TCEQ, 2006). *E. coli* is widely used as an indicator organism in freshwater, while Enterococci are more often used as an indicator organism in saltwater.

On February 27, 2018 TCEQ adopted revisions to the Texas Surface Water Quality Standards (TSWQS) (TSOS, 2018) and on November 2, 2018 the EPA approved the categorical levels of recreational use and their associated criteria for saltwater and all the categorical levels of recreation use for freshwater, except primary contact recreation 1 and primary contact recreation 2. The 2010 TSWQS is the most recent document with an EPA-approved freshwater primary contact recreation use and it specifies a single primary categorical level instead of two (TCEQ, 2010a). For freshwater and saltwater, the approved recreational use from the 2010 and 2018 TSWQS consists of four categories:

- Primary contact recreation is that with a significant risk of ingestion of water (such as swimming). Primary contract recreation for freshwater has a geometric mean criterion for *E. coli* of 126 colony forming units (cfu)[a] per 100 mL and an additional single sample criterion of 399 cfu per 100 mL and for saltwater a geometric mean criterion for Enterococci of 35 cfu per 100 mL and a single sample criterion of 130 cfu per 100 mL.
- Secondary contact recreation 1 covers activities with limited body contact and a less significant risk of ingestion of water (such as fishing). Secondary contact recreation for freshwater has a geometric mean criterion for *E. coli* of 630 cfu per 100 mL and for saltwater has a geometric mean criterion for Enterococci of 175 per 100 mL.
- Secondary contact recreation 2 is similar to secondary contact 1, but activities occur less frequently. It has a geometric mean criterion for *E. coli* of 1,030 cfu per 100 mL. The secondary contract recreation 2 category does not exist for saltwater.
- Noncontact recreation is that with no significant risk of ingestion of water, where contact recreation should not occur due to unsafe conditions. Noncontact recreation for freshwater has a geometric mean criterion for *E. coli* of 2,060 cfu per 100 mL and for saltwater has a geometric mean criterion for Enterococci of 350 per 100 mL.

The impaired AUs of Adams Bayou and Cow Bayou and associated tributaries are approved for primary contact recreation. The associated *E. coli* geometric mean criterion of 126 cfu per 100 mL and single sample of 399 cfu per 100 mL is applied to freshwater bodies addressed in this document, which includes Adams Bayou Above Tidal (AU 0508A_01), Gum Gully (AU 0508B_01) and Terry Gully (0511E_01). The associated Enterococci geometric mean criterion of 35 cfu per 100 mL and single sample of 130 cfu per 100 mL is applied to the tidal, saltwater bodies addressed in this document, which includes Adams Bayou Tidal (AUs 0508_01, 0508_02,

[a] For consistency the term colony forming units or cfu will be used exclusively in this report. Some laboratory methods for bacteria analysis are reported as most probably number (MPN). These two units (cfu and MPN) are considered as equivalent by TCEQ for assessment purposes.

0508_03 and 0508_04), Hudson Gully (AU 0508C_01), Cow Bayou Tidal (AUs 0511_01, 0511_03, and 0511_04), Coon Bayou (AU 0511B_01) and Cole Creek (AU 0511C_01).

1.3 Bacteria Impairments

The bacteria impairment(s) in Adams Bayou Tidal (Segment 0508) first appeared in the State of Texas' 1992 Clean Water Act Section 303(d) list. The bacteria impairments for Adams Bayou Above Tidal, Gum Gully, Cow Bayou Tidal, Coon Bayou, and Cole Creek first appeared in Texas' 2000 303(d) List. Hudson Gully and Terry Gully were first listed for bacteria impairments in the Texas' 2002 303(d) List. However, individual AUs were not defined for these or any other surface water body in Texas until 2006. In the intervening time (1998-2006), TCEQ instituted a number of changes in the way attainment of the contact recreation use was assessed in surface water bodies of the state, including a change in indicator bacteria from fecal coliform to *E. coli*, in fresh water bodies, and from fecal coliform to Enterococci in saltwater bodies such as bays, estuaries and tidal streams. A summary of the bacteria data resulting in the 303(d) listing of each water body is provided in Table 1.

It should be noted that the bacteria impairments in Adams Bayou Above Tidal (AU 0508A_01) and Cole Creek (AU 0511C_01) were based on exceedance of the single sample criterion for fecal coliforms and not the geometric mean criterion. The Section 303(d) listing for both of these AUs is dated back to the *2000 Texas Water Quality Inventory and 303(d) List*. In the 2010 Integrated Report, TCEQ removed the bacteria impairment in Adams Bayou Above Tidal (AU 0508A_01) from the Texas 303(d) List because additional data collected between 2001 and 2008 showed support of the contact recreation use in that water body and, in the 2012 Texas Integrated Report, TCEQ removed the bacteria impairment in Cole Creek (AU 0511C_01) from the Texas 303(d) List, because the geometric mean criterion became the sole-applicable criterion. Within the present report, pollutant load allocations will be developed for both Adams Bayou Above Tidal and Cole Creek even though the analyses to determine bacteria impairments was not consistent with the assessment protocol currently employed by TCEQ (TCEQ, 2019a). TCEQ will make a decision regarding the inclusion of Adams Bayou Above Tidal (AU 0508A_01) and Cole Creek (AU 0511C_01) in the TMDL document to be developed from this report

1.4 Report Purpose and Organization

The TMDL project for the watersheds of Adams Bayou and Cow Bayou and associated tributaries was initiated through a contract between TCEQ and the Texas Institute for Applied Environmental Research (TIAER). The activities of this project that were to be performed by TIAER were (1) acquire existing (historical) data and information necessary to support assessment activities; (2) perform the appropriate activities necessary to allocate bacteria loadings; and (3) assist TCEQ in preparing the TMDL.

Table 1. Summary of assessment bacteria data for AUs in the watersheds of Adams Bayou and Cow Bayou.

Note: Assessment based on fecal coliform data for which the geometric mean criterion was 200 cfu/100 mL.

Water Body	AU	Parameter	Station	Data Date Range	Number of Samples	Geometric Mean (cfu/100 mL)	Year First Listed
Adams Bayou Tidal	0508_01	Fecal coliform	10441	09/01/1987 – 08/31/1991	20	193	1992*
Adams Bayou Tidal	0508_02	Fecal coliform	10442	06/01/1994 – 05/31/1999**	21	600	1992 *
Adams Bayou Tidal	0508_03	Fecal coliform	16059	06/01/1994 – 05/31/1999**	21	641	1992 *
Adams Bayou Tidal	0508_04	Fecal coliform	10443, 14990	06/01/1994 – 05/31/1999**	59	372	1992 *
Adams Bayou Above Tidal	0508A_01	Fecal coliform	14964	06/01/1994 – 05/31/1999	21	528	2000
Gum Gully	0508B_01	Fecal coliform	16049	06/01/1994 – 05/31/1999	20	592	2000
Hudson Gully	0508C_01	Fecal coliform	16041	03/01/1996 – 02/28/2001	30	2,159	2002
Cow Bayou Tidal	0511_01	Fecal coliform	10449	06/01/1994 – 05/31/1999	54	356	2000
Cow Bayou Tidal	0511_03	Fecal coliform	13781	06/01/1994 – 05/31/1999	45	135	2000
Cow Bayou Tidal	0511_04	Fecal coliform	10457	06/01/1994 – 05/31/1999	23	232	2000
Coon Bayou	0511B_01	Fecal coliform	16052	06/01/1994 – 05/31/1999	21	1,002	2000
Cole Creek	0511C_01	Fecal coliform	16060	06/01/1994 – 05/31/1999	21	245	2000
Terry Gully	0511E_01	Fecal coliform	16040	03/01/1996 – 02/28/2001	26	363	2002

* The 1992 bacteria 303(d) listings were developed at the segment level using fecal coliform as the indicator bacteria. Adams Bayou Tidal (Segment 0508) listing was based on data collected at Station 10441; the listing was based on the number of exceedances (8 values) above the single sample criterion (400 cfu/100 mL). Subsequent to the 1992 303(d) listing, additional bacteria data were collected at the AU level.

** The data reported for AUs 0508_02, 0508_03, and 0508_04 are from the *2000 Texas Water Quality Inventory and 303(d) List.*

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 indicator 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 TMDL technical support document for the impaired segments. The purpose of this report is to provide technical documentation and supporting information for developing the bacteria TMDLs for Adams Bayou, Cow Bayou, and associated tributaries. This report contains:

- information on historical data,

- watershed properties and characteristics,
- summary of historical bacteria data that confirm the State of Texas 303(d) listings of the impairments due to presence of indicator bacteria (*E. coli* and Enterococci),
- development of load duration curves (LDCs), and
- application of the LDC approach for the pollutant load allocation process.

Section 2
Watershed Overview and Data Review

2.1 Description of Study Area

Adams Bayou and Cow Bayou, in southeast Texas, are sluggish streams that flow into the Sabine River just upstream of Sabine Lake in Orange County, Texas. Adams Bayou extends from its confluence with the Sabine River in a northerly direction across Orange County to near the Newton County line (Figure 1). Adams Bayou previously extended into southern Newton County, but flow from this upper section has been redirected eastward to the Sabine River. Cow Bayou extends from its confluence with the Sabine River in a northerly direction, roughly parallel to but west of Adams Bayou, across Orange County into southern Jasper County.

The lower portions of both bayous have been channelized, straightened, and dredged for navigation, creating numerous oxbows in the former, more sinuous, channels of the streams. Both bayous are under tidal influence below, and a short distance above, Interstate Highway (IH)-10. The tidal portions of Adams Bayou and Cow Bayou extend approximately 8 and 20 miles, respectively, above their confluences with the Sabine River. In the TSWQS (30 TAC §§307.1 – 307.10), the term “tidal” is defined as “descriptive of coastal waters that are subject to the ebb and flow of tides. For purposes of standards applicability, tidal waters are considered to be saltwater.” The portions of Adams Bayou and Cow Bayou upstream of tidal influence, as well as tributaries that are not tidally influenced, are generally characterized as being intermittent with pools.

The Adams Bayou watershed, of 46.355 square miles (29,667 acres), is almost entirely within Orange County. The Cow Bayou watershed comprises approximately 198.765 square miles (127,210 acres), covering substantial portions of Orange and Jasper Counties, as well as a small corner of Newton County.

The 2018 Texas Integrated Report (TCEQ, 2019b) provides the following Segment and AU descriptions for the water bodies with bacteria impairments considered in this document:

- SegID: 0508 Adams Bayou Tidal
  From the confluence with the Sabine River in Orange County to a point 1.1 km (0.7 miles) upstream of IH 10 in Orange County (approximate total length of 8 miles)
    - *AU_ID: 0508_01 – Lower 3 miles of segment*
    - *AU_ID: 0508_02 – 2-mile reach near Western Avenue*
    - *AU_ID: 0508_03 – 1 -mile reach near Green Avenue*
    - *AU_ID: 0508_04 – upper 2 miles of segment*

  The combined watershed area for all four AUs is 13.595 square miles (8,701 acres)
- SegID: 0508A Adams Bayou Above Tidal
  From a point 1.1 km (0.7 miles) upstream of IH 10 in Orange County upstream to the Orange County Line Relief Ditch east of Mauriceville.
    - *AU_ID: 0508A_01 – Entire bayou above tidal (8.8 miles)*

The watershed area associated with AU 0508_01 is 26.216 square miles (16,778 acres)

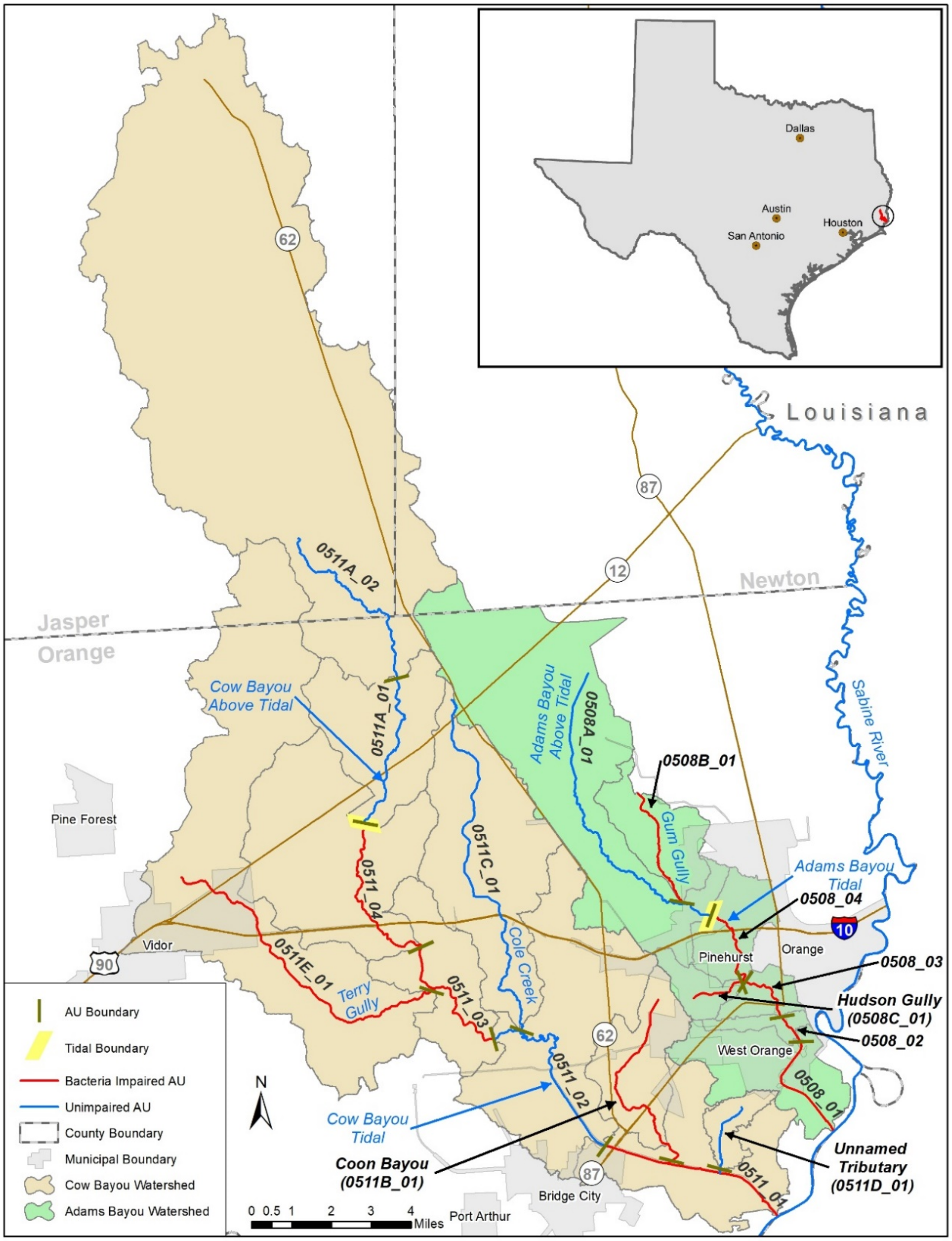


Figure 1. Overview map showing the watersheds and AUs of Adams Bayou, Cow Bayou, and associated tributaries.

- SegID: 0508B Gum Gully

  From the confluence with Adams Bayou to the upstream perennial portion of the stream northwest of Orange in Orange County

  - *AU_ID: 0508B_01 – Entire creek (3.4 miles)*

  The watershed area associated with AU 0508B_01 is 4.703 square miles (3,010 acres)

- SegID: 0508C Hudson Gully

  From the confluence with Adams Bayou to the headwaters near US 890 in Pinehurst in Orange County

  - *AU_ID: 0508C_01 – Entire creek (1.5 miles)*

  The watershed area associated with AU 0508C_01 is 1.841 square miles (1,178 acres)

- SegID: 0511 Cow Bayou Tidal

  From the confluence with the Sabine River in Orange County to a point 4.8 km (3.0 miles) upstream of IH 10 in Orange County (excluding AU 0511_02, a total length of 14 miles)

  - *AU_ID: 0511_01 – Lower 5 miles*
  - *AU_ID: 0511_03 – 5-mile reach near FM 1442 (north crossing)*
  - *AU_ID: 0511_04 – upper 4 miles*

  The combined watershed area for all three AUs is 53.364 square miles (34,153 acres)

- SegID: 0511B Coon Bayou

  From the confluence with Cow Bayou up to the extent of tidal limit in Orange County

  - *AU_ID: 0511B_01 – Entire tidal reach (5.2 miles)*

  The watershed area associated with AU 0511B_01 is 6.373 square miles (4,079 acres)

- SegID: 0511C Cole Creek

  From the confluence of Cow Bayou west of Orange in Orange County to the upstream perennial portion of the stream south of Mauriceville in Orange County

  - *AU_ID: 0511C_01 – Entire tidal reach (10.6 miles)*

  The watershed area associated with AU 0511C_01 is 16.333 square miles (10,453 acres)

- SegID: 0511E Terry Gully

  From the confluence with Cow Bayou in Orange County to the headwaters northeast of Vidor in Orange County

  - *AU_ID: 0511E_01 – Entire creek (8.9 miles)*

  The watershed area associated with AU 0511E_01 is 34.802 square miles (22,273 acres)

2.2 Watershed Climate and Meteorology

Adams Bayou and Cow Bayou experience a subtropical humid climate. The average temperature varies from 50 degrees Fahrenheit in January to 83 degrees in August. Rain is abundant in this corner of Texas, with an average annual rainfall of almost 60 inches. The frequency of significant rainfall (one half inch or more in a 24-hour period) has averaged approximately 3.2 days per month, or roughly one in ten days, over the 30-year period of 1986 - 2015. Seasonal variations in precipitation frequency and magnitude are not great. June, July and September have the most frequent rainfall, and February, March, and April have the least frequent. The 30-year climatic average of minimum and maximum temperature and precipitation, on a monthly basis, is provided in Figure 2 for Port Arthur, Texas located immediately southeast of the Cow Bayou watershed (NOAA, 2016).

2.3 Population and Population Projections

Population estimates were determined for the Adams Bayou watershed and Cow Bayou watershed using the 2010 Census information at the census block level (USCB, 2016a and 2016b) and county-level and city projections to 2020 from the 2016 regional water plan for Region I (East Texas, Allan Plummer Associates et al., 2015). The 2020 population estimate for Adams Bayou watershed is 29,776 people, indicating an average population density of approximately 642 people/ square mile. For the Cow Bayou watershed, the 2020 population estimate is 50,889 people, indicating an average population of approximately 256 people / square mile. Based on the 2016 Region I water plan information, the largest cities partially or entirely in the Adams and Cow Bayou watershed are Orange (estimated 2020 population of 19,616), Vidor (estimated 2020 population of 11,160), and Bridge City (estimated 2020 population of 8,271).

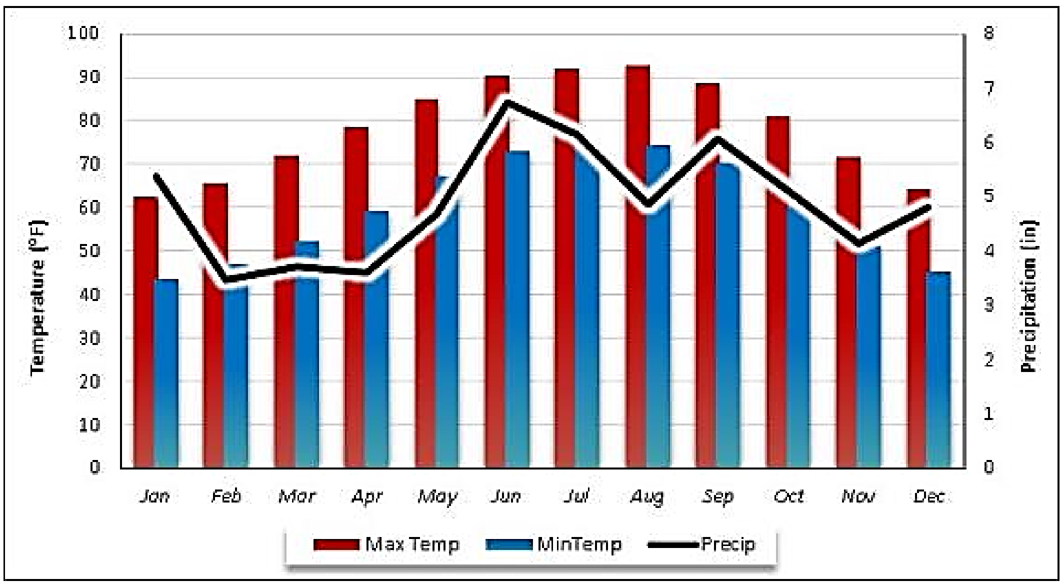


Figure 2. 30-year (1986-2015) climatic average minimum and maximum air temperatures and precipitation by month at Port Arthur Airport.

Based on information contained in the 2016 regional water plan report for Region I, the decadal population projections for 2020 to 2070 are provided for counties and cities contained partially or completely within the Adams and Cow Bayou watershed and the percent change in population from 2020 to 2070 is also provided (Table 2). The 2020 and 2070 population estimates by AU watershed in Adams and Cow Bayou are provided in Table 3. The period of 2020 to 2070 represents the same 50-year planning horizon used in development of the 2016 Texas Water Development Board (TWDB) Water Plan. To remain consistent with the Texas water planning process and their planning horizon, the same 2020 to 2070 period is used for the pollutant load development of the Adams and Cow Bayou watershed.

Table 2. 2020 Population estimate and 2030-2070 population projections for relevant counties and cities associated with the Adams Bayou and Cow Bayou watersheds.

County or City	2020 Population Estimate	2030 Population Projection	2040 Population Projection	2050 Population Projection	2060 Population Projection	2070 Population Projection	Percent Increase (2020 - 2070)
Jasper County	36,878	37,695	37,849	37,849	37,849	37,849	2.6%
Newton County	14,445	14,445	14,445	14,445	14,445	14,445	0.0%
Orange County	86,327	90,233	92,984	94,848	96,269	97,298	12.7%
City of Bridge City	8,271	8,645	8,908	9,087	9,223	9,322	12.7%
City of Orange	19,616	20,503	21,128	21,552	21,875	22,109	12.7%
City of Pinehurst	2,213	2,313	2,383	2,431	2,467	2,494	12.7%
City of Vidor	11,160	11,665	12,020	12,261	12,445	12,578	12.7%
City of West Orange	3,632	3,797	3,912	3,991	4,051	4,094	12.7%
Orangefield Water Supply Corp. (WSC)	5,203	5,438	5,604	5,717	5,802	5,864	12.7%

Table 3. Estimations 2020 population and 2070 projection by AUs of watersheds of Adams Bayou and Cow Bayou.

Assessment Unit	Estimated 2020 Population	Estimated 2070 Population Projections	Percent Increase (2020 – 2070)
0508_01	4,340	4,892	12.7
0508_02	1,562	1,761	12.7
0508_03	4,164	4,693	12.7
0508_04	6,526	7,355	12.7
0508A_01	7,745	8,702	12.4
0508B_01	1,519	1,712	12.7
0508C_01	3,920	4,418	12.7
Adams Bayou Total	29,776	33,533	12.7
0511_01	3,842	4,330	12.7
0511_02	6,817	7,683	12.7
0511_03	2,705	3,049	12.7
0511_04	4,734	5,335	12.7
0511A_01	3,777	4,257	12.7
0511A_02	7,032	7,245	3.0
0511B_01	3,390	3,820	12.7
0511C_01	4,648	5,239	12.7
0511D_01	158	178	12.7
0511E_01	13,786	15,537	12.7
Cow Bayou Total	50,889	56,673	11.4

The procedure used to determine the values shown in Table 3 are detailed in Appendix C.

2.4 Review of Routine Monitoring Data

2.4.1 Data Acquisition

Ambient fecal coliform, *E. coli,* Enterococci data for Adams Bayou, Cow Bayou and associated tributaries for the entire period of record were obtained from the TCEQ Surface Water Quality Monitoring Information System (SWQMIS) on March 25, 2019. The data represented all the historical routine ambient bacteria in the project area. Most TCEQ monitoring stations in the Adams and Cow Bayou watershed have not been monitored for bacteria since 1999 with some stations monitored through as late as 2003. The majority of the indicator bacteria collection was for fecal coliform analyses. Since 2001 to the present, Enterococci data have been collected at Station 10441 (Adams Bayou Tidal at the FM 1006 bridge crossing) and Station 10449 (Cow Bayou Tidal at the FM 1442 bridge crossing). All stations, including the two stations with the most recent indicator bacteria data as well as other pertinent stations for bacteria pollutant loading development are provided in Figure 3.

2.4.2 Analysis of Bacteria Data

As previously mentioned, recent environmental bacteria monitoring has occurred in Adams Bayou Tidal AU 0508_01 at TCEQ Station 10441 and in Cow Bayou Tidal AU 0511_01 at TCEQ Station 10449. Enterococci data collected at these stations over the seven-year period of 1 December 2005 through 30 November 2012 were used in assessing attainment of the primary contact recreation use as reported in the 2014 Texas Integrated Report (TCEQ, 2015a). The 2014 assessment indicates non-support of the primary contact recreation use in both AUs 0508_01 and 0511_01 because geometric mean concentrations exceed the geometric mean criteria of 35 cfu/100 mL for Enterococci (Table 4). The 2016 and 2018 assessment data also indicate non-support of the primary geometric mean concentration criterion (TCEQ, 2018b; TCEQ, 2019b). There was an absence of recent fecal indicator bacteria data for all other AUs in the Adams and Cow Bayou watersheds.

2.5 Land Use

The land use/land cover data for the watersheds of Adams Bayou and Cow Bayou was obtained from the U.S. Geological Survey (USGS) 2016 National Land Cover Database (NLCD; USGS, 2016a) and is displayed in Figure 4. Tabular presentation of the land use/land cover data for the Adams Bayou watershed is provided in Table 5 and for the Cow Bayou watershed in Table 6.

The land use/land cover is represented by the following categories and definitions (USGS, 2016b):

- *Open Water - areas of open water, generally with less than 25 percent cover of vegetation or soil.*
- *Developed, Open Space - areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 percent of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.*

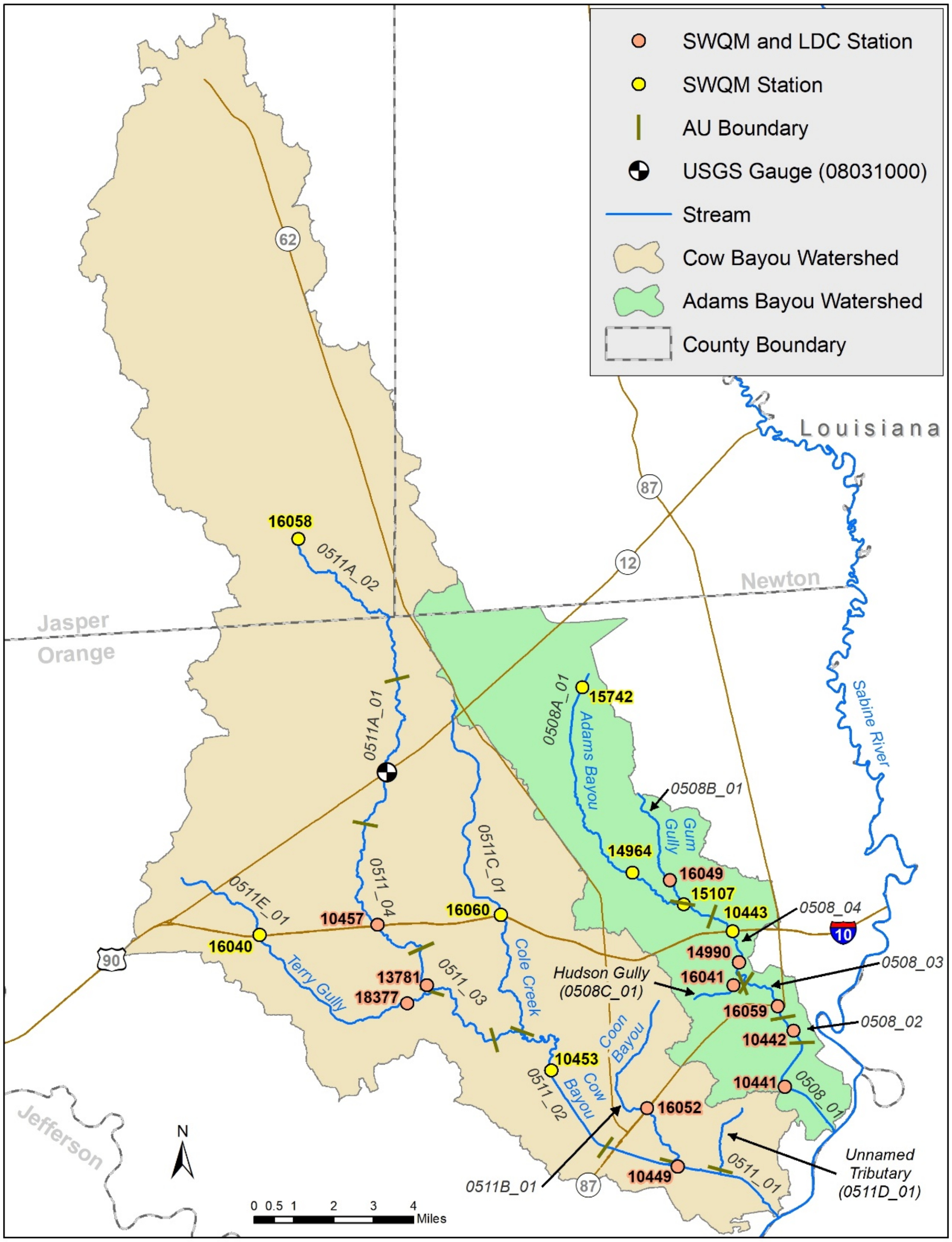


Figure 3. **TCEQ surface water quality monitoring (SWQM) stations and the USGS stream gauge station on Cow Bayou. Stations selected for LDC development are shown in orange.**

Table 4. 2014, 2016, and 2018 Integrated Report Summaries for Adams Bayou Tidal AU 0508_01 and Cow Bayou Tidal AU 0511_01.

(The geometric mean criterion for primary contact recreation use is 35 cfu/100 mL for Enterococci.)

Integrated Report Year	Water Body	Segment Number	Assessment Unit (AU)	Parameter	Data Date Range	Station	No. of Samples	Station Geometric Mean (cfu/100 mL)
2014	Adams Bayou Tidal	0508	0508_01	Enterococci	12/2005 - 11/2012	10441	39	456
2014	Cow Bayou Tidal	0511	0511_01	Enterococci	12/2005 - 11/2012	10449	39	403
2016	Adams Bayou Tidal	0508	0508_01	Enterococci	12/2007 - 11/2014	10441	63	374
2016	Cow Bayou Tidal	0511	0511_01	Enterococci	12/2007 - 11/2014	10449	63	308
2018	Adams Bayou Tidal	0508	0508_01	Enterococci	12/2009 – 11/2016	10441	82	315
2018	Cow Bayou Tidal	0511	0511_01	Enterococci	12.2009 – 11/2016	10449	84	233

- *Developed, Low Intensity - areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20 percent to 49 percent of total cover. These areas most commonly include single-family housing units.*
- *Developed, Medium Intensity - areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50 percent to 79 percent of the total cover. These areas most commonly include single-family housing units.*
- *Developed High Intensity - highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80 percent to 100 percent of the total cover.*
- *Barren Land (Rock/Sand/Clay) - areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15 percent of total cover.*
- *Deciduous Forest - areas dominated by trees generally greater than 5 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.*
- *Evergreen Forest - areas dominated by trees generally greater than 5 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.*
- *Mixed Forest - areas dominated by trees generally greater than 5 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.*
- *Shrub/Scrub - areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20 percent of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.*

- *Grassland/Herbaceous - 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.*
- *Pasture/Hay - 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. Pasture/hay vegetation accounts for greater than 20 percent of total vegetation.*
- *Cultivated Crops - areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20 percent of total vegetation. This class also includes all land being actively tilled.*
- *Woody Wetlands - areas where forest or shrubland vegetation accounts for greater than 20 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.*
- *Emergent Herbaceous Wetlands - Areas where perennial herbaceous vegetation accounts for greater than 80 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.*

Table 5. Land use / land cover within the Adams Bayou watershed.

2016 National Land Cover Database	Adams Bayou Watershed Tidal Portion †		Adams Bayou Watershed Above Tidal Portion *		Adams Bayou Watershed Total	
Classification	**Acres**	**% of Total**	**Acres**	**% of Total**	**Acres**	**% of Total**
Open Water	413	4.2%	104	0.5%	517	1.7%
Developed, Open Space	1,524	15.4%	1,739	8.8%	3,264	11.0%
Developed, Low Intensity	2,561	25.9%	1,420	7.2%	3,981	13.4%
Developed, Medium Intensity	834	8.4%	234	1.2%	1,068	3.6%
Developed, High Intensity	535	5.4%	72	0.4%	607	2.0%
Barren Land	4	0.0%	29	0.1%	33	0.1%
Deciduous Forest	6	0.1%	4	0.0%	10	0.0%
Evergreen Forest	160	1.6%	1,056	5.3%	1,216	4.1%
Mixed Forest	324	3.3%	996	5.0%	1,319	4.4%
Shrub/Scrub	7	0.1%	693	3.5%	700	2.4%
Grassland/Herbaceous	44	0.4%	434	2.2%	478	1.6%
Pasture/Hay	1,316	13.3%	6,545	33.1%	7,861	26.5%
Cultivated Crops	2	0.0%	375	1.9%	377	1.3%
Woody Wetlands	1,009	10.2%	5,487	27.7%	6,495	21.9%
Emergent Herbaceous Wetlands	1,141	11.5%	600	3.0%	1,741	5.9%
Total	9,879	100%$^{\delta}$	19,788	100%$^{\delta}$	29,667	100%$^{\delta}$

† Tidal portion includes the watersheds for AUs 0508_01, 0508_02, 0508_03, 0508_04 and 0508C_01.
* Above Tidal portion includes the watersheds of AUs 0508A_01 and 0508B_01.
$^{\delta}$ Due to rounding, the percentages by classification category may not add to exactly 100 percent.

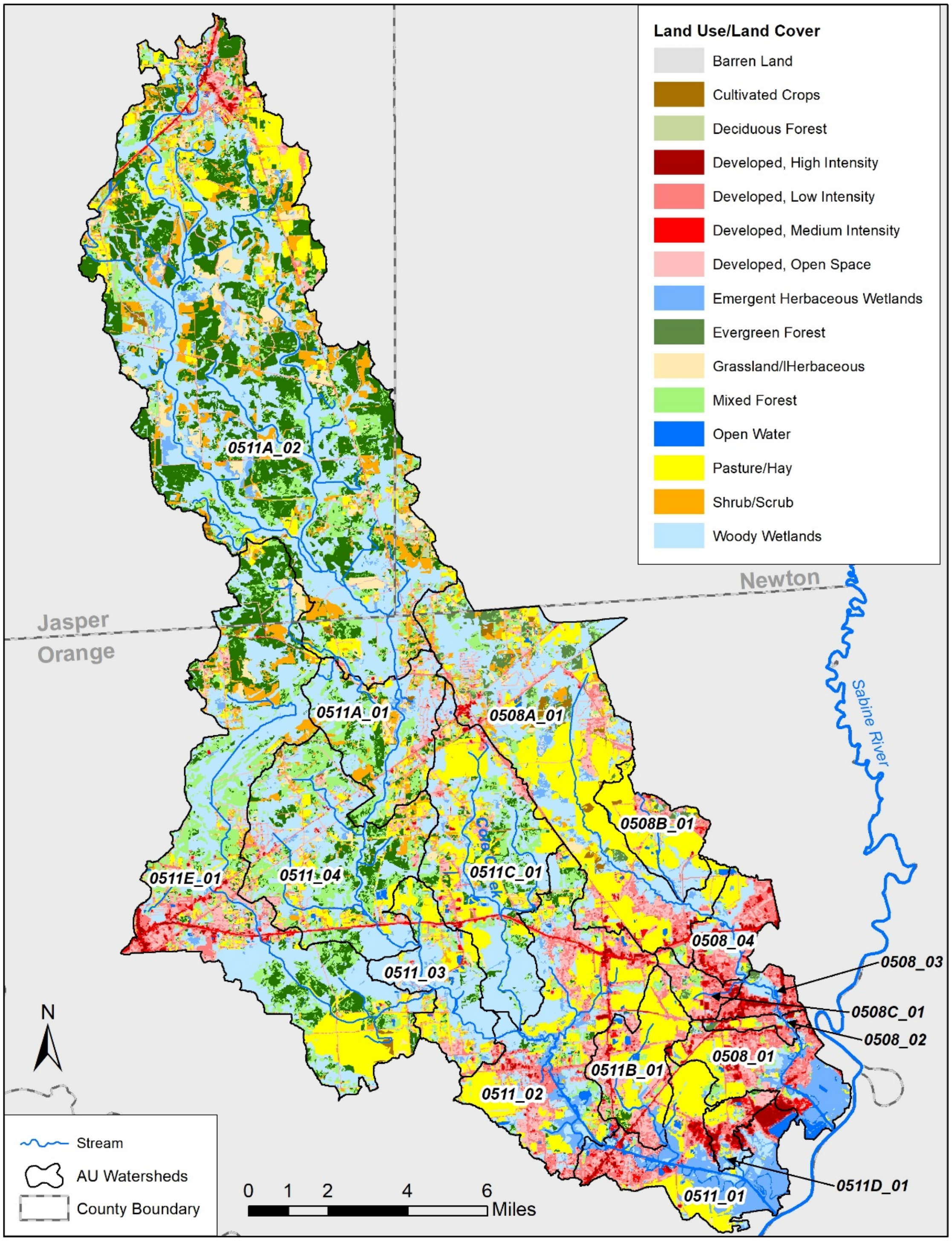


Figure 4. 2016 NLCD land use/ land cover within the watersheds of Adam Bayou and Cow Bayou.

Table 6. Land use / land cover within the Cow Bayou watershed.

2016 National Land Cover Database	Cow Bayou Watershed Tidal Portion †		Cow Bayou Watershed Above Tidal Portion *		Cow Bayou Watershed Total	
Classification	**Acres**	**% of Total**	**Acres**	**% of Total**	**Acres**	**% of Total**
Open Water	1,187	1.6%	54	0.1%	1,241	1.0%
Developed, Open Space	6,475	9.0%	2,100	3.8%	8,575	6.7%
Developed, Low Intensity	5,571	7.7%	1,229	2.2%	6,800	5.3%
Developed, Medium Intensity	1,607	2.2%	246	0.4%	1,853	1.5%
Developed, High Intensity	894	1.2%	72	0.1%	966	0.8%
Barren Land	62	0.1%	18	0.0%	80	0.1%
Deciduous Forest	23	0.0%	199	0.4%	222	0.2%
Evergreen Forest	5,983	8.3%	12,833	23.3%	18,816	14.8%
Mixed Forest	8,135	11.3%	5,838	10.6%	13,973	11.0%
Shrub/Scrub	1,979	2.7%	5,210	9.5%	7,189	5.7%
Grassland/Herbaceous	1,292	1.8%	2,767	5.0%	4,059	3.2%
Pasture/Hay	13,297	18.4%	3,746	6.8%	17,043	13.4%
Cultivated Crops	132	0.2%	178	0.3%	310	0.2%
Woody Wetlands	21,474	29.8%	19,375	35.2%	40,849	32.1%
Emergent Herbaceous Wetlands	3,999	5.5%	1,235	2.2%	5,234	4.1%
Total	72,110	100%$^{\delta}$	55,100	100%$^{\delta}$	127,210	100%$^{\delta}$

† Tidal portion includes the watersheds for AUs 0511_01, 0511_02, 0511_03, 0511_04 and 0511B_01, 0511C_01, 0511D_01 and 0511E_01.
* Above Tidal portion includes the watersheds for AUs 0511A_01 and 0511A_02.
$^{\delta}$ Due to rounding, the percentages by classification category may not add to exactly 100 percent.

2.6 Potential Sources of Fecal Indicator Bacteria

Potential sources of indicator bacteria pollution can be divided into two primary categories: *regulated* and *unregulated*. Pollution sources that are regulated have permits under the Texas Pollutant Discharge Elimination System (TPDES) and National Pollutant Discharge Elimination System (NPDES) programs. Examples of regulated sources are wastewater treatment facility (WWTF) discharges and stormwater discharges from industries, construction, and municipal separate storm sewer systems (MS4s) of cities.

Unregulated sources are typically nonpoint source in nature, meaning the pollution originates from multiple locations and is usually carried to surface waters by rainfall runoff. Nonpoint sources are not regulated by permit.

With the exception of WWTFs, which receive individual waste load allocations or WLAs (see report Section 4.7.3, Waste Load Allocation), the regulated and unregulated sources in this section are presented to give a general account of the potential sources of bacteria in the watershed.

2.6.1 Regulated Sources

Regulated sources are authorized by permit under the TPDES and the NPDES programs. The regulated sources in the watersheds of Adam Bayou and Cow Bayou include domestic and industrial WWTF outfalls and stormwater discharges from industries, construction, and MS4s.

2.6.1.1 Domestic and Industrial Wastewater Treatment Facilities

There are a total of 15 domestic and industrial WWTFs with permits to discharge in the Adams Bayou and Cow Bayou watersheds (Figure 5; Table 7). Three of the facilities discharge into Adams Bayou and each of these treats domestic wastewater. Of the 12 facilities in the Cow Bayou watershed, 6 are domestic WWTFs and 6 are industrial facilities. The wastewater effluent from five of the six industrial facilities contains a human waste component. In October 2019 TCEQ reviewed each of the six permitted industrial discharges in the Cow Bayou watershed and provided the guidance in Table 8 regarding how the human waste or domestic wastewater component should be considered for these bacteria TMDLs.

All six industrial facilities have permitted outfalls for stormwater. Four of the industrial facilities are located entirely within MS4 areas for regulated stormwater. Two facilities are located outside of MS4 areas, and those two facilities have a combined property area of 27.5 acres. Taking a conservative approach, it was assumed that the entire 27.5 acres of these facilities were regulated through the permitted stormwater outfalls.

2.6.1.2 TPDES General Wastewater Permits

In addition to the individual wastewater discharge permits listed in Table 7, certain activities are required to be covered by one of several TPDES/TCEQ general permits:

- TXG110000 – concrete production facilities
- TXG130000 – aquaculture production
- TXG340000 – petroleum bulk stations and terminals
- TXG670000 – hydrostatic test water discharges
- TXG830000 – water contaminated by petroleum fuel or petroleum substances
- TXG870000 – pesticides
- TXG920000 – concentrated animal feeding operations
- WQG20000 – livestock manure compost operations
- WQG10000 – Wastewater Evaporation

Table 7. Permitted wastewater operations in Adams Bayou and Cow Bayou watersheds with full permitted discharges and recent discharges.

Figure 5 Map No.	Permit	TPDES No.	NPDES No.	AU	Outfall	Flow (MGD)	Recent Calculated Discharge * (MGD)
13	City of Pinehurst	WQ0010597001	TX0024171	0508_03	001	0.5	0.34
15	Orange County WCID 2	WQ0010240001	TX0054810	0508_02	001	1.22	0.75
14	City of Orange†	WQ0010626001	TX0073423	0508_02	002	7.0†	1.36†
12	ARLANXEO USA LLC	WQ0001167000	TX0003654	0511_01	001	6.0	3.62
11	Honeywell International Inc.	WQ0000670000	TX0007897	0511_01	001	1.4	0.61
8	Lion Elastomers Orange, LLC	WQ0000454000	TX0002968	0511_01	001 002	1.202 NRR	0.69 NK
9	Chevron Phillips Chemical Company LP	WQ0000359000	TX0004839	0511D_01	001	3.15	1.10
10	Printpack, Inc.	WQ0002858000	TX0101192	0511D_01	001 101	0.085 0.015	0.045 0.0068
7	City of Bridge City	WQ0010051001	TX0025500	0511_01	001	1.6	0.74
4	Orangefield Water Supply Corporation	WQ0014772001	TX0129313	0511_02	001	0.75	0.20
5	Bayou Pines (proposed)	WQ0015029001	TX0133418	0511B_01	001	0.009	NA
6	Gulflander Partners Group, L.P.	WQ0013488001	TX0106437	0511B_01	001	0.01	0.0044
2	P C S Development Company	WQ0011916001	TX0074250	0511_04	001	0.09	0.0026
3	Miller Waste Mills, Inc.	WQ0002835000	TX0104710	0511_02	001 002 003 ϕ	RR RR RR	0.0065 0.108 NK
1	Jasper County WCID 1	WQ0010808001	TX0021300	0511A_02	001	0.41	0.14

NK = not known (no specific limit); NA = not applicable; NRR = no reporting requirement (stormwater only outfall); RR = required to report (no limit specified in permit)

* Recent calculated discharge is the daily average discharge over the 5-year period of January 2014 through December 2018.

† Intermittent discharge. The permittee is authorized to discharge from Outfall 002 only if, as a result of wet weather conditions, the average discharge from the facility exceeds 11,111 gallons per minute. Combined average annual discharge of Outfalls 001 and 002 is not to exceed 7.0 MGD. Discharges through Outfall 002 occurred 6 months out of the 120-month period of June 2008 through May 2018 with an average daily discharge for those months of 1.36 MGD.

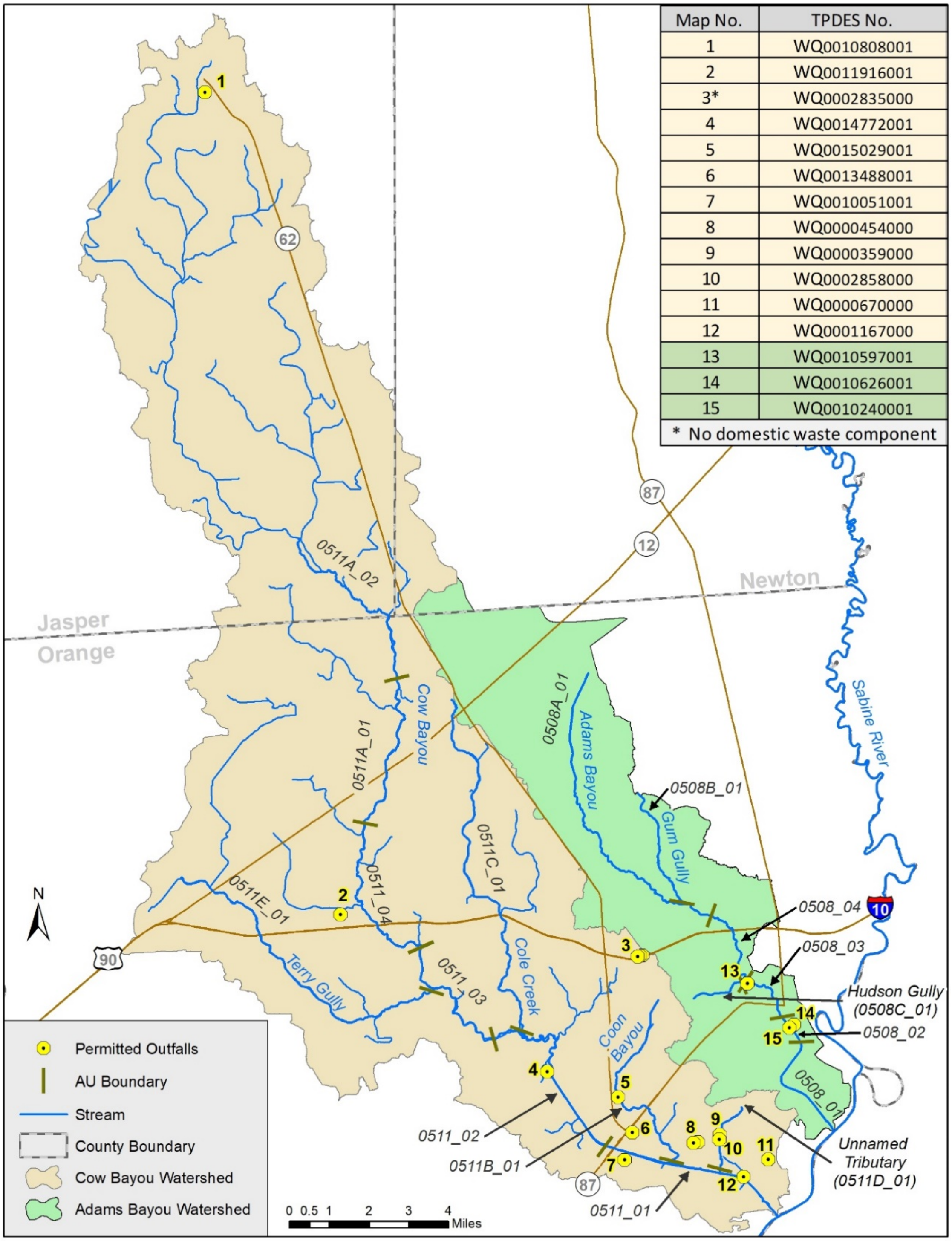
ϕ TCEQ received a request to amend permit WQ0002835000 to remove Outfall 003.

Table 8. TCEQ consideration of domestic wastewater component of industrial permits in the Cow Bayou watershed.

Permit	TPDES No.	NPDES No.	AU	Outfall	Flow (MGD)	Permit Considerations
ARLANXEO USA LLC*	WQ0001167000	TX0003654	0511_01	101	0.05	Domestic wastewater is treated in a stand-alone package plant. Bacteria limits included at new internal Outfall 101.
Honeywell International Inc.	WQ0000670000	TX0007897	0511_01	101	0.04	Domestic wastewater is treated in a stand-alone package plant. Bacteria limits included at internal Outfall 101.
Lion Elastomers Orange, LLC	WQ0000454000	TX0002968	0511_01	001	1.202	Domestic wastewater is commingled with industrial wastewater for treatment and discharged via Outfall 001. There is no stand-alone treatment of domestic wastewater. Bacteria limits included at Outfall 001.
Chevron Phillips Chemical Company LP*	WQ0000359000	TX0004839	0511D_01	101	0.024	Domestic wastewater is treated in a stand-alone package plant. Bacteria limits included at new internal Outfall 101.
Printpack, Inc.	WQ0002858000	TX0101192	0511D_01	101	0.015	Domestic wastewater is treated in a stand-alone package plant. Bacteria limits included at internal Outfall 101.
Miller Waste Mills, Inc.	WQ0002835000	TX0104710	0511_02	NA	NA	Domestic wastewater is treated using an on-site sewage facility (OSSF) and applied on-site by irrigation. No domestic wastewater is authorized to be discharged by the permit and bacteria limits will not be needed.

NA = not applicable

* Upon permit renewal, TCEQ may propose ARLANXEO USA LLC and Chevron Phillips Chemical Company LP create a new internal outfall designated as Outfall 101 in Table 8.



Map No.	TPDES No.
1	WQ0010808001
2	WQ0011916001
3*	WQ0002835000
4	WQ0014772001
5	WQ0015029001
6	WQ0013488001
7	WQ0010051001
8	WQ0000454000
9	WQ0000359000
10	WQ0002858000
11	WQ0000670000
12	WQ0001167000
13	WQ0010597001
14	WQ0010626001
15	WQ0010240001

* No domestic waste component

Figure 5. Adams Bayou and Cow Bayou watersheds showing TPDES permitted domestic and industrial regulated discharge facilities.

A review of active general permit coverage (TCEQ, 2019c) in the watersheds of Adams Bayou and Cow Bayou as of September 12, 2019 found three concrete production facilities covered by general permit TXG110000. Two of the concrete production facilities were located in the Adams Bayou watershed and one concrete production facility was located in the Cow Bayou watershed. There are also two pesticide application authorizations in the watersheds for mosquito control. These facilities were assumed to contain inconsequential amounts of indicator bacteria in their effluent; therefore, it was unnecessary to allocate bacteria load to these four facilities. No other active general wastewater permit facilities or operations were found. There were no facilities covered under the general permits for aquaculture production, wastewater evaporation, petroleum bulk stations and terminals, water contaminated by petroleum fuel or petroleum substances, concentrated animal feeding operations or livestock manure compost operations.

2.6.1.3 TPDES-Regulated Stormwater

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

1) stormwater subject to regulation, which is any stormwater originating from TPDES-regulated Phase I and Phase II MS4, stormwater discharges associated with industrial activities, and stormwater discharges from regulated construction activities; and
2) stormwater runoff not subject to regulation.

The TPDES/NPDES MS4 Phase I and II rules require municipalities and certain other entities in urban areas to obtain permits for their stormwater systems. Both the Phase I and II permits include any conveyance such as ditches, curbs, gutters, and storm sewers that do not connect to a wastewater collection system or treatment facility. Phase I permits are individual permits for large and medium sized communities with populations exceeding 100,000, whereas Phase II permits are for smaller communities located within an EPA-defined urbanized area regulated by a general permit. The purpose of an MS4 permit is to reduce discharges of pollutants in stormwater to the “maximum extent practicable” by developing and implementing a Stormwater Management Program (SWMP). The SWMPs require specification of best management practices (BMPs) for six minimum control measures:

- Public education and outreach;
- Illicit discharge detection and elimination;
- Construction site runoff control;
- Post-construction stormwater management in new development and redevelopment;
- Pollution prevention and good housekeeping for municipal operations; and
- Industrial stormwater sources.

Phase I MS4 individual permits have similar MCMs and are further required to perform water quality monitoring.

Phase I MS4 permits are associated with large urban areas and, as such, no permits of this nature are applicable for the watersheds of Adams Bayou and Cow Bayou. Discharges of stormwater from a Phase II MS4 area, industrial facility, and construction sites 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

A review of active stormwater general permits coverage conducted on September 12, 2019 (TCEQ, 2019c) found that in addition to the previously mentioned 2 concrete production facilities in the Adams Bayou watershed and 1 concrete production facility located in the Cow Bayou watershed, there were 3 active construction permits and 9 MSGPs in the Adams Bayou watershed and 4 active construction permits and 7 MSGPS in the Cow Bayou watershed.

The entities regulated under MS4 permits for the watersheds of Adams Bayou and Cow Bayou are provided in Table 9. For the AU watersheds containing entities with Phase II general permits, the areas included under these MS4 permits (Figure 6) were used with other information to estimate the regulated stormwater areas (RSAs) for construction, industrial and MS4 permits. The regulated areas for the Phase II permits were based on the 2010 Urbanized Area from the U.S. Census Bureau. AUs 0511A_01, 0511A_02, and 0511_03 of Cow Bayou have no areas under MS4 Phase II permits and AU 0511C_01 only has 3 acres of area under MS4 Phase II permits. The regulated stormwater area for these four AUs was estimated based on an empirical relationship developed between MS4 permitted area and the total developed land use area in each AU (Figure 7). The total developed land use was calculated as the sum of Developed Open Space, Low Intensity Developed, Medium Intensity Developed and High Intensity Developed in Tables 5 and 6. Estimated area under regulated stormwater industrial permits not within MS4 areas were also determined based on property boundaries and developed land uses within their boundaries. The percentage of land area under jurisdiction of stormwater permits for each of the AUs in the watersheds of Adams Bayou and Cow Bayou is presented in Table 10 and is based on 2010 Urbanized Area, the equation shown on Figure 7, and the estimated regulated stormwater for industries located outside of MS4 areas. As previously mentioned, two individual industrial permits authorize the discharge of stormwater outside of the MS4 areas; both facilities are located within the Cow Bayou watershed.

Table 9. TPDES and NPDES MS4 permits associated with the TMDL study area.

Entity *	TPDES Permit	NPDES Permit	AUs
Orange County Drainage District	Phase II MS4 General Permit (TXR040000)	TXR040029	0508_01, 0508A_01, 0508B_01, 0508C_01, 0511_01, 0511_02, 0511_04, 0511B_01, 0511D_01, 0511E_01
Orange County	Phase II MS4 General Permit (TXR040000)	TXR040030	0508_01, 0508A_01, 0508B_01, 0508C_01, 0511_01, 0511_02, 0511_04, 0511B_01, 0511D_01, 0511E_01
City of Bridge City	Phase II MS4 General Permit (TXR040000)	TXR040429	0511_01, 0511_02
City of Orange	Phase II MS4 General Permit (TXR040000)	TXR040430	0508_01, 0508_02, 0508_03, 0508_04, 0508A_01, 0508B_01, 0508C_01, 0511_01, 0511B_01, 0511C_01
City of Pinehurst	Phase II MS4 General Permit (TXR040000)	TXR040428	0508_03, 0508_04, 0508A_01 0508C_01
City of Vidor	Phase II MS4 General Permit (TXR040000)	TXR040028	0511_04, 0511E_01
City of West Orange	Phase II MS4 General Permit (TXR040000)	TXR040431	0508_01, 0508_02, 0508_03, 0511D_01

* The Texas Department of Transportation has an individual stormwater MS4 combined Phase I and II permit that applies to its MS4 areas located in UAs statewide.

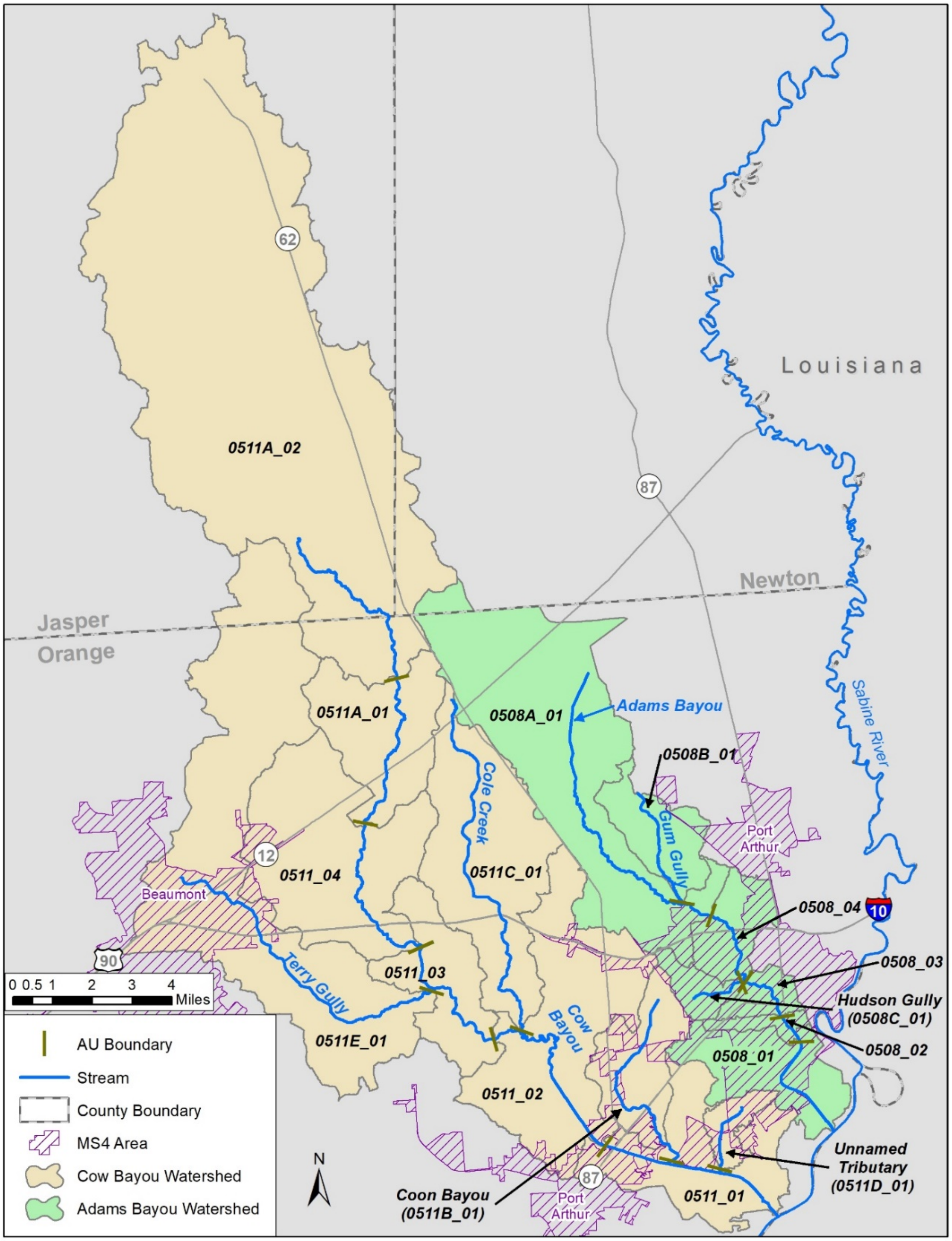


Figure 6. Regulated stormwater areas based on Phase II MS4 permit authorizations within the Adams Bayou and Cow Bayou watersheds.

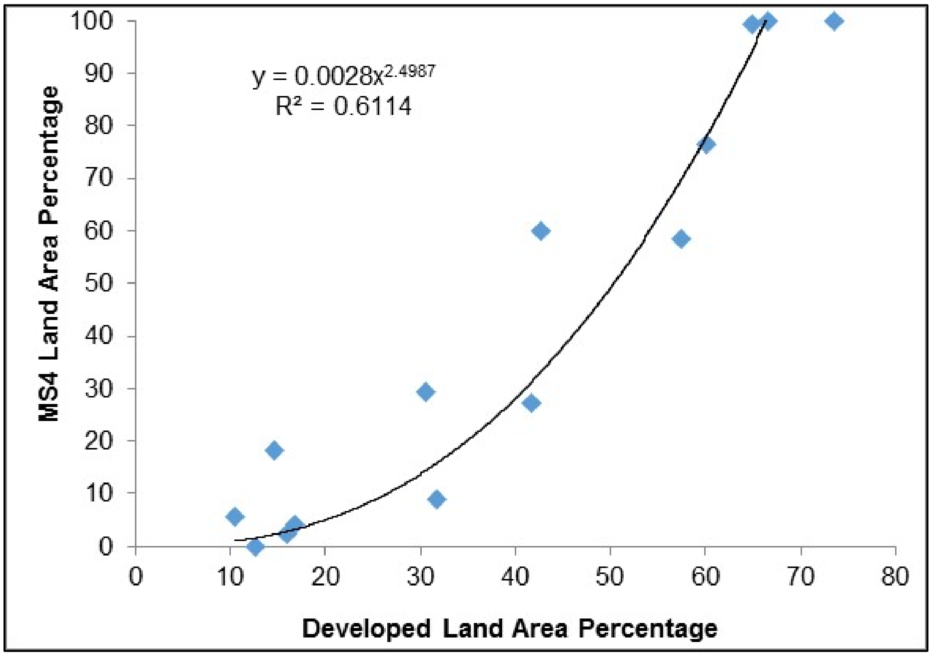


Figure 7. Relationship between MS4 permitted area and total developed land use area.

Table 10. Estimated area under stormwater permit regulation for AUs of Adams Bayou and Cow Bayou.

AU	Estimated RSA by AU (acres)	AU Watershed Area (acres)	Estimated Percent of AU Watershed Area under Stormwater Regulation (%)	Estimated Percent of Total Drainage Area of AU under Stormwater Regulation (%)
0508_01	2,653	4,431	59.87	27.95
0508_02	652	653	99.85	22.34
0508_03	1,162	1,162	100.00	20.28
0508_04	1,877	2,455	76.46	11.93
0508A_01	707	16,778	4.21	3.93
0508B_01	70	3,010	2.33	2.33
0508C_01	1,170	1,178	99.32	99.32
0511_01	1,973	6,734	29.30	7.92
0511_02	1,025	11,369	9.02	5.44
0511_03*	107	4,794	2.23	5.43
0511_04	631	11,256	5.61	1.31
0511A_01*	70	5,975	1.17	0.43
0511A_02*	165	49,125	0.34	0.34
0511B_01	1,137	4,079	27.87	27.87
0511C_01*	170	10,453	1.63	1.63
0511D_01	699	1,155	60.52	60.52
0511E_01	4,098	22,273	18.40	18.40

* For these AUs the regulated stormwater area computations used the equation presented in Figure 7; and the following percentages of the AUs as developed: 0511_03 at 14.5%; 0511A_01 at 11.2%; 0511A_02 at 6.8% and 0511C_01 at 12.6% (the area estimated for 0511C_01 also includes a small MSGP facility).

2.6.1.4 Sanitary Sewer Overflows

Sanitary sewer overflows (SSOs) are unauthorized discharges that must be addressed by the responsible party, either the TPDES permittee or the owner of the collection system that is connected to a permitted system. 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 causes of SSOs under conditions of high flow in the WWTF system. Blockages in the line may exacerbate the I&I problem. Other causes, such as a collapsed sewer line, may occur under any condition.

A Texas statewide database of SSO data reported by municipalities and industries was obtained from the TCEQ Central Office in Austin. The SSO database contains the TPDES permit number associated with the spill, beginning and end dates of the spill, estimates of the total gallons spilled, responsible entity, a general location of the spill, and correction action taken. A search of the database for the 3-year period of 2016 through 2018 for TPDES permits with service areas included in the Adams and Cow Bayou watersheds indicated a total of 54 reported spills of which 50 had reported spill volumes. A summary of the SSO information is provided in Table 11.

Table 11. Summary of SSO incidences reported in the TMDL watersheds from 2016 through 2018 for combined watersheds of Adams Bayou and Cow Bayou.

No. of incidences	No. of Incidences with reported volume	Total Volume (gallons)	Average Volume (gallons)	Median Volume (gallons)	Min Volume (gallons)	Max Volume (gallons)
54	50	1,234,984	22,454	12,000	<1	86,000

2.6.1.5 Dry Weather Discharges/Illicit Discharges

In addition to regulated stormwater, bacteria loads can enter receiving streams from illicit discharges, sometimes conveyed through permitted stormwater outfalls, under both dry and wet weather conditions. The term "illicit discharge" is defined in TPDES General Permit No. TXR040000 for Phase II MS4s as "Any discharge to a municipal separate storm sewer that is not entirely composed of stormwater, except discharges pursuant to this general permit or a separate authorization and discharges resulting from emergency firefighting activities." Illicit discharges can be categorized as either direct or indirect contributions. Examples of illicit discharges identified in the Illicit Discharge Detection and Elimination Manual: A Handbook for Municipalities (NEIWPCC, 2003) includes:

Direct illicit discharges:

- sanitary wastewater piping that is directly connected from a home to the storm sewer;
- materials (*e.g.*, used motor oil) that have been dumped illegally into a storm drain catch basin;
- a shop floor drain that is connected to the storm sewer; and
- a cross-connection between the municipal sewer and storm sewer systems.

Indirect illicit discharges:

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

2.6.1.6 Review of Compliance Information on Permitted Sources

A review of the EPA Enforcement & Compliance History Online (ECHO) database (EPA, 2019) conducted July 26, 2019 revealed no significant noncompliance issues for any of the permitted facilities in the Adams and Cow Bayou Watershed that would impact bacteria concentrations in their effluent. The majority of the facilities have chlorine residual limits in the permits without any specific indicator bacteria monitoring requirements. This compliance review was performed on July 26, 2019 by accessing the EPA ECHO database which contained information from July 2014 through July 2019 and the compliance parameters included discharge, chlorine residual, and, if included in the permit limits, indicator bacteria.

2.6.2 Unregulated Sources

Unregulated sources of indicator bacteria are generally nonpoint and can emanate from wildlife, feral hogs, various agricultural activities, agricultural animals, land application fields, urban runoff not covered by a permit, failing onsite sewage facilities (OSSFs), and domestic pets.

2.6.2.1 Wildlife and Unmanaged Animal Contributions

Fecal indicator bacteria, such as Enterococci and *E. coli*, are common inhabitants of the intestines of all warm-blooded animals, including wildlife such as mammals and birds. In developing bacteria TMDLs, it is important to identify, by watershed, the potential for bacteria contributions from wildlife. Wildlife are naturally attracted to riparian corridors of streams and rivers. With direct access to the stream channel, the direct deposition of wildlife waste can be a concentrated source of bacteria loading to a water body. Fecal bacteria from wildlife are also deposited onto land surfaces, where it may be washed into nearby streams by rainfall runoff. Unfortunately, quantitative estimates of wildlife are rare, inexact, and often limited to discrete taxa groups or geographical areas of interest so that even county-wide approximations of wildlife numbers are difficult or impossible to acquire.

For feral hogs, Texas A&M AgriLife Research (Timmons et al., 2012) estimated a range of feral hog densities within Texas (1.3 to 2.5 hogs/ square mile). The average hog density (1.9 hogs/ square mile) was multiplied by the hog-habitat area in the Adams Bayou watershed (37 square miles) and Cow Bayou watershed (182 square miles). Habitat deemed suitable for hogs followed as closely as possible to the land use selections of the AgriLife study and include from the 2011 NLCD: pasture/hay, cultivated crops, shrub/scrub, grassland/herbaceous, deciduous forest, evergreen forest, mixed forest, woody wetlands, emergent herbaceous wetlands, and developed open space. Using this methodology, there are an estimated 70 feral hogs in the Adams Bayou watershed and 345 feral hogs in the Cow Bayou watershed.

For white-tailed deer, the Texas Parks and Wildlife Department (TPWD) published data showing deer population-density estimates by Resource Management Unit (RMU) and Ecoregion in the state (TPWD, 2012). The Adams and Cow Bayou watersheds incorporates areas of RMU 13, for which the average deer density over the period 2005-2011 was calculated to be 2.44 deer/ square mile, which indicates a low density of deer when compared to other regions of the state. Applying this value to the area of the entire watershed returns an estimated 113 deer within the Adams Bayou watershed and 485 deer within the Cow Bayou watershed.

2.6.2.2 Non-Regulated Agricultural Activities and Domesticated Animals

The major agricultural activities within the watersheds include beef cattle ranching and hay production. The 2017 U.S. Department of Agriculture (USDA) census of agriculture provides an inventory of livestock at the county level (USDA, 2019). The county-level livestock data for Jasper, Newton, and Orange counties were refined to better reflect livestock numbers in the Adams Bayou and Cow Bayou watersheds based on the combined amount of the two land uses of grassland/herbaceous and pasture/hay, which were assumed to be the major land uses supporting most livestock. The sum of the area of these two land uses were determined for the three counties, and the amount of these two land uses by county was also determined within the subwatersheds of Adams Bayou Tidal, Adams Bayou Above Tidal, Cow Bayou Tidal, and Cow Bayou Above Tidal. Livestock were then proportioned to each of the four subwatersheds based on the number of each livestock category in each county and the fractional amount of the two land uses from each county in each subwatershed. Cattle are the most abundant large livestock animal by a large margin based on 2017 county-level data distribution to the subwatershed level with summation to the Adams Bayou and Cow Bayou watershed level (Table 12; USDA (2019)). Based on numbers, other abundant livestock categories include poultry, goats, and horses.

Activities, such as livestock grazing close to water bodies and farmers' use of manure as fertilizer, can contribute fecal indicator bacteria to nearby water bodies. The livestock numbers are provided to demonstrate that livestock are a potential source of bacteria in the Adams and Cow Bayou watershed. These numbers, however, are not used to develop an allocation of allowable bacteria loading to livestock.

2.6.2.3 On-site Sewage Facilities

Private residential on-site sewage facilities (OSSFs), commonly referred to as septic systems, consist of various designs based on physical conditions of the local soils. Typical designs consist of (1) one or more septic tanks and a drainage or distribution field (anaerobic system or conventional septic system) and (2) aerobic systems that have an aerated holding tank and often an above ground sprinkler system for distributing the liquid. Conventional septic tank systems rely on absorption fields to disperse liquid components of sewage into the soil, after solids have settled into the tank. In simplest terms, household waste flows into the septic tank or aerated tank, where solids settle out. The liquid portion of the water flows to the distribution system which may consist of buried perforated pipes or an above ground sprinkler system. Several factors affect the suitability of soils for septic tank absorption fields (USDA-NRCS, 2004), including frequency and duration of flooding, frequency and duration of ponding, soil water permeability, depth to the saturated zone, and tendency for subsidence.

Table 12. Estimated domesticated animal populations for Adams Bayou and Cow Bayou watersheds.

Livestock	Adams Bayou Watershed Tidal Portion [1]	Adams Bayou Watershed Above Tidal Portion [2]	Adams Bayou Watershed Total	Cow Bayou Watershed Tidal Portion [3]	Cow Bayou Watershed Above Tidal Portion [4]	Cow Bayou Watershed Total
Cattle and Calves	381	1,934	2,315	4,067	1,383	5,450
Hogs and Pigs	17	88	105	185	32	217
Sheep and Lambs	14	72	86	150	40	190
Goats	36	185	221	387	92	479
Horses and Ponies	30	151	181	316	112	428
Mules, Burros, and Donkeys	5	24	29	51	23	74
Rabbits [5]	15	74	89	154	9	163
Deer [5]	51	257	308	536	74	610
Poultry [6]	410	1,950	2,360	4,344	646	4,990

[1] Tidal portion includes AUs 0508_01, 0508_02, 0508_03, 0508_04 and 0508C_01.

[2] Above Tidal portion includes AUs 0508A_01 and 0508B_01.

[3] Tidal portion includes AUs 0511_01, 0511_02, 0511_03, 0511_04 and 0511B_01, 0511C_01, 0511D_01 and 0511E_01.

[4] Above Tidal portion includes AUs 0511A_01 and 0511A_02.

[5] Rabbits and deer are livestock in captivity

[6] Poultry includes chickens/layers and pullets, chickens/broilers, turkeys, ducks, geese, and other poultry

Several pathways of the liquid waste in OSSFs afford opportunities for bacteria to enter ground and surface waters, if the systems are not properly operating. Properly designed and operated, however, OSSFs would be expected to contribute virtually no fecal bacteria to surface waters. For example, it has been reported that less than 0.01% of fecal coliforms originating in household wastes move further than 6.5 feet down gradient of the drain field of a septic system (Weikel et al., 1996).

The 1990 U.S. federal census included a question regarding household sewage disposal. However, the 2000 and 2010 federal censuses did not include a question on sewage disposal. The 1990 federal census information was used to develop a map showing the density of the pre-1991 households with conventional septic systems, which represent those OSSFs with the highest likelihood of failure (Figure 8). The 1990 federal census information was used at the census-block level with the associated census responses to OSSF presence or absence in developing this figure. Since 1991, when Orange County adopted its OSSF program, it has been a requirement that a soil survey must be performed before installation of an OSSF. Given that almost all soils in the watersheds are unsuitable for conventional septic systems, in most cases an aerobic OSSF must be installed. Thus, since 1991 new housing in areas not served by public sewers has generally required aerobic OSSF systems, and the number of housing units utilizing conventional septic systems has likely not increased.

The Orangefield Water Supply Corporation was established in 1995 and in recent years began to provide sanitary sewer service to portions of the Cow Bayou watershed north of Bridge City. By 2013, their 0.75 MGD WWTF was treating wastewater from 1,000 connections in the Cow Bayou watershed that previously used OSSFs (Morton, 2013). This information was used to update the watershed models used in the 2007 TMDL effort in the Adams and Cow Bayou watersheds.

Based on one or more soil properties (*e.g.*, soil water permeability and depth to the saturated zone), almost all of the soils in the Adams and Cow Bayou watersheds are very limited in their utility for septic tank absorption fields (Figure 9), according to information in the Soil Survey Geographic Database developed by the Natural Resources Conservation Service (NRCS) of the USDA (USDA-NRCS, 2016). Extensive site engineering may minimize the effects of some of these factors. A survey of septic tank failure in Texas (Reed Stowe and Yanke, 2001) estimated that the overall chronic malfunction rate of OSSF systems in east Texas was 19 percent; more than any other region in the state. The estimated chronic malfunction rate rose to 54 percent for systems installed in the fine-textured, clayey soils common in the watersheds of Adams Bayou and Cow Bayou. In this region, the factor reported to have the highest impact on malfunction was unsuitable soils, followed by the high water table, then system age (Parsons, 2006). Project stakeholders with knowledge of the watersheds, including septic system inspectors, believe that the actual rate of malfunction of conventional septic systems in these watersheds is close to 100 percent. They cited observations that almost all conventional systems had the cap removed from the septic field drain line, essentially conveying the septage directly from the tank to the ditch (Parsons, 2006).

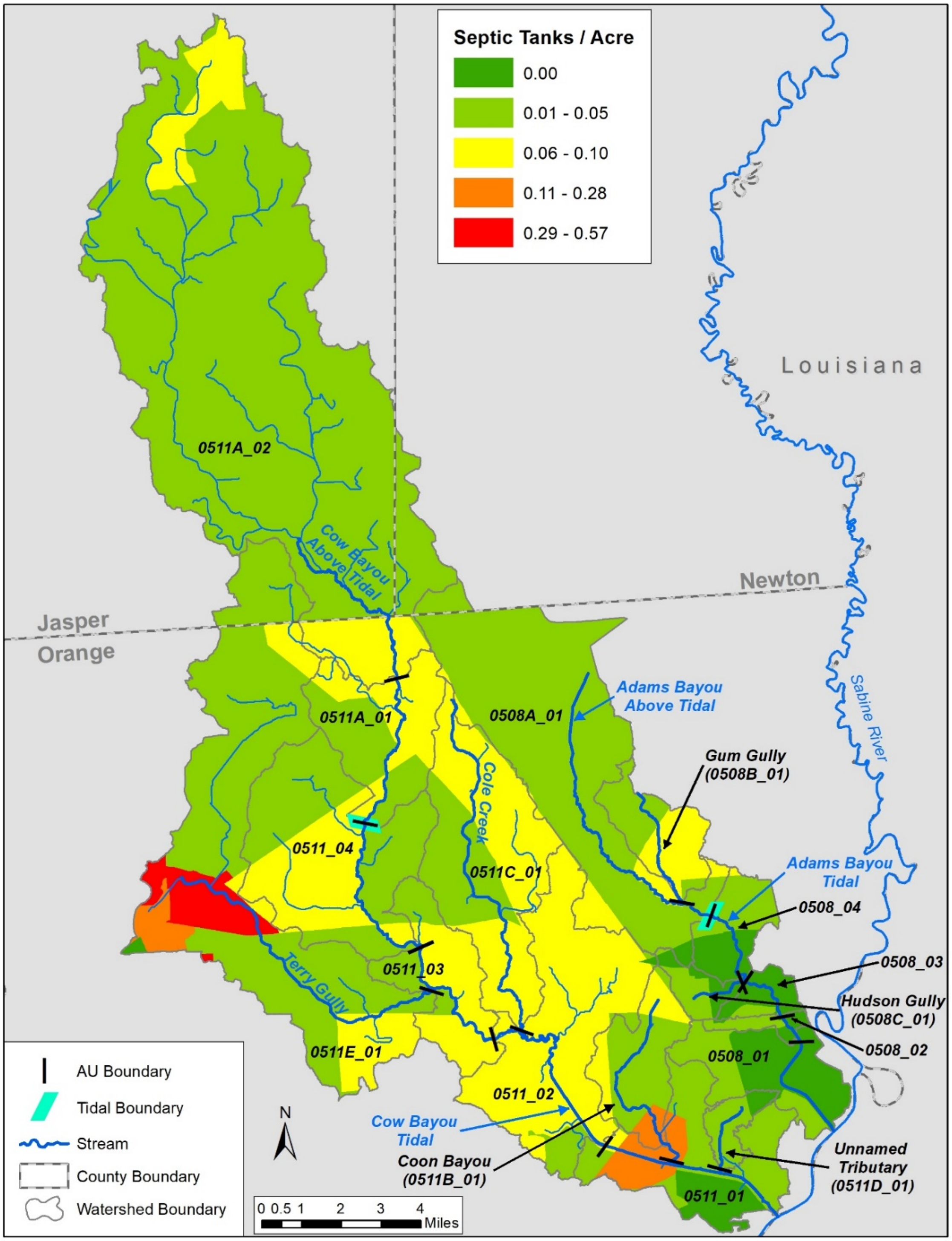


Figure 8. Septic tank densities within the Adams Bayou and Cow Bayou watersheds based on 1990 federal census data.

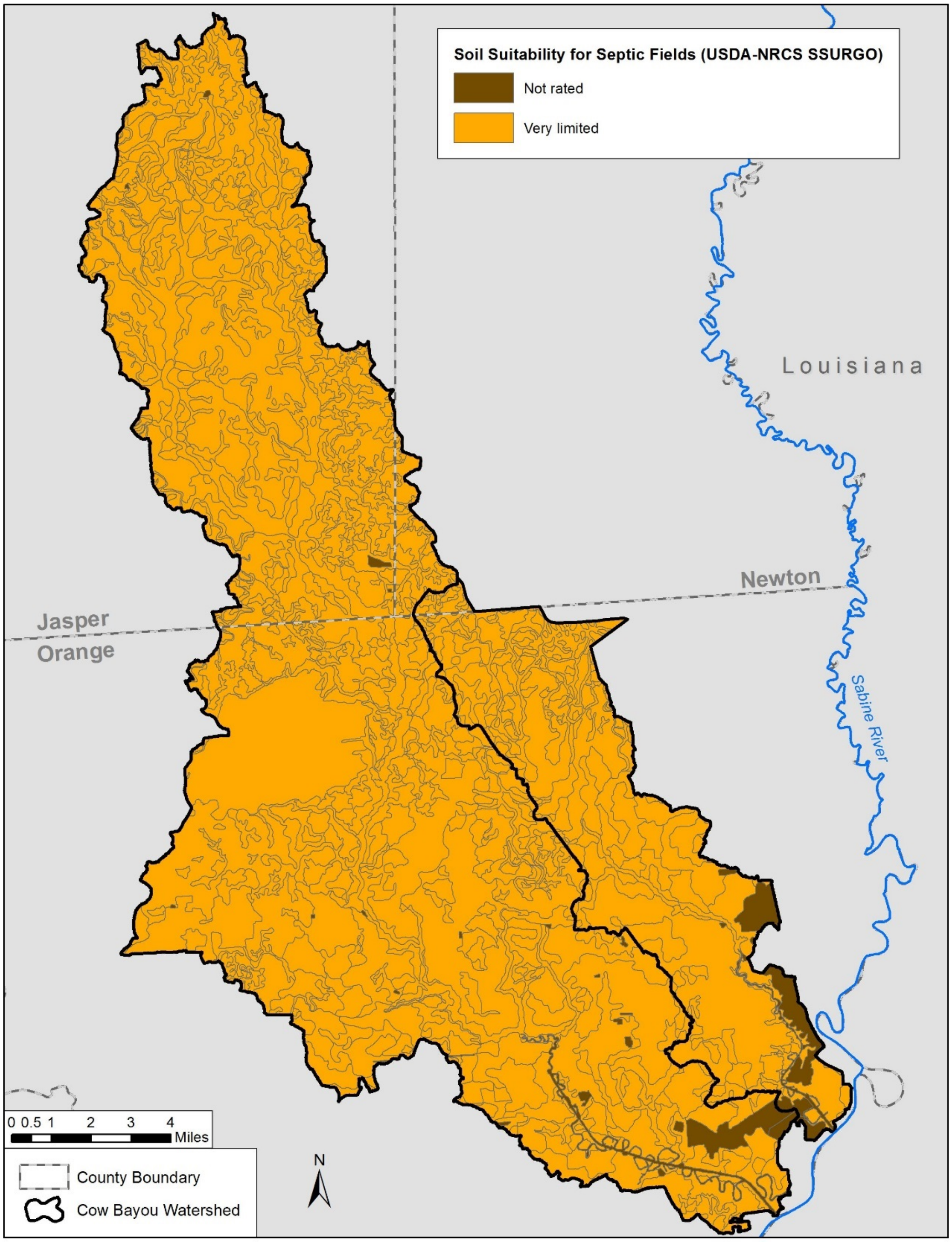


Figure 9. Soil suitability for septic fields in the Adams Bayou and Cow Bayou watersheds (USDA-NRCS, 2016).

2.6.2.4 Domestic Pets

Fecal matter from dogs and cats is transported to streams by runoff in both urban and rural areas and can be a potential source of bacteria loading. Table 13 summarizes the estimated number of dogs and cats for the TMDL watershed. Pet population estimates were calculated as the estimated number of dogs (0.584) and cats (0.638) per household (AVMA, 2012). The actual contribution and significance of fecal coliform loads from pets reaching the water bodies of the watershed is unknown.

Table 13. Estimated households and pet populations for the watersheds of Adams Bayou and Cow Bayou.

Watershed	Estimated Number of Households	Estimated Dog Population	Estimated Cat Population
Adams Bayou	11,937	6,971	7,616
Cow Bayou	18,789	10,973	11,987

2.7 Water Rights

Surface water diversions associated with water rights permits have the potential of impacting stream hydrology. A spatial query of water rights features (diversions, withdrawals, return flows) revealed that the Adams Bayou watershed contains one active water rights permit and that the Cow Bayou watershed contains no active water rights permits (TCEQ, 2019d). A review of the water use data file containing historical reported water diversions indicates that the user has not reported any use since 2000. The diversion intake point is located approximately one mile downstream of Station 10441, which is the most downstream station on Adams Bayou, and is near the confluence of Adams Bayou with the Sabine River Tidal segment (station shown on Figure 3). Further investigations indicated that this water right is not included in the Sabine River water rights modeling because the diversion was considered to consist of brackish and saline water. Based on the downstream location of the diversion associated with the water right, its inactivity for almost 20 years, and it not being included in the Sabine River watershed water rights modeling, the conclusion is that this water right does not impact any efforts associated with development of pollutant loadings in Adams Bayou.

2.8 Bacteria Survival and Die-off

Bacteria are living organisms that survive and die. Certain enteric bacteria can survive and replicate in organic materials if appropriate conditions prevail (e.g., warm temperature). Fecal organisms can survive and replicate from improperly treated effluent during their transport in pipe networks and in organic-rich materials such as compost and sludge (EPA, 2001). While the die-off of bacteria has been demonstrated in natural water systems due to the presence of sunlight and predators, the potential for their replication is less understood. Both processes (replication and die-off) are instream processes and are not considered in the bacteria source loading estimates for the TMDL watersheds.

Section 3
Development of Bacteria Tools

An essential component of a TMDL is to establish a linkage, or relationship, between pollutant sources and the water quality criteria. It is possible through this linkage to determine the capacity of the water body to assimilate bacteria loadings while still supporting its designated use. This section describes development of the tools used to provide this linkage and to provide the data for computing the pollutant load allocations of the project water bodies.

3.1 Linkage Tool Selection

The TMDL allocation process for bacteria involves assigning bacteria, *e.g.*, *E. coli* and Enterococci, loads to their sources such that the total loads do not violate the pertinent numeric criterion protecting contact recreation use. To perform the allocation process, a tool must be developed to assist in allocating bacteria loads. Selection of the appropriate bacteria tool for Adams Bayou and Cow Bayou and associated tributaries considered availability of data and other information necessary for supportable application of the selected tool and guidance in the document titled "Bacteria Total Maximum Daily Load Task Force Final Report" (TWRI, 2007). In general, two basic tools are commonly used for bacteria TMDLs—mechanistic computer models (sometimes referred to as deterministic models) and an empirical approach referred to as the load duration curve (LDC).

Mechanistic computer models were used to develop the previous bacteria TMDLs for the impaired water bodies in the watersheds of Adams Bayou and Cow Bayou (TCEQ, 2007). However, the LDC tool has become the predominate approach for developing bacteria TMDLs for freshwater streams for the State of Texas in the last decade, and in recent years a modification of the LDC tool to accommodate tidal streams has also been used on Texas tidal rivers and creeks. Recent bacteria TMDLS for non-tidal streams and rivers of the southeast portion of Texas that used the LDC tool to provide the linkage include Eastern Houston watersheds (TCEQ, 2010b), Armand Bayou watershed (TCEQ, 2015b) and East and West Forks of the San Jacinto River watersheds (TCEQ 2016a). Tidal rivers and creeks for which TCEQ has recently adopted TMDLs and the EPA has given its approval include the tidal segments of the Mission and Aransas Rivers (TCEQ, 2016b) and Tres Palacios Creek Tidal (TCEQ, 2017).

To provide greater consistency of the bacteria pollutant load allocation process for impaired AUs of Adams Bayou and Cow Bayou, and their associated tributaries, with the approaches used most frequently by TCEQ for freely flowing water bodies, the LDC method has been selected for use in these TMDLs. As will be developed in more detail later in this section, the modified LDC method used for the tidal AUs of the project area defaults to the standard LDC method under the high flow conditions used to develop pollutant load allocations, providing additional consistency in the overall approach of developing the TMDLs.

The LDC method allows for estimation of existing and allowable loads by utilizing the cumulative frequency distribution of streamflow and measured pollutant concentration data (Cleland, 2003). An adaptation of the LDC method to tidal waters has been successfully developed and applied by the State of Oregon (ODEQ, 2006). In addition to estimating stream loads, the LDC method allows for the determination of the hydrologic conditions under which impairments are typically occurring. This information can be used to identify broad categories of sources (point and nonpoint) that may be contributing to the impairment. The LDC method has found relatively broad acceptance among the regulatory community, primarily due to the simplicity of the approach and ease of application. The regulatory community recognizes the frequent information limitations, often associated with bacteria TMDLs, which constrain the use of more powerful mechanistic models. Further, the bacteria task force appointed by TCEQ and the Texas State Soil and Water Conservation Board supports application of the LDC method within their three-tiered approach to TMDL development (TWRI, 2007). The LDC method provides a means to estimate the difference in bacteria loads and relevant criterion and can give indications of broad sources of the bacteria, *i.e.*, point sources and nonpoint sources.

The modified LDC method is based on the assumption that the combining of river water with seawater increases the loading capacity in the tidal river because seawater typically contains lower concentrations of indicator bacteria, such as Enterococci, than stream water. More details on the modified LDC method are provided later in this section and in Appendix A.

3.2 Historical Data Resources

Streamflow, discharge data for WWTFs, and salinity and indicator bacteria (*E. coli* and Enterococci) data for water quality monitoring stations are the non-geospatial data required to develop standard and modified flow/load duration curves (FDCs)/LDCs. In the modified LDC approach, salinity data provide a measure of the degree of mixing of seawater and freshwater in the tidal AUs. Necessary geospatial data include such resources as digital elevation models, the National Hydrography Dataset, and the coordinates of TCEQ monitoring stations, which are needed to define the drainage area of each station for which FDCs and LDCs will be developed.

Hydrologic data in the form of daily streamflow records were available from the USGS, which operates the sole streamflow gauge in the study area on Cow Bayou in the above tidal AU 0511A_01 (Table 14; Figure 3). This gauge serves as the primary source for streamflow records used in this document (USGS, 2019).

Table 14. Basic information on the USGS streamflow gauge in the project area.

Gauge No.	Site Description	Assessment Unit (AU)	Daily Streamflow Record (beginning & end date)
08031000	Cow Bayou near Mauriceville, TX	0511A_01	March 1952 – present *

* Daily streamflow record missing for October 1, 1986 – August 27, 2002.

Self-reported data for each TPDES permitted facility, in the form of monthly discharge reports (DMRs), were available from two EPA compliance databases. The monthly average discharge data from the combined Enforcement and Compliance History Online (ECHO) and Permit Compliance System (PCS)/ Integrated Compliance Information System (ICIS) queries began as early as 1998 and continued through 2018 at the time the databases were queried. For most facilities the DMR data began in 2001 rather than 1998. Missing data were estimated from available neighboring data. For needed WWTF discharge data prior to the beginning of DMR data, the average of the oldest three years (36 months) of data were used as representative of the period going back to 1980. If permit information indicated that the facility began operation after 1980, the discharge data were only generated back to the date the facility was first permitted. The DMR data are used to estimate adjustments to streamflow resulting from WWTF discharges upstream of a location.

Ambient Enterococci, *E. coli* and fecal coliform data were available for several stations in the watersheds of Adams Bayou and Cow Bayou (Table 15). Only Station 10441 in Adams Bayou and Station 10449 in Cow Bayou are currently monitored, and the indicator bacteria collection is for Enterococci at both stations.

Table 15. Summary of bacteria data from SWQMIS for Adams Bayou and Cow Bayou and associated tributaries.

(Listing includes stations with 10 or more data points of an indicator bacteria type and an ending date of last sample collected after December 31, 1999.)

Station	Water Body and AU	Station Description	Indicator Bacteria	Count	Date Range
10441	Adams Bayou; 0508_01	Adams Bayou at FM1006	Enterococci	126	2001 - 2018
10441	Adams Bayou; 0508_01	Adams Bayou at FM1006	*E. coli*	39	1998 - 2013
10441	Adams Bayou; 0508_01	Adams Bayou at FM1006	Fecal Coliform	120	1994 – 2003
10449	Cow Bayou; 0511_01	Cow Bayou at FM 1442	Enterococci	128	2001 - 2018
10449	Cow Bayou; 0511_01	Cow Bayou at FM 1442	*E. coli*	36	2009 - 2013
10449	Cow Bayou; 0511_01	Cow Bayou at FM 1442	Fecal Coliform	106	1994 - 2003
13781	Cow Bayou; 0511_03	Cow Bayou at FM 1442 North	Enterococci	19	2001 - 2003
13781	Cow Bayou; 0511_03	Cow Bayou at FM 1442 North	Fecal Coliform	93	1994 - 2003
15107	Adams Bayou; 0508A_01	Adams Bayou at FM 3247	Enterococci	19	2001 - 2003
15107	Adams Bayou; 0508A_01	Adams Bayou at FM 3247	Fecal Coliform	92	1996 - 2003
16041	Hudson Gully; 0508C_01	Hudson Gully at Lexington	Fecal Coliform	33	1998 - 2001
16060	Cole Creek; 0511C_01	Cole Creek at IH 10	Fecal Coliform	33	1998 - 2001
16040	Terry Gully; 0511E_01	Terry Gully at IH10	Fecal Coliform	28	1998 - 2001

For the modified LDC method, in addition to the streamflow data and bacteria data, salinity data are required. Salinity in parts per thousand (ppt) was computed using field measured specific conductance (µS/cm @ 25°C) and a conversion factor of 0.00065 ppt/ µS/cm. To be consistent with the near-surface (0.3-m) grab sample depth used when collecting bacteria data, only the near surface specific conductance data were used in developing the salinity-to-flow regressions. Specific conductance data were retrieved from SWQMIS, and those data are summarized in Table 16 after their conversion to salinity. The retrieval was temporally constrained to include data beginning January 1, 1980 and ending December 31, 2018.

Table 16. Summary of near-surface salinity data computed from specific conductance data from SWQMIS for Adams Bayou and Cow Bayou and associated tributaries (data collected 1980 – 2018).

Station	Water Body and AU	Count	Median (ppt)	Mean (ppt)	Maximum (ppt)	Minimum (ppt)
Adams Bayou Watershed						
10441	Adams Bayou 0508_01	326	1.05	2.34	15.47	0.02
10442	Adams Bayou 0508_02	22	0.30	0.59	1.87	0.03
16059	Adams Bayou 0508_03	21	0.25	0.48	1.42	0.03
14990	Adams Bayou 0508_04	54	0.19	0.45	3.49	0.02
16041	Hudson Gully 0508C_01	32	0.30	0.55	4.01	0.04
Cow Bayou Watershed						
10449	Cow Bayou 0511_01	312	1.59	3.00	17.10	0.03
13781	Cow Bayou 0511_03	96	0.10	0.17	1.18	0.01
10457	Cow Bayou 0511_04	26	0.11	0.15	0.47	0.04
16052	Coon Bayou 0511B_01	21	0.45	1.06	3.06	0.13
16060	Cole Creek 0511C_01	32	0.28	0.38	1.25	0.05

3.3 Methodology for Flow Duration and Load Duration Curve Development

LDCs display the maximum allowable load over the complete range of flow conditions by a curved line, using the calculation of flow multiplied by the water quality criterion. Through LDCs, a TMDL can be expressed as a continuous function of flow as expressed through the curved line or as a discrete value derived from a specific flow condition.

The various steps required to develop LDCs are provided below. The exceptions to the standard LDC method necessitated by the modified method are noted as needed in the steps below.

Step 1: Determine the hydrologic period of record to be used in developing the flow duration curves and a hydrologic period needed for development of the salinity-to-streamflow regressions.

Step 2: Determine desired stream locations for which flow and load duration curves will be developed and determine whether the standard or modified LDC method is required.

Step 3: Develop daily naturalized streamflow records for desired stream locations.

Step 4: Develop regressions of salinity to streamflow for each tidally influenced station for use with the modified LDC method. This step is omitted for stations that are not tidally influenced.

Step 5: Develop daily streamflow records at desired stream locations using naturalized flows from Step 3, full permitted WWTF discharges, and daily tidal volumes for the modified LDC method.

Step 6: Develop FDCs at stream locations and establish discrete flow regimes.

Step 7: Develop the allowable bacteria LDCs at the stream locations based on the relevant criteria and the data from the FDCs.

Step 8: Superpose available historical bacteria data on the allowable bacteria LDCs.

Additional information explaining the LDC method may be found in (Cleland, 2003) and (NDEP, 2003). Information on the modified LDC method is found in (ODEQ, 2006).

3.3.1 Step 1: Determine Hydrologic Periods

Two different periods of hydrologic record were specified. The first period of record is that required for application of the LDC method. The same period was used for both the standard and modified methods. The second period is required for those locations where the modified LDC method is to be applied, and that hydrologic period is required for the development of the salinity-to-streamflow regressions in Step 4.

A daily hydrologic (streamflow) record was available for USGS gauge 08031000 located on Cow Bayou near Mauriceville (Table 14, Figure 3). Though the operation of the gauge began in 1952, operation has not been continuous. The streamflow record for the gauge includes the periods of October 1957 through September 1986 and August 2002 through the present, with missing data from October 1, 1986 through August 27, 2002.

Optimally, the period of record to develop FDCs should include as much data as possible in order to capture extremes of high and low streamflows and hydrologic variability from high to low precipitation years, but the flow during the period of record selected should also be representative of recent conditions experienced within the watershed and when the indicator bacteria data were collected. Due to the nearly 17-year period without streamflow data collection, the recent 16-year period of January 1, 2003 through December 31, 2018 was selected for FDC development. This 16-year period includes the collection dates of all available Enterococci data for Stations 10441 and 10449 at the time this work effort was undertaken (Table 15). A 16-year period is of sufficient duration to contain a reasonable variation from dry months and years to wet months and years and at the same time is recent enough to contain a hydrology that is responding to current conditions in the watershed.

A second period of daily streamflows was selected for the development of the salinity-to-streamflow regressions. To provide an adequate number of data points for development of the regression, this hydrologic period was selected as January 1, 1980 through December 31, 2018, excluding the period of missing data of October 1, 1986 through August 27, 2002.

3.3.2 Step 2: Determine Desired Stream Locations

Recent indicator bacteria data in the form of Enterococci analyses were only available for Station 10441 on Adams Bayou Tidal and Station 10449 on Cow Bayou Tidal (Table 15). However, to develop the pollutant load allocations for each AU addressed in this document, a SWQM station was selected in each AU (Table 17, Figure 3). The presently monitored Stations 10441 and 10449 were selected for AUs 0508_01 and 0511_01. The selection of other stations was based on a balancing of the following considerations: location at bridge crossings for easy access, a modicum of historical data collection at the location, and location as far downstream in the AU as possible to represent as much of the drainage area of the AU as possible. With the exception of Terry Gully, the application of either the standard or modified LDC method at a station was dictated by the designation of the AU as being a freshwater stream or a tidal stream with the modified approach necessitated at tidal streams (Table 17).

Table 17. List of AUs, selected station for FDC and LDC development, and method applied.

Station	Water Body and Stream Condition	AU	Indicator Bacteria	LDC Method
10441	Adams Bayou Tidal (Tidal Stream)	0508_01	Enterococci	Modified
10442	Adams Bayou Tidal (Tidal Stream)	0508_02	Enterococci	Modified
16059	Adams Bayou Tidal (Tidal Stream)	0508_03	Enterococci	Modified
14990	Adams Bayou Tidal (Tidal Stream)	0508_04	Enterococci	Modified
15107	Adams Bayou Above Tidal (Freshwater Stream)	0508A_01	*E. coli*	Standard
16049	Gum Gully (Freshwater Stream)	0508B_01	*E. coli*	Standard
16041	Hudson Gully (Tidal Stream)	0508C_01	Enterococci	Modified
10449	Cow Bayou Tidal (Tidal Stream)	0511_01	Enterococci	Modified
13781	Cow Bayou Tidal (Tidal Stream)	0511_03	Enterococci	Modified
10457	Cow Bayou Tidal (Tidal Stream)	0511_04	Enterococci	Modified
16052	Coon Bayou (Tidal Stream)	0511B_01	Enterococci	Modified
16060	Cole Creek (Tidal Stream)	0511C_01	Enterococci	Modified
18377	Terry Gully (Freshwater Stream)	0511E_01	*E.* coli / Enterococci *	Standard

* Terry Gully (AU 0511E_01) is assessed as a freshwater stream using *E. coli* as the indicator bacteria; however, Station 18377 is located in a tidal portion of the AU. Pollutant load allocations for both *E. coli* and Enterococci will be developed for Terry Gully using the standard LDC method, because of this hydrologic complexity.

Terry Gully is considered a freshwater stream for TCEQ assessment purposes. The lower portion of the stream at Station 18377, however, exhibited distinctly tidal-stream characteristics based on water-level and salinity measurements made in summer 2004 to support calibration and verification of the modeling system used to develop the existing bacteria, DO and pH TMDLs for the Cow Bayou system (Hauck *et al*., 2020). How these complexities regarding Terry Gully are addressed in the FDC and LDC development will be presented in later portions of Section 3.

3.3.3 Step 3: Develop Daily Naturalized Streamflow Records

Once the hydrologic period of record and station locations were determined, the next step is to develop naturalized flows at all needed stations. Two different periods of daily flows were required: the 16-year period (2003 – 2018) for both the standard and modified LDC methods and the longer 1980 through 2018 period required for the salinity-to-flow regressions development at those stations were the modified LDC method would be applied. As used herein, naturalized flow is referring to the flow without the additions of permitted discharges, *i.e.*, the flows that would occur in response to precipitation, evapotranspiration, near-surface geology, soils, land covers of the watershed, and other factors. The naturalized daily streamflows were developed from the extant USGS record.

The reason for developing the naturalized daily streamflow record was because the drainage area ratio (DAR) method was used to estimate the flows at the SWQM station locations in Adams Bayou and Cow Bayou. The DAR method assumes a similarity of hydrologic response resulting from commonality of landscape features such as geology, soils, and land use/land cover. Therefore, point source derived flow influences should first be considered for removal from the flow record of the Cow Bayou gauge prior to application of the DAR. There is one active WWTF discharge above the USGS gauge on Cow Bayou (Figure 5); which is Jasper County Water Control and Improvement District (WCID) 1 with recent average discharges of 0.14 MGD or 0.22 cubic feet per second (cfs). The Jasper County WCID 1 discharge is located approximately 15 miles upstream of the USGS gauge location. Because of the combination of the small size of the discharge, its distance from the gauge, and the fact that the 16-year daily streamflow record at the USGS gauge location indicated zero streamflow for 1.1 percent of the time and flow less than 0.10 cfs for 9.2 percent of the time, the assumption was made that the existing discharge does not significantly impact the gauged streamflow record. Therefore, no adjustments for the Jasper County WCID 1 discharge were made to the Cow Bayou USGS gauge record prior to application of the DARs.

With the DAR method, each USGS gauge 08031000 daily streamflow value within the 16-year period of 2003 – 2018 was multiplied by a factor to estimate the flow at a desired SWQM station location. The factor, referred to as a DAR, was determined by dividing the drainage area above the desired monitoring station location by the drainage area above the USGS gauge. The DARs for desired locations within the Adams and Cow Bayou watersheds are presented in Table 18.

For the development of the longer daily streamflow record required for the salinity-to-streamflow regressions, the same DARs were used. Each daily streamflow for the Cow Bayou USGS gauge during the period of January 1, 1980 through December 31, 2018 was multiplied by the appropriate DAR for each station where the modified FDC approach was to be applied to give the estimated naturalized flow. This long-term daily flow record has missing data from October 1, 1986 through August 27, 2002; the time period when the gauge was nonoperational.

3.3.4 Step 4: Develop Salinity-to-Streamflow Regressions

As part of the application of the modified LDC method, it was necessary to develop a relationship between estimated actual daily streamflow and measured salinity for each station located in an AU designated as a tidal stream. For this step the longer naturalized daily streamflow record from 1980 through 2018 was used. By expanding the time period considered for regression development, the number of data points available were increased over that available for the 16-year period used with application of the LDC method. To develop the required regressions, first the naturalized flows developed in Step 3 were adjusted to estimate the actual daily flows at each needed station by adding in the actual discharges from WWTFs located above each selected station. The actual discharge for each WWTF was determined based on DMR data obtained from EPA ECHO and PCS/ICIS databases, and the monthly average discharges from the databases were applied to each day of the reported month.

Table 18. DARs for locations within the Adams and Cow Bayou watersheds.

AU	Gauge/Station No.	Stream Location	Location Drainage Area (acres)	DAR
0511A_01	USGS 08031000	Cow Bayou Above Tidal	53,734	N/A
0508_01	TCEQ 10441	Adams Bayou Tidal	28,198	0.525
0508_02	TCEQ 10442	Adams Bayou Tidal	25,096	0.467
0508_03	TCEQ 16059	Adams Bayou Tidal	24,445	0.455
0508_04	TCEQ 14990	Adams Bayou Tidal	21,628	0.403
0508A_01	TCEQ 15107	Adams Bayou Above Tidal	19,173	0.357
0508B-01	TCEQ 16049	Gum Gully	1,866	0.035
0508C_01	TCEQ 16041	Hudson Gully	1,123	0.021
0511_01	TCEQ 10449	Cow Bayou Tidal	120,898	2.250
0511_03	TCEQ 13781	Cow Bayou Tidal	68,210	1.269
0511_04	TCEQ 10457	Cow Bayou Tidal	65,475	1.219
0511B_01	TCEQ 16052	Coon Bayou	3,534	0.066
0511C_01	TCEQ 16060	Cole Creek	8,292	0.154
0511E_01	TCEQ 18377	Terry Gully	22,022	0.410

Using the estimated actual streamflow (naturalized plus upstream WWTF discharges) and near-surface salinity data determined from field specific conductance measurements (summarized in Table 16), salinity-to-streamflow regressions were developed for Station 10441 on Adams Bayou Tidal and Station 10449 on Cow Bayou (Figures 10 and 11). While the paired data in both scatterplots showed high variability in response of salinity to flow, statistically significant regression equations were obtained for both sets of data and a definite inverse relationship of salinity to flow is apparent.

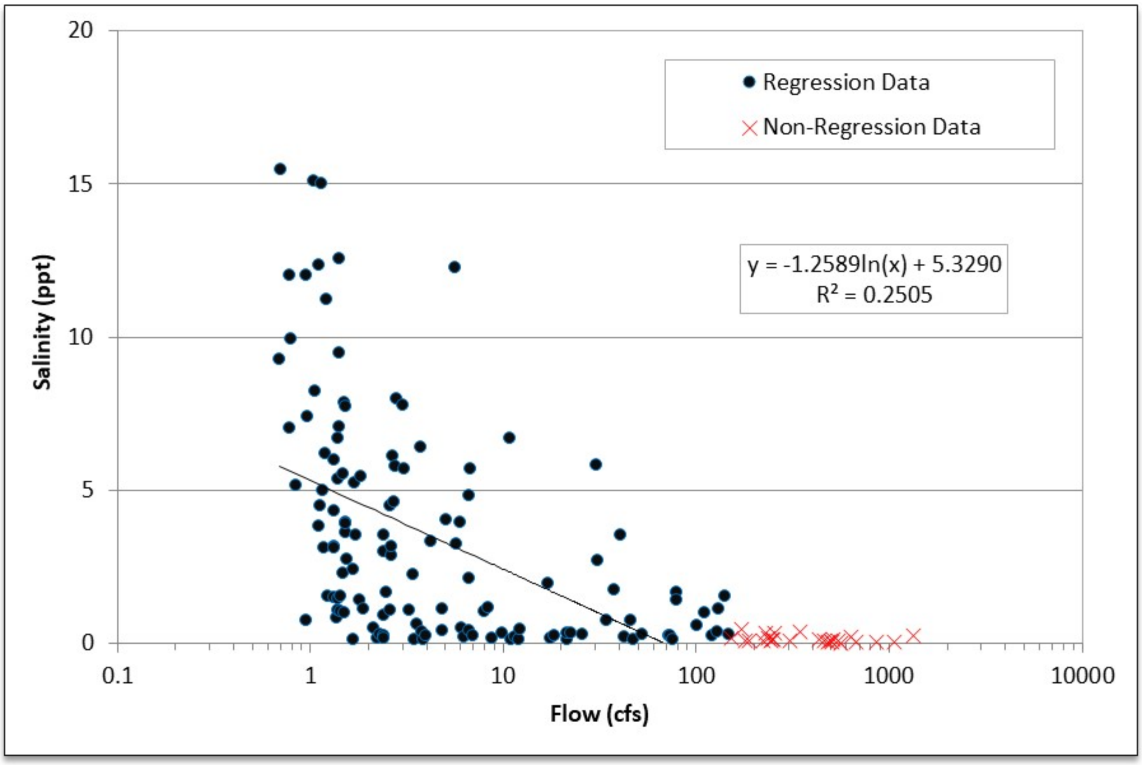


Figure 10. Salinity-to-streamflow regression for Station 10441; Adams Bayou AU 0508_01.

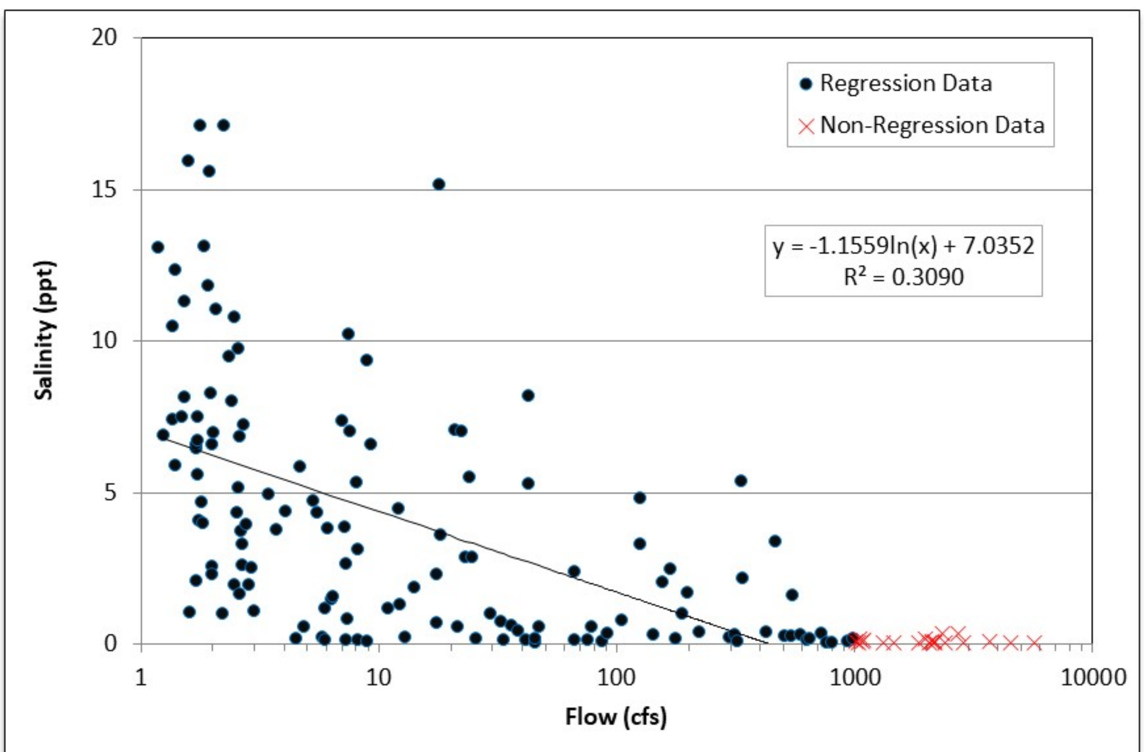


Figure 11. Salinity-to-streamflow regression for Station 10449; Cow Bayou AU 0511_01.

A different approach was required at the other stations due to two data constraints. First, the other stations for which a salinity-to-streamflow regression needed to be developed had fewer salinity data points than Stations 10441 and 10449 (Table 16). Second, typically most of the available data points were collected during the time period of October 1, 1986 through August 27, 2002 when streamflow data were not available for the Cow Bayou USGS gauge. The approach taken was to develop a linear regression between the salinity data at the desired station and the salinity data for either Station 10441 or Station 10449 depending upon the watershed location of the station. Fortunately, for the vast majority of these historical data collection efforts, specific conductance measurements were made at all the stations in the Adams Bayou watershed on the same date and the same occurred for the stations in the Cow Bayou watershed.

A summary of the linear regressions of salinity at selected stations (as the dependent variable) to salinity of either Station 10441 or Station 10449 (as the independent variable) is provided in Table 19. Generally, the stronger regressions, as measured by the coefficient of determination (R^2), were for the more downstream stations and slopes of the regressions were typically statistically significant based on p-values at the 0.01 level. The intercepts of the regression equations were often not statistically significant (*i.e*., not distinguishable from zero), which was anticipated. Cole Creek Station 16060 provided challenges to regression development because of the relatively low salinities (range of 0.05 ppt to 1.25 ppt) and the occurrence of some of same-date of collection salinity data pairs indicating higher salinity at Station 16060 than at further downstream Station 10449. Removal of contradictory and inconsistent data pairs from the linear-regression analyses was necessary to develop the regression provided in Table 19.

These regression equations were used to develop estimated salinities at each station based on the measured salinities at either Station 10441 or Station 10449. These estimated salinities were then used with the estimated actual streamflows (*i.e.*, natural flow plus upstream WWTF discharges) to develop a location-specific salinity-to-streamflow regression for each station. The resulting regressions, including the ones more directly developed for Stations 10441 and 10449 are provided in Table 20. The regressions are based on making a natural logarithmic (ln) transformation of streamflow (*i.e.*, salinity = intercept + slope * ln (streamflow).

3.3.5 Step 5: Development of Streamflow Records

For all stations, regardless of whether the standard or modified LDC method was applied, the first part of this step is common to both. To account for WWTFs at their daily permitted discharge limit, the summation of the full permitted daily average discharges from all upstream WWTFs and any additional WWTFs located downstream of the desired station but within the same AU is added to the naturalized flow developed in Step 3. Because of the TMDL pollutant load allocation is performed on an AU basis, it is necessary that the streamflow record include not only the full permitted discharge for all upstream WWTFs but also the full permitted discharge from any downstream WWTFs that are located in the same AU as the station selected for each AU. Further, additional flow is included for future growth of permitted discharges based on current permitted discharges and population projections (Table 3), which is discussed in detail in Section 4.7.4.

Table 19. Linear regression of salinity at various stations to either station 10441 in Adams Bayou or 10449 in Cow Bayou and regression performance statistics.

Station	Water Body	Intercept	Slope	p-value intercept	p-value slope	R^2
Adams Bayou Watershed (Station 10441 salinities used as independent variable in regression development)						
16041	Hudson Gully 0508C_01	0.1016	0.2837	0.390	<0.001	0.72
10442	Adams Bayou 0508_02	0.0602	0.6220	0.576	<0.001	0.67
16059	Adams Bayou 0508_03	0.1169	0.4079	0.422	0.006	0.35
14990	Adams Bayou 0508_04	-0.0153	0.2800	0.842	<0.001	0.59
Cow Bayou Watershed (Station 10449 salinities used as independent variable in regression development)						
16060	Cole Creek 0511C_01	0.0405	0.2928	0.328	<0.001	0.96
16052	Coon Bayou 0511B_01	0.1147	0.4573	0.573	<0.001	0.68
13781	Cow Bayou 0511_03	0.0383	0.0490	0.030	<0.001	0.58
10457	Cow Bayou 0511_04	0.0766	0.0583	0.008	<0.001	0.51

Table 20. Summary of salinity-to-streamflow regression at various stations in the Adams and Cow Bayou watersheds.

Station	Water Body	Intercept	Slope	p-value intercept	p-value slope	R^2
Adams Bayou Watershed						
16041	Hudson Gully 0508C_01	0.4702	-0.2012	<0.001	<0.001	0.29
10441	Adams Bayou 0508_01	5.329	-1.259	<0.001	<0.001	0.25
10442	Adams Bayou 0508_02	3.370	-0.8046	<0.001	<0.001	0.25
16059	Adams Bayou 0508_03	1.939	-0.4693	<0.001	<0.001	0.26
14990	Adams Bayou 0508_04	0.9178	-0.2078	<0.001	<0.001	0.24
Cow Bayou Watershed						
16060	Cole Creek 0511C_01	1.0005	-0.2536	<0.001	<0.001	0.32
16052	Coon Bayou 0511B_01	1.2834	-0.4033	<0.001	<0.001	0.32
10449	Cow Bayou 0511_01	7.0352	-1.1559	<0.001	<0.001	0.31
13781	Cow Bayou 0511_03	0.3142	-0.0494	<0.001	<0.001	0.36
10457	Cow Bayou 0511_04	0.4034	-0.0596	<0.001	<0.001	0.35

At this point in the computations, the streamflow records are completed for all stations for which the standard LDC method is being applied, *i.e.*, stations located in AUs for which their associated segments are designated as freshwater streams (Table 17). For all tidal streams, there is an additional part to this step wherein the daily seawater volume must be determined and added to the estimated freshwater flow determined from the DAR method and adding any WWTF discharges associated with the station location.

For each tidal AU location, the regression equations from Step 4 were used with the computed freshwater daily flow in the computation of a total daily flow volume including freshwater and seawater. The process requires manipulation of the following mass balance equation for salinity at a tidally influenced station:

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

Where

V_r = volume of daily freshwater (river) flow (cfs) = Q * 86,400 (s/d); where Q = river flow (cfs)

V_s = volume of daily seawater flow

S_t = salinity in river (part per thousand or ppt)

S_r = background salinity of upstream river water (ppt); assumed = 0 ppt

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

Through algebraic manipulation this mass balance equation can be solved for the daily volume of seawater required to be mixed with freshwater (again, freshwater having an assumed salinity ≈ 0) giving the equation found in the ODEQ (2006) technical information:

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

Where S_t was computed for each day of the 16-year streamflow record using the station-specific regression equations of Step 4 (Table 20) and the estimated daily freshwater streamflow (V_r) from this step as input to the equation. The calculation of S_t allowed V_s to be computed from Eq. 2.

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

$$V_t = V_r + V_s \quad \text{(Eq. 3)}$$

3.3.6 Step 6: Development of Flow Duration Curves

In this step, the FDCs were developed for each station in Table 17. In order to generate a FDC, the following actions were undertaken:

1) Order the daily streamflow data from highest to lowest values and assign a rank to each data point (1 for the highest flow, 2 for the second highest flow, and so on);
2) Compute the percent of days each flow was exceeded by dividing each rank by the total number of data points plus 1; and
3) Plot the corresponding flow data against exceedance percentages.

Exceedance values along the x-axis represent the percent of days that flow was at or above the associated flow value on the y-axis. Exceedance values near 100 percent occur during low flow or drought conditions while values approaching 0 percent occur during periods of high flow or flood conditions. This graphical procedure provides information on basic hydrological characteristics in the stream based upon flows observed within specific reaches.

The FDCs for all the stations in the Adams Bayou watershed are presented in Figure 12, and the FDCs for all the stations in Cow Bayou watershed are presented in Figure 13. Flows less than 0.01 cubic feet per second (cfs) are not shown on the graphs maintaining consistency with that value as the minimum nonzero flow reported for USGS streamflow gauging stations.

The FDC for Station 10441 in Adams Bayou Tidal AU 0508_01 is presented in Figure 14 as an example to depict the components of seawater and stream water comprising FDCs developed for the tidal streams using the modified approach. Note that the x-axis direction of increase on the seawater plot is reversed from that on the FDC.

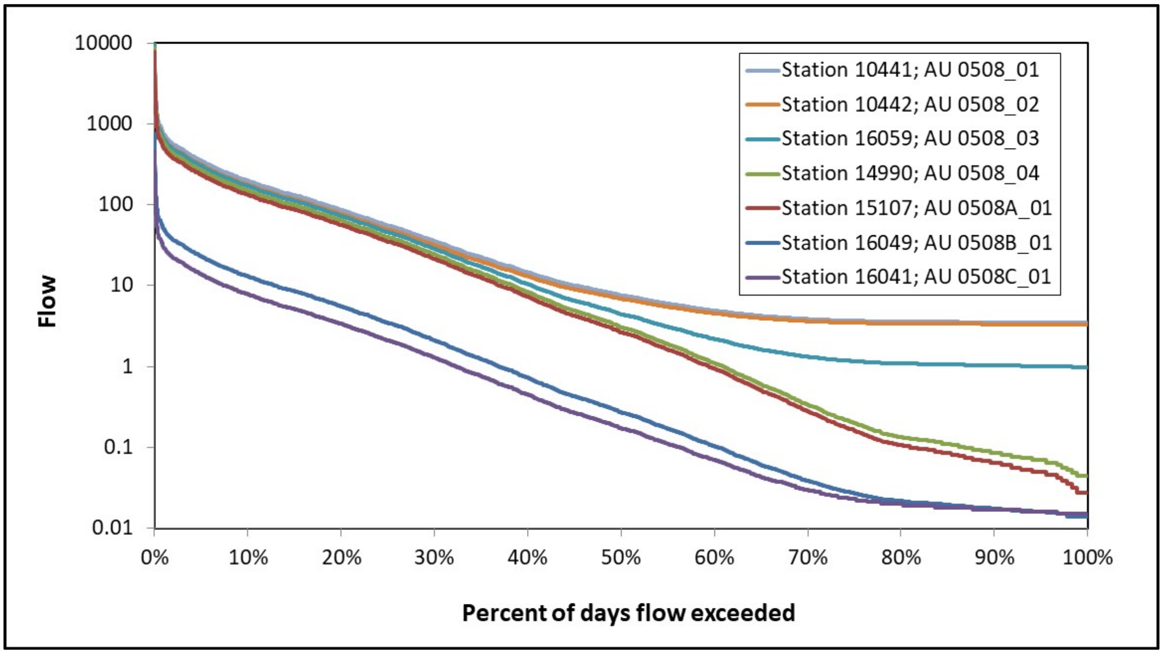


Figure 12. Flow duration curves for selected stations in Adams Bayou and two tributaries (standard or modified FDC presented as required for station).

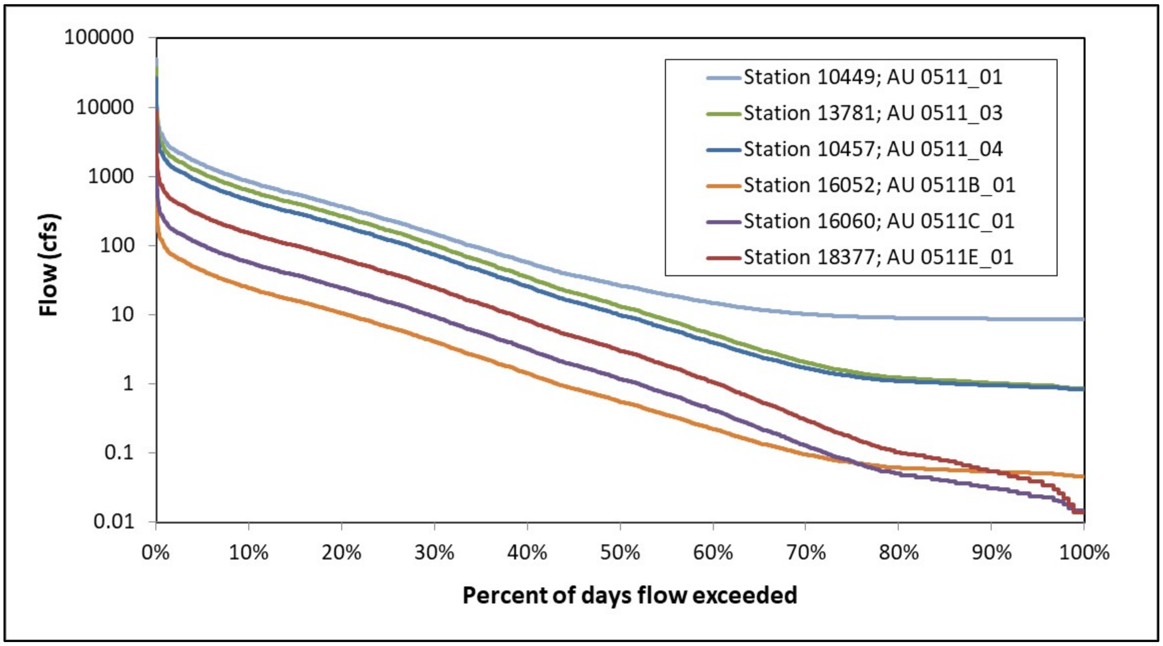


Figure 13. Flow duration curves for selected stations in Cow Bayou and three tributaries (standard or modified FDC presented as required for station).

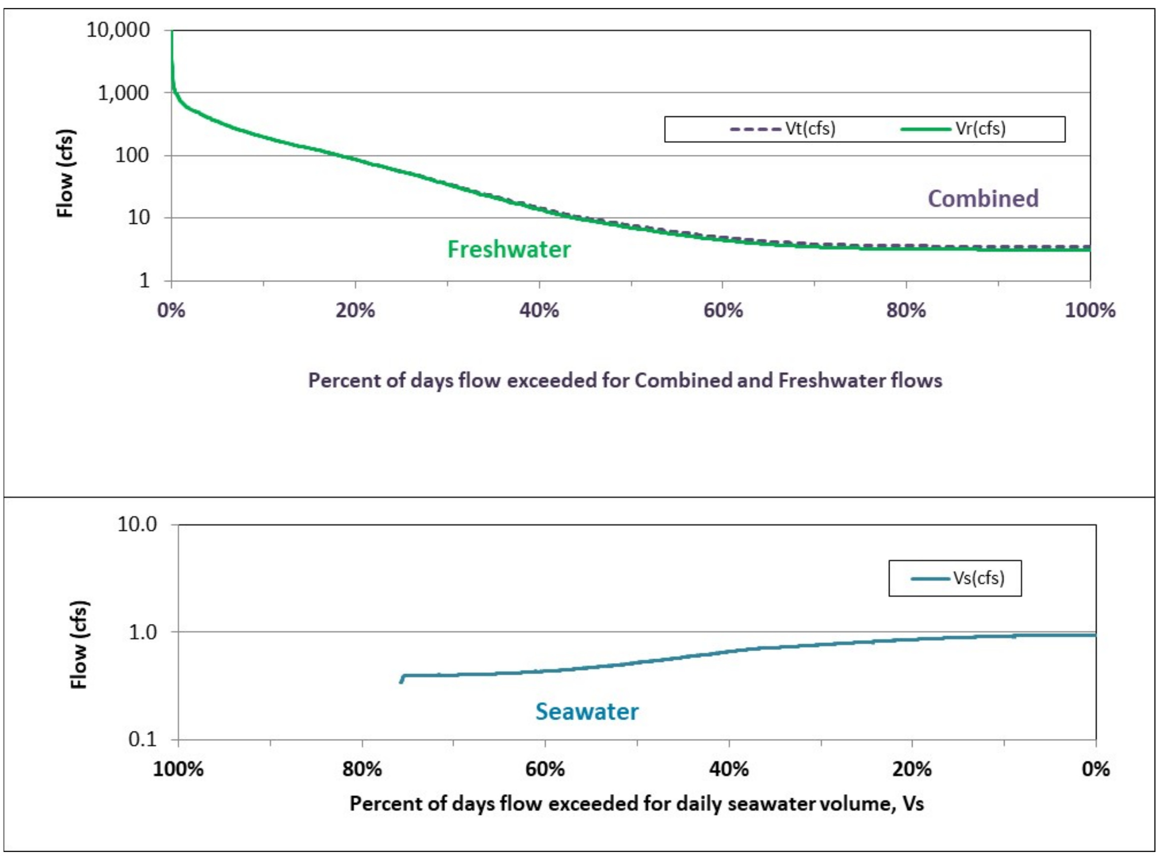


Figure 14. Modified FDC for Station 10441 in Adams Bayou Tidal AU 0508_01 depicting additional seawater daily volume.

A point of importance to the pollutant load allocation process is shown in Figure 14 regarding the fact that daily seawater volume is only computed as a nonzero value for about 80 percent of the time. This occurrence of high freshwater flows for which there are no associated seawater volume computed is also depicted in the salinity-to-streamflow regressions for Adams Bayou and Cow Bayou (Figures 10 and 11). The significance of the above observation is related to what happens within the modified LDC method when salinities are at background. As salinity approaches background, V_s in Eq. 2 approaches a value of zero, and in fact would be defined as zero when salinities are at background levels, resulting in the modified LDC flow volume (V_s + V_r) defaulting to the freshwater flow of the tidal stream, *i.e.*, <u>no modification occurring to that portion of the LDC</u>.

Therefore, regarding the pollutant load allocation process for the Adams Bayou, Cow Bayou and associated tributaries, the modified LDC method provides identical allowable loadings at higher flows to those that would be computed using the standard LDC method that does not include tidal influences. The identical results of the modified and standard LDC method for the higher flows is the physical reality indicated in the observed salinity data that at these elevated streamflows seawater is effectively "pushed" completely out of these bayou systems. But another implication is that for Adams Bayou, Cow Bayou and associated tributaries, the same pollutant load allocation results would be determined with the LDC method with or without tidal influences being considered due to development of the TMDL for the higher streamflows as described in Section 4.7. The smallest freshwater flow from the regression analysis resulting in background concentrations of salinity and its exceedance percentile for the AUs where the modified LDC method was applied are provided in Table 21.

As mentioned in Step 2 above, Terry Gully is considered a freshwater stream for TCEQ assessment purposes, but also exhibits tidal-stream characteristics in the lower portion of the stream at Station 18377. The lower portion of the stream at Station 18377 was selected for pollutant load allocation development because the drainage area at this location represents most of the Terry Gully watershed. Station 18377, however, was only sampled during the special data collection efforts that occurred during the development of the existing bacteria, DO and pH TMDLs. As a result, the amount of salinity data available for Station 18377 is inadequate in the number of measurements and the breadth of conditions over which data were collected to allow development of the salinity-to-flow regression needed for the modified FDC. Importantly and as explained in the paragraphs immediately above, under the high flow conditions the modified FDCs for the tidal AUs of Cow Bayou and its tidal tributaries are identical to the standard FDCs. The reason for this equality is because high freshwater flows are sufficient to cause background salinity conditions in the water bodies. Even if a modified FDC could be developed for Station 18377, as it should because of the tidal influences at the location, the portion of the modified FDC that would be used for developing the load for the pollutant load allocation would be identical to those from the same portion of the standard FDC. Therefore, the standard FDC can be applied at Station 18377 without affecting the value of the loading to be used in developing its pollutant load allocation, even though the FDC will not reflect the added seawater volume that would be present at lower freshwater flows.

Table 21. Smallest freshwater flow by AU predicted by the salinity-to-streamflow regressions to produce background salinities and the exceedance percentile of that flow.

Station	Water Body	Smallest Streamflow Predicted to Give Background Salinities (cfs)	Exceedance Percentile of Streamflow
Adams Bayou Watershed			
16041	Hudson Gully 0508C_01	3.83	18%
10441	Adams Bayou 0508_01	58.8	24%
10442	Adams Bayou 0508_02	51.4	24%
16059	Adams Bayou 0508_03	40.7	26%
14990	Adams Bayou 0508_04	31.6	27%
Cow Bayou Watershed			
16060	Cole Creek 0511C_01	24.0	20%
16052	Coon Bayou 0511B_01	14.7	16%
10449	Cow Bayou 0511_01	370	20%
13781	Cow Bayou 0511_03	10.1	53%
10457	Cow Bayou 0511_04	30.3	38%

3.3.7 Step 7: Development of LDCs

In Step 7 the FDCs for each selected station in the watersheds of Adams Bayou and Cow Bayou were combined with the pertinent numeric water quality criterion established to protect the contact recreation use. The pertinent criterion for the tidal streams, where the modified LDC method was applied, is the geometric mean concentration of Enterococci not to exceed 35 cfu per 100 mL, and the pertinent criterion for freshwater streams, where the standard LDC method was applied, is the geometric mean concentration of *E. coli* not to exceed 126 cfu per 100 mL. Each LDC was developed by multiplying the daily streamflow values (in cfs) from Step 6 by the appropriate bacteria criterion and by the conversion factor (2.446572×10^{-2}) to express the loadings as billion cfu per day.

The shape of each LDC is identical to that of the FDC for the same station/AU, because the data in the FDCs have all been multiplied by the same conversion factor. The label on the y-axis simply changes from Flow (cfs) to Enterococci or *E. coli* (billion cfu/day), and the label on the x-axis changes from “percent of days flow exceeded” to “percent of days load exceeded.”

A useful refinement of the LDC method is to divide the curve into flow-regime regions or hydrologic condition classes to analyze exceedance patterns in smaller portions of the duration curves. This approach can assist in determining streamflow conditions under which exceedances are occurring. A commonly used set of regimes that is provided in Cleland (2003) is based on the following five intervals along the x-axis of the FDCs and LDCs: (1) 0-10 percent (high flows); (2) 10-40 percent (moist conditions); (3) 40-60 percent (mid-range flows); (4) 60-90 percent (dry conditions); and (5) 90-100 percent (low flows).

For the TMDL watersheds, a three-interval division was selected:

- High flow regime: 0-10 percent range, related to flood conditions and non-point source loading
- Mid-range flow regime: 10-60 percent range, intermediate conditions of receding hydrographs after storm runoff and base line conditions
- Low flow regime: 60-100 percent range, related to dry conditions

The selection of the flow regime intervals was based on general observation of the shape of the FDC curves for the monitoring stations of Adams Bayou and Cow Bayou and associated tributaries. The high flow regime (0-10 percent range) consistently represents the steepest portion of the FDC. At about the 10 percent exceedance flow to the 60 percent exceedance, a relatively constant slope occurs defined as the mid-range flows. For the low flow regime of the 60-100 percent range, the FDC curve for stations influenced by point source discharges showed a more gradual decrease.

The LDC curves for *E. coli* loadings developed for the freshwater streams of Adams Bayou Above Tidal (AU 0508_01), Gum Gully (AU 0508B_01) and Terry Gully (AU 0511E_01) are provided in Figure 15. This set of LDCs were developed using the standard approach for freshwater streams. The modified approach for tidal streams was used to develop the LDC curves for Enterococci loadings for tidal Adams Bayou watershed locations and tidal Cow Bayou watershed locations, and the LDCs are provided in Figures 16 and 17.

3.3.8 Step 8: Superpose Historical Bacteria Data

In this step, the recent historical bacteria measurements (Enterococci) for Adams Bayou AU 0508_01 (Station 10441) and Cow Bay AU 0511_01 (Station 10449) were aligned with the streamflow on the day of measurement. The historical bacteria measurements were then multiplied by the streamflow value and the conversion factor, as performed in Step 7, to calculate a loading associated with each measured bacteria concentration. Note that Step 8 was only performed for the two stations with recent bacteria data (Table 15).

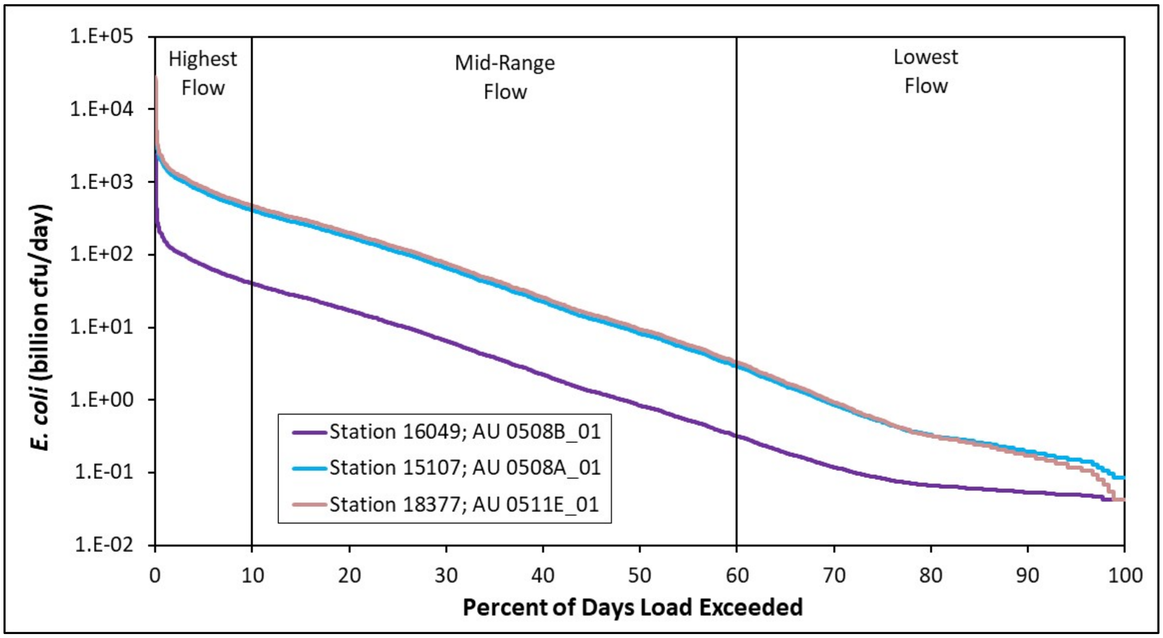


Figure 15. Load duration curves for freshwater streams of the watersheds of Adams Bayou and Cow Bayou.

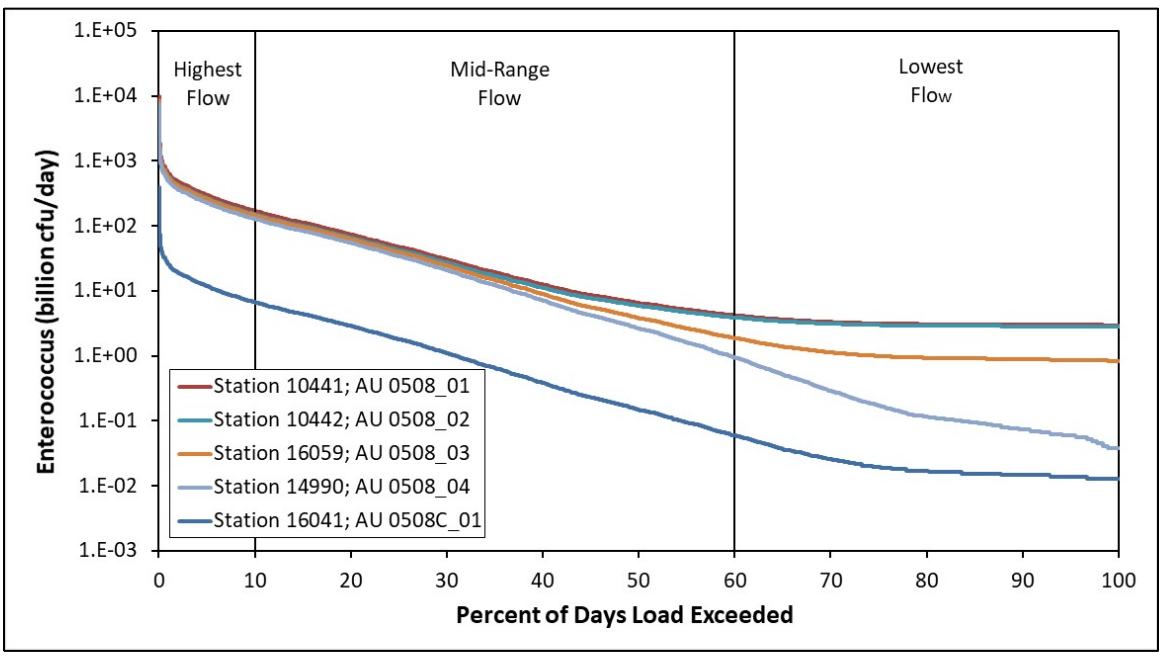
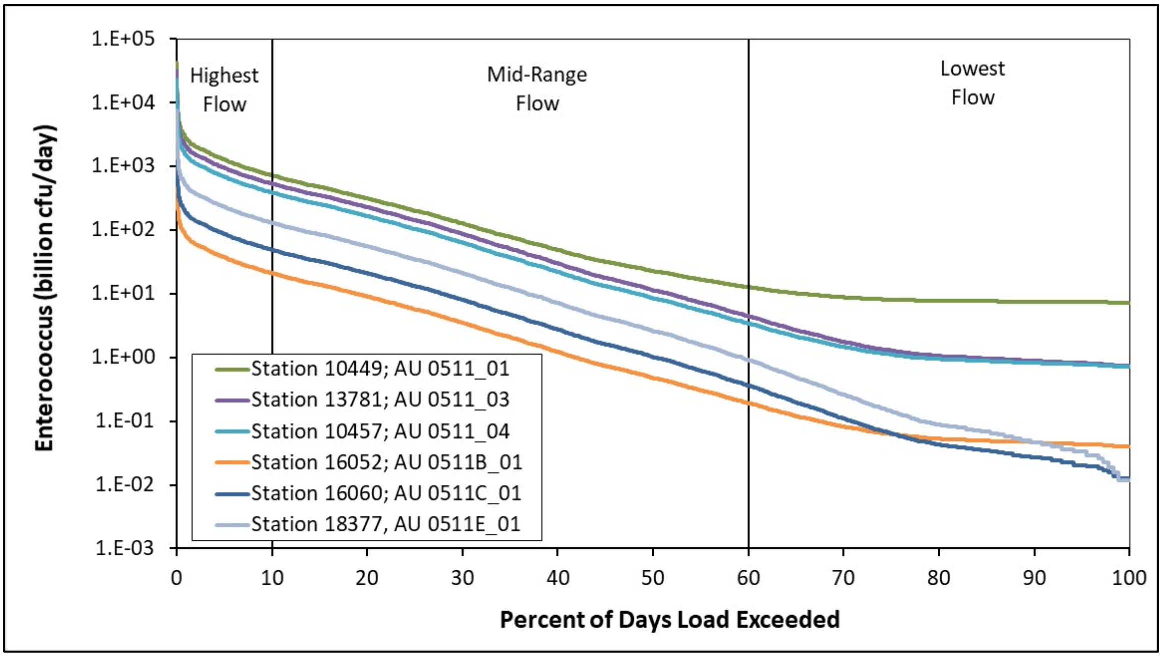


Figure 16. Load duration curves for tidal streams of the Adams Bayou watershed.



Note: At Station 18377 (AU 0511E_01), the LDC for Enterococci was constructed using the standard FDC provided in Figure 13. The *E. coli* LDC for Station 18377 is provided in Figure 15.

Figure 17. Load duration curves for tidal streams of the Cow Bayou watershed.

On each graph the measured Enterococci data are presented as associated with a “wet weather event” or a “non-wet weather event.” A sample was determined to be influenced by a wet weather event based on the reported “days since last precipitation” (DSLP) ≤ 4 days as noted on field data sheets associated with each sampling event. DSLP (TCEQ water quality parameter code 72053) is a field parameter that may be noted during a sampling event to inform of the general climatic and hydrologic conditions. Note that a wet weather event can be indicated even under low flow conditions as a result of only a small runoff event during a period of very low base flow in the stream.

Points above a curve represent exceedances of the bacteria criteria and associated allowable loadings. Geometric mean loadings for the data points within each flow regime were calculated and displayed on each figure to aid in interpretation.

An additional refinement made to each LDC at this step to aid in interpreting the plotted Enterococci measurements was the inclusion of an allowable loading curve for the single sample criterion of 104 cfu/100 mL. In an analogous manner to Step 7 computations, the single sample criterion LDC was developed by multiplying the daily streamflow values (in cfs) by 104 cfu/100 mL and by the conversion factor (2.44657×10^{-2}) to express the loadings as billion cfu per day. The single sample criterion LDC is provided on the graphs as a dashed line to both distinguish it from the geometric mean criterion LDC and to emphasize that the solid-line geometric mean criterion LDC is to be used in the pollutant load allocation computation presented in Section 4.

The LDC graphic for Adams Bayou AU 0508_01, Station 10441, with measured Enterococci data and the single sample criterion LDC added is provided in Figure 18. The LDC graphic for Cow

Bayou AU 0511_01, Station 10449, is provided in Figure 19. For both LDCs (Figures 18 and 19), the wet weather data points occurred, as expected, most frequently under the higher flow regimes and consistently exceeded the geometric mean criterion. Wet weather data points in the lowest flow regime most likely represent bacteria data collected after a small rainfall runoff event when conditions up to the event were dry. For both Adams Bayou and Cow Bayou, the measured Enterococci data generally exceed both the geometric and single sample LDC under all flow conditions. There are some occurrences of lower measured bacteria values between the exceedance percentiles of 30 to 100. On both LDCs there are a series of high loadings under the lowest flow regime that plot in the same range, almost horizontally to one another, and the Enterococci concentration for these data points were > 2,400 cfu/100 mL, with one concentration on Adams Bayou in this category at > 4,800 cfu/100 mL. In these instances, the bacteria concentration was plotted as either 2,400 or 4,800 cfu/100 mL.

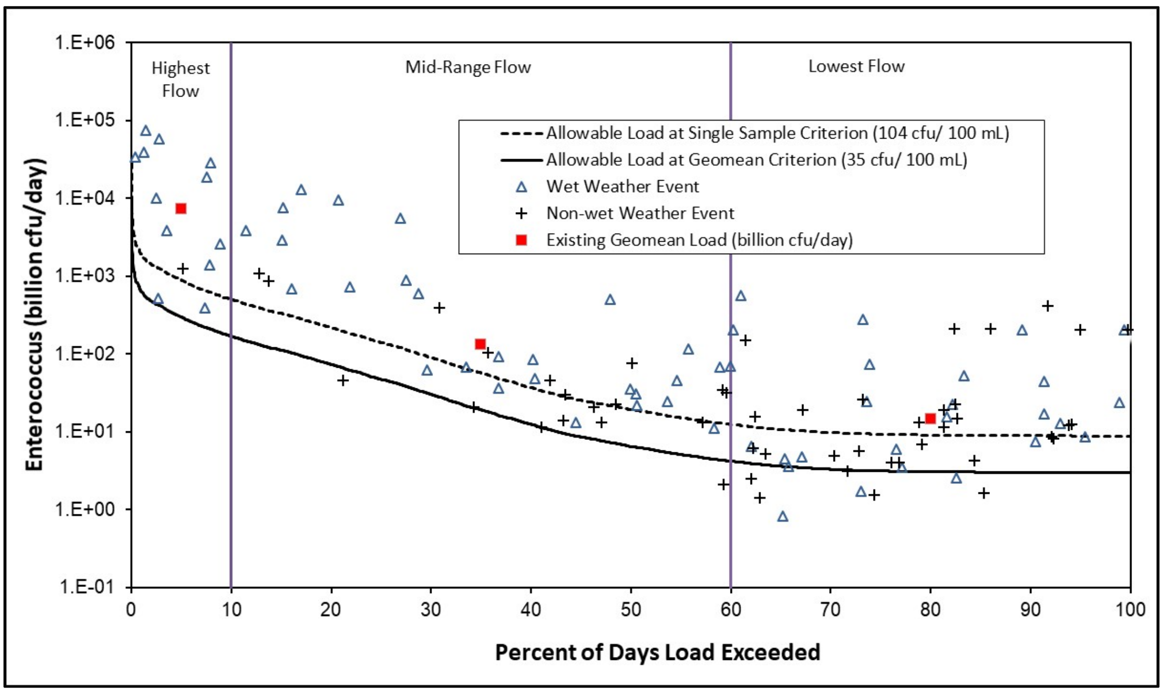


Figure 18. Load duration curve at Station 10441 on Adams Bayou Tidal (AU 0508_01).

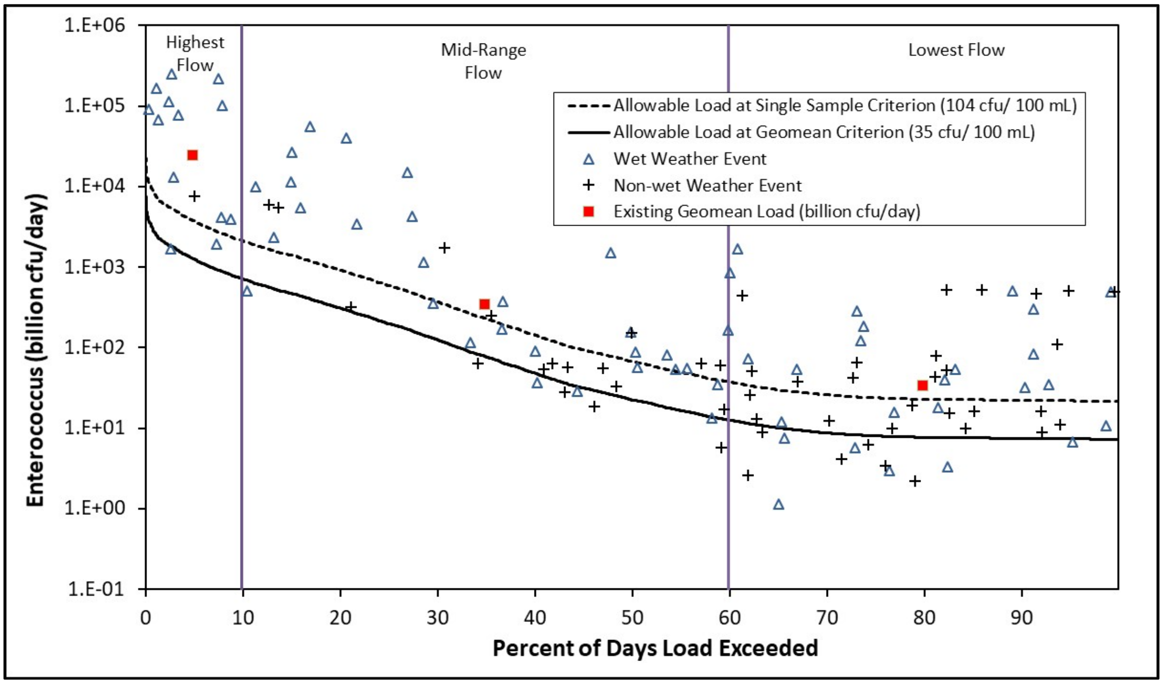


Figure 19. Load duration curve at Station 10449 on Cow Bayou Tidal (AU 0511_01).

Section 4
TMDL Allocation Analysis

Presented in this report section is the development of the bacteria TMDL allocation for the TMDL watershed. The tools used for developing the TMDL allocation were the standard LDC method for freshwater streams and the modified LDC method for tidal streams. Endpoint identification, margin of safety, load reduction analysis, TMDL allocations, and other TMDL components are described herein.

Both the standard and modified LDC methods provided flow-based approaches to determine necessary reductions in bacteria loadings and allowable loadings within the TMDL watershed. As developed previously in this report, both LDC methods use frequency distributions to assess a bacteria criterion over the historical range of flows, providing a means to determine maximum allowable loadings and the load reduction necessary to achieve support of the primary contact recreation use.

For the purposes of this TMDL study, the TMDL watershed is considered to be the watersheds of Adams Bayou, Cow Bayou and associated tributaries (AUs 0508_01, 0508_02, 0508_03, 0508_04, 0508A_01, 0508B_01, 0508C_01, 0511_01, 0511_03, 0511_04, 0511B_01, 0511C_01, and 0511E_01) as shown in the overview map (Figure 1). Though not currently listed for bacteria impairments, AUs 0508A_01 and 0511E_01 are included in the TMDL development and allocation analysis.

4.1. Endpoint Identification

All TMDLs must identify a quantifiable water quality target that indicates the desired water quality condition and provides a measurable goal for the TMDL. The TMDL endpoint also serves to focus the technical work to be accomplished and as a criterion against which to evaluate future conditions. Adams Bayou, Cow Bayou and associated tributaries have a designated use of primary contact recreation, which is measured against a numeric criterion for the indicator bacteria of *E. coli* for freshwater streams and Enterococci for tidal streams. Indicator bacteria are not generally pathogenic, but are indicative of potential viral, bacterial, and protozoan contamination originating from the feces of warm-blooded animals. The *E. coli* criterion to protect contract recreation in freshwater consists of a geometric mean concentration not to exceed 126 cfu/100 mL and the Enterococci criterion to protect contact recreation in saltwater systems consists of a geometric mean concentration not to exceed 35 cfu/100 mL (TCEQ, 2010a).

The endpoints for this TMDL are to maintain concentrations of *E. coli* below the geometric mean concentration of 126 cfu/100 mL for freshwater streams and Enterococci below the geometric mean criterion of 35 cfu/100 mL for tidal streams. These endpoints are identical to the geometric mean criterion in the 2010 Surface Water Quality Standard (TCEQ, 2010a) for primary contact recreation in freshwater and saline water bodies.

4.2 Seasonality

Seasonal variations or seasonality occur(s) when there is a cyclic pattern in streamflow and, more importantly, in water quality constituents. Federal regulations (40 CFR §130.7(c)(1)) require that TMDLs account for seasonal variation in watershed conditions and pollutant loading. Analysis of the seasonal differences in indicator bacteria concentrations were assessed by comparing Enterococci concentrations obtained from routine monitoring collected in the warmer months (May - September) against those collected during the cooler months (November - March) at Station 10441 on Adams Bayou and Station 10449 on Cow Bayou. The months of April and October were considered transitional between the warm and cool seasons and were excluded from the seasonal analysis. Enterococci data for the period of 2003 – 2018, coinciding with the period used in the LDCs, were used in the analysis. Differences in Enterococci concentrations obtained in warmer versus cooler months were then evaluated by performing a Wilcoxon Rank Sum test on the original dataset. The nonparametric Wilcoxon Rank Sum test was selected because even with logarithmic transformation the bacteria data were non-normally distributed. Results of the statistical analysis for Adams Bayou ($\alpha=0.05$, $p=<0.01$) and Cow Bayou ($\alpha=0.05$, $p=0.0494$) indicated that there is significant difference in indicator bacteria between cool and warm weather seasons for both water bodies (Table 22). The Enterococci data also indicate that the cool season generally has higher concentrations than the warm season for Adams Bayou and Cow Bayou as indicated by the geometric mean concentrations in Table 22. It should be noted that the criteria used by TCEQ to assess recreational uses apply to water bodies during all seasons of the year.

Table 22. Data summary and results of seasonality testing using Wilcoxon Rank Sum test for Station 10441 on Adams Bayou and Station 10449 on Cow Bayou.

Station (Bacteria Indicator)	AU	Water Body	Cool Season		Warm Season		Wilcoxon Rank Sum Test p-value
			Number of Data	Geometric Mean (cfu/100 mL)	Number of Data	Geometric Mean (cfu/100 mL)	
10441 (Enterococci)	0508_01	Adams Bayou	48	380	48	160	<0.01
10449 (Enterococci)	0511_01	Cow Bayou	49	265	49	122	0.0494

4.3 Linkage Analysis

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

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

Bacteria load contributions from permitted and non-permitted stormwater sources are greatest during runoff events. Rainfall runoff, depending upon the severity of the storm, has the capacity to carry indicator bacteria from the land surface into the receiving stream. Generally, this loading follows a pattern of lower concentrations in the water body just before the rain event, followed by a rapid increase in bacteria concentrations in the water body as the first flush of storm runoff enters the receiving stream. Over time, the concentrations decline because the sources of indicator bacteria are attenuated as runoff washes them from the land surface and the volume of runoff decreases following the rain event.

Load duration curves were used to examine the relationship between instream water quality and the source of indicator bacteria loads. Inherent to the use of LDCs as the mechanism of linkage analysis is the assumption of a one-to-one relationship between instream loadings and loadings originating from point sources and the landscape as regulated and unregulated sources. Further, this one-to-one relationship was also inherently assumed when using LDCs to define the TMDL pollutant load allocation (Section 4.7). That is, the allocation of pollutant loads was based on apportioning the loadings based on flows assigned to WWTFs, a fractional proportioning of the remaining flow based on the area of the watershed under stormwater regulation, and assigning the remaining portion to unregulated stormwater.

4.4 Load Duration Curve Analysis

The standard LDC method was used for the freshwater streams addressed in this document and the modified LDC method was used for the tidal streams to examine the relationship between instream water quality and the broad sources of indicator bacteria loads. These LDC methods are the basis of the TMDL allocations. The strength of this TMDL approach is the use of these two LDC methods to determine the TMDL allocations. Both LDC methods are a simple statistical method that provides a basic description of the water quality problem. This tool is easily developed and explained to stakeholders and uses available water quality and flow data. These LDC methods do not require any assumptions regarding loading rates, stream hydrology, land use conditions, and other conditions in the watershed. The EPA supports the use of the basic LDC method to characterize pollutant sources including the modifications to include tidal influences. In addition, many other states are using this basic method to develop TMDLs, though the modified LDC method is more limited in its application. As discussed in more detail in Section 4.7 (Pollutant Load Allocation), the TMDL loads were based on the median flow within the high flow regime (or 5 percent exceedance flow), where exceedances of the primary contact recreation criteria are most pronounced. Under the high flow regime, there was no seawater volume computed as being present at the selected station in each tidal AU. With an absence of seawater at these high flows, the modified LDC results effectively simplified to those of the standard LDC method for the highest flow regime without adjustments to accommodate tidal influences (as an example, see Figure 14).

The standard and modified LDC methods allow for estimation of existing and TMDL loads by utilizing the cumulative frequency distribution of streamflow and measured pollutant concentration data (Cleland, 2003) with adjustments to include tidal influences for the modified method (ODEQ, 2006). In addition to estimating stream loads, these methods allow for (1) the determination of the hydrologic conditions under which impairments are typically occurring, (2) can give indications of the broad origins of the bacteria (*i.e*., point source and stormwater) and (3) provides a means to allocate allowable loadings.

Based on the two LDCs for locations with recent historical Enterococci data added to the graphs (Station 10441 for Adams Bayou AU 0508_01 and Station 10449 for Cow Bayou AU 0511_01 presented in Figures 18 and 19) and Section 2.6 (Potential Sources of Fecal Indicator Bacteria), the following broad linkage statements can be made. The historical Enterococci data indicate that elevated bacteria loadings occur under all flow conditions, but become most elevated under the highest flows and are occasionally below the single sample criterion under the mid-range and lowest flows. Regulated stormwater areas comprises about 28 percent of the Adams Bayou watershed and about 8 percent of the Cow Bayou watershed, with the amount of regulated stormwater area highest in the lower portions of both watersheds. Thus, while the regulated stormwater area is not as great as the unregulated stormwater area, regulated stormwater should be considered a more important contributor to the bacteria load associated with rainfall-runoff events in the lower portions of both watersheds than in the more upstream portions which are predominantly rural. The elevated Enterococci loadings under the lower flow conditions cannot be reasonably attributed exclusively to WWTFs even though the majority of permitted points sources are in the lower portions of both watersheds, due to the good compliance records of these facilities, which indicates low indicator bacteria levels in effluents most of the time. Therefore, other sources of bacteria loadings under lower flows and in the absence of overland flow contributions (*i.e.*, without stormwater contribution) are most likely contributing bacteria directly to the water as could occur through failing septic systems and direct deposition of fecal material from such sources as wildlife, feral hogs and livestock. The actual contribution of bacteria loadings attributable to these direct sources of fecal material deposition cannot be determined using LDCs. A load allocation (LA) can, however, be developed for the broad category encompassing all unregulated sources based on the bacteria load remaining after the waste load, margin of safety and future growth allocations are subtracted from the TMDL, as estimated using the LDC method.

4.5 Margin of Safety

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

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

The MOS is designed to account for any uncertainty that may arise in specifying water quality control strategies for the complex environmental processes that affect water quality. Quantification of this uncertainty, to the extent possible, is the basis for assigning a margin of safety.

The TMDLs covered by this report incorporate an explicit MOS of 5% of the TMDL. The net effect of the TMDL with MOS is that the assimilative capacity or allowable pollutant loading of each water body is slightly reduced.

4.6 Load Reduction Analysis

While the TMDLs for Adams Bayou, Cow Bayou and associated tributaries were developed using an LDC and associated LAs, additional insight may, in certain situations, be gained through a load reduction analysis. A single percent load reduction required to meet the allowable loading for each of the three flow regimes was determined using the historical bacteria data for Stations 10441 and 10449, which are the two stations for which LDCs could be developed with the addition of Enterococci data. For each flow regime, the percent reduction required to achieve the geometric mean criterion was determined by calculating the difference in the existing (or measured) geometric mean Enterococci concentration and the 35 cfu/100 mL criterion and dividing that difference by the existing geometric mean concentration (Table 22). These computations indicate that the Enterococci loadings in both Adams Bayou, at Station 10441, and Cow Bayou, at Station 10449, require a reduction of 95 to 96 percent for the highest flow regime, a reduction of 77 percent to 85 percent for the mid-range flow, and 77 to 79 percent in the lowest flow regimes.

Table 23. Percent reduction calculations for bacteria by flow regime for Adams Bayou and Cow Bayou.

Station (Bacteria Indicator)	AU	Water Body	Highest Flows (0-10%)		Mid-Range Flows (10-60%)		Lowest Flows (60-100%)	
			Geometric Mean (cfu/100 mL)	Required Percent Reduction	Geometric Mean (cfu/100 mL)	Required Percent Reduction	Geometric Mean (cfu/100 mL)	Required Percent Reduction
10441 (Enterococci)	0508_01	Adams Bayou	846	96%	240	85%	166	79%
10449 (Enterococci)	0511_01	Cow Bayou	671	95%	155	77%	150	77%

4.7 Pollutant Load Allocation

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

TMDL = WLA + LA + FG + MOS (Eq. 4)

Where:

TMDL = total maximum daily load

WLA = waste load allocation, the amount of pollutant allowed by existing regulated or permitted dischargers

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

FG = loadings associated with future growth from potential regulated facilities

MOS = margin of safety

As stated in 40 CFR, §130.2(1), TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures. For *E. coli* and Enterococci, TMDLs are expressed as cfu/day, and represent the maximum one-day load the water body can assimilate while still attaining the standards for surface water quality.

The TMDL component for each AU covered in this document is derived using the median flow within the high flow regime (or 5 percent flow) of the LDC developed for the selected station (Table 17). For the remainder of this report, each section will present an explanation of the TMDL component first, followed by the results of the calculation for that component.

4.7.1 AU-Level TMDL Computations

The bacteria TMDLs for the seven AUs of the Adams Bayou watershed and six AUs of the Cow Bayou watershed addressed in this document were developed as a pollutant load allocation based on information from LDCs developed in each AU (Figures 15, 16, and 17). As discussed in more detail in Section 3, bacteria LDCs were developed by multiplying each flow value along the flow duration curves by the *E. coli* criterion (126 cfu/100 mL) for freshwater streams and the Enterococci criterion (35 cfu/100 mL) for tidal streams and by the conversion factor used to represent maximum loading in cfu/day. Effectively, the “Allowable Load” displayed in the LDC at the 5 percent exceedance value (the median value of the high-flow regime) is the TMDL:

TMDL (billion cfu/day) = Criterion * Flow (cfs) * Conversion Factor (Eq. 5)

Where:

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

Flow = the 5 percent exceedance value from the FDCs

Conversion Factor (to billion cfu/day) = 283.168 deciliters (100 mL)/cubic feet (ft^3) * 86,400 seconds per day (s/d) * 1.0E-09 billion = 0.02446572

At the 5% load duration exceedance value, the TMDL values are provided in Table 24.

Table 24. Summary of allowable loading calculations for the AUs in Adams Bayou, Cow Bayou and associated tributaries.

Water Body	Station	AU	5% Exceedance Flow (cfs)[£]	Indicator Bacteria	5% Exceedance Load (billion cfu/day)	TMDL (billion cfu/day)
Adams Bayou Tidal	10441	0508_01	349.0	Enterococci	2.988487E+02	298.849
Adams Bayou Tidal	10442	0508_02	310.8	Enterococci	2.661380E+02	266.138
Adams Bayou Tidal	16059	0508_03	300.8	Enterococci	2.575750E+02	257.575
Adams Bayou Tidal	14990	0508_04	265.6	Enterococci	2.274333E+02	227.433
Adams Bayou Above Tidal	15107	0508A_01	235.3	*E. coli*	7.253546E+02	725.355
Gum Gully	16049	0508B_01	23.08	*E. coli*	7.114826E+01	71.148
Hudson Gully	16041	0508C_01	13.85	Enterococci	1.185976E+01	11.860
Cow Bayou Tidal	10449	0511_01	1,490	Enterococci	1.275887E+03	1,275.887
Cow Bayou Tidal	13781	0511_03	1,107	Enterococci	9.479241E+02	947.924
Cow Bayou Tidal	10457	0511_04	804.1	Enterococci	6.885509E+02	688.551
Coon Bayou	16052	0511B_01	43.54	Enterococci	3.728330E+01	37.283
Cole Creek	16060	0511C_01	101.5	Enterococci	8.691445E+01	86.914
Terry Gully	18377	0511E_01	270.2	*E. coli*	8.329402E+02	832.940
				Enterococci	2.313723E+02	231.372

[£] Flow from FDCs, Figures 12 and 13

4.7.2 Margin of Safety

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

$$MOS = 0.05 * TMDL \qquad \text{(Eq. 6)}$$

Where:

MOS = margin of safety load

TMDL = total maximum allowable load

Since the MOS is based solely on the TMDL term, the calculation is straightforward (Table 25).

Table 25. MOS for AUs of Adams Bayou, Cow Bayou, and associated tributaries.

Water Body	AU	Indicator Bacteria	TMDL * (billion cfu/day)	MOS (billion cfu/day)
Adams Bayou Tidal	0508_01	Enterococci	298.849	14.942
Adams Bayou Tidal	0508_02	Enterococci	266.138	13.307
Adams Bayou Tidal	0508_03	Enterococci	257.575	12.879
Adams Bayou Tidal	0508_04	Enterococci	227.433	11.372
Adams Bayou Above Tidal	0508A_01	*E. coli*	725.355	36.268
Gum Gully	0508B_01	*E. coli*	71.148	3.557
Hudson Gully	0508C_01	Enterococci	11.86	0.593
Cow Bayou Tidal	0511_01	Enterococci	1275.887	63.794
Cow Bayou Tidal	0511_03	Enterococci	947.924	47.396
Cow Bayou Tidal	0511_04	Enterococci	688.551	34.428
Coon Bayou	0511B_01	Enterococci	37.283	1.864
Cole Creek	0511C_01	Enterococci	86.914	4.346
Terry Gully	0511E_01	*E. coli*	832.94	41.647
		Enterococci	231.372	11.569

[a] TMDL from Table 24

4.7.3 Waste Load Allocation

The Waste Load Allocation (WLA) consists of two parts – the waste load that is allocated to TPDES-regulated wastewater treatment facilities (WLA_{WWTF}) and the waste load that is allocated to regulated stormwater dischargers (WLA_{SW}).

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

TPDES-permitted wastewater treatment facilities are allocated a daily waste load (WLA_{WWTF}) calculated as their full permitted discharge flow rate multiplied by (35 cfu/100mL) and freshwater *E. coli* primary contract recreation geometric mean criterion of 126 cfu/100 mL are used in the computation of the WLA for WWTFs (WLA_{WWTF}) to provide flexibility in issuance of permit limits. The WLA_{WWTF} term is expressed in the following equation:

$$WLA_{WWTF} = \text{Criterion} * \text{Flow} * \text{Conversion Factor} \quad \text{(Eq. 8)}$$

Where:

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

Flow = full permitted flow (MGD)

Conversion Factor (to billion cfu/day) = 1.54723 cfs/MGD * 283.168 deciliters (100 mL)/cubic feet (ft^3) * 86,400 s/d * 1.0E-09 billion = 0.03785412

Thus, the daily allowable loading of Enterococci and *E. coli* assigned to WLA_{WWTF} was determined based on the full permitted flow of each WWTFs using Eq. 8.

Table 26 presents the waste load allocations for each individual WWTF located within the TMDL watershed. According to permit language, the City of Orange WWTF TPDES permit number WQ0010626001) is allowed to discharge through Outfall 002 into Adams Bayou only when the average discharge from the facility exceeds 11,111 gallons per minute. For the 120-month period of June 2008 through May 2018, there were 6 months of non-zero discharge reported for this Outfall 002. The average discharge of those four months of 1.36 MGD was used as the permitted flow for the pollutant load allocation process. Note that Miller Waste Mills, Inc. (TPDES permit number WQ0002835000) is not assigned a bacteria permit limit within this TMDL because there is no human waste component associated with its discharge, therefore this facility is not included in Table 26.

Table 27 presents the waste load allocation for WWTFs by AU considering all WWTFs located in the AU plus all upstream WWTFs.

Stormwater discharges from MS4, industrial, and construction areas are considered permitted or regulated point sources. Therefore, the WLA calculations must also include an allocation for permitted stormwater discharges (WLA_{SW}). A simplified approach for estimating the WLA for these areas was used in the development of these TMDLs due to the limited amount of data available, the complexities associated with simulating rainfall runoff, and the variability of stormwater loading. The percentage of each watershed that is under the jurisdiction of stormwater permits is used to estimate the amount of the overall runoff load that should be allocated as the permitted stormwater contribution in the WLA_{SW} component of the TMDL.

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

$$WLA_{SW} = (TMDL - WLA_{WWTF} - FG - MOS) * FDA_{SWP} \quad \text{(Eq. 9)}$$

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

MOS = margin of safety load

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

The fractional proportion of the drainage area under the jurisdiction of stormwater permits (FDA_{SWP}) must be determined in order to estimate the amount of overall runoff load that should be allocated to WLA_{SW}. The percent of the total drainage area or watershed of each AU under storm water regulation, obtained from Table 10 in Section 2.6.1.3, was used to define FDA_{SWP}. Table 28 summarizes the computation of the term WLA_{SW} as calculated using Equation 9. In order to calculate WLA_{SW} (Equation 9), the Future Growth (FG) term must be known. The calculation method for the FG term is presented in Section 4.7.4. The results of the FG calculations are presented in Table 29, but are also included in Table 28 for continuity.

Table 26. Waste load allocations for TPDES-permitted facilities in watersheds of Adams Bayou and Cow Bayou.

Facility	TPDES No.	NPDES No.	AU	Outfall	Full Permitted Flow (MGD) [a]	*E. coli* WLA_{WWTF} (billion cfu/ day) [b]	Enterococci WLA_{WWTF} (billion cfu/ day) [b]
City of Pinehurst	WQ0010597001	TX0024171	0508_03	001	0.5	2.385	0.662
Orange County WCID 2	WQ0010240001	TX0054810	0508_02	001	1.22	5.819	1.616
City of Orange [c]	WQ0010626001	TX0073423	0508_02	002	1.36	6.487	1.802
ARLANXEO USA LLC	WQ0001167000	TX0003654	0511_01	101	0.05	0.238	0.066
Honeywell International Inc.	WQ0000670000	TX0007897	0511_01	101	0.04	0.191	0.053
Lion Elastomers Orange, LLC	WQ0000454000	TX0002968	0511_01	001	1.202	5.733	1.593
Chevron Phillips Chemical Company LP	WQ0000359000	TX0004839	0511D_01 [d]	101	0.024	0.114	0.032
Printpack, Inc.	WQ0002858000	TX0101192	0511D_01 [d]	101	0.015	0.072	0.020
City of Bridge City	WQ0010051001	TX0025500	0511_01	001	1.6	7.631	2.120
Orangefield Water Supply Corporation	WQ0014772001	TX0129313	0511_02 [e]	001	0.75	3.577	0.994
Bayou Pines (proposed)	WQ0015029001	TX0133418	0511B_01	001	0.009	0.043	0.012
Gulflander Partners Group, L.P.	WQ0013488001	TX0106437	0511B_01	001	0.01	0.048	0.013
P C S Development Company	WQ0011916001	TX0074250	0511_04	001	0.09	0.429	0.119
Jasper County WCID 1	WQ0010808001	TX0021300	0511A_02	001	0.41	1.956	0.543

[a] Permitted Flow from Tables 7 and 8.

[b] WLA_{WWTF} = Criterion * Flow * Conversion Factor (Eq. 8)

[c] intermittent discharge. The permittee is authorized to discharge from Outfall 002 only if, as a result of wet weather conditions, the average discharge from the facility exceeds 11,111 gallons per minute. Combined average annual discharge of Outfalls 001 and 002 is not to exceed 7.0 MGD. Discharges through Outfall 002 occurred only 6 months out of the 120--month period of June 2008 through May 2018 with an average for those 6 months of 1.36 MGD. The flow of 1.36 MGD was assigned to this facility for pollutant load allocation purposes. Outfall 001 discharges to the Sabine River.

[d] WLAs for WTTFs discharging into AU 0511D_01 (Unnamed Tributary of Cow Bayou) are added directly into AU 0511_01, which is the AU into which AU 0511D_01 flows. AU 0511D_01 is not listed as impaired for bacteria and is not considered separately in the TMDL computations.

[e] Orangefield Water Supply Corporation WWTF discharges into AU 0511_02, which is added to AU 0511_01. AU 0511_02 is not listed as impaired for bacteria and is not considered separately in the TMDL computations.

Table 27. Waste load allocation for WWTFs of the AUs of Adams Bayou, Cow Bayou, and associated tributaries addressed in this document.

Water Body	Station	AU	Indicator Bacteria	Total AU WWTF Flow (MGD) *	WLA_{WWTF} (billion cfu/ day)
Adams Bayou Tidal	10441	0508_01	Enterococci	3.080	4.081
Adams Bayou Tidal	10442	0508_02	Enterococci	3.080	4.081
Adams Bayou Tidal	16059	0508_03	Enterococci	0.500	0.662
Adams Bayou Tidal	14990	0508_04	Enterococci	0.000	0.000
Adams Bayou Above Tidal	15107	0508A_01	*E. coli*	0.000	0.000
Gum Gully	16049	0508B_01	*E. coli*	0.000	0.000
Hudson Gully	16041	0508C_01	Enterococci	0.000	0.000
Cow Bayou Tidal	10449	0511_01	Enterococci	4.200	5.565
Cow Bayou Tidal	13781	0511_03	Enterococci	0.500	0.662
Cow Bayou Tidal	10457	0511_04	Enterococci	0.500	0.662
Coon Bayou	16052	0511B_01	Enterococci	0.019	0.025
Cole Creek	16060	0511C_01	Enterococci	0.000	0.000
Terry Gully	18377	0511E_01	*E. coli*	0.000	0.000
			Enterococci	0.000	0.000

* Note: Jasper County WCID #1 (in unimpaired 0511A_02) contributes to the total WWTF flow in 0511_04 and to all other downstream 0511 AUs; Orangefield Water Supply Corporation contributes WWTF flow to unimpaired 0511_02, which contributes to the total WWTF flow in 0511_01; Printpack and Chevron Phillips Chemical company contribute WWTF flows to unimpaired 0511D_01, which in turn contributes those WWTF flows to 0511_01.

4.7.4 Future Growth

The FG component of the TMDL equation addresses the requirement of TMDLs to account for future loadings that may occur as a result of population growth, changes in community infrastructure, and development. The assimilative capacity of streams increases as the amount of flow increases. Increases in flow allow for additional indicator bacteria loads if the concentrations are at or below the contact recreation standard. The FG equation (Eq. 10) is based on the projected population growth between 2020 and 2070 and current facilities treating and discharging domestic wastewater.

$$FG = Criterion * [\%POP_{2020\text{-}2070} * WWTF_{FP}] * Conversion\ Factor \quad \text{(Eq. 10)}$$

Where:

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

$\%POP_{2010\text{-}2070}$ = estimated % increase in population between 2020 and 2070

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

Conversion Factor = 1.54723 cfs/MGD * 283.168 100 mL/ft^3 * 86,400 s/d * 1.0E-09 billion

Table 28. Regulated stormwater calculations for AUs of Adams Bayou, Cow Bayou and associated tributaries.

Load units expressed as billion cfu/day

Water Body	Station	Segment	Indicator Bacteria	TMDL [a]	WLA_{WWTF} [b]	FG [c]	MOS [d]	FDA_{SWP} [e]	WLA_{SW} [f]
Adams Bayou Tidal	10441	0508_01	Enterococci	298.849	4.081	0.349	14.942	0.2795	78.114
Adams Bayou Tidal	10442	0508_02	Enterococci	266.138	4.081	0.337	13.307	0.2234	55.495
Adams Bayou Tidal	16059	0508_03	Enterococci	257.575	0.662	0.132	12.879	0.2028	49.463
Adams Bayou Tidal	14990	0508_04	Enterococci	227.433	0.000	0.036	11.372	0.1193	25.772
Adams Bayou Above Tidal	15107	0508A_01	*E. coli*	725.355	0.000	0.086	36.268	0.0393	27.078
Gum Gully	16049	0508B_01	*E. coli*	71.148	0.000	0.043	3.557	0.0233	1.574
Hudson Gully	16041	0508C_01	Enterococci	11.860	0.000	0.012	0.593	0.9932	11.178
Cow Bayou Tidal	10449	0511_01	Enterococci	1,275.887	5.565	0.714	63.794	0.0792	95.500
Cow Bayou Tidal	13781	0511_03	Enterococci	947.924	0.662	0.065	47.396	0.0543	48.859
Cow Bayou Tidal	10457	0511_04	Enterococci	688.551	0.662	0.041	34.428	0.0131	8.560
Coon Bayou	16052	0511B_01	Enterococci	37.283	0.025	0.012	1.864	0.2787	9.861
Cole Creek	16060	0511C_01	Enterococci	86.914	0.000	0.012	4.346	0.0163	1.346
Terry Gully	18377	0511E_01	*E. coli*	832.940	0.000	0.043	41.647	0.1840	145.590
			Enterococci	231.372	0.000	0.012	11.569	0.1840	40.442

[a] TMDL from Table 24
[b] WLA_{WWTF} from Table 27
[c] FG from Table 29
[d] MOS from Table 25
[e] FDA_{SWP} from Table 10
[f] $WLA_{SW} = (TMDL - WLA_{WWTF} - FG - MOS) * FDA_{SWP}$ (Eq. 9)

The term $\%POP_{2020\text{-}2070}$ is obtained from the population projections found in Tables 2 and 3. A minimum FG flow or discharge of 0.009 MGD was assigned to impaired and unimpaired AUs in the Adams Bayou and Cow Bayou watersheds, either in the absence of any WWTFs in the immediate watershed of the AU or whenever the computed FG discharge for an AU, based on WWTFs within the immediate watershed of the AU, was less than 0.009 MGD. This minimum FG discharge is equal to the permitted discharge of the smallest facility in the Adams Bayou and Cow Bayou watersheds (Table 26). Therefore, at least a small FG loading is assigned to each AU addressed in this document. This small FG loading was added to impaired AUs 0508_01, 0508_04, 0508B_01, 0508C_01, 0511_03, and 0511E_01 and unimpaired AUs 0508A_01, 0511_02, 0511A_01, 0511A_02, and 0511C_01.

In a similar manner as performed with the WAL_{WWTF} computations, the total FG for each AU is based on summing the loadings computed from Equation 10 for each facility in the immediate drainage area of an AU and all upstream facilities, including the small FG loading assigned to AUs that do not have an existing WWTF in their immediate drainage area. The calculation results for the AU watersheds are shown in Table 29.

4.7.5 Load Allocation

The load allocation (LA) is the sum of loads from unregulated sources, and is calculated as:

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

Where:

LA = allowable loads from unregulated sources

TMDL = total maximum daily load

WLA_{WWTF} = sum of all WWTF loads

WLA_{SW} = sum of all regulated stormwater loads

FG = sum of all future growth loads from potential permitted facilities

MOS = margin of safety load

The calculation results are shown in Table 30.

4.8 Summary of TMDL Calculations

Table 31 summarizes the TMDL calculations for the seven AUs of the Adams Bayou watershed and the six AUs of the Cow Bayou watershed. The TMDL was calculated based on the median flow in the 0-10 percentile range (5% exceedance, high flow regime) for flow exceedance from the LDC developed for the selected SWQM station in each AU. Allocations are based on the current geometric mean criterion for Enterococci of 35 cfu/100 mL for each component of the TMDL of tidal streams and the current geometric mean criterion for *E. coli* in freshwater streams of 126 cfu/100 mL.

The final TMDL allocations (Table 32) needed to comply with the requirements of 40 CFR 130.7 include the future growth component within the WLA_{WWTF}.

In the event that the criterion changes due to future revisions in the state's surface water quality standards, Appendix B provides guidance for recalculating the allocations in Table 31.

Figure B-1 through B-14 were developed to demonstrate how assimilative capacity, TMDL calculations, and pollutant load allocations change in relation to a number of proposed water quality criteria for Enterococci or *E. coli*, depending upon whether the stream is tidal or freshwater. The equations provided, along with Figures B-1 through B-14, allow calculation of new TMDLs and pollutant load allocations based on any potential new water quality criterion for Enterococci or *E. coli*.

Table 29. Future Growth calculations for the AUs of Adams Bayou, Cow Bayou and associated tributaries.

Water Body	Station	AU	Indicator Bacteria	Total AU FG Discharge (MGD)*	FG (billion cfu/ day)
Adams Bayou Tidal	10441	0508_01	Enterococci	0.2634	0.349
Adams Bayou Tidal	10442	0508_02	Enterococci	0.2544	0.337
Adams Bayou Tidal	16059	0508_03	Enterococci	0.0995	0.132
Adams Bayou Tidal	14990	0508_04	Enterococci	0.0270	0.036
Adams Bayou Above Tidal	15107	0508A_01	*E. coli*	0.0180	0.086
Gum Gully	16049	0508B_01	*E. coli*	0.0090	0.043
Hudson Gully	16041	0508C_01	Enterococci	0.0090	0.012
Cow Bayou Tidal	10449	0511_01	Enterococci	0.5388	0.714
Cow Bayou Tidal	13781	0511_03	Enterococci	0.0491	0.065
Cow Bayou Tidal	10457	0511_04	Enterococci	0.0311	0.041
Coon Bayou	16052	0511B_01	Enterococci	0.0090	0.012
Cole Creek	16060	0511C_01	Enterococci	0.0090	0.012
Terry Gully	18377	0511E_01	*E. coli*	0.0090	0.043
			Enterococci	0.0090	0.012

*Note: Printpack and Chevron Phillips Chemical Company contribute WWTF flows to unimpaired 0511D_01, which in turn contributes those WWTF flows to 0511_01.

Table 30. Load allocation calculations for the AUs of Adams Bayou, Cow Bayou and associated tributaries.

Load units expressed as billion cfu/day

Water Body	Station	AU	Indicator Bacteria	TMDL [a]	WLA_{WWTF} [b]	WLA_{SW} [c]	FG [d]	MOS [e]	LA [f]
Adams Bayou Tidal	10441	0508_01	Enterococci	298.849	4.081	78.114	0.349	14.942	201.363
Adams Bayou Tidal	10442	0508_02	Enterococci	266.138	4.081	55.495	0.337	13.307	192.918
Adams Bayou Tidal	16059	0508_03	Enterococci	257.575	0.662	49.463	0.132	12.879	194.439
Adams Bayou Tidal	14990	0508_04	Enterococci	227.433	0.000	25.772	0.036	11.372	190.253
Adams Bayou Above Tidal	15107	0508A_01	E. coli	725.355	0.000	27.078	0.086	36.268	661.923
Gum Gully	16049	0508B_01	E. coli	71.148	0.000	1.574	0.043	3.557	65.974
Hudson Gully	16041	0508C_01	Enterococci	11.860	0.000	11.178	0.012	0.593	0.077
Cow Bayou Tidal	10449	0511_01	Enterococci	1,275.887	5.565	95.500	0.714	63.794	1,110.314
Cow Bayou Tidal	13781	0511_03	Enterococci	947.924	0.662	48.859	0.065	47.396	850.942
Cow Bayou Tidal	10457	0511_04	Enterococci	688.551	0.662	8.560	0.041	34.428	644.860
Coon Bayou	16052	0511B_01	Enterococci	37.283	0.025	9.861	0.012	1.864	25.521
Cole Creek	16060	0511C_01	Enterococci	86.914	0.000	1.346	0.012	4.346	81.210
Terry Gully	18377	0511E_01	*E. coli*	832.940	0.000	145.590	0.043	41.647	645.660
			Enterococci	231.372	0.000	40.442	0.012	11.569	179.349

[a] TMDL from Table 24
[b] WLA_{WWTF} from Table 27
[c] WLA_{SW} from Table 28
[d] FG from Table 29
[e] MOS from Table 25
[f] LA = TMDL – WLA_{WWTF} - WLA_{SW} - FG – MOS (Eq. 11)

Table 31. TMDL allocation summary for the AUs of Adams Bayou, Cow Bayou and associated tributaries.

Load units expressed as billion cfu/day

Water Body	Station	AU	Indicator Bacteria	TMDL [a]	WLA_{SW} [b]	WLA_{WWTF} [c]	LA [d]	FG [e]	MOS [f]
Adams Bayou Tidal	10441	0508_01	Enterococci	298.849	78.114	4.081	201.363	0.349	14.942
Adams Bayou Tidal	10442	0508_02	Enterococci	266.138	55.495	4.081	192.918	0.337	13.307
Adams Bayou Tidal	16059	0508_03	Enterococci	257.575	49.463	0.662	194.439	0.132	12.879
Adams Bayou Tidal	14990	0508_04	Enterococci	227.433	25.772	0.000	190.253	0.036	11.372
Adams Bayou Above Tidal	15107	0508A_01	*E. coli*	725.355	27.078	0.000	661.923	0.086	36.268
Gum Gully	16049	0508B_01	*E. coli*	71.148	1.574	0.000	65.974	0.043	3.557
Hudson Gully	16041	0508C_01	Enterococci	11.860	11.178	0.000	0.077	0.012	0.593
Cow Bayou Tidal	10449	0511_01	Enterococci	1,275.887	95.500	5.565	1,110.314	0.714	63.794
Cow Bayou Tidal	13781	0511_03	Enterococci	947.924	48.859	0.662	850.942	0.065	47.396
Cow Bayou Tidal	10457	0511_04	Enterococci	688.551	8.560	0.662	644.860	0.041	34.428
Coon Bayou	16052	0511B_01	Enterococci	37.283	9.861	0.025	25.521	0.012	1.864
Cole Creek	16060	0511C_01	Enterococci	86.914	1.346	0.000	81.210	0.012	4.346
Terry Gully	18377	0511E_01	*E. coli*	832.940	145.590	0.000	645.660	0.043	41.647
			Enterococci	231.372	40.442	0.000	179.349	0.012	11.569

[a] TMDL from Table 24
[b] WLA_{WWTF} from Table 27
[c] WLA_{SW} from Table 28
[d] LA from Table 30
[e] FG from Table 29
[f] MOS from Table 25

Table 32. Final TMDL allocations for the AUs of Adams Bayou, Cow Bayou and associated tributaries.

Load units expressed as billion cfu/day

Water Body	AU	Indicator Bacteria	TMDL	WLA_{WWTF} [a]	WLA_{SW}	LA	MOS
Adams Bayou Tidal	0508_01	Enterococci	298.849	4.430	78.114	201.363	14.942
Adams Bayou Tidal	0508_02	Enterococci	266.138	4.418	55.495	192.918	13.307
Adams Bayou Tidal	0508_03	Enterococci	257.575	0.794	49.463	194.439	12.879
Adams Bayou Tidal	0508_04	Enterococci	227.433	0.036	25.772	190.253	11.372
Adams Bayou Above Tidal	0508A_01	*E. coli*	725.355	0.086	27.078	661.923	36.268
Gum Gully	0508B_01	*E. coli*	71.148	0.043	1.574	65.974	3.557
Hudson Gully	0508C_01	Enterococci	11.86	0.012	11.178	0.077	0.593
Cow Bayou Tidal	0511_01	Enterococci	1,275.89	6.279	95.500	1,110.314	63.794
Cow Bayou Tidal	0511_03	Enterococci	947.924	0.727	48.859	850.942	47.396
Cow Bayou Tidal	0511_04	Enterococci	688.551	0.703	8.560	644.860	34.428
Coon Bayou	0511B_01	Enterococci	37.283	0.037	9.861	25.521	1.864
Cole Creek	0511C_01	Enterococci	86.914	0.012	1.346	81.210	4.346
Terry Gully	0511E_01	*E. coli*	832.94	0.043	145.590	645.660	41.647
		Enterococci	231.372	0.012	40.442	179.349	11.569

[a] WLA_{WWTF} includes the FG component

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Appendix A. Modified Load Duration Curve

Traditionally the LDC method has been restricted in TMDL development to freshwater, non-tidally influenced streams and rivers. The reason for excluding application of LDCs in TMDL development for tidally influenced stream and river systems is the presence of seawater in these river systems, *i.e.*, an additional flow that has a loading. An assumption behind the LDC method is that the loadings of bacteria are derived exclusively from the sources of the streamflows. These sources and their associated loadings may be varied, but it is inherently assumed that they may be computationally determined based on the streamflow at the selected exceedance frequency on the LDC used for the load allocation. But in a tidal system there is other water (*i.e.*, seawater) that is a source with an associated loading that must be considered.

If the LDC method is to be adapted to tidally influenced streams and rivers, some means of addressing the additional water and loadings from the seawater that mixes with freshwater in tidal rivers is needed. Oregon's Umpqua Basin Bacteria TMDL provides a modification of the LDC method that accounts for the seawater component (ODEQ, 2006).

Their approach is based on determining the volume of seawater that must be mixed with the volume of freshwater going down the river to arrive at the "observed" salinity using a simple mass balance approach as provided in the following:

$$(V_r + V_s)*S_t = V_r*S_r + V_s*S_s \qquad \text{(A-1)}$$

Where

V_r = volume daily river flow (m^3) = Q (cfs)*86,400 (sec/day); where Q = river flow (cfs)

V_s = volume of seawater

S_t = salinity in river (parts per thousand or ppt)

S_r = background salinity of river water (ppt); assumed to be close to 0 ppt

S_s = salinity of seawater (35 ppt)

As noted in the computation of V_r, the volumes are actually time-associated using a day as the temporal measure, thus providing the proper association for the daily pollutant load computation. Through algebraic manipulation this mass balance equation can be solved for the daily volume of seawater required to be mixed with freshwater (again, freshwater having an assumed salinity ≈ 0) giving the equation found in the ODEQ (2006) technical information:

$$V_s = V_r / (S_s/S_t - 1);$$

for S_t > than background salinity; otherwise $V_s = 0$ (A-2)

For the Umpqua Basin tidal streams (*e.g.*, Figure A-1), as well as the present application to Adams Bayou and Cow Bayou and associated tributaries, regressions were developed of S_t to Q using measured salinity data (S_t) with freshwater flows (Q). These regressions all had some streamflow above which $S_t = 0$. The daily Q and regression developed S_t were then used to compute V_s. As S_t approaches 0.0, V_s likewise approaches a value of 0.0 in Equation A-2, meaning the only flow present is the river flow (Q or V_r).

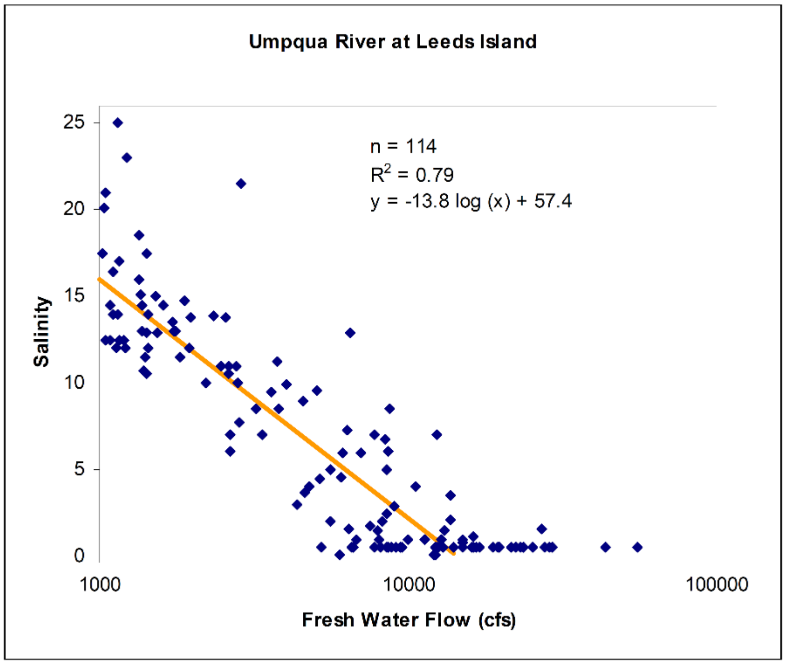

Figure A-1. Example salinity to flow regression from Umpqua Basin Tidal streams (ODEQ, 2006).

It is also relevant to discuss the response of measured salinities at assessment stations to streamflow and the streamflows above which salinities approach background levels (again, assumed to be ≈0.0) within the context of FDC for Adams Bayou and Cow Bayou and associated tributaries. These FDCs and the plotted flow exceedance values where salinities approach background should be viewed from the perspective of TCEQ's approach for bacteria TMDLs. Within the TCEQ TMDL approach with indicator bacteria, the highest flow regime is selected for developing the pollutant load allocation. This flow regime is defined as the range of 0-10% for the Adams Bayou and Cow Bayou and associated tributaries. All the flows in the highest flow regime are greater than the amount of streamflow indicated by the regression analysis as needed to result in an absence of seawater (see Table 21 in the report).

The significance of the above observation is related to what happens within the modified LDC method when salinities are at background. As salinity approaches background, V_s in Equation A-2 approaches a value of zero, and in fact would be defined as zero when salinities are at background levels, resulting in the Modified LDC flow volume ($V_s + V_r$) defaulting to the flow of the river, *i.e.*, no modification occurring to that portion of the LDC. Therefore, regarding the pollutant load allocation process for Adams Bayou and Cow Bayou and associated tributaries, the modified LDC method provides identical allowable loadings in the highest flow regime to those that would be computed using the standard LDC method that does not include tidal influences. The identical results of the modified and standard LDC method for the highest flow regime is the physical reality indicated in the observed salinity data that at these elevated streamflows seawater is effectively pushed completely out of each water body. But the other implication, in hindsight, is that for Adams Bayou and Cow Bayou and associated tributaries the same Pollutant Load Allocation results would be determined with the LDC method with or without tidal influences being considered due to development of the TMDL for the higher streamflows.

Continuing with the theoretical development of the modified LDC for the Umpqua TMDLs, a total daily volume (V_t) is comprised of V_r computed from Q and the volume of seawater (V_s):

$$V_t = V_r + V_s \quad \text{(A-3)}$$

Resulting in

$$\text{TMDL (cfu/day)} = \text{Criterion} * V_t * \text{Conversion factor} \quad \text{(A-4)}$$

The modified LDC method as captured in Equation A-4 is based on the assumption that combining of river water with seawater increases the loading capacity in the tidal river because seawater typically contains lower concentrations of indicator bacteria, such as Enterococci, than river water.

Appendix B. Equations for Calculating TMDL Allocations for Changed Contact Recreation Standard

Adams Bayou Tidal (AU 0508_01): Equations for calculating new TMDL and allocations for Enterococci (in billion cfu/day)

TMDL	=	8.5385333 * Std + 0.0004590
WLA_{WWTF}	=	4.4300000
WLA_{SW}	=	2.2671937 * Std - 1.2378197
LA	=	5.8444126 * Std - 3.1913607
MOS	=	0.4269269 * Std - 0.0003607

Where:

Std	=	Revised Contact Recreation Standard
WLA_{WWTF}	=	Waste load allocation (permitted WWTF load + future growth)
WLA_{SW}	=	Waste load allocation (permitted stormwater)
LA	=	Total load allocation (unregulated sources)
MOS	=	Margin of Safety

Table A-1 Enterococci TMDL allocations for Adams Bayou Tidal (AU 0508_01) for potential changed contact recreation standards.

Units expressed as billion cfu/ day Enterococci except contact recreation criterion

Contact Recreation Criterion (cfu/100 mL)	TMDL	WLA_{WWTF}	WLA_{SW}	LA	MOS
35	298.849	4.430	78.114	201.363	14.942
175	1,494.244	4.430	395.521	1,019.581	74.712
350	2,988.487	4.430	792.280	2,042.353	149.424

Adams Bayou Tidal (AU 0508_02): Equations for calculating new TMDL and allocations for Enterococci (in billion cfu/day)

TMDL	=	7.6039429 * Std + 0.0000000
WLA_{WWTF}	=	4.4180000
WLA_{SW}	=	1.6137874 * Std - 0.9876393
LA	=	5.6099588 * Std - 3.4306393
MOS	=	0.3801967 * Std + 0.0002787

Where:

Std	=	Revised Contact Recreation Standard
WLA_{WWTF}	=	Waste load allocation (permitted WWTF load + future growth)
WLA_{SW}	=	Waste load allocation (permitted stormwater)
LA	=	Total load allocation (unregulated sources)
MOS	=	Margin of Safety

Table A-2 Enterococci TMDL allocations for Adams Bayou Tidal (AU 0508_02) for potential changed contact recreation standards.

Units expressed as billion cfu/ day Enterococci except contact recreation criterion

Contact Recreation Criterion (cfu/100 mL)	TMDL	WLA_{WWTF}	WLA_{SW}	LA	MOS
35	266.138	4.418	55.495	192.918	13.307
175	1,330.690	4.418	281.425	978.312	66.535
350	2,661.380	4.418	563.838	1,960.055	133.069

Adams Bayou Tidal (AU 0508_03): Equations for calculating new TMDL and allocations for Enterococci (in billion cfu/day)

TMDL = 7.3592857 * Std + 0.0000000
WLA_{WWTF} = 0.7940000
WLA_{SW} = 1.4178412 * Std - 0.1613607
LA = 5.5734794 * Std - 0.6328197
MOS = 0.3679651 * Std + 0.0001803

Where:

Std = Revised Contact Recreation Standard
WLA_{WWTF} = Waste load allocation (permitted WWTF load + future growth)
WLA_{SW} = Waste load allocation (permitted stormwater)
LA = Total load allocation (unregulated sources)
MOS = Margin of Safety

Table A-3 Enterococci TMDL allocations for Adams Bayou Tidal (AU 0508_03) for potential changed contact recreation standards.

Units expressed as billion cfu/ day Enterococci except contact recreation criterion

Contact Recreation Criterion (cfu/100 mL)	TMDL	WLA_{WWTF}	WLA_{SW}	LA	MOS
35	257.575	0.794	49.463	194.439	12.879
175	1,287.875	0.794	247.961	974.726	64.394
350	2,575.750	0.794	496.083	1,950.085	128.788

Adams Bayou Tidal (AU 0508_04): Equations for calculating new TMDL and allocations for Enterococci (in billion cfu/day)

TMDL = 6.4980953 * Std - 0.0004590
WLA_{WWTF} = 0.0360000
WLA_{SW} = 0.7364604 * Std - 0.0042787
LA = 5.4367300 * Std - 0.0322623
MOS = 0.3249049 * Std + 0.0000820

Where:

Std = Revised Contact Recreation Standard
WLA_{WWTF} = Waste load allocation (permitted WWTF load + future growth)
WLA_{SW} = Waste load allocation (permitted stormwater)
LA = Total load allocation (unregulated sources)
MOS = Margin of Safety

Table A-4 Enterococci TMDL allocations for Adams Bayou Tidal (AU 0508_04) for potential changed contact recreation standards.

Units expressed as billion cfu/ day Enterococci except contact recreation criterion

Contact Recreation Criterion (cfu/100 mL)	TMDL	WLA_{WWTF}	WLA_{SW}	LA	MOS
35	227.433	0.036	25.772	190.253	11.372
175	1,137.166	0.036	128.876	951.396	56.858
350	2,274.333	0.036	257.757	1,902.823	113.717

Adams Bayou Above Tidal (AU 0508A_01): Equations for calculating new TMDL and allocations for *E. coli* (in billion cfu/day)

TMDL = 5.7567821 * Std + 0.0004104
WLA_{WWTF} = 0.0860000
WLA_{SW} = 0.2149292 * Std - 0.0031698
LA = 5.2540144 * Std - 0.0828821
MOS = 0.2878385 * Std + 0.0004623

Where:

Std = Revised Contact Recreation Standard
WLA_{WWTF} = Waste load allocation (permitted WWTF load + future growth)
WLA_{SW} = Waste load allocation (permitted stormwater)
LA = Total load allocation (unregulated sources)
MOS = Margin of Safety

Table A-5 *E. coli* TMDL allocations for Adams Bayou Above Tidal (AU 0508A_01) for potential changed contact recreation standards.

Units expressed as billion cfu/ day *E. coli* except contact recreation criterion

Contact Recreation Criterion (cfu/100 mL)	TMDL	WLA_{WWTF}	WLA_{SW}	LA	MOS
126	725.355	0.086	27.078	661.923	36.268
630	3,626.773	0.086	135.402	3,309.946	181.339
1030	5,929.486	0.086	221.374	5,411.552	296.474

Gum Gully (AU 0508B_01): Equations for calculating new TMDL and allocations for *E. coli* (in billion cfu/day)

TMDL = 0.5646692 * Std - 0.0004104
WLA_{WWTF} = 0.0430000
WLA_{SW} = 0.0124989 * Std - 0.0009859
LA = 0.5239369 * Std - 0.0421179
MOS = 0.0282334 * Std - 0.0003066

Where:

Std = Revised Contact Recreation Standard
WLA_{WWTF} = Waste load allocation (permitted WWTF load + future growth)
WLA_{SW} = Waste load allocation (permitted stormwater)
LA = Total load allocation (unregulated sources)
MOS = Margin of Safety

Table A-6 *E. coli* TMDL allocations for Gum Gully (AU 0508B_01) for potential changed contact recreation standards.

Units expressed as billion cfu/ day *E. coli* except contact recreation criterion

Contact Recreation Criterion (cfu/100 mL)	TMDL	WLA_{WWTF}	WLA_{SW}	LA	MOS
126	71.148	0.043	1.574	65.974	3.557
630	355.741	0.043	7.873	330.038	17.787
1030	581.609	0.043	12.873	539.613	29.080

Hudson Gully (AU 0508C_01): Equations for calculating new TMDL and allocations for Enterococci (in billion cfu/day)

$TMDL$ = 0.3388508 * Std + 0.0001803
WLA_{WWTF} = 0.0120000
WLA_{SW} = 0.3197206 * Std - 0.0121803
LA = 0.0021874 * Std + 0.0003607
MOS = 0.0169429 * Std + 0.0000000

Where:

Std = Revised Contact Recreation Standard
WLA_{WWTF} = Waste load allocation (permitted WWTF load + future growth)
WLA_{SW} = Waste load allocation (permitted stormwater)
LA = Total load allocation (unregulated sources)
MOS = Margin of Safety

Table A-7 Enterococci TMDL allocations for Hudson Gully (AU 0508C_01) for potential changed contact recreation standards.

Units expressed as billion cfu/ day Enterococci except contact recreation criterion

Contact Recreation Criterion (cfu/100 mL)	TMDL	WLA_{WWTF}	WLA_{SW}	LA	MOS
35	11.860	0.012	11.178	0.077	0.593
175	59.299	0.012	55.939	0.383	2.965
350	118.598	0.012	111.890	0.766	5.930

Cow Bayou Tidal (AU 0511_01): Equations for calculating new TMDL and allocations for Enterococci (in billion cfu/day)

$TMDL$ = 36.4539143* Std + 0.0000000
WLA_{WWTF} = 6.2790000
WLA_{SW} = 2.7427937 * Std - 0.4978197
LA = 31.8884222 * Std - 5.7808197
MOS = 1.8226984 * Std - 0.0003607

Where:

Std = Revised Contact Recreation Standard
WLA_{WWTF} = Waste load allocation (permitted WWTF load + future growth)
WLA_{SW} = Waste load allocation (permitted stormwater)
LA = Total load allocation (unregulated sources)
MOS = Margin of Safety

Table A-8 Enterococci TMDL allocations for Cow Bayou Tidal (AU 0511_01) for potential changed contact recreation standards.

Units expressed as billion cfu/ day Enterococci except contact recreation criterion

Contact Recreation Criterion (cfu/100 mL)	TMDL	WLA_{WWTF}	WLA_{SW}	LA	MOS
35	1,275.887	6.279	95.500	1,110.314	63.794
175	6,379.435	6.279	479.491	5,574.693	318.972
350	12,758.870	6.279	959.480	11,155.167	637.944

Cow Bayou Tidal (AU 05011_03): Equations for calculating new TMDL and allocations for Enterococci (in billion cfu/day)

TMDL	=	27.0835459 * Std + 0.0000984
WLA_{WWTF}	=	0.7270000
WLA_{SW}	=	1.3971047 * Std - 0.0395410
LA	=	24.3322635 * Std - 0.6871803
MOS	=	1.3541778 * Std - 0.0001803

Where:

Std	=	Revised Contact Recreation Standard
WLA_{WWTF}	=	Waste load allocation (permitted WWTF load + future growth)
WLA_{SW}	=	Waste load allocation (permitted stormwater)
LA	=	Total load allocation (unregulated sources)
MOS	=	Margin of Safety

Table A-9 Enterococci TMDL allocations for Cow Bayou Tidal (AU 05011_03) for potential changed contact recreation standards.

Units expressed as billion cfu/ day Enterococci except contact recreation criterion

Contact Recreation Criterion (cfu/100 mL)	TMDL	WLA_{WWTF}	WLA_{SW}	LA	MOS
35	947.924	0.727	48.859	850.942	47.396
175	4,739.621	0.727	244.454	4,257.459	236.981
350	9,479.241	0.727	488.947	8,515.605	473.962

Cow Bayou Tidal (AU 0511_04): Equations for calculating new TMDL and allocations for Enterococci (in billion cfu/day)

TMDL	=	19.6728827 * Std - 0.0000984
WLA_{WWTF}	=	0.7030000
WLA_{SW}	=	0.2448286 * Std - 0.0090000
LA	=	18.4444129 * Std - 0.6947377
MOS	=	0.9836412 * Std + 0.0006393

Where:

Std	=	Revised Contact Recreation Standard
WLA_{WWTF}	=	Waste load allocation (permitted WWTF load + future growth)
WLA_{SW}	=	Waste load allocation (permitted stormwater)
LA	=	Total load allocation (unregulated sources)
MOS	=	Margin of Safety

Table A-10 Enterococci TMDL allocations for Cow Bayou Tidal (AU 0511_04) for potential changed contact recreation standards.

Units expressed as billion cfu/ day Enterococci except contact recreation criterion

Contact Recreation Criterion (cfu/100 mL)	TMDL	WLA_{WWTF}	WLA_{SW}	LA	MOS
35	688.551	0.703	8.560	644.860	34.428
175	3,442.754	0.703	42.836	3,227.077	172.138
350	6,885.509	0.703	85.681	6,454.850	344.275

Coon Bayou (AU 05011B_01): Equations for calculating new TMDL and allocations for Enterococci (in billion cfu/day)

TMDL = 1.0652379 * Std - 0.0000820
WLA_{WWTF} = 0.0370000
WLA_{SW} = 0.2820382 * Std - 0.0104590
LA = 0.7299363 * Std - 0.0264426
MOS = 0.0532635 * Std - 0.0001803

Where:

Std = Revised Contact Recreation Standard
WLA_{WWTF} = Waste load allocation (permitted WWTF load + future growth)
WLA_{SW} = Waste load allocation (permitted stormwater)
LA = Total load allocation (unregulated sources)
MOS = Margin of Safety

Table A-11 Enterococci TMDL allocations for Coon Bayou (AU 05011B_01) for potential changed contact recreation standards.

Units expressed as billion cfu/ day Enterococci except contact recreation criterion

Contact Recreation Criterion (cfu/100 mL)	TMDL	WLA_{WWTF}	WLA_{SW}	LA	MOS
35	37.283	0.037	9.861	25.521	1.864
175	186.417	0.037	49.346	127.713	9.321
350	372.833	0.037	98.703	255.451	18.642

Cole Creek (AU 0511C_01): Equations for calculating new TMDL and allocations for Enterococci (in billion cfu/day)

TMDL = 2.4832731 * Std - 0.0006393
WLA_{WWTF} = 0.0120000
WLA_{SW} = 0.0384541 * Std - 0.0000984
LA = 2.3206571 * Std - 0.0130000
MOS = 0.1241618 * Std + 0.0004590

Where:

Std = Revised Contact Recreation Standard
WLA_{WWTF} = Waste load allocation (permitted WWTF load + future growth)
WLA_{SW} = Waste load allocation (permitted stormwater)
LA = Total load allocation (unregulated sources)
MOS = Margin of Safety

Table A-12 Enterococci TMDL allocations for Cole Creek (AU 0511C_01) for potential changed contact recreation standards.

Units expressed as billion cfu/ day Enterococci except contact recreation criterion

Contact Recreation Criterion (cfu/100 mL)	TMDL	WLA_{WWTF}	WLA_{SW}	LA	MOS
35	86.914	0.012	1.346	81.210	4.346
175	434.572	0.012	6.729	406.102	21.729
350	869.145	0.012	13.459	812.217	43.457

Terry Gully (AU 05011E_01): Equations for calculating new TMDL and allocations for *E. coli* (in billion cfu/day)

$TMDL$ = 6.6106361 * Std - 0.0000236
WLA_{WWTF} = 0.0430000
WLA_{SW} = 1.1555388 * Std - 0.0077406
LA = 5.1245653 * Std - 0.0351934
MOS = 0.3305321 * Std - 0.0000896

Where:

Std = Revised Contact Recreation Standard
WLA_{WWTF} = Waste load allocation (permitted WWTF load + future growth)
WLA_{SW} = Waste load allocation (permitted stormwater)
LA = Total load allocation (unregulated sources)
MOS = Margin of Safety

Table A-13 *E. coli* TMDL allocations for Terry Gully (AU 05011E_01) for potential changed contact recreation standards.

Units expressed as billion cfu/ day *E. coli* except contact recreation criterion

Contact Recreation Criterion (cfu/100 mL)	TMDL	WLA_{WWTF}	WLA_{SW}	LA	MOS
126	832.940	0.043	145.590	645.660	41.647
630	4,164.701	0.043	727.982	3,228.441	208.235
1030	6,808.955	0.043	1,190.197	5,278.267	340.448

Terry Gully (AU 0511E_01): Equations for calculating new TMDL and allocations for Enterococci (in billion cfu/day)

TMDL = 6.6106382* Std - 0.0004590
WLA_{WWTF} = 0.0120000
WLA_{SW} = 1.1555398 * Std - 0.0020984
LA = 5.1245681 * Std - 0.0107213
MOS = 0.3305302 * Std + 0.0003607

Where:

Std = Revised Contact Recreation Standard
WLA_{WWTF} = Waste load allocation (permitted WWTF load + future growth)
WLA_{SW} = Waste load allocation (permitted stormwater)
LA = Total load allocation (unregulated sources)
MOS = Margin of Safety

Table A-14 Enterococci TMDL allocations for Terry Gully (AU 0511E_01) for potential changed contact recreation standards.

Units expressed as billion cfu/ day Enterococci except contact recreation criterion

Contact Recreation Criterion (cfu/100 mL)	TMDL	WLA_{WWTF}	WLA_{SW}	LA	MOS
35	231.372	0.012	40.442	179.349	11.569
175	1,156.861	0.012	202.217	896.789	57.843
350	2,313.723	0.012	404.437	1,793.588	115.686

Appendix C. Method Used to Determine Population Projections in the Adams Bayou and Cow Bayou Watersheds

The following steps detail the method used to estimate the projected 2020 and 2070 populations in the subwatersheds of all AUs in the Adams Bayou and Cow Bayou watersheds.

1) Block-level population data was obtained from the U.S. Census Bureau for the area of East Texas encompassing the Adams Bayou and Cow Bayou watersheds.
2) 2010 watershed populations were developed using the block level data for the subwatershed areas of the individual AUs comprising Adams Bayou and Cow Bayou and their associated tributaries.
3) For blocks not entirely within the subwatershed areas, a simple fraction of area within the AU subwatershed was proportioned.
4) The 2016 Regional Water Plan for Region I (Alan Plummer Associates, Inc., et al., 2015), which contains county and city level populations from the 2010 Census data and decadal projections from 2020 through 2070, was obtained.
5) The Region I 2016 Regional Water Plan provided the decadal projections for the larger cities and communities and the rural areas of the three counties (Jasper, Newton, and Orange) having areas within Adams Bayou and Cow Bayou watersheds. For Jasper, Newton, and Orange counties, the Region I 2016 Regional Water Plan projections provide unique percent increases for the decadal projections for each county. These percentages were used to estimate population projections for cities and rural areas within each county.
6) The decadal percent population increases for each county were applied to the AU-level 2010 populations and the percent of the population in each AU from Jasper, Newton, and Orange counties resulting in the 2020 and 2070 population estimates for Adams Bayou and Cow Bayou watersheds.